



Environment  
Canada

Environnement  
Canada

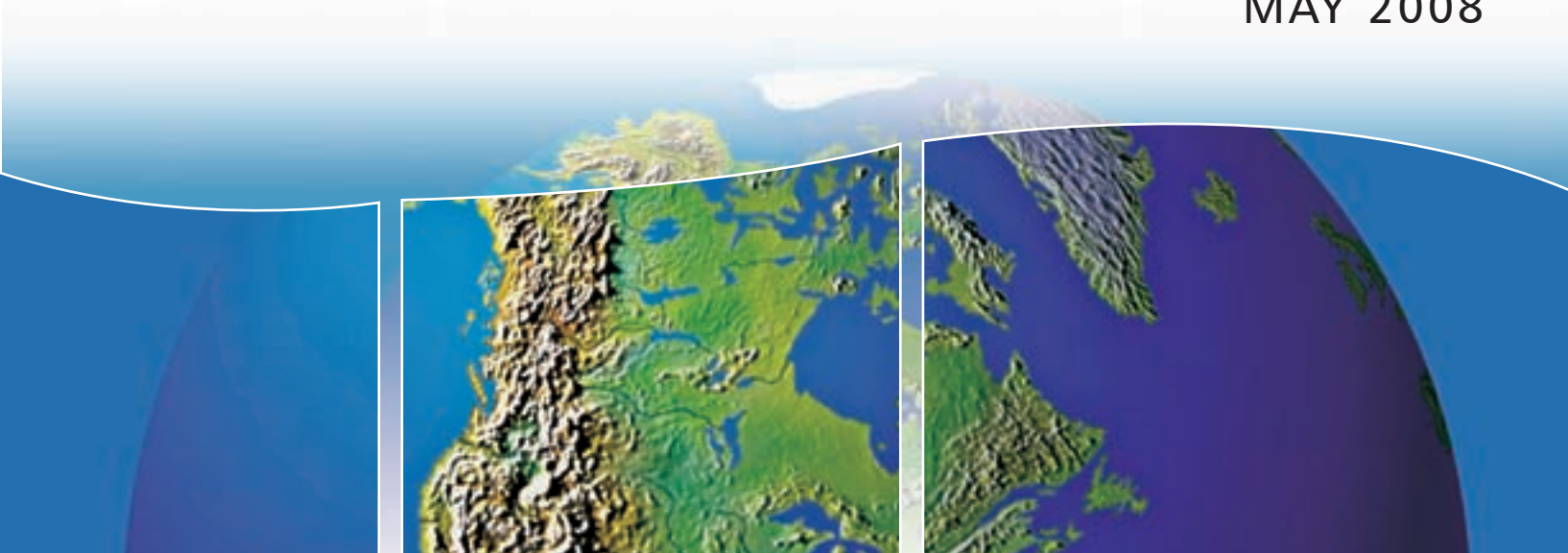
# National Inventory Report

1990–2006

Greenhouse Gas Sources and Sinks in Canada

The Canadian Government's Submission  
to the UN Framework Convention  
on Climate Change

MAY 2008



Canada 

## **Library and Archives Canada Cataloguing in Publication**

Canada.

Main entry under title:

National Inventory Report 1990—2006: Greenhouse Gas Sources and Sinks in Canada

Annual

1990/2006.

Issued by Greenhouse Gas Division.

Other editions available: Rapport d'inventaire national 1990—2006 : Sources et puits de gaz à effet de serre au Canada.

Continues: Canada's Greenhouse Gas Inventory.

This document is available on Environment Canada's web site at [www.ec.gc.ca/ghg](http://www.ec.gc.ca/ghg).

ISSN: 1706-3353

ISBN: 978-1-100-11176-6

Cat. no.: En81-4/2006E

1. Greenhouse gases—Canada—Measurement—Periodicals.
2. Methane—Environmental aspects—Canada—Periodicals.
3. Nitrous oxide—Environmental aspects—Canada—Periodicals.
4. Carbon dioxide—Environmental aspects—Canada—Periodicals.
5. Pollution—Canada—Measurement—Periodicals.
- I. Canada. Environment Canada.
- II. Greenhouse Gas Division.
- III. Title.
- IV. Title: Greenhouse gas sources and sinks in Canada.

TD885.5

363.738'74'097105

C2006-980262-9

# Acknowledgements

The Greenhouse Gas Division of Environment Canada wishes to acknowledge the many individuals and organizations that contributed to the 2008 National Inventory Report. Although the list of all researchers, government employees, and consultants who provided technical support is too long to include here, Environment Canada's Greenhouse Gas Division would like to thank the authors and contributors as well as the reviewers whose work helped to improve this year's report.

Authors and reviewers of Canada's *National Inventory Report: 1990-2006, Greenhouse Gas Sources and Sinks in Canada* include:

## **Executive Summary**

Art Jaques, Frank Neitzert, Robin White

## **Chapter 1: Introduction**

Dominique Blain, Nicole Folliet, Mario Hui, Afshin Matin, Jackie Mercer, Frank Neitzert, Craig Palmer, Duane Smith

## **Chapter 2: Greenhouse Gas Emission Trends, 1990–2006**

Alice Au, Pascal Bellavance, Dominique Blain, Chia Ha, Chang Liang, Afshin Matin, Scott McKibbin, Frank Neitzert, Craig Palmer, Rock Radovan

## **Chapter 3: Energy (CRF Sector 1)**

Warren Baker, Pascal Bellavance, Chia Ha, Scott McKibbin, Frank Neitzert, Rock Radovan

## **Chapter 4: Industrial Processes (CRF Sector 2)**

Alice Au, Afshin Matin, Maryse Pagé

## **Chapter 5: Solvent and Other Product Use (CRF Sector 3)**

Alice Au, Afshin Matin

## **Chapter 6: – Agriculture (CRF Sector 4)**

Chang Liang, Anne-Marie Chapman

## **Chapter 7: Land Use, Land-Use Change and Forestry (CRF Sector 5)**

Dominique Blain, Chang Liang, Mark McGovern, Ana Morales

## **Chapter 8: Waste (CRF Sector 6)**

Afshin Matin, Craig Palmer

## **Chapter 9: Recalculations and Improvements**

Mohamed Abdul, Alice Au, Dominique Blain, Nicole Folliet, Afshin Matin, Craig Palmer

## **Annexes**

Alice Au (annexes 3, 5, 7, and 12), Pascal Bellavance (annexes 2, 8, 10 and 12), Dominique Blain (annexes 1, 3, 10), Anne-Marie Chapman (annexes 3 and 10) Nicole Folliet (annexes 6, 7, 8, 11, 13, 14), Chia Ha (annexes 1, 2, 3, 4, 8, and 12), Chang Liang (annexes 3 and 10), Afshin Matin (annexes 5, 7, and 13), Mark McGovern (annexes 1 and 3), Scott McKibbin (Annex 1, 5, 8, 10, 11 and 12), Ana Morales (Annex 3), Frank Neitzert (annexes 4, 5, 8, 9, 10 and 13), Maryse Pagé (annexes 5, 7), Craig Palmer (annexes 3, 5, and 7), Francine Portenier (annexes 3 and 12),

## ACKNOWLEDGEMENTS

Lindsay Pratt (annex 14), Rock Radovan (annexes 1, 2, 4, 5, 8, 9, 10, 12 and 13), Duane Smith (annexes 6, 7, 8, 11, 13), Syed Wasay (annex 3)

Overall compilation of the National Inventory Report was managed by Serge Guilmette & Liette Cormier. Overall coordination of the National Inventory Report was undertaken by Francine Portenier and Nicole Folliet.

Lastly, we would also like to acknowledge the efforts of our colleagues at Statistics Canada, especially Gary Smalldridge and Louise Stewart, for their help in analyzing and interpreting Canada's energy supply and demand data. We are also grateful to our federal colleagues from the national Land Use, Land-Use Change and Forestry (LULUCF) Monitoring, Accounting and Reporting System, who contributed estimates for the LULUCF and Agriculture sectors. In particular, we would like to thank Caren Dymond, Werner Kurz, Don Leckie, Tony Lemprière, Sally Tinis, Thomas White, and Jim Wood of the Canadian Forest Service of Natural Resources Canada, Marie Boehm, Murray Bentham, Darrel Cerkowniak, Ted Huffman, Julian Hutchinson, Tim Martin, Brian McConkey, Philippe Rochette and Devon Smith of Agriculture and Agri-Food Canada, and Wenjun Chen of the Canadian Centre for Remote Sensing. Of the many people and organizations that provided support and information, we are especially indebted to the many individuals in various industries, industry associations, engineering consulting firms, and universities who provided engineering and scientific support.

### **Readers' Comments**

Comments regarding the contents of this report should be addressed to:

Art Jaques, P. Eng.  
Director, Greenhouse Gas Division  
Science and Risk Assessment Directorate  
Environment Canada  
351 St. Joseph Blvd.  
Gatineau, Quebec  
K1A 0H3

## Foreword

Canada ratified the United Nations Framework Convention on Climate Change (UNFCCC) on December 4, 1992 and the Kyoto Protocol to the UNFCCC on December 17, 2002. Under Decisions 3/CP.1, 9/CP.2 and 3/CP.5 of the UNFCCC, national inventories for UNFCCC Annex I Parties should be submitted to the UNFCCC Secretariat each year, by April 15. In addition, in accordance with Decision 15/CMP.1, Annex I Parties that wish to participate fully in the Kyoto Protocol mechanisms under Articles 6, 12 and 17 should begin reporting their annual inventory and assigned amount information, when applicable in the context of their annual submissions under the Kyoto Protocol, from the year following the submission of the initial report required by decision 13/CMP.1. As such, this report represents Canada's annual inventory submission under the Framework Convention and the Kyoto Protocol.

The UNFCCC and Kyoto Protocol monitoring, reporting and review guidelines for national inventories, incorporate the methodological Good Practice Guidance that has been developed by the Intergovernmental Panel on Climate Change. These guidelines stipulate how emission estimates are to be prepared and what is to be included in the annual inventory report. By including additional information, the national inventory report (NIR) serves as a much better tool from which to generate indicators to compare Parties' performance under the UNFCCC and the Kyoto Protocol. These guidelines also commit Parties to improve the quality of national and regional emissions and removals estimates on an ongoing basis. Priority areas for improvement include both the quality of input data and the methodologies utilized to develop emission and removal estimates. A number of areas have undergone improvements over the last few years as we improve the quality of the inventory. These improvements are described within the report.

Environment Canada, in consultation with a range of stakeholders, is responsible for preparing Canada's official national inventory. This National Inventory Report, prepared by staff of the Greenhouse Gas Division of Environment Canada, complies with the UNFCCC reporting guidelines on annual inventories. It represents the efforts of many years of work and builds upon the results of previous reports, published in 1992, 1994, 1996, 1997, and yearly from 1999 to 2007 and incorporates a number of changes including those most recently recommended by a UN Expert Review Team that reviewed Canada's initial report under the Kyoto Protocol in the fall of 2007. In addition to the inventory data, the inventory report contains relevant supplementary information, where appropriate on Canada's National System and National Registry and an analysis of recent trends in emissions and removals.

In an effort to improve Canada's ability to monitor, report, and verify our greenhouse gas emissions, on March 15, 2004, the Government of Canada, in partnership with the provincial and territorial governments, launched a national mandatory greenhouse gas reporting system. The 2008 National Inventory Report contains a summary of the greenhouse gas emissions data reported by industrial facilities in Canada for the year 2006, as well as links to Environment Canada's Internet-based greenhouse gas emissions query site.

Since the publication of the 1990 emissions inventory, an ever-increasing number of people have become interested in climate change and, more specifically, greenhouse gas emissions. While this interest has sparked a number of research activities, only a limited number have focused on measuring emissions and developing better emission estimates. There will always be uncertainties associated with emission inventories; however, ongoing work, both in Canada and elsewhere, will continue to improve the estimates and reduce uncertainties associated with them.

Art Jaques, P. Eng.  
April 15, 2008

Director, Greenhouse Gas Division  
Science and Risk Assessment Directorate  
Science and Technology Branch  
Environment Canada

## List of Acronyms, Abbreviations, and Units

AAC	Aluminum Association of Canada
AAFC	Agriculture and Agri-Food Canada
AC	air conditioning
AEUB	Alberta Energy and Utilities Board
Al	aluminium
Al <sub>2</sub> O <sub>3</sub>	alumina
API	American Petroleum Institute
ASH	manure ash content
ATV	all-terrain vehicle
AWMS	animal waste management system
B <sub>0</sub>	maximum methane production potential
BOD	biochemical oxygen demand
BOD <sub>5</sub>	five-day biochemical oxygen demand
C	carbon
CAC	Criteria Air Contaminant
CaCO <sub>3</sub>	calcium carbonate; limestone
CaMg(CO <sub>3</sub> ) <sub>2</sub>	dolomite (also CaCO <sub>3</sub> ·MgCO <sub>3</sub> )
CanFI	Canada's National Forest Inventory
CANSIM	Statistics Canada's key socioeconomic database
CanSIS	Canadian Soil Information System
CaO	lime; quicklime; calcined limestone
CAPP	Canadian Association of Petroleum Producers
CBM	Carbon Budget Model
CBM-CFS3	Carbon Budget Model for the Canadian Forest Sector, version 3
CCFM	Canadian Council of Forest Ministers
CEA	Canadian Electricity Association
CEPA 1999	Canadian Environmental Protection Act, 1999
CF <sub>4</sub>	carbon tetrafluoride
C <sub>2</sub> F <sub>6</sub>	carbon hexafluoride
CFC	chlorofluorocarbon
CFS	Canadian Forest Service
CGA	Canadian Gas Association
CH <sub>3</sub> OH	methanol
CH <sub>4</sub>	methane
CIEEDAC	Canadian Industrial Energy End-Use Data Analysis Centre
CKD	cement kiln dust
CO	carbon monoxide
CO <sub>2</sub>	carbon dioxide
CO <sub>2</sub> eq	carbon dioxide equivalent
COD	chemical oxygen demand
CPPI	Canadian Petroleum Products Institute

## LIST OF ACRONYMS, ABBREVIATIONS, AND UNITS

CRF	Common Reporting Format
CT	conventional tillage
CTS	crop and tillage system
CVS	Canadian Vehicle Survey
DE	digestible energy
DM	dry matter
DMI	dry matter intake
DOC	degradable organic carbon
DOCF	degradable organic carbon dissimilated
DOM	dead organic matter
EAF	electric arc furnace
EC	Environment Canada
EF	emission factor
EF <sub>BASE</sub>	basic emission factor
EPA	Environmental Protection Agency (United States)
EPGTD	Electric Power Generation, Transmission and Distribution
eq	equivalent
ERCB	Energy Resources Conservation Board
ERT	Expert Review Team
EU	European Union
FAACS	Feasibility Assessment of Afforestation for Carbon Sequestration
FCR	fuel consumption ratio
FGD	flue gas desulphurization
FLCL	forest land converted to cropland
FLSL	forest land converted to settlement
FLWL	forest land converted to wetland
FTA	fraction of BOD in sludge that degrades anaerobically
F <sub>TILL</sub>	tillage ratio factor
g	gram
GCV	gross calorific value
GDP	gross domestic product
GE	gross energy
Gg	gigagram
GHG	greenhouse gas
GHGRP	Greenhouse gas reporting program
GHV	gross heating value
GIS	geographic information system
GL	gigalitre
Gt	gigatonne
GTIS	Global Trade Information Services
GVWR	gross vehicle weight rating
GWP	global warming potential
H <sub>2</sub>	hydrogen
H <sub>2</sub> O	water

## LIST OF ACRONYMS, ABBREVIATIONS, AND UNITS

ha	hectare
HCFC	hydrochlorofluorocarbon
HCl	hydrochloric acid
HDD	heating degree-day
HDDT	heavy-duty diesel truck
HDDV	heavy-duty diesel vehicle
HDGV	heavy-duty gasoline vehicle
HE	harvest emissions
HFC	hydrofluorocarbon
HHV	higher heating value
HM	heavy metal
HNO <sub>3</sub>	nitric acid
HRAI	Heating, Refrigeration and Air Conditioning Institute of Canada
HWP	harvested wood product
HWP-C	carbon stored in harvested wood products
IAI	International Aluminium Institute
IE	included elsewhere
IEA	International Energy Agency
I/M	inspection and maintenance
IPCC	Intergovernmental Panel on Climate Change
IT	intensive tillage
ITL	International Transaction Log
k	methane generation rate constant
K <sub>2</sub> CO <sub>3</sub>	potassium carbonate
kg	kilogram
kha	kilohectare
kPa	kilopascal
kt	kilotonne
kWh	kilowatt-hour
L	litre
L <sub>0</sub>	methane generation potential
lb.	pound
LDDT	light-duty diesel truck
LDDV	light-duty diesel vehicle
LDGT	light-duty gasoline truck
LDGV	light-duty gasoline vehicle
LFG	landfill gas
LHV	lower heating value
LMC	land management change
LPG	liquefied petroleum gas
LTO	landing and takeoff
LULUCF	Land Use, Land-Use Change and Forestry
m	metre
m <sup>3</sup>	cubic metre



## LIST OF ACRONYMS, ABBREVIATIONS, AND UNITS

MAI	mean annual increment
MARS	Monitoring, Accounting and Reporting System
MC	motorcycle
MCED	Manufacturing, Construction and Energy Division of Statistics Canada
MCF	methane conversion factor
Mg	magnesium; also megagram
MgCO <sub>3</sub>	magnesite; magnesium carbonate
MGEM	Mobile Greenhouse Gas Emission Model
MGEM07	Mobile Greenhouse Gas Emission Model 2007
MgO	magnesia; dolomitic lime
Mha	megahectare
ML	megalitre
mol	mole
MS	manure system distribution factor
MSW	municipal solid waste
Mt	megatonne
mV	millivolt
MW	megawatt
N	nitrogen
N <sub>2</sub>	nitrogen gas
Na <sub>2</sub> CO <sub>3</sub>	sodium carbonate; soda ash
Na <sub>3</sub> AlF <sub>6</sub>	cryolite
NA	not applicable
N/A	not available
NAICS	North American Industry Classification System
NCV	net calorific value
NE	not estimated
NEB	National Energy Board
NGL	natural gas liquid
NH <sub>3</sub>	ammonia
NH <sub>4</sub> <sup>+</sup>	ammonium
NH <sub>4</sub> NO <sub>3</sub>	ammonium nitrate
NIR	National Inventory Report
NMVOC	non-methane volatile organic compound
N <sub>2</sub> O	nitrous oxide
NO	nitric oxide; also used for not occurring
NO <sub>2</sub>	nitrogen dioxide
NO <sub>3</sub> <sup>-</sup>	nitrate
NO <sub>x</sub>	nitrogen oxides
NOC	Nitrous Oxide of Canada
NPRI	National Pollutant Release Inventory
NRCan	Natural Resources Canada
NSCR	non-selective catalytic reduction
NT	no tillage

## LIST OF ACRONYMS, ABBREVIATIONS, AND UNITS

O <sub>2</sub>	oxygen
ODS	ozone-depleting substance
OECD	Organisation for Economic Co-operation and Development
OEM	original equipment manufacturer
OS/HOU	oil sands and heavy oil upgrading
PFC	perfluorocarbon
PJ	petajoule
POP	persistent organic pollutant
ppb	part per billion
ppbv	part per billion by volume
P/PE	precipitation/potential evapotranspiration
ppm	part per million
QA	quality assurance
QC	quality control
RA	reference approach
RES D	Report on Energy Supply–Demand in Canada
RPP	refined petroleum product
RT	reduced tillage
SA	sectoral approach
SCR	selective catalytic reduction
SF <sub>6</sub>	sulphur hexafluoride
SIC	Standard Industrial Classification
SLC	Soil Landscapes of Canada
SMR	steam methane reforming
SO <sub>2</sub>	sulphur dioxide
SO <sub>x</sub>	sulphur oxides
SOC	soil organic carbon
SUV	sport utility vehicle
t	tonne
t-km	tonne-kilometre
TJ	terajoule
TWh	terrawatt-hour
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
UPCIS	Use Patterns and Controls Implementation Section
UOG	upstream oil and gas
VKT	vehicle kilometres travelled
VOC	volatile organic compound
VS	volatile solids
WMO	World Meteorological Organization
wt	weight

# Table of Contents

<b>ACKNOWLEDGEMENTS .....</b>	<b>iii</b>
<b>FOREWORD .....</b>	<b>v</b>
<b>LIST OF ACRONYMS, ABBREVIATIONS, AND UNITS .....</b>	<b>vi</b>
<b>EXECUTIVE SUMMARY .....</b>	<b>1</b>
<b>ES.1 Greenhouse Gas Inventories and Climate Change .....</b>	<b>1</b>
<i>ES.1.1 Developing Canada's National Greenhouse Gas Inventory .....</i>	<i>2</i>
<b>ES.2 Summary of National Trends in Greenhouse Gas Emissions and Removals .....</b>	<b>3</b>
<b>ES.3 Emission and Removal Estimates and Trends .....</b>	<b>7</b>
<i>ES.3.1 2006 Emissions and Removals .....</i>	<i>7</i>
<i>ES.3.2 Sector Trends .....</i>	<i>9</i>
<b>ES.4 Other Information .....</b>	<b>14</b>
<i>ES.4.1 Emissions Associated with the Export of Oil and Natural Gas .....</i>	<i>14</i>
<i>ES.4.2 Provincial/Territorial GHG Emissions .....</i>	<i>16</i>
<i>ES.4.3 The International Context .....</i>	<i>17</i>
<b>1 INTRODUCTION .....</b>	<b>18</b>
<b>1.1 GHG Inventories and Climate Change .....</b>	<b>18</b>
<i>1.1.1 CO<sub>2</sub> .....</i>	<i>19</i>
<i>1.1.2 CH<sub>4</sub> .....</i>	<i>20</i>
<i>1.1.3 N<sub>2</sub>O .....</i>	<i>21</i>
<i>1.1.4 HFCs, PFCs, and SF<sub>6</sub> .....</i>	<i>22</i>
<i>1.1.5 GHGs and the Use of GWPs .....</i>	<i>22</i>
<i>1.1.6 Canada's Contribution .....</i>	<i>23</i>
<b>1.2 Institutional Arrangements for Inventory Preparation .....</b>	<b>25</b>
<i>1.2.1 The National Inventory System .....</i>	<i>25</i>
<i>1.2.2 Institutional Arrangements .....</i>	<i>26</i>
<b>1.3 Process for Inventory Preparation .....</b>	<b>28</b>
<b>1.4 Methodologies and Data Sources .....</b>	<b>29</b>
<i>1.4.1 Mandatory Reporting System for GHGs .....</i>	<i>31</i>
<b>1.5 Key Categories .....</b>	<b>34</b>
<b>1.6 QA/QC .....</b>	<b>35</b>
<b>1.7 Inventory Uncertainty .....</b>	<b>36</b>
<b>1.8 Completeness Assessment .....</b>	<b>37</b>
<b>2 GREENHOUSE GAS EMISSION TRENDS, 1990–2006 .....</b>	<b>39</b>
<b>2.1 Summary of Emission Trends .....</b>	<b>39</b>
<b>2.2 Emission Trends by Gas .....</b>	<b>39</b>
<b>2.3 Emission Trends by Category .....</b>	<b>39</b>
<i>2.3.1 Energy Sector .....</i>	<i>39</i>
<i>2.3.2 Industrial Processes Sector .....</i>	<i>49</i>
<i>2.3.3 Solvent and Other Product Use Sector .....</i>	<i>52</i>
<i>2.3.4 Agriculture Sector .....</i>	<i>52</i>
<i>2.3.5 Land Use, Land-Use Change, and Forestry Sector .....</i>	<i>54</i>
<i>2.3.6 Waste Sector .....</i>	<i>56</i>
<b>2.4 Emission Trends for Ozone and Aerosol Precursors .....</b>	<b>58</b>

## TABLE OF CONTENTS

<b>3</b>	<b>ENERGY (CRF SECTOR 1).....</b>	<b>59</b>
3.1	Overview .....	59
3.2	Fuel Combustion (CRF Category 1.A).....	59
3.2.1	Energy Industries (CRF Category 1.A.1).....	61
3.2.2	Manufacturing Industries and Construction (CRF Category 1.A.2).....	65
3.2.3	Transport (CRF Category 1.A.3) .....	68
3.2.4	Other Sectors (CRF Category 1.A.4) .....	73
3.2.5	Other: Energy—Fuel Combustion Activities (CRF Category 1.A.5) .....	75
3.3	Fugitive Emissions (CRF Category 1.B).....	75
3.3.1	Solid Fuels (CRF Category 1.B.1) .....	76
3.3.2	Oil and Natural Gas (CRF Category 1.B.2) .....	77
3.4	Memo Items (CRF Category 1.C) .....	84
3.4.1	International Bunker Fuels (CRF Category 1.C1).....	84
3.4.2	CO <sub>2</sub> Emissions from Biomass.....	85
3.5	Other Issues .....	87
3.5.1	Comparison of Sectoral and Reference Approaches.....	87
3.5.2	Feedstocks and Non-Energy Use of Fuels.....	88
3.5.3	CO <sub>2</sub> Capture and Storage .....	89
3.5.4	Country-Specific Issues: Emissions Associated with the Export of Fossil Fuels .....	89
<b>4</b>	<b>INDUSTRIAL PROCESSES (CRF SECTOR 2) .....</b>	<b>90</b>
4.1	Overview .....	90
4.2	Cement Production (CRF Category 2.A.1) .....	92
4.2.1	Source Category Description.....	92
4.2.2	Methodological Issues.....	93
4.2.3	Uncertainties and Time-Series Consistency.....	93
4.2.4	Category-Specific QA/QC and Verification .....	94
4.2.5	Category-Specific Recalculations .....	94
4.2.6	Category-Specific Planned Improvements .....	94
4.3	Lime Production (CRF Category 2.A.2) .....	94
4.3.1	Source Category Description.....	94
4.3.2	Methodological Issues.....	95
4.3.3	Uncertainties and Time-Series Consistency.....	95
4.3.4	Category-Specific QA/QC and Verification .....	95
4.3.5	Category-Specific Recalculations .....	96
4.3.6	Category-Specific Planned Improvements .....	96
4.4	Limestone and Dolomite Use (CRF Category 2.A.3) .....	96
4.4.1	Source Category Description.....	96
4.4.2	Methodological Issues.....	96
4.4.3	Uncertainties and Time-Series Consistency.....	97
4.4.4	Category-Specific QA/QC and Verification .....	97
4.4.5	Category-Specific Recalculations .....	97
4.4.6	Category-Specific Planned Improvements .....	97
4.5	Soda Ash Production and Use (CRF Category 2.A.4) .....	97
4.5.1	Source Category Description.....	97
4.5.2	Methodological Issues.....	98
4.5.3	Uncertainties and Time-Series Consistency.....	98
4.5.4	Category-Specific QA/QC and Verification .....	98

4.5.5	Category-Specific Recalculations .....	99
4.5.6	Category-Specific Planned Improvements .....	99
4.6	Magnesite Use (CRF Category 2.A.7.2) .....	99
4.6.1	Source Category Description .....	99
4.6.2	Methodological Issues .....	99
4.6.3	Uncertainties and Time-Series Consistency .....	100
4.6.4	Category-Specific QA/QC and Verification .....	100
4.6.5	Category-Specific Recalculations .....	100
4.6.6	Category-Specific Planned Improvements .....	100
4.7	Ammonia Production (CRF Category 2.B.1) .....	100
4.7.1	Source Category Description .....	100
4.7.2	Methodological Issues .....	101
4.7.3	Uncertainties and Time-Series Consistency .....	102
4.7.4	Category-Specific QA/QC and Verification .....	102
4.7.5	Category-Specific Recalculations .....	102
4.7.6	Category-Specific Planned Improvements .....	102
4.8	Nitric Acid Production (CRF Category 2.B.2) .....	103
4.8.1	Source Category Description .....	103
4.8.2	Methodological Issues .....	104
4.8.3	Uncertainties and Time-Series Consistency .....	105
4.8.4	Category-Specific QA/QC and Verification .....	105
4.8.5	Category-Specific Recalculations .....	106
4.8.6	Category-Specific Planned Improvements .....	106
4.9	Adipic Acid Production (CRF Category 2.B.3) .....	106
4.9.1	Source Category Description .....	106
4.9.2	Methodological Issues .....	106
4.9.3	Uncertainties and Time-Series Consistency .....	107
4.9.4	Category-Specific QA/QC and Verification .....	108
4.9.5	Category-Specific Recalculations .....	108
4.9.6	Category-Specific Planned Improvements .....	108
4.10	Iron and Steel Production (CRF Category 2.C.1) .....	108
4.10.1	Source Category Description .....	108
4.10.2	Methodological Issues .....	108
4.10.3	Uncertainties and Time-Series Consistency .....	110
4.10.4	Category-Specific QA/QC and Verification .....	110
4.10.5	Category-Specific Recalculations .....	111
4.10.6	Category-Specific Planned Improvements .....	111
4.11	Aluminium Production (CRF Category 2.C.3) .....	111
4.11.1	Source Category Description .....	111
4.11.2	Methodological Issues .....	112
4.11.3	Uncertainties and Time-Series Consistency .....	117
4.11.4	Category-Specific QA/QC and Verification .....	118
4.11.5	Category-Specific Recalculations .....	118
4.11.6	Category-Specific Planned Improvements .....	118
4.12	Magnesium Metal Production and Casting (CRF Categories 2.C.5.1 & 2.C.4.2) .....	118
4.12.1	Source Category Description .....	118
4.12.2	Methodological Issues .....	119
4.12.3	Uncertainties and Time-Series Consistency .....	120

## TABLE OF CONTENTS

4.12.4	Category-Specific QA/QC and Verification .....	120
4.12.5	Category-Specific Recalculations .....	120
4.12.6	Category-Specific Planned Improvements .....	120
4.13	Production of Halocarbons (CRF Category 2.E).....	120
4.13.1	Source Category Description .....	120
4.13.2	Methodological Issues.....	121
4.13.3	Uncertainties and Time-Series Consistency.....	121
4.13.4	Category-Specific QA/QC and Verification .....	122
4.13.5	Category-Specific Recalculations .....	122
4.13.6	Category-Specific Planned Improvements .....	122
4.14	Consumption of Halocarbons (CRF Category 2.F) .....	122
4.14.1	Methodological Issues.....	122
4.14.2	Uncertainties and Time-Series Consistency.....	130
4.14.3	Category-Specific QA/QC and Verification .....	130
4.14.4	Category-Specific Recalculations .....	131
4.14.5	Category-Specific Planned Improvements .....	131
4.15	Production and Consumption of SF <sub>6</sub> (CRF Categories 2.E & 2.F) .....	131
4.15.1	Source Category Description .....	131
4.15.2	Methodological Issues.....	131
4.15.3	Uncertainties and Time-Series Consistency.....	132
4.15.4	Category-Specific QA/QC and Verification .....	133
4.15.5	Category-Specific Recalculations .....	133
4.15.6	Category-Specific Planned Improvements .....	133
4.16	Other and Undifferentiated Production (CRF Category 2.G).....	133
4.16.1	Source Category Description .....	133
4.16.2	Methodological Issues.....	133
4.16.3	Uncertainties and Time-Series Consistency.....	134
4.16.4	Category-Specific QA/QC and Verification .....	134
4.16.5	Category-Specific Recalculations .....	134
4.16.6	Category-Specific Planned Improvements .....	134
<b>5</b>	<b>SOLVENT AND OTHER PRODUCT USE (CRF SECTOR 3) .....</b>	<b>135</b>
5.1	Overview .....	135
5.1.1	Source Category Description .....	136
5.1.2	Methodological Issues.....	136
5.1.3	Uncertainties and Time-Series Consistency.....	137
5.1.4	QA/QC and Verification.....	138
5.1.5	Recalculations .....	138
5.1.6	Planned Improvements.....	138
<b>6</b>	<b>AGRICULTURE (CRF SECTOR 4) .....</b>	<b>139</b>
6.1	Overview .....	139
6.2	Enteric Fermentation (CRF Category 4.A) .....	140
6.2.1	Source Category Description .....	140
6.2.2	Methodological Issues.....	140
6.2.3	Uncertainties and Time-Series Consistency.....	141
6.2.4	QA/QC and Verification.....	142
6.2.5	Recalculations .....	142
6.2.6	Planned Improvements.....	142

6.3	Manure Management (CRF Category 4.B) .....	143
6.3.1	<i>CH<sub>4</sub> Emissions from Manure Management (CRF Category 4.B (a))</i> .....	143
6.3.2	<i>N<sub>2</sub>O Emissions from Manure Management (CRF Category 4.B (b))</i> .....	144
6.4	N <sub>2</sub> O Emissions from Agricultural Soils (CRF Category 4.D) .....	146
6.4.1	<i>Direct N<sub>2</sub>O Emissions from Soils (CRF Category 4.D.1)</i> .....	146
6.4.2	<i>Manure on Pasture, Range, and Paddock (CRF Category 4.D.2)</i> .....	153
6.4.3	<i>Indirect Emissions of N<sub>2</sub>O from Soils (CRF Category 4.D.3)</i> .....	154
7	<b>LAND USE, LAND-USE CHANGE AND FORESTRY (CRF SECTOR 5) .....</b>	<b>157</b>
7.1	Overview .....	157
7.2	Land Category Definition and Representation of Managed Lands .....	158
7.3	Forest Land .....	161
7.3.1	<i>Forest Land Remaining Forest Land</i> .....	161
7.3.2	<i>Land Converted to Forest Land</i> .....	165
7.4	Cropland .....	166
7.4.1	<i>Cropland Remaining Cropland</i> .....	166
7.4.2	<i>Land Converted to Cropland</i> .....	173
7.5	Grassland .....	176
7.6	Wetlands .....	177
7.6.1	<i>Managed Peatlands</i> .....	177
7.6.2	<i>Flooded Lands (Reservoirs)</i> .....	179
7.7	Settlements .....	181
7.7.1	<i>Settlements Remaining Settlements</i> .....	181
7.7.2	<i>Land Converted to Settlements</i> .....	181
7.8	Forest Conversion .....	182
7.8.1	<i>Methodological Issues</i> .....	183
7.8.2	<i>Uncertainties and Time-Series Consistency</i> .....	184
7.8.3	<i>QA/QC and Verification</i> .....	184
7.8.4	<i>Recalculations</i> .....	184
7.8.5	<i>Planned Improvements</i> .....	184
8	<b>WASTE (CRF SECTOR 6) .....</b>	<b>185</b>
8.1	Overview .....	185
8.2	Solid Waste Disposal on Land (CRF Category 6.A) .....	186
8.2.1	<i>Source Category Description</i> .....	186
8.2.2	<i>Methodological Issues</i> .....	187
8.2.3	<i>Uncertainties and Time-Series Consistency</i> .....	192
8.2.4	<i>QA/QC and Verification</i> .....	193
8.2.5	<i>Recalculations</i> .....	193
8.2.6	<i>Planned Improvements</i> .....	193
8.3	Wastewater Handling (CRF Category 6.B) .....	193
8.3.1	<i>Source Category Description</i> .....	193
8.3.2	<i>Methodological Issues</i> .....	194
8.3.3	<i>Uncertainties and Time-Series Consistency</i> .....	195
8.3.4	<i>QA/QC and Verification</i> .....	196
8.3.5	<i>Recalculations</i> .....	196
8.3.6	<i>Planned Improvements</i> .....	196
8.4	Waste Incineration (CRF Category 6.C) .....	196
8.4.1	<i>Source Category Description</i> .....	196

## TABLE OF CONTENTS

8.4.2	<i>Methodological Issues</i> .....	197
8.4.3	<i>Uncertainties and Time-Series Consistency</i> .....	198
8.4.4	<i>QA/QC and Verification</i> .....	199
8.4.5	<i>Recalculations</i> .....	199
8.4.6	<i>Planned Improvements</i> .....	199
<b>9</b>	<b>RECALCULATIONS AND IMPROVEMENTS</b> .....	<b>200</b>
9.1	Explanations and Justifications for Recalculations – 2008 Submission.....	202
9.1.1	<i>Implications for Emission Levels</i> .....	204
9.1.2	<i>Implications for Emission Trends</i> .....	204
9.2	Recalculations – Energy Sector.....	205
9.2.1	<i>Stationary Fossil Fuel Combustion</i> .....	205
9.2.2	<i>Transport</i> .....	206
9.2.3	<i>Fugitive Sources</i> .....	206
9.3	Recalculations – Industrial Processes Sector .....	208
9.4	Recalculations – Solvent and Other Product Use Sector.....	210
9.5	Recalculations – Agriculture Sector.....	210
9.5.1	<i>Cross-cutting Recalculations</i> .....	210
9.5.2	<i>Enteric Fermentation</i> .....	211
9.5.3	<i>Manure Management</i> .....	211
9.5.4	<i>Direct N<sub>2</sub>O Emissions from Agricultural Soils</i> .....	211
9.5.5	<i>Indirect Emissions of N<sub>2</sub>O from Soils</i> .....	213
9.6	Recalculations – Land Use, Land-Use Change and Forestry Sector .....	213
9.6.1	<i>Forest Land Remaining Forest Land</i> .....	214
9.6.2	<i>Cropland</i> .....	217
9.6.3	<i>Wetlands</i> .....	217
9.6.4	<i>Forest Land Conversion</i> .....	218
9.7	Recalculations – Waste Sector .....	219
9.8	Planned Improvements .....	220
9.8.1	<i>National System</i> .....	221
9.8.2	<i>National Registry</i> .....	221
9.8.3	<i>Mandatory Facility Level Reporting</i> .....	221
9.8.4	<i>Quality Assurance/Quality Control</i> .....	221
9.8.5	<i>Uncertainties</i> .....	221
9.8.6	<i>Key Categories</i> .....	222
9.8.7	<i>Energy Sector</i> .....	222
9.8.8	<i>Industrial Processes Sector</i> .....	222
9.8.9	<i>Agriculture Sector</i> .....	223
9.8.10	<i>Land Use, Land-Use Change and Forestry Sector</i> .....	223
9.8.11	<i>Waste Sector</i> .....	223
	<b>REFERENCES</b> .....	<b>224</b>
<b>ANNEX 1</b>	<b>KEY CATEGORIES</b> .....	<b>241</b>
A1.1	Key Categories—Methodology.....	241
A1.1.1	<i>Summary Assessment</i> .....	244
A1.2	Key Category Tables.....	246
A1.2.1	<i>Level Assessment With and Without LULUCF</i> .....	246
A1.2.2	<i>Trend Assessment With and Without LULUCF</i> .....	250
A1.2.3	<i>Qualitative Assessment</i> .....	254



References .....	256
<b>ANNEX 2 METHODOLOGY AND DATA FOR ESTIMATING EMISSIONS FROM FOSSIL FUEL COMBUSTION .....</b>	<b>258</b>
A2.1 Methodology .....	258
A2.2 Activity Data from Statistics Canada .....	259
A2.3 Fuel Combustion Emission Factors.....	260
A2.3.1 CO <sub>2</sub> Emission Factors.....	260
A2.3.2 Non-CO <sub>2</sub> Emission Factors.....	261
A2.3.3 Biomass.....	261
A2.4 Methodology for Stationary Combustion and Transport.....	261
A2.4.1 Stationary Combustion.....	261
A2.4.2 Transport (CRF Category 1.A.3) .....	280
References .....	286
<b>ANNEX 3 ADDITIONAL METHODOLOGIES .....</b>	<b>288</b>
A3.1 Methodology for Fugitive Emissions from Fossil Fuel Production, Processing, Transmission, and Distribution .....	288
A3.1.1 Solid Fuels.....	288
A3.1.2 Oil and Natural Gas.....	290
A3.2 Methodology for Industrial Processes.....	302
A3.2.1 CO <sub>2</sub> Emissions from Other and Undifferentiated Production.....	303
A3.2.2 CO <sub>2</sub> Emissions from Ammonia Production .....	305
A3.3 Methodology for the Agriculture Sector .....	307
A3.3.1 Animal Population Data Sources.....	307
A3.3.2 Cattle Characterization.....	308
A3.3.3 CH <sub>4</sub> Emissions from Enteric Fermentation.....	313
A3.3.4 CH <sub>4</sub> Emissions from Manure Management.....	315
A3.3.5 N <sub>2</sub> O Emissions from Manure Management.....	322
A3.3.6 N <sub>2</sub> O Emissions from Agricultural Soils.....	324
A3.4 Methodology for Land Use, Land-Use Change and Forestry.....	339
A3.4.1 Spatial Framework for LULUCF Estimate Development and Area Reconciliation .....	339
A3.4.2 Forest Land and Forest-Related Land-Use Change .....	341
A3.4.3 Cropland .....	358
A3.4.4 Grassland.....	380
A3.4.5 Wetlands.....	382
A3.4.6 Settlements .....	389
A3.4.7 Estimation of Delayed CO <sub>2</sub> Emissions from Harvested Wood Products (HWP).....	391
A3.5 Methodology for Waste.....	393
A3.5.1 CH <sub>4</sub> Emissions from Solid Waste Disposal on Land.....	393
A3.5.2 CH <sub>4</sub> Emissions from Wastewater Treatment.....	410
A3.5.3 N <sub>2</sub> O Emissions from Wastewater Treatment.....	415
A3.5.4 CO <sub>2</sub> Emissions from Municipal Waste Incineration.....	417
A3.5.5 N <sub>2</sub> O Emissions from Waste Incineration.....	420
A3.5.6 CH <sub>4</sub> Emissions from Waste Incineration.....	421
References .....	423
<b>ANNEX 4 COMPARISON OF SECTORAL AND REFERENCE APPROACHES.....</b>	<b>441</b>
A4.1 Comparison of Reference Approach with Sectoral Approach .....	441
A4.2 Reference-approach Methodology .....	442
A4.3 National Energy Balance.....	445

## TABLE OF CONTENTS

References .....	447
<b>ANNEX 5 ASSESSMENT OF COMPLETENESS .....</b>	<b>448</b>
<b>A5.1 Energy .....</b>	<b>448</b>
<b>A5.1.1 Emissions from Combustion of Waste Fuels .....</b>	<b>448</b>
<b>A5.1.2 Fuel Combustion—Transportation .....</b>	<b>448</b>
<b>A5.2 Industrial Processes .....</b>	<b>448</b>
<b>A5.2.1 Mineral Products .....</b>	<b>448</b>
<b>A5.2.2 Chemical Production .....</b>	<b>449</b>
<b>A5.2.3 Metal Production .....</b>	<b>449</b>
<b>A5.2.4 Production and Consumption of Halocarbons and SF<sub>6</sub> .....</b>	<b>449</b>
<b>A5.2.5 Other and Undifferentiated Production .....</b>	<b>449</b>
<b>A5.3 Solvent and Other Product Use .....</b>	<b>449</b>
<b>A5.4 Agriculture .....</b>	<b>450</b>
<b>A5.4.1 Enteric Fermentation and Manure Management .....</b>	<b>450</b>
<b>A5.4.2 Residue Burning .....</b>	<b>450</b>
<b>A5.4.3 Rice Production .....</b>	<b>450</b>
<b>A5.5 Land Use, Land-Use Change and Forestry .....</b>	<b>450</b>
<b>A5.5.1 Forest Land .....</b>	<b>450</b>
<b>A5.5.2 Cropland .....</b>	<b>451</b>
<b>A5.5.3 Grassland .....</b>	<b>451</b>
<b>A5.5.4 Wetlands .....</b>	<b>451</b>
<b>A5.5.5 Settlements .....</b>	<b>451</b>
<b>A5.6 Waste .....</b>	<b>451</b>
<b>A5.6.1 Unmanaged Solid Waste Disposal .....</b>	<b>452</b>
<b>A5.6.2 Domestic and Commercial Wastewater .....</b>	<b>452</b>
<b>A5.6.3 Industrial Wastewater .....</b>	<b>452</b>
<b>A5.6.4 Waste Incineration .....</b>	<b>452</b>
References .....	453
<b>ANNEX 6 QUALITY ASSURANCE AND QUALITY CONTROL .....</b>	<b>454</b>
<b>A6.1 Characteristics of the QA/QC Plan for the National Inventory .....</b>	<b>454</b>
<b>A6.2 Annual Inventory Development Process .....</b>	<b>455</b>
<b>A6.3 QC Procedures .....</b>	<b>456</b>
<b>A6.3.1 Tier 1 QC .....</b>	<b>456</b>
<b>A6.3.2 Tier 2 QC .....</b>	<b>456</b>
<b>A6.4 QA Procedures .....</b>	<b>457</b>
<b>A6.5 Verification .....</b>	<b>457</b>
<b>A6.6 Key QA/QC Achievements in the 2008 Inventory Submission .....</b>	<b>457</b>
References .....	458
<b>ANNEX 7 UNCERTAINTY .....</b>	<b>459</b>
<b>A7.1 Introduction .....</b>	<b>459</b>
<b>A7.2 Overall Inventory Uncertainty for 2001 (Reported in NIR 2003) .....</b>	<b>459</b>
<b>A7.3 Scope of 2004–2005 Uncertainty Study .....</b>	<b>460</b>
<b>A7.3.1 General Concepts .....</b>	<b>460</b>
<b>A7.3.2 Input Data for the Uncertainty Model .....</b>	<b>461</b>
<b>A7.3.3 Level of Aggregation Adopted for Uncertainty Analysis .....</b>	<b>461</b>
<b>A7.3.4 Sensitivity Analysis .....</b>	<b>463</b>
<b>A7.4 Summary of Sector Uncertainties .....</b>	<b>463</b>

A7.4.1	Energy.....	473
A7.4.2	Industrial Processes.....	474
A7.4.3	Solvent and Other Product Use.....	475
A7.4.4	Agriculture.....	476
A7.4.5	Land Use, Land-Use Change and Forestry.....	476
A7.4.6	Waste.....	476
References	.....	477
<b>ANNEX 8</b>	<b>CANADA'S GREENHOUSE GAS EMISSION TABLES, 1990–2006.....</b>	<b>479</b>
<b>ANNEX 9</b>	<b>ELECTRICITY INTENSITY TABLES.....</b>	<b>498</b>
A9.1	Methodology and Limitations.....	498
A9.2	National Trends.....	499
A9.3	Sectoral Discussion.....	501
A9.4	Regional Discussion.....	504
A9.5	GHG Emission Intensities.....	506
References	.....	519
<b>ANNEX 10</b>	<b>PROVINCIAL/TERRITORIAL ANALYSIS.....</b>	<b>520</b>
A10.1	Newfoundland and Labrador.....	522
A10.1.1	Long-Term Trends (1990–2006).....	523
A10.1.2	Short-Term Changes (2005–2006).....	523
A10.2	Prince Edward Island.....	525
A10.2.1	Long-Term Trends (1990–2006).....	526
A10.2.2	Short-Term Changes (2005–2006).....	527
A10.3	Nova Scotia.....	528
A10.3.1	Long-Term Trends (1990–2006).....	529
A10.3.2	Short-Term Changes (2005–2006).....	530
A10.4	New Brunswick.....	532
A10.4.1	Long-Term Trends (1990–2006).....	533
A10.4.2	Short-Term Changes (2005–2006).....	533
A10.5	Quebec.....	535
A10.5.1	Long-Term Trends (1990–2006).....	536
A10.5.2	Short-Term Changes (2005–2006).....	537
A10.6	Ontario.....	539
A10.6.1	Long-Term Trends (1990–2006).....	540
A10.6.2	Short-Term Changes (2005–2006).....	540
A10.7	Manitoba.....	543
A10.7.1	Long-Term Trends (1990–2006).....	544
A10.7.2	Short-Term Changes (2005–2006).....	544
A10.8	Saskatchewan.....	546
A10.8.1	Long-Term Trends (1990–2006).....	547
A10.8.2	Short-Term Changes (2005–2006).....	548
A10.9	Alberta.....	550
A10.9.1	Long-Term Trends (1990–2006).....	551
A10.9.2	Short-Term Changes (2005–2006).....	552
A10.10	British Columbia.....	554
A10.10.1	Long-Term Trends (1990–2006).....	555
A10.10.2	Short-Term Changes (2005–2006).....	556
A10.11	Yukon, Northwest Territories, and Nunavut.....	558

## TABLE OF CONTENTS

References .....	562
<b>ANNEX 11 PROVINCIAL/TERRITORIAL GREENHOUSE GAS EMISSION TABLES, 1990–2006 .....</b>	<b>566</b>
<b>ANNEX 12 EMISSION FACTORS.....</b>	<b>595</b>
<b>A12.1 Fuel Combustion .....</b>	<b>595</b>
<i>A12.1.1 Natural Gas and Natural Gas Liquids .....</i>	<i>595</i>
<i>A12.1.2 Refined Petroleum Products.....</i>	<i>596</i>
<i>A12.1.3 Coal and Coal Products.....</i>	<i>598</i>
<i>A12.1.4 Mobile Combustion .....</i>	<i>600</i>
<b>A12.2 Fugitive Emission Factors: Coal Mining.....</b>	<b>602</b>
<b>A12.3 Industrial Processes .....</b>	<b>602</b>
<i>A12.3.1 Mineral, Chemical, and Metal Industries .....</i>	<i>602</i>
<i>A12.3.2 Consumption of Halocarbons.....</i>	<i>604</i>
<i>A12.3.3 Other and Undifferentiated Production .....</i>	<i>606</i>
<b>A12.4 Solvent and Other Product Use .....</b>	<b>606</b>
<b>A12.5 Agriculture .....</b>	<b>607</b>
<b>A12.6 Biomass Combustion .....</b>	<b>608</b>
<i>A12.6.1 CO<sub>2</sub>.....</i>	<i>608</i>
<i>A12.6.2 CH<sub>4</sub>.....</i>	<i>609</i>
<i>A12.6.3 N<sub>2</sub>O.....</i>	<i>609</i>
References .....	610
<b>ANNEX 13 ROUNDING PROTOCOL.....</b>	<b>613</b>
References .....	615
<b>ANNEX 14 OZONE AND AEROSOL PRECURSORS .....</b>	<b>616</b>

## List of Tables

Table S-1:	Canada's GHG Emissions and Accompanying Variables, 1990–2006.....	5
Table S-2:	Canada's GHG Emissions by Gas and Sector, 2006.....	8
Table S-3:	Canada's GHG Emissions by Sector, 1990–2006.....	12
Table S-4:	Crude Oil: Production, Export, and GHG Emission Trends, 1990–2006 .....	15
Table S-5:	Natural Gas: Production, Export, and GHG Emission Trends, 1990–2006 .....	15
Table S-6:	Combined Crude Oil and Natural Gas: Production, Export, and GHG Emission Trends, 1990–2006 .....	15
Table 1-1:	GWPs and Atmospheric Lifetimes .....	23
Table 1-2:	Facility-Reported 2006 GHG Emissions by Gas.....	32
Table 1-3:	Facility-Reported 2006 GHG Emissions by Province/Territory .....	33
Table 1-4:	Sectoral contribution to reported GHG emissions, 2004 to 2006.....	34
Table 2-1:	GHG Emissions from Energy by UNFCCC CRF Sector, 1990–2006 .....	40
Table 2-2:	GHG Emissions from Public Electricity and Heat Production, 1990–2006.....	41
Table 2-3:	GHG Emissions from Petroleum Refining and Manufacture of Solid Fuels and Other Energy Industries, 1990–2006 .....	42
Table 2-4:	GHG Emissions from Manufacturing, Construction, and Mining, 1990–2006 ..	43
Table 2-5:	GHG Emissions from Transport, 1990–2006.....	44
Table 2-6:	Trends in Vehicle Populations for Canada, 1990–2006 .....	45
Table 2-7:	Fugitive GHG Emissions Intensity of Oil and Gas Production by Category, Selected Years .....	48
Table 2-8:	GHG Emissions from Industrial Processes by Category, Selected Years .....	50
Table 2-9:	GHG Emissions from Waste, Selected Years .....	56
Table 3-1:	GHG Emissions from Energy, Selected Years.....	59
Table 3-2:	Energy Industries GHG Contribution.....	61
Table 3-3:	Manufacturing Industries and Construction GHG Contribution .....	66
Table 3-4:	Transport GHG Contribution .....	68
Table 3-5:	Other Sectors GHG Contribution .....	74
Table 3-6:	Fugitive GHG Contribution.....	76
Table 3-7:	Uncertainty in Oil Production Industry Fugitive Emissions .....	82
Table 3-8:	Uncertainty in Natural Gas Production Industry Fugitive Emissions .....	82
Table 3-9:	Uncertainty in Oil Refining Fugitive Emissions .....	83
Table 3-10:	GHG Emissions from Domestic and International Aviation, 1990–2006.....	85
Table 3-11:	GHG Emissions from Domestic and International Navigation, 1990–2006 .....	85
Table 3-12:	Ethanol Used for Transport in Canada, 1990–2006 .....	87
Table 3-13:	Reconciliation of Reference Approach and Sectoral Approach for Canada .....	88
Table 4-1:	GHG Emissions from the Industrial Processes Sector, Selected Years .....	92
Table 4-2:	Nitric Acid Industry–Typical Emission Factors.....	105
Table 4-3:	Default Tier 2 Parameter Values for the Estimation of CO <sub>2</sub> Emissions from Anode Consumption.....	114
Table 4-4:	Default Tier 2 Parameter Values for the Estimation of CO <sub>2</sub> Emissions from Anode Baking.....	115
Table 4-5:	Tier 2 Default Slope and Overvoltage Coefficients (IAI 2006) .....	116

## LIST OF TABLES

Table 4-6:	PFC Emission Factors .....	117
Table 4-7:	Percentage of Losses during Assembly (k) for Various Applications.....	125
Table 4-8:	Annual Leakage Rates (x) for Various Applications .....	126
Table 4-9:	PFC Emission Rates .....	129
Table 5-1:	Solvent and Other Product Use Sector GHG Emission Summary, Selected Years .....	135
Table 6-1:	Short- and Long-Term Changes in GHG Emissions from the Agriculture Sector .....	140
Table 6-2:	Animal Categories and Sources of Population Data .....	141
Table 7-1:	LULUCF Sector Net GHG Flux Estimates, Selected Years .....	157
Table 7-2:	Managed Land Areas (kha) in the 2006 LULUCF Accounting System .....	160
Table 7-3:	GHG Balance of Managed Forests by Reporting Zone, 2006.....	162
Table 7-4:	Base and Recent Year Emissions and Removals Associated with Various Land Management Changes on Cropland remaining Cropland .....	166
Table 7-5:	Level and Trend Uncertainty Estimates for Various Land Management Changes in Mineral Soils of Cropland Remaining Cropland .....	169
Table 8-1:	Waste Sector GHG Emission Summary, Selected Years .....	186
Table 8-2:	MSW Landfill k Value Estimates for Each Province/Territory .....	189
Table 8-3:	CH <sub>4</sub> Generation Potential (L <sub>0</sub> ) from 1941 to Present .....	191
Table 8-4:	N <sub>2</sub> O Emission Factors .....	195
Table 9-1:	Summary of Recalculations.....	203
Table 9-2:	Comparison of manure nitrogen excretion rates between ASAE (2003) and IPCC (2006).....	210
Table 9-3:	Estimate of Managed Forest Area for inventory year 1990 .....	215
Table 9-4:	Average Net Forest Primary Productivity in the 2006 and 2008 Submissions .	216
Table 9-5:	Areas of managed forest burned, with immediate emissions, 2006 and 2008 submissions .....	217
Table 9-6:	Emissions from Deforestation, 2006 and 2008 submissions.....	219
Table A1-1:	Key Category Analysis Summary, 2006 Inventory.....	244
Table A1-2:	2006 Key Categories by Level Assessment With and Without LULUCF .....	247
Table A1-3:	2006 Key Categories by Trend Assessment With and Without LULUCF.....	251
Table A1-4:	Key Categories by Significant Mitigation Techniques and Technologies .....	254
Table A1-5:	Key Categories Identified from Anticipated High Emission Growth .....	255
Table A1-6:	Key Categories with a High Composite Uncertainty .....	256
Table A2-1:	Estimation Methodology for GHG Emissions from Stationary Combustion....	263
Table A2-2:	General Fuel Type Categories for Stationary Combustion Methodology .....	277
Table A2-3:	Activity Data Model References .....	277
Table A2-4:	Technology Penetration for HDGVs, HDDVs, LDDVs, LDDTs, and MCs.....	282
Table A3-1:	Fugitive Emission Factors for Coal Mining .....	290
Table A3-2:	Allocation of UOG Inventory Emissions to CRF Fugitive Categories .....	291
Table A3-3:	Required Activity Data and Their Source .....	294
Table A3-4:	Activity Data Used to Pro-rate Emission Sectors and Sources .....	295
Table A3-5:	Natural Gas Transmission Emission Factors for 1997–2006 .....	296
Table A3-6:	CH <sub>4</sub> Emission Factors for Fugitive Natural Gas Distribution Emissions.....	299

Table A3-7:	Emission Source Categories and Process Areas in the Bitumen Report (CAPP 2006) .....	300
Table A3-8:	Activity Data Required for the Extrapolation Model .....	302
Table A3-9:	CO <sub>2</sub> Emission Factors for Natural Gas Liquids .....	304
Table A3-10:	CO <sub>2</sub> Emission Factors for Non-Energy Petroleum Products .....	305
Table A3-11:	Derivation of Ammonia Production–Based Emission Factor .....	306
Table A3-12:	Data Sources for Animal Populations .....	308
Table A3-13:	Characteristics of Dairy Production in 2001 in Canada .....	309
Table A3-14:	Average Milk Production from 1990 to 2006 and Number of Milking Days at a Provincial Level.....	310
Table A3-15:	Characteristics of Beef Production in Canada in 2001 .....	311
Table A3-16:	Carcass weights used as an indicator of live body weight change over time for some of non-dairy cattle .....	313
Table A3-17:	CH <sub>4</sub> Emission Factors for Enteric Fermentation for Cattle from 1990 to 2006 .....	314
Table A3-18:	Approximate Digestible Energy (DE) for Selected Livestock and Data Sources.....	317
Table A3-19:	Dry Matter Intake for Selected Livestock .....	317
Table A3-20:	Manure Ash Content for Selected Livestock and Data Sources.....	318
Table A3-21:	Mean Volatile Solids and associated 95% confidence interval, expressed as a percentage of the mean for non-cattle category per province .....	319
Table A3-22:	Percentage of Manure Handled by Animal Waste Management Systems (AWMS) (Marinier et al. 2004) .....	320
Table A3-23:	CH <sub>4</sub> Emission Factors for Manure Management for Dairy and Non-Dairy Cattle from 1990 to 2006.....	321
Table A3-24:	CH <sub>4</sub> Emission Factors for Manure Management for Non-Cattle .....	321
Table A3-25:	Manure N excretion rates for non-cattle.....	323
Table A3-26:	Manure N excretion rates time series for cattle (kg N/head/year).....	323
Table A3-27:	Total N and NH <sub>3</sub> - and NO <sub>x</sub> -N Losses Associated with Various Livestock and Manure Management Systems.....	329
Table A3-28:	Spatial Analysis Units of Managed Forests.....	340
Table A3-29:	Estimates of Land, Water, Managed Forest and Cropland Areas in 2006 .....	341
Table A3-30:	Forest Carbon Pools in IPCC and CBM-CFS3 .....	342
Table A3-31:	Main Sources of Information and Data, Managed Forests .....	346
Table A3-32:	GHG Emissions/Removals of Managed Forests, 2006 .....	357
Table A3-33:	Generalized Values of Parameters for $F_{LMC}(t) = \Delta C_{LMCmax} \times [1 - \exp^{-(k \times t)}]$ to Predict Change from Land Management Change (LMC) and Effective Linear Coefficients of SOC Change.....	365
Table A3-34:	SOC for Forested and Agricultural Land in Eastern and Western Canada from the Canadian Soil Information System Database (0- to 30-cm soil depth).....	376
Table A3-35:	Parameters and Emission Factors for Estimating CO <sub>2</sub> -C Emissions from Wetlands (Peatlands).....	384
Table A3-36:	Multiple Linear Regression Polynomial Coefficients Used in Estimating the Amount of MSW Landfilled for 1991–1997 and 2005 .....	396
Table A3-37:	MSW Landfilled for 1990–2006 .....	397
Table A3-38:	Wood Waste Generated and Landfilled in Canada for 1990–2006.....	398

## LIST OF TABLES

Table A3-39:	Mean Annual Precipitation and MSW Landfill k Value Estimates for Provincial Landfill Sites .....	399
Table A3-40:	MSW Landfill k Value Estimates for Each Province .....	401
Table A3-41:	Solid Waste Disposal Site CH <sub>4</sub> Correction Factors .....	402
Table A3-42:	Provincial and Territorial CH <sub>4</sub> Generation Potential (L <sub>0</sub> ) Values .....	403
Table A3-43:	Provincial and Territorial CH <sub>4</sub> Generation Potential (L <sub>0</sub> ) Values .....	405
Table A3-44:	Estimated MSW CH <sub>4</sub> Captured, Flared, and Emitted for 1990–2006 .....	409
Table A3-45:	Percentage of Wastewater Treated Anaerobically by Province .....	412
Table A3-46:	Multiple Linear Regression Polynomial Coefficients Used in Estimating the Amount of Industrial Wastewater Treated for 1987–1990 and 1992–1995 .....	413
Table A3-47:	Volume of Wastewater Treated per Industry Type for 1986–2006 .....	414
Table A3-48:	COD Values Used in CH <sub>4</sub> Emission Estimates per Industry Type .....	415
Table A3-49:	Canadian Protein Consumption .....	416
Table A3-50:	Estimated MSW Incinerated by Province for 1990–2006 .....	418
Table A3-51:	Estimated MSW Organic Composition .....	418
Table A3-52:	Estimated Sewage Sludge Incinerated for 1990–2006 .....	422
Table A4-1:	Comparison of Adjusted Reference Approach and Sectoral Approach for Canada .....	442
Table A4-2:	Reference Approach Energy Conversion and Emission Factors for Canada ....	444
Table A7-1:	Quantitative Tier 2 Uncertainty Assessment of Overall National Inventory GHG Emissions and Trends for 2001 by Gas .....	460
Table A7-2:	Level of Aggregation Adopted for the Uncertainty Analysis, by Key Source Category (Canada’s Greenhouse Gas Inventory, 1990–2001, Submitted by Environment Canada in 2003) .....	462
Table A7-3:	Tier 2 Uncertainty Reporting—Energy (Stationary Combustion) .....	464
Table A7-4:	Tier 2 Uncertainty Reporting—Energy (Transport) .....	466
Table A7-5:	Tier 2 Uncertainty Reporting—Energy (Fugitives) .....	468
Table A7-6:	Tier 2 Uncertainty Reporting—Industrial Processes, Solvent and Other Product Use .....	469
Table A7-7:	Tier 2 Uncertainty Reporting—Agriculture .....	471
Table A7-8:	Tier 2 Uncertainty Reporting—Waste .....	471
Table A8-1:	GHG Source/Sink Category Description .....	479
Table A8-2:	Canada’s 1990–2006 GHG Emissions by Sector .....	480
Table A8-3:	2006 GHG Emission Summary for Canada .....	481
Table A8-4:	2005 GHG Emission Summary for Canada .....	482
Table A8-5:	2004 GHG Emission Summary for Canada .....	483
Table A8-6:	2003 GHG Emission Summary for Canada .....	484
Table A8-7:	2002 GHG Emission Summary for Canada .....	485
Table A8-8:	2001 GHG Emission Summary for Canada .....	486
Table A8-9:	2000 GHG Emission Summary for Canada .....	487
Table A8-10:	1999 GHG Emission Summary for Canada .....	488
Table A8-11:	1998 GHG Emission Summary for Canada .....	489
Table A8-12:	1997 GHG Emission Summary for Canada .....	490
Table A8-13:	1996 GHG Emission Summary for Canada .....	491
Table A8-14:	1995 GHG Emission Summary for Canada .....	492



Table A8-15:	1994 GHG Emission Summary for Canada .....	493
Table A8-16:	1993 GHG Emission Summary for Canada .....	494
Table A8-17:	1992 GHG Emission Summary for Canada .....	495
Table A8-18:	1991 GHG Emission Summary for Canada .....	496
Table A8-19:	1990 GHG Emission Summary for Canada .....	497
Table A9-1:	Electricity Generation and GHG Emission Details for Canada .....	507
Table A9-2:	Electricity Generation and GHG Emission Details for Newfoundland and Labrador .....	508
Table A9-3:	Electricity Generation and GHG Emission Details for Prince Edward Island ..	509
Table A9-4:	Electricity Generation and GHG Emission Details for Nova Scotia .....	510
Table A9-5:	Electricity Generation and GHG Emission Details for New Brunswick.....	511
Table A9-6:	Electricity Generation and GHG Emission Details for Quebec .....	512
Table A9-7:	Electricity Generation and GHG Emission Details for Ontario .....	513
Table A9-8:	Electricity Generation and GHG Emission Details for Manitoba .....	514
Table A9-9:	Electricity Generation and GHG Emission Details for Saskatchewan .....	515
Table A9-10:	Electricity Generation and GHG Emission Details for Alberta .....	516
Table A9-11:	Electricity Generation and GHG Emission Details for British Columbia.....	517
Table A9-12:	Electricity Generation and GHG Emission Details for Yukon, Northwest Territories, and Nunavut.....	518
Table A10-1:	Trends in GHG Emissions and GHG Intensity, Newfoundland and Labrador .	522
Table A10-2:	Trends in GHG Emissions and GHG Intensity, Prince Edward Island .....	525
Table A10-3:	Trends in GHG Emissions and GHG Intensity, Nova Scotia.....	528
Table A10-4:	Trends in GHG Emissions and GHG Intensity, New Brunswick.....	532
Table A10-5:	Trends in GHG Emissions and GHG Intensity, Quebec .....	535
Table A10-6:	Trends in GHG Emissions and GHG Intensity, Ontario .....	539
Table A10-7:	Trends in GHG Emissions and GHG Intensity, Manitoba .....	543
Table A10-8:	Trends in GHG Emissions and GHG Intensity, Saskatchewan.....	546
Table A10-9:	Trends in GHG Emissions and GHG Intensity, Alberta .....	550
Table A10-10:	Trends in GHG Emissions and GHG Intensity, British Columbia.....	554
Table A10-11:	Trends in GHG Emissions and GHG Intensity, Total Territories .....	558
Table A10-12:	Trends in GHG Emissions, Yukon.....	558
Table A10-13:	Trends in GHG Emissions, Northwest Territories and Nunavut.....	559
Table A11-1:	GHG Category Description .....	567
Table A11-2:	1990–2006 GHG Emission Summary for Newfoundland and Labrador .....	568
Table A11-3:	2006 GHG Emission Summary for Newfoundland and Labrador .....	569
Table A11-4:	1990–2006 GHG Emission Summary for Prince Edward Island .....	570
Table A11-5:	2006 GHG Emission Summary for Prince Edward Island .....	571
Table A11-6:	1990–2006 GHG Emission Summary for Nova Scotia.....	572
Table A11-7:	2006 GHG Emission Summary for Nova Scotia.....	573
Table A11-8:	1990–2006 GHG Emission Summary for New Brunswick.....	574
Table A11-9:	2006 GHG Emission Summary for New Brunswick .....	575
Table A11-10:	1990–2006 GHG Emission Summary for Quebec .....	576
Table A11-11:	2006 GHG Emission Summary for Quebec .....	577
Table A11-12:	1990–2006 GHG Emission Summary for Ontario .....	578

## LIST OF TABLES

Table A11-13:	2006 GHG Emission Summary for Ontario .....	579
Table A11-14:	1990–2006 GHG Emission Summary for Manitoba .....	580
Table A11-15:	2006 GHG Emission Summary for Manitoba .....	581
Table A11-16:	1990–2006 GHG Emission Summary for Saskatchewan.....	582
Table A11-17:	2006 GHG Emission Summary for Saskatchewan.....	583
Table A11-18:	1990–2006 GHG Emission Summary for Alberta .....	584
Table A11-19:	2006 GHG Emission Summary for Alberta .....	585
Table A11-20:	1990–2006 GHG Emission Summary for British Columbia.....	586
Table A11-21:	2006 GHG Emission Summary for British Columbia.....	587
Table A11-22:	1990–2006 GHG Emission Summary for Yukon .....	588
Table A11-23:	2006 GHG Emission Summary for Yukon .....	589
Table A11-24:	1999–2006 GHG Emission Summary for Northwest Territories.....	590
Table A11-25:	2006 GHG Emission Summary for Northwest Territories.....	591
Table A11-26:	1999–2006 GHG Emission Summary for Nunavut.....	592
Table A11-27:	2006 GHG Emission Summary for Nunavut.....	593
Table A11-28:	1990–1998 GHG Emission Summary for Northwest Territories (including Nunavut) .....	594
Table A12-1:	Emission Factors for Natural Gas and NGLs .....	596
Table A12-2:	Emission Factors for Refined Petroleum Products.....	597
Table A12-3:	CO <sub>2</sub> Emission Factors for Petroleum Coke and Still Gas .....	598
Table A12-4:	N <sub>2</sub> O Emission Factors for Petroleum Coke.....	598
Table A12-5:	CO <sub>2</sub> Emission Factors for Coal and Coal Products .....	599
Table A12-6:	CH <sub>4</sub> and N <sub>2</sub> O Emission Factors for Coals .....	600
Table A12-7:	Emission Factors for Energy Mobile Combustion Sources .....	601
Table A12-8:	Emission Factors for Fugitive Sources—Coal Mining .....	602
Table A12-9:	Emission Factors for Industrial Process Sources.....	603
Table A12-10:	Emission Factors for Consumption of HFCs in 1995 .....	604
Table A12-11:	Emission Rates for Consumption of HFCs and PFCs .....	605
Table A12-12:	CO <sub>2</sub> Emission Factors for Natural Gas Liquids .....	606
Table A12-13:	CO <sub>2</sub> Emission Factors for Non-Energy Petroleum Products.....	606
Table A12-14:	Emission Factors for Solvent and Other Product Use .....	606
Table A12-15:	CH <sub>4</sub> Emission Factors for Enteric Fermentation for Non-Cattle Animals .....	607
Table A12-16:	Values of Maximum CH <sub>4</sub> Producing Potential (B <sub>0</sub> ) for Various Livestock Types .....	607
Table A12-17:	CH <sub>4</sub> Conversion Factor (MCF) by animal category and manure management system.....	608
Table A12-18:	Percentage of Manure N Lost as N <sub>2</sub> O-N for Specific Animal Waste Management Systems (IPCC/OECD/IEA (1997)).....	608
Table A12-19:	Emission Factors for Biomass .....	610
Table A13-1:	Number of Significant Figures Applied to GHG Summary Tables .....	614
Table A14-1:	Carbon Monoxide Emissions Summary for Canada .....	617
Table A14-2:	Nitrogen Oxides Emissions Summary for Canada.....	618
Table A14-3:	Non-Methane Volatile Organic Compounds Emissions Summary for Canada .....	619
Table A14-4:	Sulphur Oxides Emissions Summary for Canada .....	620

## List of Figures

Figure S-1:	Canadian GHG Emission Trend and Kyoto Target.....	4
Figure S-2:	Trends in Energy, Population and GHG Emissions Indicators, 1990–2006 .....	6
Figure S-3:	Sectoral Breakdown of Canada’s GHG Emissions, 2006 .....	9
Figure S-4:	Total Provincial/Territorial GHG Emissions, 1990 and 2006.....	16
Figure 1-1:	Annual Canadian Temperature Departures and Long-Term Trend, 1948–2006 (°C).....	18
Figure 1-2:	Global Atmospheric Concentrations of CO <sub>2</sub> , 1992–2006 .....	20
Figure 1-3:	Global Atmospheric Concentrations of CH <sub>4</sub> , 1992–2006 .....	21
Figure 1-4:	Global Atmospheric Concentrations of N <sub>2</sub> O, 1993–2006.....	22
Figure 1-5:	Per Capita GHG Emission Trend for Canada, 1990–2006.....	24
Figure 1-6:	Change in Aggregate GHG Emissions for Annex I Parties without LULUCF, 1990–2005 .....	25
Figure 1-7:	Partners of the National Inventory System.....	27
Figure 2-1:	Canada’s GHG Emissions by Gas, 1990 and 2006 (excluding LULUCF) .....	39
Figure 2-2:	GHG Emissions and HDDs from Residential and Commercial Sectors, 1990–2006 .....	46
Figure 2-3:	GHG Emissions from Industrial Processes by Category, 1990–2006.....	50
Figure 2-4:	GHG Emissions from Agriculture, 1990–2006.....	53
Figure 2-5:	GHG Emissions from LULUCF Relative to Total Canadian Emissions, 1990–2006.....	54
Figure 2-6:	Selected GHG Emissions and Removals in LULUCF, 1990–2006 .....	55
Figure 2-7:	GHG Emissions from Waste, 1990–2006 .....	57
Figure 2-8:	Per Capita GHG Emission Trend for Waste, 1990–2006.....	58
Figure 3-1:	GHG Emissions from Fuel Combustion, 1990–2006.....	60
Figure 7-1:	Reporting Zones Spatial Framework for LULUCF Estimate Development .....	160
Figure 7-2:	Large Annual Carbon Fluxes to and from the Atmosphere in Managed Forests, 1990–2006 .....	163
Figure 7-3:	Areas of and CO <sub>2</sub> Emissions from Managed Peatlands, 1990–2006 (LWL: land converted to wetlands; WLWL: wetlands remaining wetlands).....	178
Figure 9-1:	Emissions/removals in the 2006 and 2008 submissions, LULUCF Sector .....	214
Figure 9-2:	Trends in the Managed Forest Land Category, 2006 and 2008 submissions ....	215
Figure A1-1:	Contributions of Key Categories to Level Assessment With and Without LULUCF .....	249
Figure A1-2:	Contributions of Key Categories to Trend Assessment With and Without LULUCF .....	253
Figure A2-1:	GHG Estimation Process Flow.....	259
Figure A2-2:	Technology Penetration for Light-Duty Gasoline Vehicles and Trucks .....	282
Figure A3-1:	Non-dairy cattle carcass weight, based on data collected by CBGA and published by AAFC.....	312
Figure A3-2:	N <sub>2</sub> O Emissions as a function of long-term ratio of precipitation over potential evapotranspiration (P/PE) from 1971 to 2000.....	326
Figure A3-3:	Determination of the Ecodistrict FRAC <sub>LEACH</sub> Values .....	339

## TABLE OF FIGURES

Figure A3-4:	Carbon Transfers Between Pools at Each Annual Time Step as Modelled in CBM-CFS3.....	343
Figure A3-5:	Disturbance Matrix Simulating the Carbon Transfers Associated with Forest Conversion with Harvest and Slash Burning, Applied to Forest Conversion in Reporting Zone 9 (Boreal Shield West) .....	344
Figure A3-6:	Managed and Unmanaged Forests in Canada .....	347
Figure A3-7:	Deforestation Strata and Areas Sampled for the 2006 and 2007 Submissions..	349
Figure A3-8:	Sampling Grids over Imagery for Forest Conversion Mapping and Delineated Forest Conversion Events.....	350
Figure A3-9:	Procedure to Develop a Consistent Time Series of Rates of Forest Conversion	352
Figure A3-10:	Annual Rates of Forest Conversion in Canada.....	353
Figure A3-11:	Soil Organic Carbon (SOC) for a Base Crop Mix, for Perennial (Alfalfa) Substituted for Annual Crops (Wheat), and for No-Till (NT) Substituted for Intensive Till (IT) Based on Century Runs for a Lethbridge Loam .....	362
Figure A3-12:	Change in SOC for Simulations with Substitutions Relative to Simulations with Base Crop Mix .....	362
Figure A3-13:	$F_{LMC}$ from Exponential Equation.....	364
Figure A3-14:	Century-simulated SOC dynamics after breaking of Grassland to Cropland for the Brown (pink) and Dark Brown (black) Chernozemic soils .....	374
Figure A3-15:	Century-Simulated SOC Following Deforestation of Long-Term Deciduous Forest to Cropland .....	377
Figure A3-16:	Logarithmic Curve Fits for a) Taiga/Boreal/Hudson Plain Reservoirs and b) Montane Cordillera Reservoirs .....	386
Figure A3-17:	Cumulative Areas in the Lands Converted to Wetlands (Flooded Lands) Category .....	388
Figure A3-18:	Study Areas for the Determination of Above-Ground Biomass.....	390
Figure A3-19:	Scholl Canyon Model Representation of Landfill Degradation .....	394
Figure A4-1:	Sample of an Energy Balance Flow Diagram for Canada.....	445
Figure A4-2:	Fossil Fuel and Energy Data Input .....	446
Figure A6-1:	Typical Inventory Process Figure.....	455
Figure A9-1:	Utility-Generated Electricity by Source .....	499
Figure A9-2:	Electricity Consumption by Manufacturing Industry .....	502
Figure A9-3:	Electricity Generation by Region and Source, 1990 and 2006.....	505
Figure A10-1:	Provincial GHG Contributions – 1990 (592 Mt).....	521
Figure A10-2:	Provincial GHG Contributions – 2006 (721 Mt).....	521
Figure A10-3:	Newfoundland and Labrador Long-Term Emission Trends, 1990–2006.....	524
Figure A10-4:	Newfoundland and Labrador Short-Term Emission Changes, 2005–2006.....	525
Figure A10-5:	Prince Edward Island Long-Term Emission Trends, 1990–2006 .....	527
Figure A10-6:	Prince Edward Island Short-Term Emission Changes, 2005–2006 .....	528
Figure A10-7:	Nova Scotia Long-Term Emission Trends, 1990–2006 .....	531
Figure A10-8:	Nova Scotia Short-Term Emission Changes, 2005–2006 .....	531
Figure A10-9:	New Brunswick Long-Term Emission Trends, 1990–2006.....	534
Figure A10-10:	New Brunswick Short-Term Emission Changes, 2005–2006 .....	535
Figure A10-11:	Quebec Long-Term Emission Trends, 1990–2006 .....	538
Figure A10-12:	Quebec Short-Term Emission Changes, 2005–2006.....	538

Figure A10-13: Ontario Long-Term Emission Trends, 1990–2006 .....	542
Figure A10-14: Ontario Short-Term Emission Changes, 2005–2006.....	542
Figure A10-15: Manitoba Long-Term Emission Trends, 1990–2006 .....	545
Figure A10-16: Manitoba Short-Term Emission Changes, 2005–2006 .....	546
Figure A10-17: Saskatchewan Long-Term Emission Trends, 1990–2006.....	549
Figure A10-18: Saskatchewan Short-Term Emission Changes, 2005–2006 .....	549
Figure A10-19: Alberta Long-Term Emission Trends, 1990–2006.....	553
Figure A10-20: Alberta Short-Term Emission Changes, 2005–2006.....	553
Figure A10-21: British Columbia Long-Term Emission Trends, 1990–2006 .....	557
Figure A10-22: British Columbia Short-Term Emission Changes, 2005–2006 .....	557
Figure A10-23: Yukon Long-Term Emission Trends, 1990–2006.....	560
Figure A10-24: Northwest Territories and Nunavut Long-Term Emission Trends, 1990–2006.....	561
Figure A10-25: Yukon Short-Term Emission Changes, 2005–2006.....	561
Figure A10-26: Northwest Territories and Nunavut Short-Term Emission Changes, 2005–2006.....	562



# EXECUTIVE SUMMARY

## ***ES.1 Greenhouse Gas Inventories and Climate Change***

The United Nations Framework Convention on Climate Change (UNFCCC)—Article 4(1)(a), Article 12(1)(a), and Decision 3/CP.5—requires Annex I Parties to submit an annual greenhouse gas (GHG) inventory report using the UNFCCC’s guidelines. The year 2008 marks the production of Canada’s 14th National Inventory Report (NIR). It is also the fourth inventory since the Kyoto Protocol to the UNFCCC, which Canada ratified in 2002, came into force. Underpinning the UNFCCC is the national GHG inventory, composed of the National Inventory Report and Common Reporting Format tables. It is the key tool for monitoring and reporting on emissions from sources and removals by sinks and, with respect to the Kyoto Protocol, is the ultimate measure for assessing compliance with the national emissions target. Canada considers the GHG National Inventory Program a priority, and Environment Canada is committed to ensuring adequate funding.

Guidelines under the UNFCCC and the Kyoto Protocol have a number of implications for reporting and review requirements. Annex I countries are expected to estimate GHG emissions by sources and removals by sinks using agreed-upon methodologies, as outlined in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997), *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000), and *Good Practice Guidance for Land Use, Land-Use Change and Forestry* (IPCC 2003). As a result, the UNFCCC requires that countries identify, quantify, and reduce uncertainty of estimates as much as practicable. This results in a process of continuous evaluation and improvement of methods, models, and documentation to ensure that internationally agreed upon standards are met. These activities are designed to ensure that all sources and sinks, and therefore all emission reductions and enhancements of removals, are properly accounted for.

The national inventory system includes all institutional, legal, and procedural arrangements made within a Party for estimating emissions and removals of GHGs according to the above methodologies, as well as for reporting and archiving the inventory information. Canada’s initial report, as required under the Kyoto Protocol, was submitted to the UNFCCC last year. It included, among other things, a description of the national system and a calculation of Canada’s assigned amount (emission target) under Article 7.4. The initial report, along with the inventory submitted in 2006, was subjected to a full review by a UNFCCC expert review team in the fall of 2007.

As a result of this review, which identified areas for improvement in the inventory, Canada has made a number of refinements in its methodologies and incorporated them in a resubmission of its 2006 estimates on January 23, 2008. All of these methodological refinements are reported on in this document. In addition, as these improvements affect the estimates originally submitted in the *2007 National Inventory Report*, that inventory is now superseded by this report, which acts as both Canada’s 2007 resubmission and its 2008 submission.

This report therefore incorporates two years of improvements in the estimation methodologies, including:

- in the Energy Sector — results of a detailed study on fugitive emissions from the non-conventional oil extraction industry, new data on vehicles and new emission factors for transport-related CH<sub>4</sub> and N<sub>2</sub>O have been incorporated;

- in the Waste Sector — revised estimation methods;
- in the Agricultural Sector — improvements to estimates, including the incorporation of new census data;
- in the Land Use, Land Use Change and Forestry (LULUCF) Sector — better estimates, based upon new activity data and estimation parameters.

In developing the estimates, quality assurance / quality control procedures continue to be used to formally ensure and document the quality of the estimates.

The current report includes an inventory of anthropogenic (human-induced) emissions by sources, and removals by sinks, of the six main GHGs not controlled by the Montreal Protocol. This executive summary highlights some of the latest developments in the inventory, discusses underlying trends in the emissions, provides some international context, and presents national and provincial/territorial emissions for 1990–2006. Chapter 1, Introduction, provides an overview of climate and GHG concentration trends, as well as Canada's legal, institutional, and procedural arrangements for producing the inventory (i.e. the national inventory system), a brief description of estimation methodologies and quality assurance / quality control procedures, a description of Canada's facility emission reporting system and assessments of completeness and uncertainty. Chapter 2 provides an in-depth analysis of Canada's GHG emission trends in accordance with the UNFCCC reporting guidelines. Chapters 3–8 provide descriptions and additional analysis for each broad emission and removal category according to UNFCCC Common Reporting Format requirements. Chapter 9 presents a summary of recalculations and planned improvements. This year that summary is an expanded one, as it reports on recalculations incorporated since the 2006 inventory submission. Annexes 1 to 7 provide a key category analysis, detailed explanations of estimation methodologies, a comparison of the sectoral and reference approaches, a more complete description of quality assurance / quality control procedures, completeness assessments, and a discussion of inventory uncertainty. Summary tables of GHG emissions tabulated by jurisdiction, sector, and gas are presented in Annexes 8 and 11. Annexes 9 and 10 present additional details on the GHG intensity of electricity generation and trend analyses by province/territory, respectively. Emission factors are provided in Annex 12, and a description of rounding procedures is found in Annex 13. Finally, brief summary tables of emissions of ozone and aerosol precursors are provided in Annex 14.

### **ES.1.1 Developing Canada's National Greenhouse Gas Inventory**

On behalf of the Government of Canada, Environment Canada develops and publishes Canada's GHG inventory annually. The GHGs for which emissions and removals have been estimated in the national inventory are:

- carbon dioxide (CO<sub>2</sub>);
- methane (CH<sub>4</sub>);
- nitrous oxide (N<sub>2</sub>O);
- sulphur hexafluoride (SF<sub>6</sub>);
- perfluorocarbons (PFCs); and
- hydrofluorocarbons (HFCs).

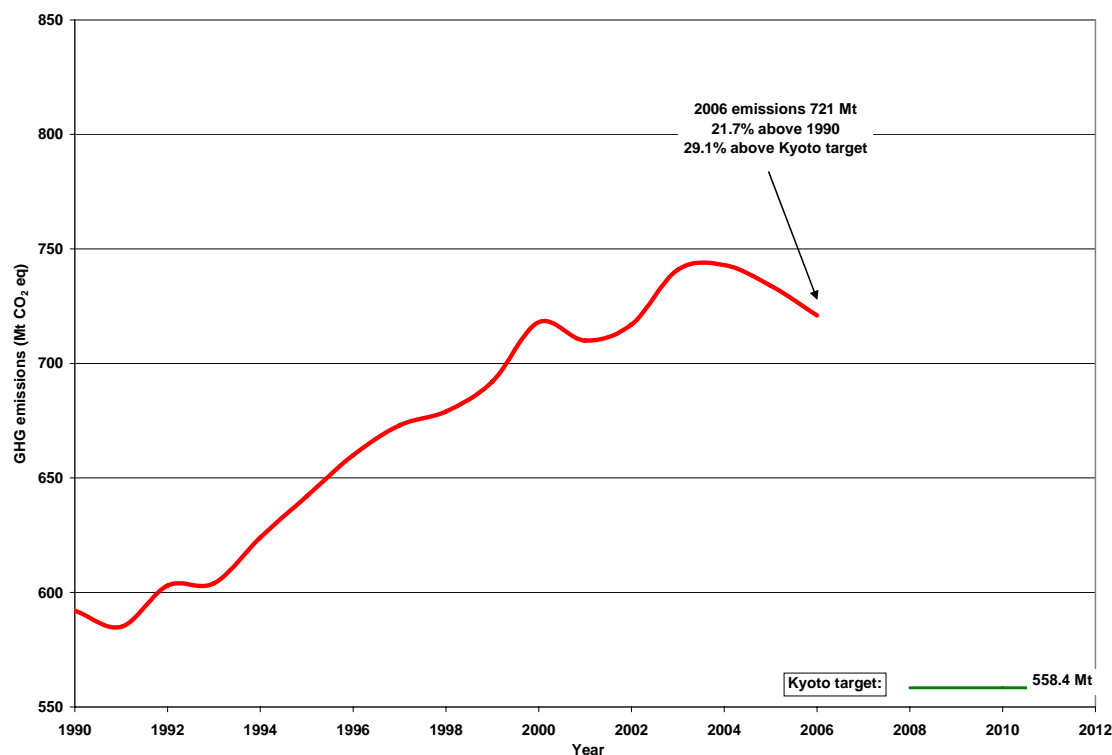


The inventory reporting format is based on international reporting methods agreed to by the Parties to the UNFCCC, using the procedures of the Intergovernmental Panel on Climate Change (IPCC/OECD/IEA/ 1997; IPCC 2000; IPCC 2003). The inventory uses an internationally agreed upon reporting format that groups emissions into the following six sectors: Energy; Industrial Processes; Solvent and Other Product Use; Agriculture; Land Use, Land-Use Change and Forestry (LULUCF); and Waste. Each of these sectors is further subdivided within the inventory and follows, as closely as possible, the UNFCCC subsector divisions.<sup>1</sup> Detailed descriptions of the methodologies used to estimate the sector emissions and removals and their respective trends are provided in chapters 3 through 8 and Annexes 2 and 3. In keeping with UNFCCC reporting requirements for Annex I Parties, this report also contains information on the ozone precursors nitrogen oxides (NO<sub>x</sub>), carbon monoxide (CO), and non-methane volatile organic compounds (NMVOCs), as well as on sulphur dioxide (SO<sub>2</sub>).

## ***ES.2 Summary of National Trends in Greenhouse Gas Emissions and Removals***

In 2006, Canadians contributed about 721 megatonnes of CO<sub>2</sub> equivalent<sup>2</sup> (Mt CO<sub>2</sub> eq)<sup>3</sup> of GHGs to the atmosphere (Figure S-1), a 1.9% reduction from 2005. This followed a year of relatively very low growth in emissions and another year of decline, such that the overall change from 2003 is a reduction of 2.8%. Canada's economic GHG intensity—the amount of GHGs emitted per unit of economic activity—was 5% lower in 2006 than in 2005. Since 1990, emissions have increased by about 22%.

- 
1. Minor differences exist between the United Nations Framework Convention on Climate Change and Canada's national inventory sector designations. These are explained in footnotes throughout this report. More details can be found in chapters 3 through 8, where the methodology used in Canada's inventory is described.
  2. Each of the GHGs has a unique average atmospheric lifetime over which it is an effective climate-forcing agent. The concept of global warming potential has been introduced to equate this climate forcing for different GHGs to that of CO<sub>2</sub>. A more detailed explanation is provided in Section 1.1.5 of this document.
  3. Unless explicitly stated otherwise, all emission estimates given in Mt represent emissions of GHGs in Mt CO<sub>2</sub> eq.



-----  
**Figure S-1: Canadian GHG Emission Trend and Kyoto Target**  
 -----

Table S-1 depicts Canada's total GHG emissions from 1990 to 2006, along with several primary indicators: gross domestic product (GDP), population, energy use, energy production, and energy export. From the table, it is evident that the 21.7% increase in GHG emissions during the 16-year period outpaced increases in population (which totalled 17.9%) and was almost identical to the increase in energy use (which was 21.5%). However, the growth in total emissions was well short of the 54% growth in GDP between 1990 and 2006.

**Table S-1: Canada's GHG Emissions and Accompanying Variables, 1990–2006**

<b>Year</b>	<b>1990</b>	<b>1995</b>	<b>2000</b>	<b>2003</b>	<b>2004</b>	<b>2005</b>	<b>2006</b>
<b>Total GHG (Mt)</b>	<b>592</b>	<b>642</b>	<b>718</b>	<b>741</b>	<b>743</b>	<b>734</b>	<b>721</b>
<i>Growth Since 1990 (%)</i>	NA	8.3	21.2	25.1	25.4	24.0	21.7
<i>Annual Change (%)</i>	NA	2.8	3.7	3.4	0.2	-1.1	-1.9
<i>Average Annual Change (%)</i>	NA	1.7	2.1	1.9	1.8	1.6	1.4
<b>GDP - Expense<sup>1</sup></b>	<b>706 959</b>	<b>772 485</b>	<b>943 183</b>	<b>1 000 805</b>	<b>1 031 910</b>	<b>1 060 539</b>	<b>1 090 295</b>
<i>Growth Since 1990 (%)</i>	NA	9.3	33.4	41.6	46.0	50.0	54.2
<i>Annual Change (%)</i>	NA	2.6	5.3	2.0	3.1	2.8	2.8
<i>Average Annual Change (%)</i>	NA	1.9	3.3	3.2	3.3	3.3	3.4
<b>GHG Intensity (Mt/\$B GDP)</b>	<b>0.84</b>	<b>0.83</b>	<b>0.76</b>	<b>0.740</b>	<b>0.720</b>	<b>0.693</b>	<b>0.661</b>
<i>Growth Since 1990 (%)</i>	NA	-0.9	-9.2	-11.6	-14.1	-17.3	-21.1
<i>Annual Change (%)</i>	NA	0.2	-1.5	1.4	-2.8	-3.8	-4.6
<i>Average Annual Change (%)</i>	NA	-0.2	-0.9	-0.9	-1.0	-1.2	-1.3
<b>GHG Efficiency (\$GDP/kt GHG)</b>	<b>1.19</b>	<b>1.20</b>	<b>1.31</b>	<b>1.351</b>	<b>1.389</b>	<b>1.444</b>	<b>1.513</b>
<i>Growth Since 1990 (%)</i>	NA	0.9	10.1	13.1	16.4	21.0	26.8
<i>Annual Change (%)</i>	NA	-0.2	1.5	-1.4	2.9	3.9	4.8
<i>Average Annual Change (%)</i>	NA	0.2	1.0	1.0	1.2	1.4	1.7
<b>Population (000s)<sup>2</sup></b>	<b>27 698</b>	<b>29 302</b>	<b>30 689</b>	<b>31 676</b>	<b>31 995</b>	<b>32 312</b>	<b>32 649</b>
<i>Growth Since 1990 (%)</i>	NA	5.8	10.8	14.4	15.5	16.7	17.9
<i>Annual Change (%)</i>	NA	1.0	0.9	1.0	1.0	1.0	1.0
<i>Average Annual Change (%)</i>	NA	1.2	1.1	1.1	1.1	1.1	1.1
<b>GHG Per Capita (tonnes/person)</b>	<b>21.4</b>	<b>21.9</b>	<b>23.4</b>	<b>23.4</b>	<b>23.2</b>	<b>22.7</b>	<b>22.1</b>
<i>Growth Since 1990 (%)</i>	NA	2.4	9.4	9.4	8.6	6.3	3.2
<i>Annual Change (%)</i>	NA	1.8	2.8	2.4	-0.8	-2.1	-2.9
<i>Average Annual Change (%)</i>	NA	0.5	0.9	0.7	0.6	0.4	0.2
<b>Energy Use (PJ)<sup>3</sup></b>	<b>9 230</b>	<b>9 695</b>	<b>10 830</b>	<b>11 363</b>	<b>11 528</b>	<b>11 310</b>	<b>11 216</b>
<i>Growth Since 1990 (%)</i>	NA	5.0	17.3	23.1	24.9	22.5	21.5
<i>Annual Change (%)</i>	NA	1.4	3.0	2.6	1.5	-1.9	-0.8
<i>Average Annual Change (%)</i>	NA	1.0	1.7	1.8	1.8	1.5	1.3
<b>Energy Produced (PJ)<sup>4</sup></b>	<b>7 906</b>	<b>10 530</b>	<b>11 979</b>	<b>12 638</b>	<b>12 835</b>	<b>12 819</b>	<b>13 149</b>
<i>Growth Since 1990 (%)</i>	NA	33.2	51.5	59.8	62.3	62.1	66.3
<i>Annual Change (%)</i>	NA	4.4	3.6	0.9	1.6	-0.1	2.6
<i>Average Annual Change (%)</i>	NA	6.6	5.2	4.6	4.5	4.1	4.1
<b>Energy Exported (PJ)</b>	<b>2 999</b>	<b>5 373</b>	<b>6 937</b>	<b>7 321</b>	<b>7 645</b>	<b>7 588</b>	<b>7 861</b>
<i>Growth Since 1990 (%)</i>	NA	79.2	131.3	144.1	155.0	153.1	162.2
<i>Annual Change (%)</i>	NA	8.6	7.9	-0.7	4.4	-0.7	3.6
<i>Average Annual Change (%)</i>	NA	15.8	13.1	11.1	11.1	10.2	10.1
<b>Emissions Associated with Exports (Mt)</b>	<b>27.8</b>	<b>51.0</b>	<b>65.0</b>	<b>69.4</b>	<b>72.6</b>	<b>71.8</b>	<b>75.4</b>
<i>Growth Since 1990 (%)</i>	NA	83.5	134.0	149.5	161.2	158.4	171.4
<i>Annual Change (%)</i>	NA	12.1	8.6	0.2	4.7	-1.1	5.0
<i>Average Annual Change (%)</i>	NA	16.7	13.4	11.5	11.5	10.6	10.7

Notes:

1. GDP: Industrial Sector GDP by NAICS Code (1990–1996: Constant 1997\$; 1997–2006: Chained 1997\$) (millions), Statistics Canada 2008

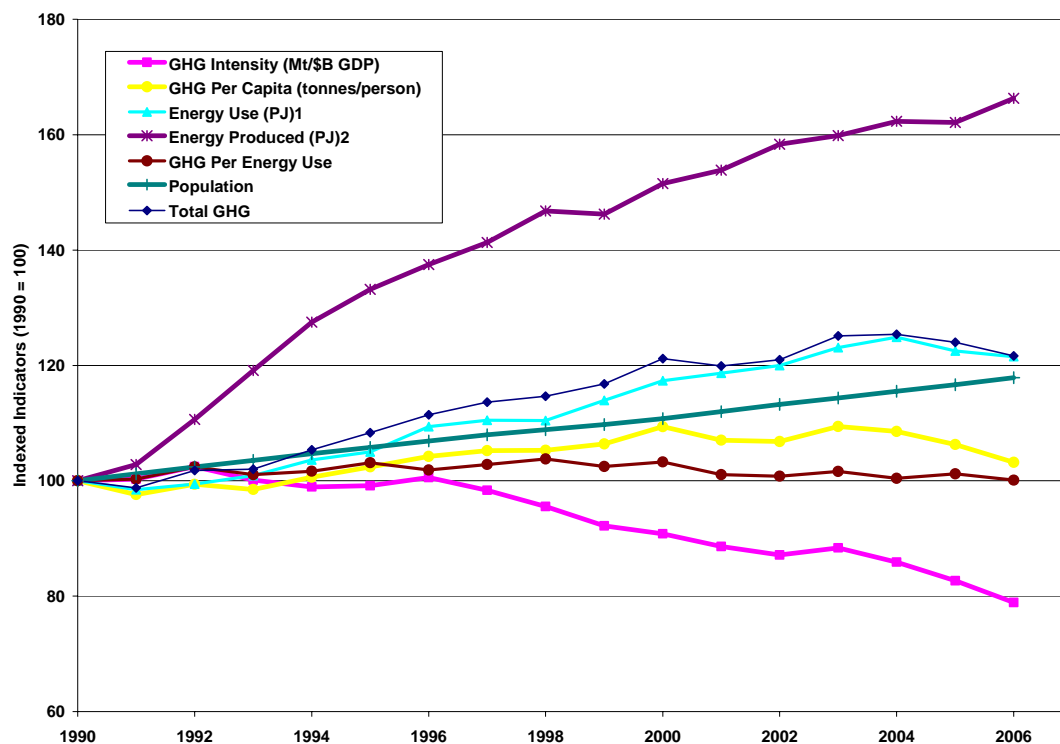
2. Source: Statistics Canada, *Annual Demographic Statistics, 2008*3. Statistics Canada's *Report on Energy Supply-Demand In Canada 2006 (57-003)*, Table S, Line 2 (Availability - Total Primary)

4. Natural Gas and Crude Oil only

PJ = petajoule. A petajoule, or 1,000 trillion joules, is a measure of energy content.

NA = not applicable

The result is that economic GHG intensity has decreased by a total of 21% over the period, an average of 1.3% per year. More goods were manufactured, more commercial activity occurred, and more travel took place per unit of GHG emissions. These trends are summarized graphically in Figure S-2. The indexed curves clearly show that GHG emissions per energy used remained static over the period, while economic GHG intensity decreased.



1. Statistics Canada's *Report on Energy Supply-Demand In Canada 2006* (57-003), Table S, Line 2 (Availability – Total Primary)  
 2. Statistics Canada's *Report on Energy Supply-Demand In Canada 2006* (57-003), Natural Gas and Crude Oil

Figure S-2: Trends in Energy, Population and GHG Emissions Indicators, 1990–2006

Another trend worth noting is the much larger growth in energy *production* compared with energy *use* between 1990 and 2005. This is a consequence of Canada's large fossil fuel resources and an economy geared to take advantage of them, with increasing quantities of energy being delivered to the international market. The resultant sharp growth in energy exports over the period has had a significant impact on the emission trend. (See Section ES.4.1 for more details.)

### Changes from the Previous National Inventory Report

As a result of review and improvements to the inventory, estimates for the 1990–2005 period have been revised. Each year GHG inventories as submitted to the United Nations Framework Convention on Climate Change (UNFCCC) secretariat are reviewed by a team of experts drawn from a UNFCCC roster of experts. Moreover, for purposes of the Kyoto Protocol, each Annex 1 Party that is also a party to the Kyoto Protocol was required to submit an initial report. Canada's initial report under the Kyoto Protocol was filed on March 15, 2007, and underwent an in-country review by a United Nations Expert Review Team (ERT) in November 2007. The initial report is an essential pre-commitment period reporting obligation that Canada and other Kyoto Protocol signatories with targets must meet in order to establish their initial assigned amount (emissions budget over the 2008–2012 period) and to be eligible to utilize the Kyoto mechanisms of trading and joint implementation projects. The initial report and accompanying material, specifically the annual *National Inventory Report* (NIR) and Common Reporting Format (CRF) tables, must demonstrate our capacity to manage and maintain our national system for the ongoing development and reporting of GHG emissions and removals, and our capacity to maintain the national registry to account for tradable emissions units, according to the relevant decisions of the Conference of the Parties (CoP) to the UNFCCC and the Meeting of the Parties (MOP) to the Kyoto Protocol. As part of this process, each country's assigned amount, or Kyoto target, referenced to the 1990 base year, was reviewed.

The ERT recommended that Canada revise some of the emission estimates contained in the inventory submitted as part of the initial report (the submission made in 2006), re-submit certain estimates for the 1990–2004 period, and submit other as new estimates for the 1990–2005 period. The revisions have resulted in a recalculation of the base year (1990) emissions (from 599 Mt CO<sub>2</sub> eq to 594 Mt CO<sub>2</sub> eq for the 2006 year submission) and therefore a recalculation of the assigned amount, now finalized as 2 791 792 771 tonnes CO<sub>2</sub> eq. This final revision to the assigned amount represents a 0.8% reduction from the value calculated in the initial report submitted in March 2007.

Specific areas requiring revision, as identified by the ERT, included categories in the Energy, Waste, Agriculture, and Industrial Process sectors. These revisions, including improved methodologies and country-specific emission factors, meant that recalculations of values were necessary throughout the time series, including those for the 1990 base year (see Annex 9).

While Canada's 1990 estimate has been set at 594 Mt CO<sub>2</sub> eq as the basis for calculating its assigned amount under the Kyoto Protocol, additional improvements to methods and data can and will result in changes to all years in the time series from 1990 onwards. Updates to Statistics Canada's preliminary energy data reported in 2007 have affected the 2005 estimates. As a result, total GHG emissions previously reported (in May 2007) have in this year's inventory been revised downward from 596 to 592 Mt for 1990 while those for 2005 have been revised downward from 747 Mt to 734 Mt (both figures without the Land-Use, Land Use Change and Forestry Sector). The overall impact of these changes is that emission growth over the 1990–2005 period, previously reported to be 25.3%, is now estimated to be 24.0%.

## ES.3 Emission and Removal Estimates and Trends

### ES.3.1 2006 Emissions and Removals

Table S-2 details Canada's emissions and removals for 2006. On an individual GHG basis, CO<sub>2</sub> contributed 78% of the total emissions, while CH<sub>4</sub> accounted for 14%. N<sub>2</sub>O accounted for 7% of the emissions, while PFCs, SF<sub>6</sub>, and HFCs constituted the remainder (less than 2%).

## EXECUTIVE SUMMARY

Approximately 72% of total GHG emissions in 2006 resulted from the combustion of fossil fuels. Another 9% were from fugitive sources, with the result that about 81% of emissions were from the Energy Sector. A sectoral breakdown of Canada's total emissions for 2006 is shown in Figure S-3.

**Table S-2: Canada's GHG Emissions by Gas and Sector, 2006**

GHGs sectors and categories									
Global Warming Potential Unit	CO <sub>2</sub>	CH <sub>4</sub>	CH <sub>4</sub>	N <sub>2</sub> O	GHGs	HFCs	PFCs	SF <sub>6</sub>	Round totals
	kt	kt	kt CO <sub>2</sub> equivalent	kt	kt CO <sub>2</sub> equivalent	kt CO <sub>2</sub> equivalent	kt CO <sub>2</sub> equivalent	kt CO <sub>2</sub> equivalent	kt CO <sub>2</sub> equivalent
TOTAL <sup>1</sup>	560 000	4 900	100 000	150	48 000	5 300	2 600	2 700	721 000
<b>ENERGY</b>	<b>519 000</b>	<b>2 600</b>	<b>54 000</b>	<b>30</b>	<b>10 000</b>	—	—	—	<b>583 000</b>
<b>a. Stationary Combustion Sources</b>	<b>317 000</b>	<b>200</b>	<b>4 000</b>	<b>8</b>	<b>2 000</b>	—	—	—	<b>324 000</b>
Electricity and Heat Generation	116 000	4.6	96	2	700	—	—	—	117 000
Fossil Fuel Industries	65 200	100	2 000	1	400	—	—	—	68 000
Petroleum Refining and Upgrading	16 000	—	—	0.4	100	—	—	—	16 000
Fossil Fuel Production	49 100	100	2 000	1	300	—	—	—	52 000
Mining & Oil and Gas Extraction	16 400	0.3	7	0.4	100	—	—	—	16 500
Manufacturing Industries	45 800	3	60	2	500	—	—	—	46 300
Iron and Steel	6 310	0.2	5	0.2	60	—	—	—	6 380
Non Ferrous Metals	3 030	0.07	1	0.04	10	—	—	—	3 050
Chemical	6 450	0.14	2.9	0.1	40	—	—	—	6 490
Pulp and Paper	5 650	2	40	0.8	300	—	—	—	5 950
Cement	4 840	0.1	2	0.04	10	—	—	—	4 850
Other Manufacturing	19 500	0.4	8	0.4	100	—	—	—	19 600
Construction	1 290	0.02	0.5	0.03	10	—	—	—	1 300
Commercial & Institutional	33 200	0.6	10	0.7	200	—	—	—	33 400
Residential	37 300	100	2 000	2	500	—	—	—	40 000
Agriculture & Forestry	1 900	0.03	0.7	0.06	20	—	—	—	1 920
<b>b. Transport<sup>2</sup></b>	<b>184 000</b>	<b>30</b>	<b>600</b>	<b>20</b>	<b>7 000</b>	—	—	—	<b>190 000</b>
Civil Aviation (Domestic Aviation)	8 190	0.4	9	0.7	200	—	—	—	8 400
Road Transportation	130 000	9.3	200	11	3 400	—	—	—	133 000
Light-Duty Gasoline Vehicles	37 700	2.9	62	3.6	1 100	—	—	—	38 900
Light-Duty Gasoline Trucks	43 100	3.2	68	5.3	1 600	—	—	—	44 800
Heavy-Duty Gasoline Vehicles	6 130	0.35	7.4	0.44	140	—	—	—	6 280
Motorcycles	254	0.17	3.5	0.01	1.6	—	—	—	259
Light-Duty Diesel Vehicles	423	0.01	0.2	0.03	10	—	—	—	433
Light-Duty Diesel Trucks	2 270	0.06	1	0.2	60	—	—	—	2 330
Heavy-Duty Diesel Vehicles	39 000	2	40	1	400	—	—	—	39 400
Propane & Natural Gas Vehicles	784	0.7	20	0.02	5	—	—	—	800
Railways	5 660	0.3	7	2	700	—	—	—	6 000
Navigation (Domestic Marine)	5 380	0.4	8	1	400	—	—	—	5 800
Other Transportation	35 000	20	400	8	3 000	—	—	—	40 000
Off-Road Gasoline	6 000	8	200	0.1	40	—	—	—	7 000
Off-Road Diesel	19 000	1	20	8	2 000	—	—	—	20 000
Pipelines	9 390	9.4	200	0.3	80	—	—	—	9 660
<b>c. Fugitive Sources</b>	<b>17 000</b>	<b>2 400</b>	<b>49 000</b>	<b>0.1</b>	<b>40</b>	—	—	—	<b>66 800</b>
Coal Mining	—	30	600	—	—	—	—	—	600
Oil and Natural Gas	17 400	2 320	48 800	0.1	40	—	—	—	66 200
Oil	190	262	5 490	0.1	30	—	—	—	5 710
Natural Gas	65.6	1 010	21 300	—	—	—	—	—	21 300
Venting	11 200	1 040	21 900	0.01	4.61	—	—	—	33 100
Flaring	5 900	4.1	86	0.01	3	—	—	—	6 000
<b>INDUSTRIAL PROCESSES</b>	<b>41 000</b>	—	—	<b>7.88</b>	<b>2 440</b>	<b>5 300</b>	<b>2 600</b>	<b>2 700</b>	<b>54 400</b>
<b>a. Mineral Products</b>	<b>9 600</b>	—	—	—	—	—	—	—	<b>9 600</b>
Cement Production	7 300	—	—	—	—	—	—	—	7 300
Lime Production	1 600	—	—	—	—	—	—	—	1 600
Mineral Product Use <sup>3</sup>	600	—	—	—	—	—	—	—	600
<b>b. Chemical Industry</b>	<b>6 600</b>	—	—	<b>7.88</b>	<b>2 440</b>	—	—	—	<b>9 000</b>
Ammonia Production	6 600	—	—	—	—	—	—	—	6 600
Nitric Acid Production	—	—	—	3.98	1 230	—	—	—	1 230
Adipic Acid Production	—	—	—	3.9	1 200	—	—	—	1 200
<b>c. Metal Production</b>	<b>12 800</b>	—	—	—	—	—	<b>2 600</b>	<b>1 410</b>	<b>16 800</b>
Iron and Steel Production	7 760	—	—	—	—	—	—	—	7 760
Aluminum Production	5 000	—	—	—	—	—	2 600	13.1	7 600
SF <sub>6</sub> Used in Magnesium Smelters and Casters	—	—	—	—	—	—	—	1 390	1 390
<b>d. Consumption of Halocarbons and SF<sub>6</sub></b>	—	—	—	—	—	<b>5 300</b>	<b>30</b>	<b>1 300</b>	<b>6 600</b>
<b>e. Other &amp; Undifferentiated Production</b>	<b>12 000</b>	—	—	—	—	—	—	—	<b>12 000</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>	—	—	—	<b>1.0</b>	<b>320</b>	—	—	—	<b>320</b>
<b>AGRICULTURE</b>	—	<b>1 300</b>	<b>27 000</b>	<b>110</b>	<b>34 000</b>	—	—	—	<b>62 000</b>
<b>a. Enteric Fermentation</b>	—	1 200	24 000	—	—	—	—	—	24 000
<b>b. Manure Management</b>	—	160	3 300	15	4 800	—	—	—	8 000
<b>c. Agriculture Soils</b>	—	—	—	96	30 000	—	—	—	30 000
Direct Sources	—	—	—	49	15 000	—	—	—	15 000
Pasture, Range and Paddock Manure	—	—	—	12	3 800	—	—	—	3 800
Indirect Sources	—	—	—	30	10 000	—	—	—	10 000
<b>WASTE</b>	<b>190</b>	<b>950</b>	<b>20 000</b>	<b>2</b>	<b>700</b>	—	—	—	<b>21 000</b>
<b>a. Solid Waste Disposal on Land</b>	—	940	20 000	—	—	—	—	—	20 000
<b>b. Wastewater Handling</b>	—	12	260	2	700	—	—	—	930
<b>c. Waste Incineration</b>	190	0.07	1	0.2	50	—	—	—	240
<b>LAND USE, LAND-USE CHANGE AND FORESTRY</b>	<b>19 000</b>	<b>360</b>	<b>7 500</b>	<b>15</b>	<b>4 700</b>	—	—	—	<b>31 000</b>
<b>a. Forest Land</b>	11 000	340	7 200	14	4 500	—	—	—	23 000
<b>b. Cropland</b>	-1 700	7	200	0.4	100	—	—	—	-1 400
<b>c. Grassland</b>	—	—	—	—	—	—	—	—	—
<b>d. Wetlands</b>	2 000	0	—	0	—	—	—	—	2 000
<b>e. Settlements</b>	8 000	5	100	0.2	50	—	—	—	8 000

Notes:

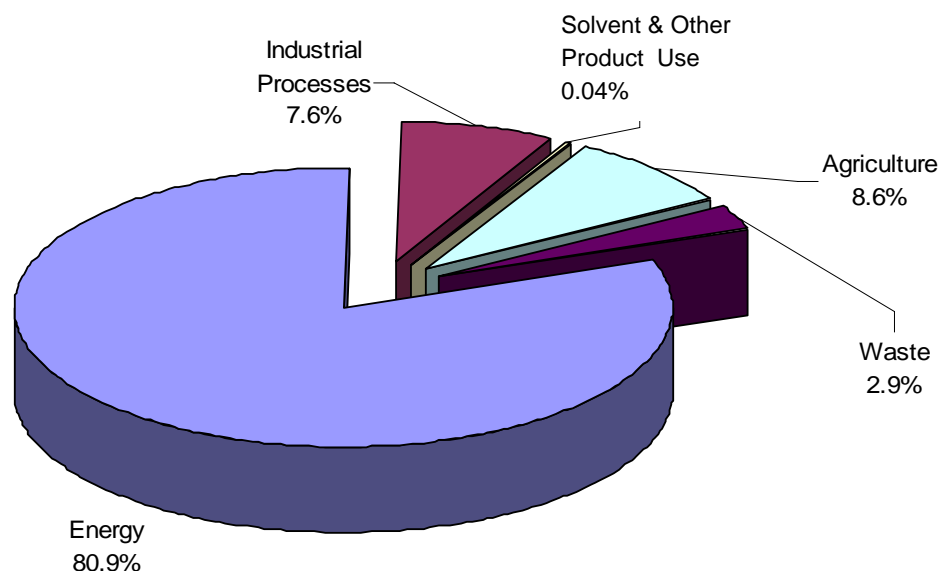
1. National totals exclude all GHGs from the Land Use, Land-use Change and Forestry sector.

2. Emissions from Fuel Ethanol are reported within the gasoline transportation sub-categories.

3. The category Mineral Product Use includes CO<sub>2</sub> emissions coming from the use of limestone and dolomite, soda ash, and magnesite.

- Indicates no emissions.

0.0 Indicates emissions truncated due to rounding.



-----  
**Figure S-3: Sectoral Breakdown of Canada's GHG Emissions, 2006**  
 -----

As per reporting requirements, the Land-Use, Land-Use Change and Forestry Sector estimates are not included in the national totals. This sector displays net overall emissions of 31 Mt for 2006. This would, if included, increase total Canadian GHG emissions by 4%.

### **ES.3.2 Sector Trends**

#### *ES.3.2.1 Short-Term Changes*

Table S-3 outlines Canada's GHG emissions and removals, by sector, between 1990 and 2006. As indicated above, emissions in 2006 are estimated at about 721 Mt, which represents a 1.9% decrease from 2005 levels and a 2.8% decrease from 2003 levels. Overall, the long-term trend shows that emissions in 2006 were about 22% above the revised 1990 total of 592 Mt, indicating a difference between the long-term trend and more recent changes.

Since 2003, GHG emission trends first showed a slowdown in growth and then decreased until 2006. This decrease was more than 20 Mt (2.8%). As can be seen from Table S-1, the emission change has been accompanied by declining domestic energy use. Though there were some significant increases in certain areas (notably Road Transportation and, to a smaller extent, Industrial Processes) these were more than offset by a large decline in emissions from Electricity and Heat Generation and a reduction in emissions from the Fossil Fuel Industries, both of which are reversals from the long-term trend. Residential and Commercial & Institutional GHGs fell significantly as well.

Between 2003 and 2006, greenhouse gas emissions from Electricity and Heat Generation fell by 18 Mt (13%). This drop occurred as a result of reduced coal and oil generation, which was

replaced by increased electricity from hydro, nuclear, and, to some extent, wind power sources. Hydroelectric power generation increased throughout Canada as a result of higher water levels (precipitation in each of 2004, 2005, and 2006 was greater than the 30-year average). At the same time, efforts have been made in Ontario to decrease coal generation while bringing more nuclear plant back on line. Overall, coal power generation in Canada fell by 6% between 2003 and 2006, its lowest level since 1997.

The fossil fuel industries,<sup>4</sup> consisting of oil, gas, and coal production; refining; and transmission showed a 4 Mt decrease between 2003 and 2006. During the period, the price of crude oil rose 75%.<sup>5</sup> Though crude oil production increased by 6%, crude oil exports rose much more quickly (15%), while total domestic energy use fell by 1.3%. Emissions associated with Petroleum Refining and Upgrading alone fell by 3.2 Mt (17%). This was accompanied by a 2.5% reduction in the amount of crude oil refined in Canada, but fuel switching from coke to less carbon-intensive natural gas consumption at refineries appears to have made the largest impact on GHG reductions in this area.

On average, Canadian homes and businesses have required lower energy quantities for space heating each successive year since 2003, due to overall milder winter temperatures. In 2006, Heating Degree Days, an indicator of the necessity for space heating due to the severity of cold weather, were down almost 13% compared to 2003 on a national basis. This fact almost certainly had an impact on fossil fuel consumption, specifically in the residential and commercial & institutional sectors, where emissions declined by a total of 9.6 Mt (12%) since 2003.

### *ES.3.2.2 Long-Term Trends*

The long-term (1990–2006) sub-sector emission trends showed both declines and increases, but the increases were well ahead of the declines, for a net growth of 128 Mt, or 22%. The largest portion of the growth is observed in the Energy Sector, where the energy industries (fossil fuel industries plus Electricity and Heat Generation), Road Transportation, Commercial and Institutional, and Mining categories made the greatest contributions.

The activities of the energy industries' fossil fuel industries include both combustion sources (Fossil Fuel Industries and Pipelines) and fugitive sources (Coal Mining and Oil and Natural Gas).<sup>6</sup> The fossil fuel industries registered a net increase of about 43 Mt of GHG emissions from 1990 to 2006 (43% growth). These emissions are related to coal mining and the production, transmission, processing, refining, and distribution of all oil and gas products.

By 2006, total production of crude oil and natural gas showed a 66% increase over 1990 levels. Elevated demand, particularly in the United States, drove these trends, with the export market growing by far the most rapidly<sup>7</sup> (see Section ES.4.1). Although increasing demand provides a portion of the explanation for the emission trend, it does not paint the complete picture.

---

4. Sum of Fossil Fuel Industries, Pipelines (Transportation), and Fugitives.

5. Crude oil prices: (1990–2005) — Natural Resources Canada, Government of Canada, [http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/handbook\\_tables.cfm?attr=0](http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/handbook_tables.cfm?attr=0); (2006) – Canadian Association of Petroleum Producers, *2007 Statistical Handbook*, <http://www.capp.ca/SHB/Sheet.asp?SectionID=5&SheetID=291> (both accessed March 2008).

6. There is also some overlap with Mining (which as a result of categorizations by the Alberta Energy Utilities Board and Statistics Canada includes a portion of oil sands production activities), but emissions from Mining are not included in this discussion of the fossil fuel industries.

7. A large portion of the refined petroleum products consumed in Canada are derived from imported oil.



Since well before 1990, easily removable reserves of conventional crude have been falling. Thus, energy consumption per unit of conventional oil produced has been increasing (Neitzert et al. 1999). In fact, between 1990 and 2000, the energy requirements per barrel of conventional light/medium oil extracted nearly doubled (Nyboer and Tu 2008). At the same time, highly energy- and GHG-intensive<sup>8</sup> synthetic oil production (i.e. from oil sands) has become increasingly competitive with conventional oil extraction. These trends contribute significantly to the rapidly rising emission increases in the oil and gas industry over the 1990–2006 period.

Electricity and Heat Generation, representing the other portion of the energy industries, also saw large increases in emissions. Rising demand for electricity caused GHG emissions to grow by 22 Mt between 1990 and 2006. Comparatively, in 2006, total electricity demand was approximately 95 TWh (terawatt-hours) above the 1990 level.<sup>9</sup> Although up until the last few years of the period an increasing percentage of high-emitting fossil fuel generation in the mix had worsened the average GHG intensity of electricity production, more recently this trend has reversed. The end result is that from 1990 to 2006, though generation rose 26%, GHG emissions increased 23%, or slightly less than the generation increase.

Of primary importance in this trend is that the GHG emissions associated with coal-fired electricity generation, which had been increasing since the mid-1990s, have begun to decrease since peaking between 2000 and 2002. As indicated in the shorter-term trends, this is due to the return to service of a number of nuclear units and a commitment to reduced coal-fired electricity generation in Ontario, as well as fuel switching to natural gas in a number of regions of the country. Although having some effect in the pre-2006 period, non-hydro renewable energy sources are predicted to have a more significant impact on emission reductions post-2006. The reason for this is that the installed capacity of wind power in Canada has begun to rise rapidly. Nevertheless, fuel and generation costs are likely to continue to play a major role in determining whether coal-fired generation and the associated GHG emissions will be reduced further in the future.

Emissions from Road Transportation rose by 35 Mt (35%) between 1990 and 2006. Of particular interest in this subsector is a 24 Mt (almost 120%) increase in emissions from Light-Duty Gasoline Trucks (LDGTs). This was partially offset by 7 and 1.4 Mt emission reductions from gasoline-fuelled cars (Light-Duty Gasoline Vehicles, or LDGVs) and alternatively fuelled cars (Propane and Natural Gas Vehicles).

---

8. Nyboer and Tu (2006) estimated that, per unit of output, GHG emissions from oil sands mining and upgrading are about five times greater than those from conventional light/medium crude oil production.

9. Statistics Canada, *Energy Statistics Handbook*, Feb. 2008.

# EXECUTIVE SUMMARY

**Table S-3: Canada's GHG Emissions by Sector, 1990–2006**

Greenhouse Gas Categories	1990	1995	2000	2001	2002	2003	2004	2005	2006
	<i>kt CO<sub>2</sub> equivalent</i>								
<b>TOTAL<sup>1</sup></b>	<b>592 000</b>	<b>642 000</b>	<b>718 000</b>	<b>710 000</b>	<b>717 000</b>	<b>741 000</b>	<b>743 000</b>	<b>734 000</b>	<b>721 000</b>
<b>ENERGY</b>	<b>470 000</b>	<b>510 000</b>	<b>587 000</b>	<b>582 000</b>	<b>588 000</b>	<b>609 000</b>	<b>604 000</b>	<b>596 000</b>	<b>583 000</b>
<b>a. Stationary Combustion Sources</b>	<b>282 000</b>	<b>294 000</b>	<b>344 000</b>	<b>340 000</b>	<b>345 000</b>	<b>360 000</b>	<b>350 000</b>	<b>338 000</b>	<b>324 000</b>
Electricity and Heat Generation	95 400	101 000	132 000	134 000	129 000	135 000	127 000	125 000	117 000
Fossil Fuel Industries	52 000	54 000	67 000	68 000	73 000	74 000	73 000	69 000	68 000
Petroleum Refining and Upgrading	16 000	14 000	14 000	16 000	19 000	19 000	18 000	17 000	16 000
Fossil Fuel Production	36 000	40 000	53 000	53 000	54 000	54 000	55 000	52 000	52 000
Mining & Oil and Gas Extraction	6 190	7 860	10 400	10 300	11 800	15 700	14 800	15 600	16 500
Manufacturing Industries	54 900	53 000	53 100	48 900	49 000	49 400	51 000	47 300	46 300
Iron and Steel	6 500	7 050	7 190	5 900	6 490	6 380	6 490	6 480	6 380
Non Ferrous Metals	3 190	3 090	3 190	3 460	3 220	3 200	3 230	3 270	3 050
Chemical	7 100	8 450	7 860	6 760	6 120	5 810	6 770	6 340	6 480
Pulp and Paper	13 700	11 700	11 000	9 840	9 250	9 060	9 400	7 180	5 950
Cement	3 690	3 670	3 890	3 860	4 090	4 080	4 210	4 590	4 850
Other Manufacturing	20 700	19 000	19 900	19 000	19 800	20 800	20 900	19 400	19 600
Construction	1 870	1 170	1 070	1 010	1 230	1 300	1 350	1 360	1 300
Commercial & Institutional	25 700	28 900	33 100	33 100	35 200	37 800	37 700	36 700	33 400
Residential	44 000	45 000	45 000	42 000	43 000	45 000	43 000	42 000	40 000
Agriculture & Forestry	2 390	2 760	2 540	2 200	2 100	2 200	2 090	1 980	1 920
<b>b. Transport<sup>2</sup></b>	<b>150 000</b>	<b>160 000</b>	<b>180 000</b>	<b>180 000</b>	<b>180 000</b>	<b>180 000</b>	<b>190 000</b>	<b>190 000</b>	<b>190 000</b>
Civil Aviation (Domestic Aviation)	6 400	5 900	6 500	6 100	6 700	7 200	7 800	8 600	8 400
Road Transportation	98 400	109 000	119 000	121 000	123 000	125 000	130 000	131 000	133 000
Light-Duty Gasoline Vehicles	45 800	44 400	42 100	41 800	41 900	41 400	41 100	39 900	38 900
Light-Duty Gasoline Trucks	20 700	27 900	36 800	37 500	39 100	40 500	42 000	43 100	44 800
Heavy-Duty Gasoline Vehicles	7 810	6 080	5 290	6 000	5 870	6 050	6 410	6 300	6 280
Motorcycles	146	121	158	182	206	226	245	251	259
Light-Duty Diesel Vehicles	355	327	353	368	389	398	431	432	433
Light-Duty Diesel Trucks	707	1 330	1 690	1 710	1 810	1 880	1 990	2 130	2 330
Heavy-Duty Diesel Vehicles	20 700	26 500	31 300	32 400	32 700	34 100	36 500	37 900	39 400
Propane & Natural Gas Vehicles	2 200	2 100	1 100	1 100	840	820	860	720	800
Railways	7 000	6 000	7 000	6 000	6 000	6 000	6 000	6 000	6 000
Navigation (Domestic Marine)	5 000	4 400	5 100	5 500	5 500	6 100	6 600	6 400	5 800
Other Transportation	30 000	30 000	40 000	40 000	40 000	40 000	40 000	40 000	40 000
Off-Road Gasoline	7 000	6 000	8 000	7 000	8 000	8 000	8 000	7 000	7 000
Off-Road Diesel	20 000	20 000	20 000	20 000	20 000	20 000	20 000	20 000	20 000
Pipelines	6 900	12 000	11 300	10 300	10 900	9 100	8 520	10 100	9 660
<b>c. Fugitive Sources</b>	<b>42 700</b>	<b>57 000</b>	<b>64 700</b>	<b>65 600</b>	<b>65 400</b>	<b>66 000</b>	<b>66 300</b>	<b>65 500</b>	<b>66 800</b>
Coal Mining <sup>4</sup>	2 000	2 000	900	1 000	1 000	900	700	700	600
Oil and Natural Gas	40 700	55 300	63 700	64 600	64 400	65 100	65 600	64 800	66 200
Oil	4 180	5 150	5 430	5 770	5 580	5 770	5 930	5 650	5 710
Natural Gas	12 900	16 500	19 400	19 600	19 700	20 100	20 400	20 800	21 300
Venting	19 300	28 600	33 500	34 200	33 600	33 700	33 700	32 800	33 100
Flaring	4 400	5 100	5 400	5 000	5 400	5 600	5 600	5 500	6 000
<b>INDUSTRIAL PROCESSES</b>	<b>54 800</b>	<b>56 600</b>	<b>51 100</b>	<b>49 800</b>	<b>49 700</b>	<b>51 200</b>	<b>55 300</b>	<b>54 800</b>	<b>54 400</b>
<b>a. Mineral Products</b>	<b>8 300</b>	<b>8 800</b>	<b>9 600</b>	<b>9 000</b>	<b>9 000</b>	<b>9 100</b>	<b>9 500</b>	<b>9 500</b>	<b>9 600</b>
Cement Production	5 400	6 100	6 700	6 500	6 700	6 800	7 100	7 200	7 300
Lime Production	1 700	1 800	1 900	1 600	1 700	1 600	1 800	1 700	1 600
Mineral Product Use <sup>3</sup>	1 090	878	1 020	844	636	612	585	589	600
<b>b. Chemical Industry</b>	<b>17 000</b>	<b>18 000</b>	<b>8 900</b>	<b>8 200</b>	<b>8 700</b>	<b>8 500</b>	<b>11 000</b>	<b>10 000</b>	<b>9 000</b>
Ammonia Production	5 000	6 500	6 800	6 100	6 200	6 100	6 800	6 300	6 600
Nitric Acid Production	1 010	1 000	1 230	1 280	1 260	1 260	1 230	1 250	1 230
Adipic Acid Production	11 000	11 000	900	800	1 300	1 100	3 100	2 600	1 200
<b>c. Metal Production</b>	<b>19 500</b>	<b>19 200</b>	<b>18 900</b>	<b>17 400</b>	<b>17 500</b>	<b>17 200</b>	<b>16 700</b>	<b>16 200</b>	<b>16 800</b>
Iron and Steel Production	7 060	7 880	7 900	7 280	7 120	7 040	7 200	7 020	7 760
Aluminum Production	9 300	9 200	8 200	7 700	7 500	7 700	7 300	7 900	7 600
SF <sub>6</sub> Used in Magnesium Smelters and Casters	3 110	2 110	2 780	2 360	2 940	2 480	2 190	1 290	1 390
<b>d. Consumption of Halocarbons and SF<sub>6</sub></b>	<b>2 300</b>	<b>2 000</b>	<b>4 500</b>	<b>5 500</b>	<b>5 000</b>	<b>6 000</b>	<b>5 500</b>	<b>6 400</b>	<b>6 600</b>
<b>e. Other &amp; Undifferentiated Production</b>	<b>8 000</b>	<b>8 400</b>	<b>9 200</b>	<b>9 600</b>	<b>9 500</b>	<b>10 000</b>	<b>13 000</b>	<b>12 000</b>	<b>12 000</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>	<b>170</b>	<b>210</b>	<b>240</b>	<b>210</b>	<b>170</b>	<b>220</b>	<b>210</b>	<b>180</b>	<b>320</b>
<b>AGRICULTURE</b>	<b>49 000</b>	<b>56 000</b>	<b>60 000</b>	<b>59 000</b>	<b>58 000</b>	<b>61 000</b>	<b>63 000</b>	<b>63 000</b>	<b>62 000</b>
<b>a. Enteric Fermentation</b>	<b>18 000</b>	<b>21 000</b>	<b>22 000</b>	<b>23 000</b>	<b>23 000</b>	<b>23 000</b>	<b>24 000</b>	<b>25 000</b>	<b>24 000</b>
<b>b. Manure Management</b>	<b>6 100</b>	<b>6 900</b>	<b>7 500</b>	<b>7 800</b>	<b>7 900</b>	<b>7 900</b>	<b>8 100</b>	<b>8 200</b>	<b>8 000</b>
<b>c. Agriculture Soils</b>	<b>25 000</b>	<b>28 000</b>	<b>30 000</b>	<b>28 000</b>	<b>27 000</b>	<b>29 000</b>	<b>30 000</b>	<b>29 000</b>	<b>30 000</b>
Direct Sources	14 000	15 000	15 000	14 000	13 000	15 000	15 000	15 000	15 000
Pasture, Range and Paddock Manure	2 600	3 200	3 500	3 700	3 700	3 700	3 800	3 900	3 800
Indirect Sources	9 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000
<b>WASTE</b>	<b>18 000</b>	<b>19 000</b>	<b>20 000</b>	<b>20 000</b>	<b>20 000</b>	<b>20 000</b>	<b>20 000</b>	<b>21 000</b>	<b>21 000</b>
<b>a. Solid Waste Disposal on Land</b>	<b>17 000</b>	<b>18 000</b>	<b>19 000</b>	<b>18 000</b>	<b>19 000</b>	<b>19 000</b>	<b>19 000</b>	<b>19 000</b>	<b>20 000</b>
<b>b. Wastewater Handling</b>	<b>780</b>	<b>820</b>	<b>880</b>	<b>910</b>	<b>910</b>	<b>910</b>	<b>930</b>	<b>940</b>	<b>930</b>
<b>c. Waste Incineration</b>	<b>400</b>	<b>350</b>	<b>250</b>	<b>250</b>	<b>220</b>	<b>230</b>	<b>230</b>	<b>240</b>	<b>240</b>
<b>Land Use, Land-use Change and Forestry</b>	<b>-110 000</b>	<b>160 000</b>	<b>-98 000</b>	<b>-88 000</b>	<b>51 000</b>	<b>12 000</b>	<b>41 000</b>	<b>-8 400</b>	<b>31 000</b>
<b>a. Forest Land</b>	<b>-130 000</b>	<b>150 000</b>	<b>-110 000</b>	<b>-100 000</b>	<b>39 000</b>	<b>500</b>	<b>31 000</b>	<b>-18 000</b>	<b>23 000</b>
<b>b. Cropland</b>	<b>14 000</b>	<b>6 800</b>	<b>2 600</b>	<b>1 700</b>	<b>1 500</b>	<b>640</b>	<b>76</b>	<b>-860</b>	<b>-1 400</b>
<b>c. Grassland</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>
<b>d. Wetlands</b>	<b>4 000</b>	<b>3 000</b>	<b>2 000</b>	<b>2 000</b>	<b>2 000</b>	<b>2 000</b>	<b>2 000</b>	<b>2 000</b>	<b>2 000</b>
<b>e. Settlements</b>	<b>9 000</b>	<b>9 000</b>	<b>8 000</b>	<b>8 000</b>	<b>8 000</b>	<b>8 000</b>	<b>8 000</b>	<b>8 000</b>	<b>8 000</b>

Notes:

- National totals exclude all GHGs from the Land Use, Land-use Change and Forestry sector.
  - Emissions from Fuel Ethanol are reported within the gasoline transportation sub-categories.
  - The category Mineral Product Use includes CO<sub>2</sub> emissions coming from the use of limestone and dolomite, soda ash, and magnesite.
  - Fugitive emissions from coal mining activities for 2002 and 2003 have been extrapolated based on publicly available coal production data.
- Indicates no emissions.  
0.0 Indicates emissions truncated due to rounding.

The primary source of this net trend of rising emissions is the increase in the number of passenger-kilometres travelled (more people drove further) (NRCan 2005). However, it was the passenger-kilometres driven by light trucks that increased, while those driven by cars decreased. Contributing to this trend was the fact that the number of light trucks on the road doubled between 1990 and 2005, while the number of automobiles declined slightly. Since light trucks have higher emissions per kilometre than automobiles, the rising popularity of sport utility vehicles (SUVs) and pickups worsened the emission impact of increasing numbers of people driving further.

Research suggests<sup>10</sup> that, between 1990 and 2004, about 10% of the emission increase from automobiles and light trucks could be attributed purely to the shift in the type of private vehicles being driven. Perhaps of greater interest is the overall trend towards increasing horsepower for all classes of passenger vehicles, which has negated the rather substantial efficiency improvements made in internal combustion engines.

Emissions from HDDVs (large freight trucks) rose by about 19 Mt between 1990 and 2006, a 91% increase. Spurred on by free trade and the deregulation of the trucking industry, the amount of freight shipped grew rapidly over the period. In addition, the quantity shipped by truck (as opposed to other modes of transport, such as rail) increased as a result of customer requirements for just-in-time delivery and cross-border freight (NRCan 2005).

The Commercial & Institutional category displayed an 8 Mt (30%) increase in GHG emissions between 1990 and 2006. Driving this trend was a 25.5% increase in the floor space of commercial and institutional buildings (e.g. offices, schools, stores, and government edifices) between 1990 and 2005, a result of Canada's growing economy over the period. Energy demand in commercial buildings is also influenced by weather. In terms of Heating Degree Days, 2006 was about 3% warmer than 1990, so this helped to reduce emission growth; nevertheless, the impact of floor space dominates.

Mining showed a large increase in emissions between 1990 and 2006—10 Mt (about 167%), largely because of increasing economic activity.

Another sector that contributed, although to a lesser extent than Energy, to the longer-term growth in GHG emissions is Agriculture. This sector showed a 12 Mt increase (25%) between 1990 and 2006, resulting primarily from the expansion of the beef cattle, swine, and poultry industries, as well as an increase in the application of synthetic nitrogen fertilizer in the Prairies.

In addition to the already-mentioned reduction in emissions from automobiles, three subsectors, all within the Industrial Processes Sector, contributed towards counteracting 1990–2006 emission growth—Adipic Acid Production (Chemical Industry), Aluminum Production, and SF<sub>6</sub> used in Magnesium Smelters and Casters (both constituents of Metal Production).

At Canada's sole adipic acid production plant in Canada, the installation of an emission abatement system in 1997 resulted in significant reductions of N<sub>2</sub>O emissions. Although this system was temporarily off-line in 2004 (and therefore N<sub>2</sub>O reductions were not as great that year), emissions in 2006 were down 9.5 Mt (89%) in comparison to 1990.

---

10. Adapted from NRCan (2005).

In the aluminium industry (which emits both CO<sub>2</sub> and PFCs), PFC emissions were reduced as a result of better control of anode events in smelters by increasing use of electronic monitoring and automated emission controls. As a result, between 1990 and 2006, total GHG process emissions from the aluminium industry decreased by 1.7 Mt (15%), while primary aluminium production increased significantly.

Although it does not contribute to national totals, it is of interest to consider the trends in the LULUCF Sector. The changes in emissions from sources and removals by sinks in the LULUCF sector suggests that the whole sector tended to turn from a sink to a source of CO<sub>2</sub>. In 2006, the net flux from this sector amounted to a net source of 31 Mt. Trends in the LULUCF sector are primarily driven by those in forest land. The net flux in forest land displays an important annual variability due to the erratic pattern of forest wildfires, which masks other, underlying patterns in the sector directly associated with human activities. For example, between 1990 and 1998 the amount of carbon removed in harvested wood biomass increased by 50%; it has since then stabilized around an annual average of 42 Mt C, corresponding to annual emissions of 155 Mt CO<sub>2</sub>. Nevertheless, the impact of major forest disturbances in recent years, notably the mountain pine beetle infestation in Western Canada and the large areas burned by wildfires in 1995, 1998, 2002, 2003 and 2004, dominates the sector.

#### ***ES.4 Other Information***

##### **ES.4.1 Emissions Associated with the Export of Oil and Natural Gas**

Canada is rich in fossil fuel resources, and the associated industry contributes significantly to the economy. A much greater quantity of Canada's oil and gas production is sold internationally now than in the past. Between 1990 and 2006, oil exports grew by 171% to 3 955 petajoules (PJ)<sup>11</sup> (almost three times the rate of growth of oil production) (Table S-4), while exports of natural gas increased 154% to 3 906 PJ (almost twice the rate of growth of natural gas production) (Table S-5).<sup>12</sup> Furthermore, the sum total of oil and gas energy exports increased by 162% over the same period (Table S-6). It is important to note that natural gas exports have exhibited little change since 2000. Future increases in natural gas exports are unlikely given projected production declines from diminishing reserves in Canada's largest natural gas reservoir (the Western Sedimentary Basin) (Nyboer and Tu 2006).

Increased Canadian fossil fuel exports have been offset, in part, by increased fossil fuel imports. Indeed, 58% more oil was imported in 2006 than in 1990. The balance between changes in exports, imports and production reflect an increase in apparent domestic consumption of 23% between 1990 and 2006 (Table S-6).

Activities associated with the oil and gas industry result in considerable GHG emissions. Between 1990 and 2006, increases in oil and gas production for export (principally to the United States) contributed substantially to emissions growth. Total emissions associated with the production, processing, and transmission of all oil and gas destined for export were about 75 Mt in 2006, up 171% from 1990 (Table S-6).

---

11. A petajoule (PJ) is a measure of the energy content of fuels.

12. The source for all export and energy production data is Statistics Canada's *Report on Energy Supply–Demand in Canada* (RES-D, #57-003). The 1990–1995 GHG emissions associated with net exports are taken from a report prepared for Environment Canada (McCann 1997), while the 1996–2006 estimates were extrapolated from this report.

**Table S-4: Crude Oil: Production, Export, and GHG Emission Trends, 1990–2006**

<b>Crude Oil Trends</b>	<b>1990</b>	<b>1995</b>	<b>2000</b>	<b>2003</b>	<b>2004</b>	<b>2005</b>	<b>2006</b>
Domestic Production (PJ)	3 723	4 401	4 917	5 572	5 740	5 626	5 930
<i>Growth Since 1990 (%)</i>	NA	18.2	32.1	49.7	54.2	51.1	59.3
Energy Imported (PJ)	1 199	1 318	2 041	2 026	2 088	2 070	1 897
<i>Growth Since 1990 (%)</i>	NA	9.9	70.2	68.9	74.1	72.6	58.2
Energy Exported (PJ)	1 461	2 362	3 091	3 444	3 623	3 522	3 955
<i>Growth Since 1990 (%)</i>	NA	62	111	136	148	141	171
Apparent Domestic Consumption (PJ)	3 461	3 357	3 867	4 154	4 205	4 174	3 872
<i>Growth Since 1990 (%)</i>	NA	-3.0	11.7	20.0	21.5	20.6	11.9
Emissions Associated with Gross Exports (Mt CO <sub>2</sub> eq.)	13.9	24.5	31.9	36.0	38.0	36.9	41.8
<i>Growth Since 1990 (%)</i>	NA	76	130	159	174	165	201
Emissions Associated with Net Exports <sup>1</sup> (Mt CO <sub>2</sub> eq.)	8.8	17.8	16.5	20.7	22.0	21.0	28.1
<i>Growth Since 1990 (%)</i>	NA	102	87	135	150	139	219

Notes:

1. See box on Net Export Emissions.

NA = Not applicable.

**Table S-5: Natural Gas: Production, Export, and GHG Emission Trends, 1990–2006**

<b>Crude Oil Trends</b>	<b>1990</b>	<b>1995</b>	<b>2000</b>	<b>2003</b>	<b>2004</b>	<b>2005</b>	<b>2006</b>
Domestic Production (PJ)	4 184	6 129	7 062	7 065	7 096	7 192	7 220
<i>Growth Since 1990 (%)</i>	NA	47	69	69	70	72	73
Energy Imported (PJ)	24.2	25.7	61.8	369.8	415.0	364.4	369.3
<i>Growth Since 1990 (%)</i>	NA	6	155	1427	1613	1405	1425
Energy Exported (PJ)	1 537	3 011	3 846	3 876	4 022	4 066	3 906
<i>Growth Since 1990 (%)</i>	NA	96	150	152	162	164	154
Apparent Domestic Consumption (PJ)	2 671	3 144	3 278	3 559	3 489	3 491	3 683
<i>Growth Since 1990 (%)</i>	NA	18	23	33	31	31	38
Emissions Associated with Gross Exports (Mt CO <sub>2</sub> eq.)	13.9	26.5	33.1	33.4	34.6	34.9	33.6
<i>Growth Since 1990 (%)</i>	NA	91	138	140	149	151	142
Emissions Associated with Net Exports <sup>1</sup> (Mt CO <sub>2</sub> eq.)	12.7	25.1	31.1	25.6	25.9	27.2	25.8
<i>Growth Since 1990 (%)</i>	NA	98	145	101	104	114	103

Notes:

1. See box on Net Export Emissions.

NA = Not applicable.

**Table S-6: Combined Crude Oil and Natural Gas: Production, Export, and GHG Emission Trends, 1990–2006**

<b>Crude Oil Trends</b>	<b>1990</b>	<b>1995</b>	<b>2000</b>	<b>2003</b>	<b>2004</b>	<b>2005</b>	<b>2006</b>
Domestic Production (PJ)	7 906	10 530	11 979	12 638	12 835	12 819	13 149
<i>Growth Since 1990 (%)</i>	NA	33	52	60	62	62	66
Energy Imported (PJ)	1 224	1 344	2 103	2 396	2 503	2 435	2 267
<i>Growth Since 1990 (%)</i>	NA	9.9	72	96	105	99	85
Energy Exported (PJ)	2 999	5 373	6 937	7 321	7 645	7 588	7 861
<i>Growth Since 1990 (%)</i>	NA	79	131	144	155	153	162
Apparent Domestic Consumption (PJ)	6 131	6 501	7 144	7 713	7 694	7 665	7 555
<i>Growth Since 1990 (%)</i>	NA	6.0	17	26	25	25	23
Emissions Associated with Gross Exports (Mt CO <sub>2</sub> eq.)	27.8	51.0	65.0	69.4	72.6	71.8	75.4
<i>Growth Since 1990 (%)</i>	NA	83	134	149	161	158	171
Emissions Associated with Net Exports <sup>1</sup> (Mt CO <sub>2</sub> eq.)	21.5	42.9	47.5	46.2	47.9	48.3	53.9
<i>Growth Since 1990 (%)</i>	NA	100	121	115	123	125	151

Notes:

1. See box on Net Export Emissions.

NA = Not applicable.

### Net Export Emissions

The production, processing, and transmission of oil and gas results in considerable GHG emissions. Since Canada both exports and imports significant quantities of fuel, determination of emissions associated with net exports provides a clearer picture of emissions arising from domestic energy demand. Net export emissions are the Canadian emissions associated with extracting, processing, and transporting exported fuels minus the foreign emissions associated with the same activities for imported fuels. The emissions associated with net exports approximate the quantity of GHGs that would be ascribed to Canada if it was responsible only for those related to its own demand. Net exports rose from about 22 Mt in 1990 to 54 Mt in 2006 (a 151% increase; Table S-6).\*

\*Note that the long-term trends for net export emissions are more accurate than net export emissions calculated for any given year.

### ES.4.2 Provincial/Territorial GHG Emissions

It is important to note that Canada's GHG emissions vary from region to region. This is linked to the distribution of natural resources and heavy industry within the country. While the use of natural resources and industrial products benefits all regions of North America, emissions from their production tend to be concentrated in particular geographic regions. Thus, certain jurisdictions in Canada tend to produce more GHG emissions because of their economic and industrial structure and their relative dependence on fossil fuels for producing energy. Figure S-4 illustrates the provincial/territorial distribution of emissions for 1990 and 2006.

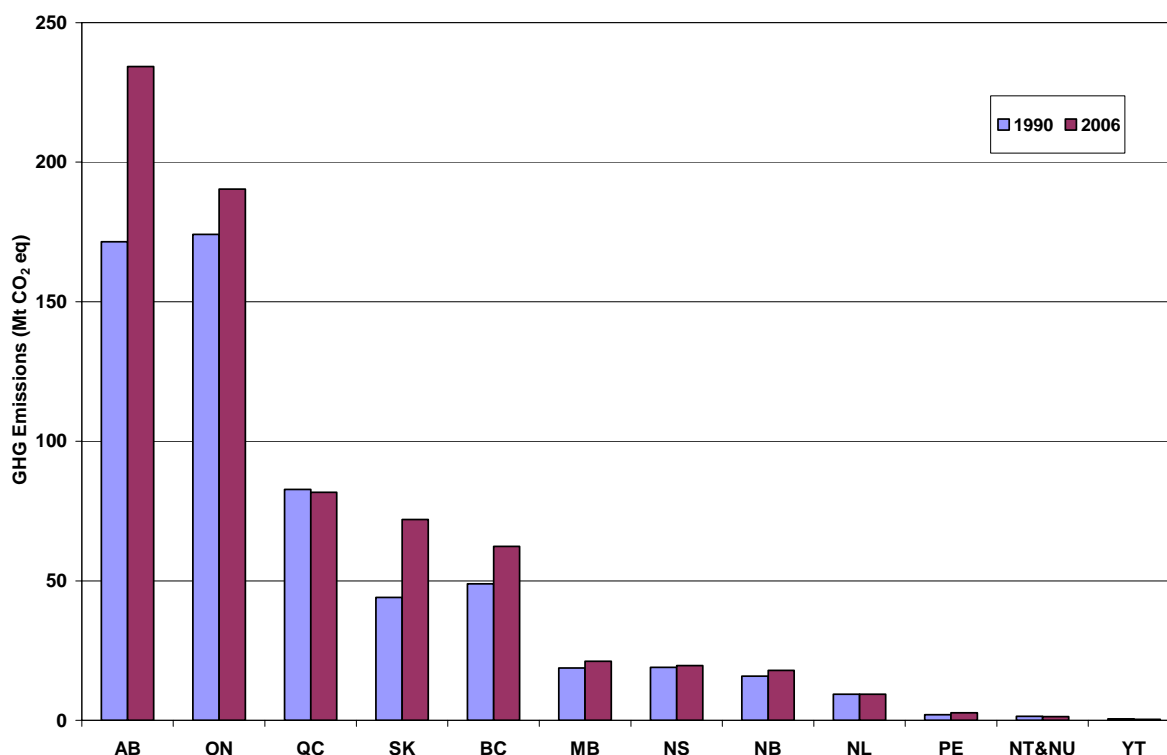


Figure S-4: Total Provincial/Territorial GHG Emissions, 1990 and 2006

### ES.4.3 The International Context

Canada contributes about 2% of total global GHG emissions. It is one of the highest per capita emitters, largely the result of its size, climate (i.e. energy demands), and resource-based economy. In 2005, Canada emitted a little over 22 t of GHGs per capita, which represents 3.2% growth since 1990, but a 5.7% *decline* since 2003 (see Table S-1).

In terms of total anthropogenic GHG emissions, Canada ranks seventh among the eight Annex I Parties whose emissions increased more than 25% over the 1990–2005 period,<sup>13</sup> and first among the G8 nations. Canada, which has a -6% Kyoto target and a growth of +25% (based on its 2007 inventory submission) compares with Spain's +53% growth (-8% target<sup>14</sup>), Greece's +27% rise (-8% target<sup>14</sup>), and Japan's +7% increase (-6% target). Parties whose emissions decreased by 2005 include the European Union (EU), by -1.5% (-8% target<sup>14</sup>), the United Kingdom, by -15% (-8% target<sup>14</sup>), and Germany, by -18% (-8% target<sup>14</sup>).

---

13. These aggregate estimates are based on data from Parties that submitted inventories to the UNFCCC in 2007. Source: UNFCCC (2007), [http://unfccc.int/ghg\\_emissions\\_data/ghg\\_data\\_from\\_unfccc/time\\_series\\_Annex\\_i/items/3841.php](http://unfccc.int/ghg_emissions_data/ghg_data_from_unfccc/time_series_Annex_i/items/3841.php)

14. Although this -8% target was agreed to by all European Union (EU) Parties individually under the Kyoto Protocol, these countries also have a separate agreement under the "EU Bubble." This agreement calls for each EU member to meet different targets, which were set in order to account for individual differences, so as to attain the collective EU target of -8%.

# 1 Introduction

## 1.1 GHG Inventories and Climate Change

In order to understand climate change, it is important to differentiate between weather and climate. Weather is the state of the atmosphere at a given time and place and is usually reported as temperature, air pressure, humidity, wind, cloudiness, and precipitation. The term weather is used mostly when reporting these conditions over short periods of time.

On the other hand, climate is the average pattern of weather (usually taken over a 30-year period) for a particular region. Climatic elements include precipitation, temperature, humidity, sunshine, wind velocity, phenomena such as fog, frost, and hailstorms, and other measures of the weather.

Climate change refers to changes in long-term weather patterns caused by natural phenomena and human activities that alter the chemical composition of the atmosphere through the buildup of GHGs, which trap heat and reflect it back to the Earth's surface. According to the IPCC's *Fourth Assessment Report* (IPCC 2007a), the impacts of climate change will vary regionally. In general, temperatures and sea levels are expected to rise, and the frequency of extreme weather events is expected to increase. In some regions, the impacts could be devastating, while other regions could benefit from climate change. The impacts will depend on the form and magnitude of the change and, in the case of adverse effects, the ability of natural and human systems to adapt to the changes. Canada's temperatures have generally been increasing nationally, with temperatures remaining above normal since 1996 and showing a warming trend of 1.3°C over the period 1948–2006 (Figure 1-1).

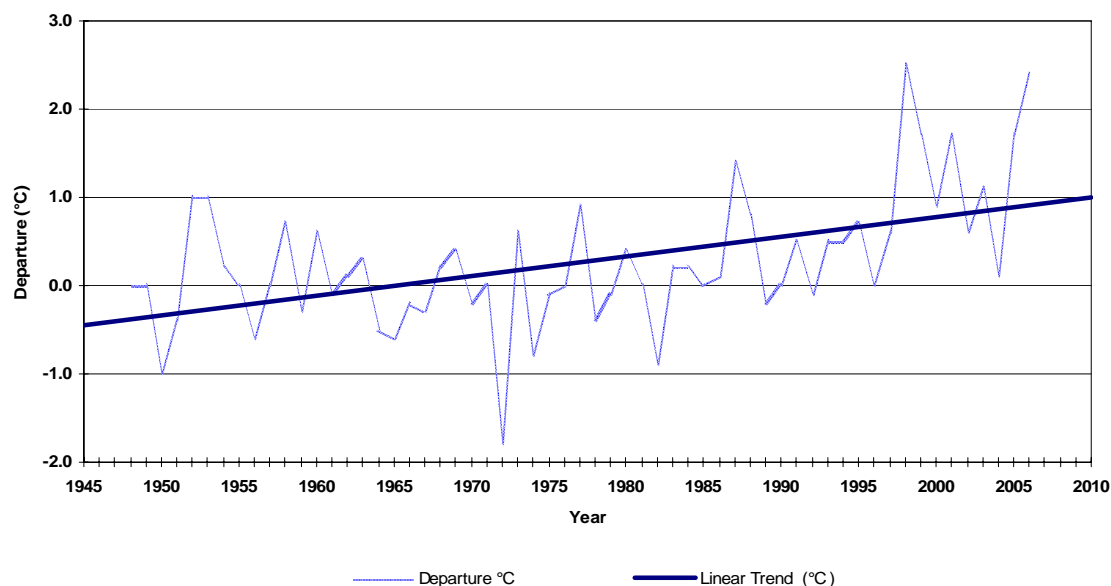


Figure 1-1: Annual Canadian Temperature Departures and Long-Term Trend, 1948–2006 (°C)

Source: Environment Canada ([www.msc-smc.ec.gc.ca/ccrm/bulletin/annual06/national\\_e.cfm](http://www.msc-smc.ec.gc.ca/ccrm/bulletin/annual06/national_e.cfm)).



It is now well-known that atmospheric concentrations of GHGs have grown significantly since pre-industrial times. Since 1750, the concentration of CO<sub>2</sub> has increased by 35%, CH<sub>4</sub> has increased by 155%, and the concentration of N<sub>2</sub>O has increased by 18% (WMO 2007). And between 1970 and 2004, global GHG emissions due to human activities have increased by approximately 70% (IPCC 2007b). These trends can be largely attributed to fossil fuel use (including energy supply, transportation, residential and commercial buildings, and industrial use) and land-use change, including permanent loss of forest cover.

The ultimate objective of the United Nations Framework Convention on Climate Change (UNFCCC) is to achieve stabilization of GHG concentrations in the atmosphere at a level that would prevent dangerous interference with the climate system. In its actions to achieve its objective and to implement its provisions, the UNFCCC lays out a number of guiding principles and commitments. Articles 4 and 12 and Decision 3/CP.5 of the Convention commit all Parties to develop, periodically update,<sup>15</sup> publish, and make available to the Conference of the Parties national inventories of anthropogenic<sup>16</sup> emissions by sources and removals by sinks of all GHGs not controlled by the Montreal Protocol using comparable methodologies.

This report provides estimates of Canada's emissions and removals of the following GHGs: CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, SF<sub>6</sub>, PFCs, and HFCs. In addition, and in keeping with the UNFCCC reporting guidelines for Annex I Parties, this report contains estimates of the ozone precursors NO<sub>x</sub>, CO, and NMVOCs, as well as SO<sub>2</sub>.

### 1.1.1 CO<sub>2</sub>

The global atmospheric concentration of CO<sub>2</sub> increased from a pre-industrial value of about 280 parts per million (ppm) to 381ppm in 2006 (WMO 2007) (Figure 1-2).

On the basis of global emission information, total world<sup>17</sup> CO<sub>2</sub> emissions in 2004 reached 26 319.9 Mt CO<sub>2</sub>, a 25.2% increase from 1990 (IPCC/OECD/IEA 2007). The primary sources of CO<sub>2</sub> generated from anthropogenic activities are fossil fuel combustion (including both stationary and mobile sources), and industrial processes, such as cement production. CO<sub>2</sub> emissions from land-use practices (including deforestation, forest and cropland management), were estimated to account for about 17% of anthropogenic CO<sub>2</sub> emissions (IPCC 2007b).

The primary natural sources of CO<sub>2</sub> include respiration by plants and animals, decomposing organic matter and fermentation, volcanoes, forest/grass fires, and oceans. The two main natural carbon-balancing processes, photosynthesis in terrestrial and aquatic ecosystems and storage in ocean sediments, remove substantial amounts of CO<sub>2</sub> from the atmosphere. However, the absorption capacity of these natural sinks appears to be exceeded, as atmospheric concentrations of CO<sub>2</sub> and other GHGs are increasing.

---

15. Annex I Parties (or developed countries) are required to submit a national inventory annually by April 15.

16. Anthropogenic refers to human-induced emissions and removals that occur on managed lands.

17. "Total world" includes non-OECD and OECD totals, as well as international marine bunkers and international aviation.

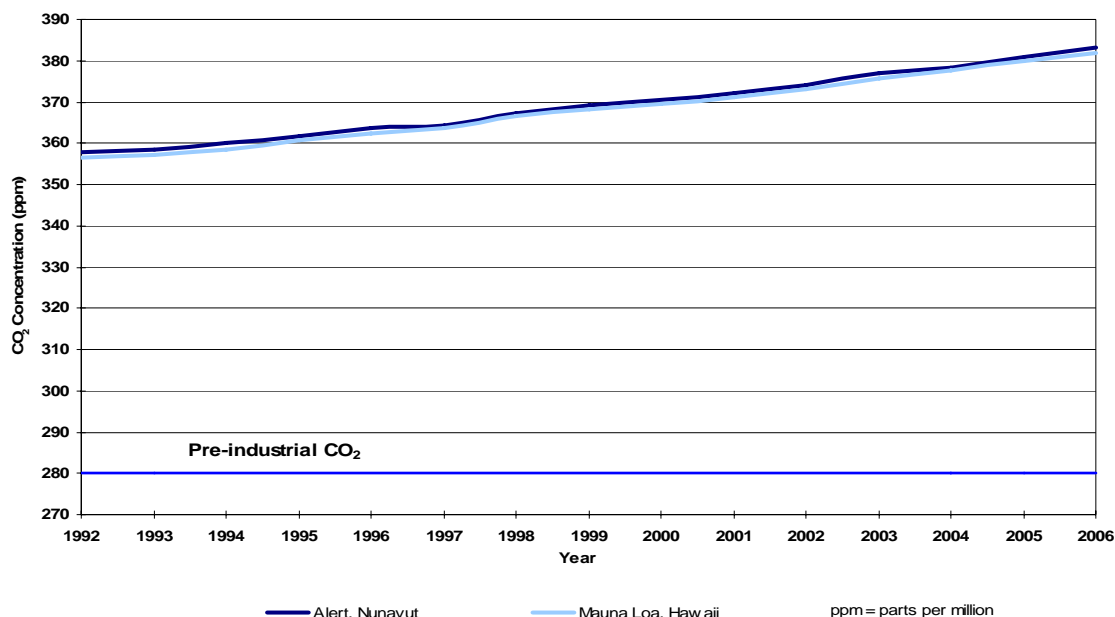


Figure 1-2: Global Atmospheric Concentrations of CO<sub>2</sub>, 1992–2006

Source: World Data Centre for Greenhouse Gases, Japan Meteorological Agency/World Meteorological Organization (<http://gaw.kishou.go.jp/wdcgg/>).

### 1.1.2 CH<sub>4</sub>

Recent atmospheric measurements of CH<sub>4</sub> concentrations are shown in Figure 1-3. The global atmospheric concentration of CH<sub>4</sub> has increased from a pre-industrial value of about 715 parts per billion (ppb) to 1 782 ppb in 2006 (WMO 2007). Growth rates have declined since the early 1990s, averaging approximately 2.4 ppb per year over the period 1996–2006 (WMO 2007). This is consistent with total emissions (sum of anthropogenic and natural sources) being nearly constant during this period (IPCC 2007b).

CH<sub>4</sub> emissions generated from human activities are primarily biogenic in nature and the result of activities such as livestock and rice cultivation as well as biomass burning, with smaller contributions from industrial sources, including natural gas delivery systems, landfills, and coal mining. Wetlands are also a natural source of CH<sub>4</sub> emissions (IPCC 2007a).

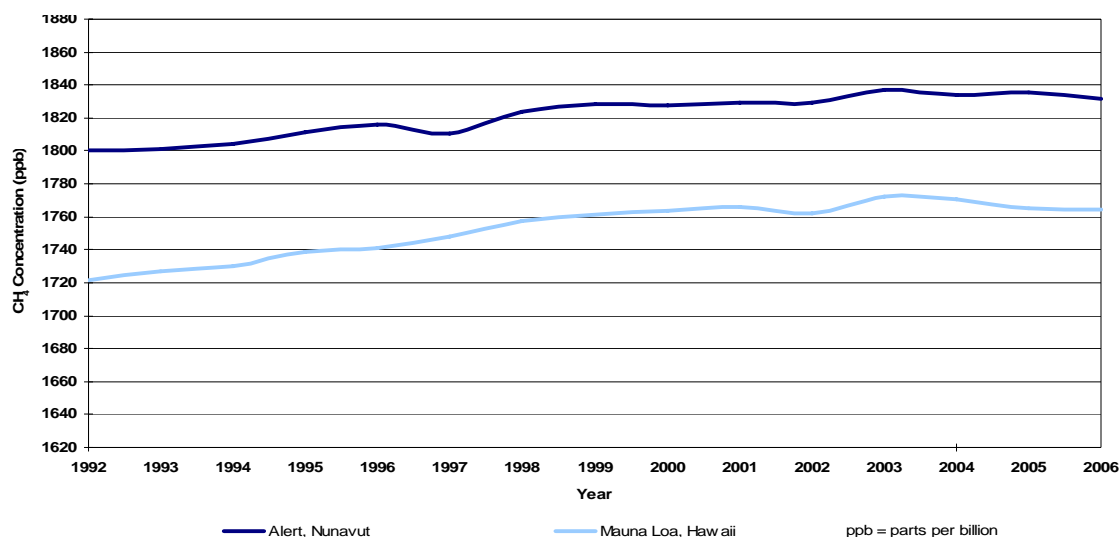


Figure 1-3: Global Atmospheric Concentrations of CH<sub>4</sub>, 1992–2006

Source: World Data Centre for Greenhouse Gases, Japan Meteorological Agency/World Meteorological Organization (<http://gaw.kishou.go.jp/wdcgg/>).

### 1.1.3 N<sub>2</sub>O

Atmospheric concentrations of N<sub>2</sub>O have grown by about 19% since the mid-1700s (WMO 2007), as the global atmospheric N<sub>2</sub>O concentration increased from a pre-industrial value of about 270 ppb to 317 ppb in 2006 (IPCC 2007b). Figure 1-4 shows global atmospheric N<sub>2</sub>O concentrations from 1993 to 2006.

It is estimated that approximately 40% of global atmospheric N<sub>2</sub>O is of human origin (IPCC 2007b), resulting primarily from the application of nitrogen fertilizers, soil cultivation, and the combustion of fossil fuels and wood, while the remaining global atmospheric N<sub>2</sub>O comes from soil and water denitrification under anaerobic conditions.

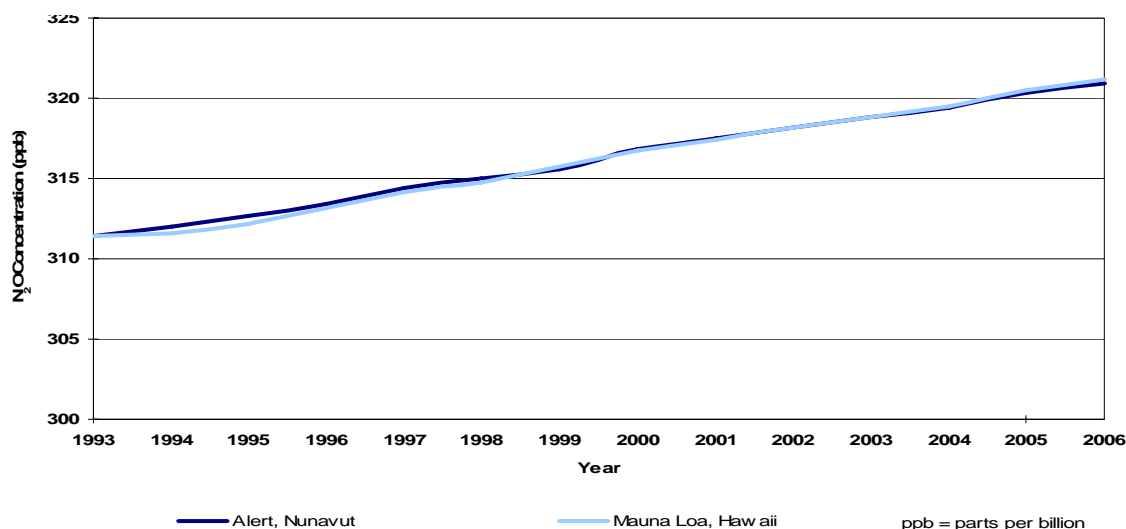


Figure 1-4: Global Atmospheric Concentrations of N<sub>2</sub>O, 1993–2006

Source: World Data Centre for Greenhouse Gases, Japan Meteorological Agency/World Meteorological Organization (<http://gaw.kishou.go.jp/wdcgg/>).

#### 1.1.4 HFCs, PFCs, and SF<sub>6</sub>

The final group of GHGs included in this report is the synthetic (not naturally occurring) fluorinated gases, HFCs, PFCs, and SF<sub>6</sub>. These gases, while emitted in very small amounts, are having a lasting effect on atmospheric composition and, potentially, the climate, because they are strong absorbers of infrared radiation and have very long atmospheric lifetimes. As shown in Table 1-1, all of the PFCs have atmospheric lifetimes of 2600 years or greater, with perfluoromethane estimated to last 50 000 years.

#### 1.1.5 GHGs and the Use of GWPs

To interpret the emission data presented in this report, it is important to understand that the radiative forcing<sup>18</sup> effect of a gas within the atmosphere is a reflection of its ability to cause atmospheric warming. Direct effects occur when the gas itself is a GHG, whereas indirect radiative forcing occurs when chemical transformation of the original gas produces a gas or gases that are GHGs or when a gas influences the atmospheric lifetimes of other gases.

The concept of “global warming potential” (GWP) has been developed to allow scientists and policy-makers to compare the ability of each GHG to trap heat in the atmosphere relative to another gas. By definition, a GWP is the time-integrated change in radiative forcing due to the instantaneous release of 1 kg of the gas expressed relative to the radiative forcing from the release of 1 kg of CO<sub>2</sub>. In other words, a GWP is a relative measure of the warming effect that the emission of a radiative gas (i.e. a GHG) might have on the surface troposphere. The GWP of a GHG takes into account both the instantaneous radiative forcing due to an incremental concentration increase and the lifetime of the gas. The 100-year GWPs, recommended by the

18. The term “radiative forcing” refers to the amount of heat-trapping potential for any given GHG. It is measured in units of power (watts) per unit of area (metres squared).

IPCC (Table 1-1) and required for inventory reporting under the UNFCCC (adopted at the third Conference of the Parties), are used in this report.

**Table 1-1: GWPs and Atmospheric Lifetimes**

<b>GHG</b>	<b>Formula</b>	<b>100-Year GWP</b>	<b>Atmospheric Lifetime (years)</b>
Carbon Dioxide	CO <sub>2</sub>	1	Variable
Methane	CH <sub>4</sub>	21	12 ± 3
Nitrous Oxide	N <sub>2</sub> O	310	120
Sulphur Hexafluoride	SF <sub>6</sub>	23 900	3 200
Hydrofluorocarbons (HFCs)			
HFC-23	CHF <sub>3</sub>	11 700	264
HFC-32	CH <sub>2</sub> F <sub>2</sub>	650	5.6
HFC-41	CH <sub>3</sub> F	150	3.7
HFC-43-10mee	C <sub>5</sub> H <sub>2</sub> F <sub>10</sub>	1 300	17.1
HFC-125	C <sub>2</sub> HF <sub>5</sub>	2 800	32.6
HFC-134	C <sub>2</sub> H <sub>2</sub> F <sub>4</sub> (CHF <sub>2</sub> CHF <sub>2</sub> )	1 000	10.6
HFC-134a	C <sub>2</sub> H <sub>2</sub> F <sub>4</sub> (CH <sub>2</sub> FCF <sub>3</sub> )	1 300	14.6
HFC-143	C <sub>2</sub> H <sub>3</sub> F <sub>3</sub> (CHF <sub>2</sub> CH <sub>2</sub> F)	300	1.5
HFC-143a	C <sub>2</sub> H <sub>3</sub> F <sub>3</sub> (CF <sub>3</sub> CH <sub>3</sub> )	3 800	3.8
HFC-152a	C <sub>2</sub> H <sub>4</sub> F <sub>2</sub> (CH <sub>3</sub> CHF <sub>2</sub> )	140	48.3
HFC-227ea	C <sub>3</sub> HF <sub>7</sub>	2 900	36.5
HFC-236fa	C <sub>3</sub> H <sub>2</sub> F <sub>6</sub>	6 300	209
HFC-245ca	C <sub>3</sub> H <sub>3</sub> F <sub>5</sub>	560	6.6
Perfluorocarbons (PFCs)			
Perfluoromethane	CF <sub>4</sub>	6 500	50 000
Perfluoroethane	C <sub>2</sub> F <sub>6</sub>	9 200	10 000
Perfluoropropane	C <sub>3</sub> F <sub>8</sub>	7 000	2 600
Perfluorobutane	C <sub>4</sub> F <sub>10</sub>	7 000	2 600
Perfluorocyclobutane	c-C <sub>4</sub> F <sub>8</sub>	8 700	3 200
Perfluoropentane	C <sub>5</sub> F <sub>12</sub>	7 500	4 100
Perfluorohexane	C <sub>6</sub> F <sub>14</sub>	7 400	3 200

Sources:

GWP: IPCC (1996).

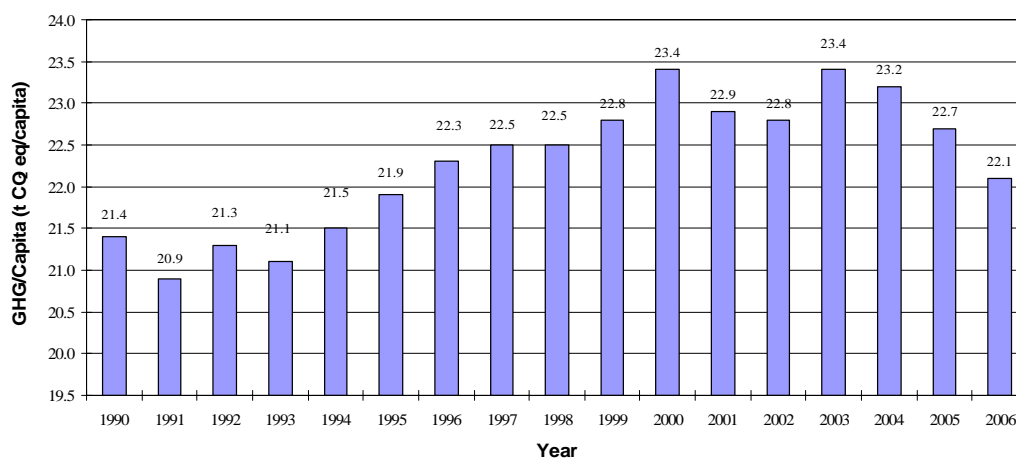
Atmospheric Lifetime: IPCC (1995), Table 2.9.

Note:

The CH<sub>4</sub> GWP includes the direct effect and those indirect effects due to the production of tropospheric ozone and stratospheric water vapour. Not included is the indirect effect due to the production of CO<sub>2</sub>.

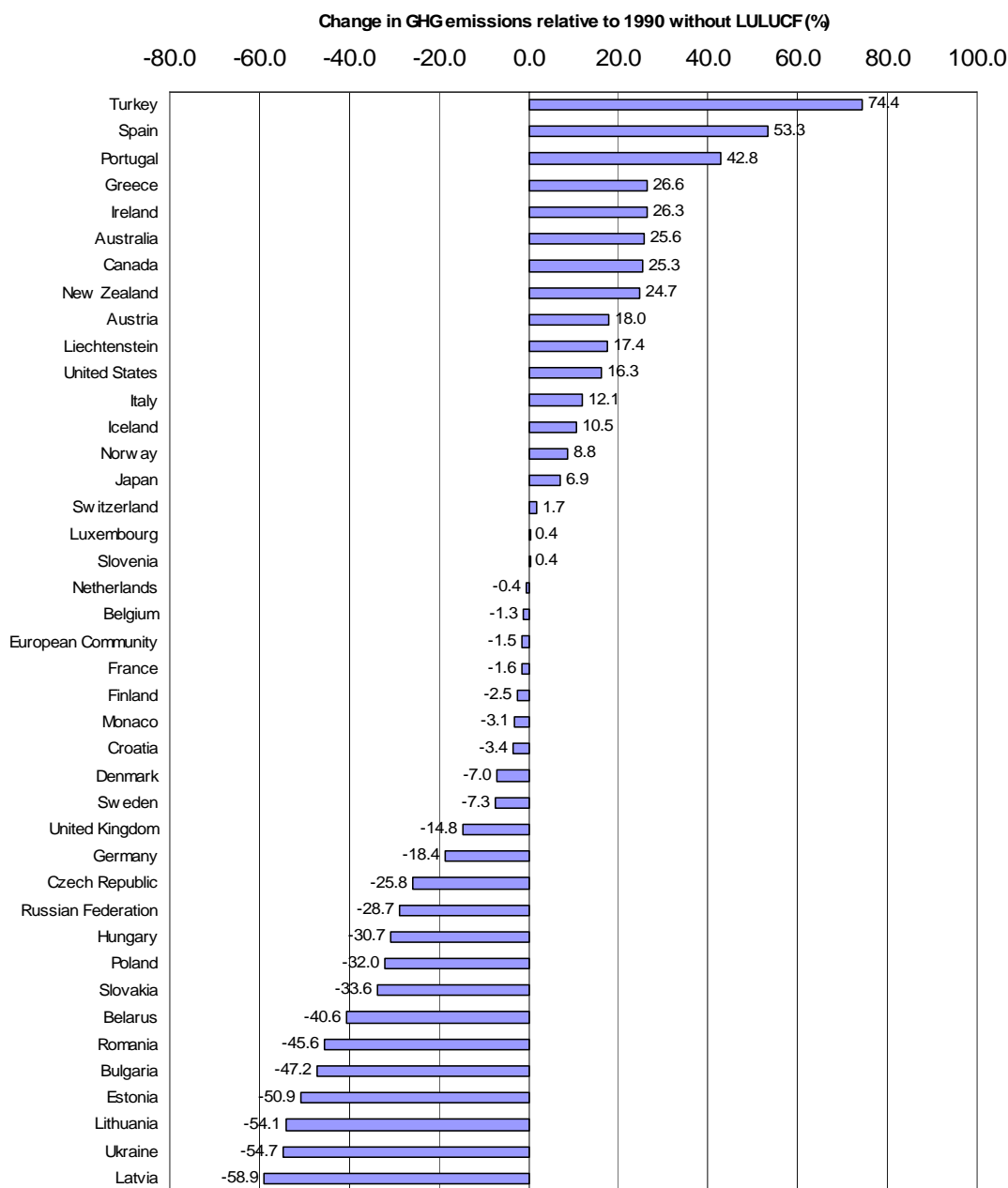
### 1.1.6 Canada's Contribution

While Canada contributes only about 2% of total global GHG emissions, it is one of the highest per capita emitters, largely the result of its size, climate (i.e. energy demands), and resource-based economy. In 1990, Canadians released 21.4 t of GHGs per capita. By 2006, this had increased to 22.1 t of GHGs per capita (Figure 1-5).



-----  
**Figure 1-5: Per Capita GHG Emission Trend for Canada, 1990–2006**  
 -----

In terms of growth in total anthropogenic GHG emissions without LULUCF, Canada ranks seventh among the eight Annex I Parties whose emissions increased more than 25.3% over the 1990–2005 period (Figure 1-6) and first among the G8 countries.



-----  
**Figure 1-6: Change in Aggregate GHG Emissions for Annex I Parties without LULUCF, 1990–2005**  
 -----

Source:

UNFCCC (2007), [http://unfccc.int/ghg\\_emissions\\_data/ghg\\_data\\_from\\_unfccc/time\\_series\\_annex\\_i/items/3841.php](http://unfccc.int/ghg_emissions_data/ghg_data_from_unfccc/time_series_annex_i/items/3841.php)

## **1.2 Institutional Arrangements for Inventory Preparation**

### **1.2.1 The National Inventory System**

Under Article 5.1 of the Kyoto Protocol, each Party to the Protocol included in Annex I shall have in place, no later than January 1, 2007, a national system for the estimation of anthropogenic

emissions from sources and removals by sinks of all GHGs not controlled by the Montreal Protocol. The national (inventory) system encompasses the institutional, legal, and procedural arrangements necessary to ensure that Parties meet their reporting obligations, that quality inventories are prepared, and that proper documentation and archiving occur in order to facilitate third-party review and to assess compliance with targets under the Kyoto Protocol. The following section describes the roles and responsibilities of the various agencies and players in the implementation of the national inventory system in Canada. The process for the preparation of the inventory is outlined in section 1.3.

### 1.2.2 Institutional Arrangements

The *Canadian Environmental Protection Act, 1999* (CEPA 1999) is the legislative authority for Environment Canada to establish the national inventory system and to designate Environment Canada's Greenhouse Gas Division as the single national entity with responsibility for the preparation and submission of the national inventory to the UNFCCC (Canada 1999). Recognizing the need to draw on the best available technical and scientific expertise and information in accordance with good practice and international quality standards, the Greenhouse Gas Division has defined roles and responsibilities for the preparation of the inventory, both internally and externally. Figure 1-7 identifies the different partners of the inventory agency and their contribution.

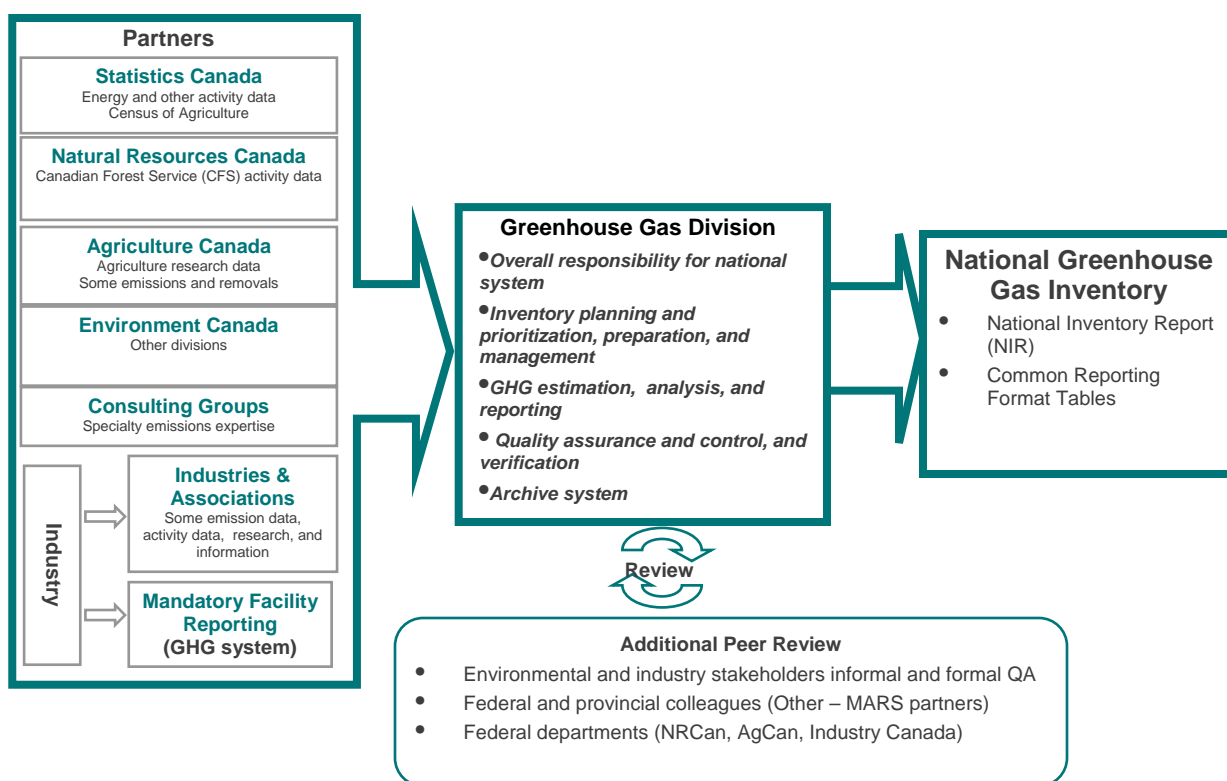
Inventory experts in the Greenhouse Gas Division develop, analyze, and verify activity data, methods, emission factors, and the emission and removal estimates. The division develops, reports, and publishes the NIR and the Common Reporting Format (CRF) tables. The Greenhouse Gas Division also manages the quality and the archiving systems, performs trend analysis, publishes fact sheets, and acts as a clearinghouse for GHG information and technical guidance on GHG quantification. Moreover, the Greenhouse Gas Division manages the Greenhouse Gas Emissions Reporting Program, requiring annual reporting from facilities emitting over 100 kt CO<sub>2</sub> eq as described in section 1.4.1.

Groups at Environment Canada other than the Greenhouse Gas Division also contribute data on waste and waste management, residential fuel use of biomass, and emissions of SF<sub>6</sub>, ozone, and aerosol precursors.

Because sources and sinks of GHGs originate from a tremendous range of economic sectors and activities, the Greenhouse Gas Division is involved in many partnerships with data providers and expert contributors in a variety of ways, ranging from informal to formal arrangements.

Canada's national statistical agency, Statistics Canada, provides Environment Canada with a large portion of the underlying activity data to estimate GHG emissions for the Energy and the Industrial Processes sectors. The Manufacturing, Construction and Energy Division (MCED) of Statistics Canada is responsible for the collection, compilation, and dissemination of the energy balance in its *Annual Report on Energy Supply and Demand in Canada* (RESO). The energy balance is transmitted annually to Environment Canada according to the terms of a Memorandum of Understanding established between the two departments.





-----  
**Figure 1-7: Partners of the National Inventory System**  
 -----

Energy and fossil fuel data are collected based on a mix of annual and monthly censuses and surveys from industries, federal agencies, provincial energy departments, and the Canadian Industrial Energy End-Use Data and Analysis Centre (CIEEDAC). MCED also conducts an annual Industrial Consumption of Energy survey, a bottom-up approach that feeds into the development of the energy balance and is also used to verify the data collected through its supply and disposition surveys.

Statistics Canada's quality management system for the energy balance includes an internal and external review process. Owing to the complexity of energy data, a Working Group on Energy Statistics consisting of members from Statistics Canada, Environment Canada, and Natural Resources Canada (NRCan) was established to provide advice, direction, and recommendations on improvements to the energy balance. Refer to Annex 2 of this report for additional information on the development of the energy balance and its quality checks.

Other groups in Statistics Canada are also responsible for gathering and reporting transport activity data, such as vehicle fleet, and other non-energy-related industrial information, including urea and ammonia production. The statistics agency also collects agricultural activity data through the Census of Agriculture and provides data on other activities such as disposal of solid waste on land, as well as population data.

NRCan is a key partner of Environment Canada; it provides energy expertise and analysis, serves as expert reviewer for the Energy Sector, and collects and provides activity data on mineral production, ethanol consumption, and wood residues. The Analysis and Modelling Division of

NRCan is responsible for preparing GHG emission forecasts for the Energy Sector. Fleet fuel efficiency data are provided by the federal transport department.

Since 2004, Environment Canada has officially designated responsibilities to the Canadian Forest Service (CFS) of NRCan and to Agriculture and Agri-Food Canada (AAFC) for the development of key components of the LULUCF Sector and has established formal and explicit governance mechanisms to that effect through Memoranda of Understanding. The LULUCF component of the national system, called the Monitoring, Accounting and Reporting System (MARS) for LULUCF, is managed by an interdepartmental steering committee chaired by Environment Canada and with representatives from the Research Branch of AAFC and from NRCan-CFS. Three technical working groups address the subsectors of Forestry, Agriculture, and Land-Use Change, respectively, to ensure that the best available information and data from scientific research are integrated into the LULUCF Sector of the inventory.

NRCan-CFS annually develops and delivers forest-related GHG estimates of the LULUCF Sector (including deforestation and afforestation), and AAFC delivers cropland- and grassland-related GHG estimates. Provided by December 1 annually, estimates must be accompanied by complete and transparent documentation, including uncertainty analysis and QC. NRCan-CFS has developed the National Forest Carbon MARS, and AAFC, the Canadian Agricultural Greenhouse Gas MARS, both of which contributed major improvements to the LULUCF Sector. Environment Canada develops estimates for other LULUCF categories, undertakes QA, and plays an integrating role, ensuring consistency in the land representation system. In addition to its responsibility in the MARS for LULUCF, AAFC also plays a major role in the Agriculture Sector inventory preparation in concert with Environment Canada.

The Canadian Space Agency and the Earth Science Sector of NRCan contribute earth observation expertise and remote sensing data to the LULUCF MARS.

The Greenhouse Gas Division collaborates with provincial and territorial governments, both on a bilateral basis and through the Emissions and Projection Working Group (see section 1.3).

When required, and resources permitting, contracts are established with consulting firms and universities to conduct in-depth studies—for example, on updating emission factors. The industrial sector is a key partner in all sectors of the inventory, providing technical hands-on expertise on emission factors, activity data, and GHG estimates. A bilateral agreement with the Aluminum Association of Canada (AAC) has been signed, by which process-related emission estimates for CO<sub>2</sub>, PFCs, and SF<sub>6</sub> are to be provided annually to Environment Canada. A similar agreement has been negotiated with the Canadian Electricity Association (CEA) for provision of SF<sub>6</sub> emissions and supplementary data relating to power transmission systems.

### ***1.3 Process for Inventory Preparation***

Continuous data collection and improvements are integral parts of the national inventory planning and quality management cycles (see section 1.6). Each year, an evaluation is conducted based on the results of the lessons learned review of the previous inventory cycle, QA/QC follow-up, the UNFCCC review report, and the improvement plan to identify priorities and areas for improvement. Based on these outcomes, methodologies and emission factors are reviewed, developed, and/or refined. QA reviews of methodologies and emission factors are undertaken for categories where a change in methodology or emission factor is proposed and for categories that are scheduled for a QA review of methodology or emission factor.

The data used to compile the national inventory are generally from published sources. Data are collected either electronically or manually (hard copies) from the source agencies and are entered into spreadsheet-based emission accounting systems, databases, and/or models. Emissions are calculated by designated inventory experts, reviewed internally, and then reported according to UNFCCC guidelines in the CRF and the NIR. QC checks and estimates are signed off by sectoral managers before the report and national totals are prepared. The inventory process also involves key category assessment, recalculations, uncertainty work, and documentation preparation.

An external review is undertaken by members of a formal provincial and territorial expert working group on emissions who review pertinent sections of the draft inventory. Sections are also reviewed at the same time by experts and scientists in other government departments.

Comments from the review are documented and, where appropriate, incorporated in the NIR and CRF, which are normally submitted to the UNFCCC electronically prior to April 15 of each year. Initial checks on the April submission are performed by the UNFCCC in May and June. A final inventory report is prepared and submitted, if necessary. Once finalized, the CRF and NIR are then further edited, translated, and readied for publication.

#### **1.4 Methodologies and Data Sources**

The inventory is structured to match the reporting requirements of the UNFCCC and is divided into six main sectors:

- Energy;
- Industrial Processes;
- Solvent and Other Product Use;
- Agriculture;
- LULUCF; and
- Waste.

Each of these sectors is further subdivided within the inventory. The methods described have been grouped, as closely as possible, by UNFCCC sector and subsector.

The methodologies contained in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997), *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000), and *Good Practice Guidance for Land Use, Land-Use Change and Forestry* (IPCC 2003) are followed to estimate emissions and removals of each of the following direct GHGs:

- CO<sub>2</sub>;
- CH<sub>4</sub>;
- N<sub>2</sub>O;
- HFCs;
- PFCs; and
- SF<sub>6</sub>.

While not mandatory, the new UNFCCC reporting guidelines encourage Annex I Parties to provide information on the following indirect GHGs:

- sulphur oxides (SO<sub>x</sub>);
- NO<sub>x</sub>;
- CO; and
- NMVOCs.

For all categories except LULUCF, these gases (referred to as the Criteria Air Contaminants, or CACs) are inventoried and reported separately. CAC emissions in Canada are reported to the United Nations Economic Commission for the Environment.<sup>19</sup> As noted, a summary of these emissions is also included in the NIR (see annex 14: Ozone and Aerosol Precursors).

In general, an emissions and removals inventory can be defined as a comprehensive account of anthropogenic sources of emissions and removals by sinks and associated data from source categories within the inventory area over a specified time frame. It can be prepared “top-down,” “bottom-up,” or using a combination approach. Canada’s national inventory is prepared using a “top-down” approach, providing estimates at a sectoral and provincial/territorial level of segregation without attribution to individual emitters. Environment Canada is continuously working to improve the accuracy, completeness, and transparency of its inventory. A comprehensive bottom-up inventory is neither practicable nor possible at the present time, although estimates are derived from detailed source-specific data for some sectors.

The inventory distinguishes between point and area sources. Point sources refer to individual sources or facilities, whereas area sources are spatially diffuse and/or very numerous, involving the gathering of information on many individual sources. Point source emissions may be measured or estimated from information assembled from individual plant or facility throughput and emission factors.

Emissions or removals—whether for point or for area sources—are usually calculated or estimated using mass balance, stoichiometry, or emission factor relationships under average conditions. In many cases, provincial/territorial activity data are combined with average emission factors to produce a “top-down” national inventory. Large-scale regional estimates, based on average conditions, have been compiled for diffuse sources, such as transportation. Emissions from landfills are determined using a simulation model to account for the long-term slow generation and release of these emissions.

Manipulated biological systems, such as agricultural lands, forestry, and land converted to other uses, are typical sources or sinks diffused over very large areas. Processes that cause emissions and removals display considerable spatial and interannual variability, and they also span several years or decades. The most practical approach to estimating emissions and removals may require a combination of repeated measurements and modelling. The need, unique to these systems, to separate anthropogenic impacts from large natural fluxes creates an additional challenge.

In general, GHG emission and removal estimates may be derived for a given process or combination of operations by one or more of the following methods:

---

19. See website: <http://www.unece.org/>

*Direct Measurement:* With few exceptions, GHG emission or removal measurements apply to point sources. At present, a very limited number of sources have measured and reported GHG emissions.

*Mass Balance:* This approach determines atmospheric emissions from the difference between the amounts of the component (e.g. carbon) contained in feed materials or fuels and those contained in the products, process wastes, or non-emitted residuals. Mass balances are most appropriately applied to fuel carbon contributions and mineral processing activities, where sufficient data are available to derive average carbon contents of process streams. Generally, CO<sub>2</sub> emissions resulting from fuel combustion are readily estimated by the carbon balance method.

*Technology-Specific Emission Factor Calculations:* Company-specific emission factors can be used to estimate the rate at which a pollutant is released into the atmosphere (or captured) as a result of some process activity or unit throughput. Although emissions or removals may not be measured, individual facilities may have measured rate data for various parameters for their plants. These can be combined with other plant-specific information, such as throughput, activity data, and the number of such sources, to derive plant-specific emissions or removals for a point source or “bottom-up” inventory.

*Average or General Emission Factor Calculations:* If plant-specific data are not available, average or general-use emission factors can be used for a given source or sector. These can be combined with company-specific, sector-specific, process-specific, or general activity and population data to calculate emissions for a top-down inventory. Average or general emission factors for most of the sectors in the inventory have been developed by Environment Canada, in consultation with other government departments, industry associations, and agencies and organizations. These values reflect the most accurate methodologies based on currently available data and include information currently being developed by the IPCC for the UNFCCC.

The methodologies and emission factors described in this document are considered to be the best available to date given the available activity data. That being said, in some cases, a more accurate method or emission factor may be available, but the necessary activity data are lacking at the national level, so the more accurate method cannot be used. Some methods have undergone revision and improvement over time, and some new sources have been added to the inventory over time. Annexes 2 and 3 contain further information on the methodologies used in this report.

Methodology and data improvement activities, which take into account results of QA/QC procedures, reviews, and verification, are planned and implemented on a continuous basis by the staff of Environment Canada’s Greenhouse Gas Division, with a view to further refine and increase the transparency, completeness, accuracy, consistency, and comparability of the national inventory. As a result, changes in data or methods often lead to the recalculation of GHG estimates for the entire times series, from the 1990 base year to the most recent year available. Further discussion of recalculations and improvements can be found in Chapter 9.

### **1.4.1 Mandatory Reporting System for GHGs**

In March 2004, the Government of Canada established the Greenhouse Gas Emissions Reporting Program under section 46(1) of CEPA 1999, specifically targeting industrial GHG emitters in Canada. As published in the *Canada Gazette*, facilities that emit 100 kt CO<sub>2</sub> eq or more annually must submit a GHG emission report by June 1 of the following year. Voluntary submissions from facilities with GHG emissions below the reporting threshold are encouraged. The Greenhouse Gas Emissions Reporting Program applies only to the largest industrial GHG emitters in Canada.

The reported facility emissions represent just over one third (~38%) of Canada's total emissions as presented in the national GHG inventory.

The types of industrial facilities reporting GHG emissions include power generation plants that use fossil fuels to produce electricity, heat, or steam; integrated steel mills; oil and gas extraction; facilities involved in mining, smelting, and refining of metals; pulp, paper, and saw mills; petroleum refineries; and chemical producers. Specific estimation methods are not prescribed, and reporters can choose the quantification methodologies most appropriate for their own particular industry or application. Methods include monitoring and direct measurement, mass balance, emission factors, and engineering estimates, and reporting facilities are encouraged to use methods for estimating emissions that are consistent with the guidelines adopted by the UNFCCC and developed by the IPCC and used in the preparation of the national GHG inventory.

Although not a UNFCCC requirement, collection of facility-level GHG emission data can be used, where appropriate, to confirm emission estimates in the NIR, developed from national and provincial statistics, and at the same time to provide Canadians with timely information on GHG emissions and help the provinces and territories meet their requirements for GHG emissions reporting. The extent to which the reported GHG emission information can be fully integrated is dependent upon the level of detail and type of data available. Environment Canada will continue to use these data as an important component of the overall inventory development process in comparing and verifying the inventory estimates.

The GHG dissemination website (<http://www.ec.gc.ca/ghg>) provides public access to the reported GHG emission information (GHG totals by gas and by facility). The GHG data are provided in a summary report, and key tables are available for viewing in a searchable database and in a downloadable format.

#### *1.4.1.1 Reported 2006 Facility GHG Emissions*

A total of 343 facilities reported GHG emissions for the 2006 calendar year, collectively emitting a total of 273 Mt of GHGs.<sup>20</sup> Information on the direct releases of six GHGs must be reported annually if the facility meets or exceeds the reporting threshold. Of these gases, CO<sub>2</sub> represents the majority of total reported emissions, at approximately 94%, whereas CH<sub>4</sub> accounts for 3%, and N<sub>2</sub>O represents just over 2%. HFCs and PFCs (reported by species) and SF<sub>6</sub>, originating primarily from the manufacturing sector, account for the remaining 1% (see Table 1-2).

**Table 1-2: Facility-Reported 2006 GHG Emissions by Gas**

<b>GHG</b>	<b>Total Emissions (kt CO<sub>2</sub> eq)</b>	<b>% of Total</b>
CO <sub>2</sub>	256 306	94
CH <sub>4</sub>	8 521	3
N <sub>2</sub> O	4 418	2
HFCs	41	0
PFCs	2 626	1
SF <sub>6</sub>	1 246	0.5
Total	273 157	100

20. Data presented are current as of August 1, 2007.

Note: Totals may not add up due to rounding.

The reported GHG emissions vary from region to region and depend on a number of factors, including natural resource availability and the types of industrial activities taking place. Facilities in Alberta accounted for the largest share of reported 2006 GHG emissions, with approximately 42% of the total, followed by those in Ontario, which accounted for about 26%. Quebec and Saskatchewan were the next largest contributors, both at about 8% of reported emissions, although there were 52 reporting facilities in Quebec, compared with 23 facilities in Saskatchewan (see Table 1-3).

**Table 1-3: Facility-Reported 2006 GHG Emissions by Province/Territory**

<b>Province/Territory</b>	<b>Number of Reporting Facilities</b>	<b>Total Reported Emissions (kt of CO<sub>2</sub> eq)</b>	<b>% of Total</b>
Alberta	103	115 421	42
Ontario	86	71 709	26
Quebec	52	22 307	8
Saskatchewan	23	22 522	8
British Columbia	38	12 316	5
New Brunswick	14	10 191	4
Nova Scotia	8	10 880	4
Newfoundland and Labrador	8	4 953	2
Manitoba	8	2 438	1
Northwest Territories	2	319	0
Prince Edward Island	1	100	0
Nunavut	NA	0	0
Yukon	NA	0	0
<b>Total</b>	<b>343</b>	<b>273 156</b>	<b>100</b>

Notes: Totals may not add up due to rounding.  
NA = Not applicable.

#### *1.4.1.2 Reported 2006 GHG Emissions by Sector*

Reporting facilities must identify the main sector of activity responsible for their reported emissions using the corresponding North American Industry Classification System (NAICS) code. Three industrial sectors accounted for the majority of GHG emissions: utilities, manufacturing, and mining and oil and gas extraction (see Table 1-4). Fluctuation in the number of reporting facilities is not unexpected from year to year, as changes in production levels, process and technology, and/or type of fuel used at a facility could all result in either an increase or a decrease in the annual emissions reported by a facility. As a result, a facility may go below or attain the reporting threshold of 100 kt CO<sub>2</sub> eq.

Emissions from the utilities sector accounted for 43% of the total reported 2006 GHG emissions, with slightly over 99% of these GHG emissions produced by electric power generation, transmission, and distribution. The manufacturing sector accounted for 32% of the 2006 GHG emissions, whereas GHG emissions from the mining and oil and gas extraction sector accounted for 20% of the total, an increase of 2% from previous reporting years. The bulk of these

emissions were produced by iron and steel mills and ferro-alloy manufacturing, along with non-conventional oil extraction and petroleum refining.

**Table 1-4: Sectoral contribution to reported GHG emissions, 2004 to 2006**

NAICS <sup>1</sup>	Sector	Parameter	Reporting Year		
			2004	2005	2006
21	Mining and Oil and Gas Extraction	Number of facilities	71	75	79
		Emissions (kt CO <sub>2</sub> eq)	50 909	50 335	54 791
		Percentage of yearly total (%)	18	18	20
		Annual change (%)	NA	–1	9
		Change since 2004 (%)	NA	–1	8
22	Utilities	Number of facilities	75	75	76
		Emissions (kt CO <sub>2</sub> eq)	122 018	124 661	116 826
		Percentage of yearly total (%)	44	45	43
		Annual change (%)	NA	2	–6
		Change since 2004 (%)	NA	2	–4
31–33	Manufacturing	Number of facilities	75	75	76
		Emissions (kt CO <sub>2</sub> eq)	122 018	124 661	116 826
		Percentage of yearly total (%)	44	45	43
		Annual change (%)	NA	2	–6
		Change since 2004 (%)	NA	2	–4
Other <sup>2</sup>	Other	Number of facilities	21	28	33
		Emissions (kt CO <sub>2</sub> eq)	11 627	14 233	13 480
		Percentage of yearly total (%)	4	5	5
		Annual change (%)	NA	22	–5
		Change since 2004 (%)	NA	22	16
All	All	Number of facilities	326	337	343
		Emissions (kt CO <sub>2</sub> eq)	279 989	279 712	273 157
		Annual Change (%)	NA	0	–2

Notes: Totals may not add up due to rounding.

1. NAICS = North American Industry Classification System.

2. Other = Includes a number of smaller sectors (e.g. Pipeline transportation of natural gas and waste treatment and disposal); NA = Not applicable

## 1.5 Key Categories

The IPCC Good Practice Guidance (IPCC 2000, 2003) defines procedures (in the form of decision trees) for the choice of estimation methods recommended in the IPCC Guidelines. The decision trees formalize the choice of estimation method most suited to national circumstances considering at the same time the need for accuracy and the available resources (both financial and human). Generally, the precision and accuracy of inventory estimates can be improved by using the most rigorous (highest tier) methods; however, owing to practical limitations the exhaustive development of all emissions categories is not possible. Therefore, it is good practice to identify and prioritize key categories in order to make the most efficient use of available resources.

In this context, a *key category* is one that is prioritized within the national inventory system because its estimate has a significant influence on a country's total inventory of direct GHG



emissions in terms of the absolute level of emissions (level assessment) and/or the trend in emissions (trend assessment). As much as possible, key categories should receive special consideration in terms of two important inventory aspects:

1. The preferential use of detailed, higher tier methods.
2. The key categories should receive additional attention with respect to QA/QC.

A cumulative contribution total of 95% for both level and trend assessments is a reasonable approximation of categories that account for about 90% of the uncertainty in the inventory (IPCC 2000). In the absence of quantitative data on uncertainties, a simplified, Tier 1 method of identifying key categories provides a good approximation of those areas to which priority should be given to improve inventory estimates.

For the 1990–2006 GHG inventory, level, trend, and qualitative key category assessments were performed according to the Tier 1 approach, as presented in the IPCC Good Practice Guidance (IPCC 2000, 2003). The emission and removal categories used for the key category assessment generally follow those in the CRF and the LULUCF CRF; however, they have been aggregated in some cases and are specific to the Canadian inventory.

Major key categories based on the level and trend assessments (including LULUCF) are the fuel combustion categories (Road Transportation, Public Electricity and Heat Production, Other Sectors, and Manufacturing Industries and Construction), Adipic Acid Production, Enteric Fermentation in the Agriculture Sector and the LULUCF category Forest Land Remaining Forest Land. Details and results of the assessments are presented in Annex 1.

## 1.6 QA/QC

The national inventory and NIR must be prepared in accordance with international reporting guidelines and methods agreed to by the UNFCCC. The inventory is developed according to the methodological procedures and guidelines prescribed by the IPCC, and it draws from the best available data and scientifically sound methodologies. QA/QC and verification procedures are an integral part of the preparation of the inventory. The Greenhouse Gas Division annually conducts detailed QA/QC activities and is committed to improving data and methods in collaboration with industry, the provinces and territories, academia, and the international community to ensure that a credible and defensible inventory is developed. Improvement activities, which take into account results of QA/QC procedures, reviews, and verification, are planned and implemented on a continuous basis by the staff of Environment Canada's Greenhouse Gas Division, with a view to further refine and increase the transparency, completeness, accuracy, consistency, and comparability of the national inventory. As a result, changes in data or methods often lead to the recalculation of GHG estimates for the entire times series, from the 1990 base year to the most recent year available.

To enable the full development and implementation of Canada's Quality Management System, a QA/QC coordinator position was staffed in 2006. While the review and revision of the Quality Management System, including a revised QA/QC plan, was major project in 2006, a key focus for 2007 has been the implementation of the QA/QC plan. The implementation has had emphasis on the transition from an informal approach of QA/QC to an approach that is formally defined and consistent across sectors. Full implementation of the plan is envisaged to span several years, encompassing both Tier 1 and Tier 2 QC procedures, as well as QA reviews and audits.

In addition, a Prioritization and Planning Committee, established in 2006, was used in the current inventory year to centralize inventory decision making, particularly on approaches to QA and planned improvements.

QA/QC achievements for 2007 include:

- conducting a lessons learned review to identify potential improvements and risks for the inventory;
- hiring of a new project manager to manage inventory timeline and the development of an inventory schedule;
- conducting an internal audit for completeness and transparency of QC checklists;
- implementation of a new electronic archiving structure and creation of a hardcopy reference library;
- establishment of a Tier 1 QC working group, resulting in revised Tier 1 checklists and a new guidance manual;
- formalization of Tier 2 and QA activities in the Industrial Process and Energy sectors and initiation of Tier 2 and QA guidance documents; and
- development of a new process and documentation requirement prior to the implementation of methodological changes.

The reader is referred to annex 6 of this report for more information.

### ***1.7 Inventory Uncertainty***

While national GHG inventories should be accurate, complete, comparable, transparent, and verifiable, estimates will always inherently carry some uncertainty. Uncertainties<sup>21</sup> in the inventory estimates may be caused by systematic model uncertainty or (more likely) due to random uncertainties present within the input parameters. While reducing model uncertainty requires in-depth reviews of the estimation models, random uncertainties may be reduced by improvements to the activity data regimes and evaluation of emission factors and other model parameters. The primary purpose of quantitative uncertainty information is to set priorities to improve the accuracy of future inventories and to guide decisions about which methods to use. Typically, the uncertainties associated with the trends and the national totals are much lower than those associated with individual gases and sectors.

The UNFCCC reporting guidelines on annual inventories state that Annex I Parties shall quantitatively estimate uncertainties in data for all source and sink categories using at least the Tier 1 method, as provided in the IPCC Good Practice Guidance (IPCC 2000). Parties may use the Tier 2 method in the IPCC Good Practice Guidance to address technical limitations in the Tier 1 method.

Throughout 2004 and 2005, a Tier 2 quantitative study on uncertainty was performed on Canada's greenhouse gas inventory (ICF Consulting 2004, 2005). The results of the study were

---

21. Inventory definition of uncertainty: A general and imprecise term that refers to the lack of certainty (in inventory components) resulting from any causal factor, such as unidentified sources and sinks, lack of transparency, etc. (IPCC 2000).

provided in Canada's 2005 NIR. In Canada's 2007 NIR, additional information from the Tier 2 study was incorporated, including information on the overall inventory trend uncertainty for 1990–2001 and the sensitivity of overall inventory uncertainty to the source category uncertainties. In the 2008 NIR, Canada continues to make use of this study as the primary source for quantitative uncertainty reporting (refer to annex 7 for more information on uncertainty).

The overall level uncertainty of the national inventory (without LULUCF), as at 2001 (2003 NIR submission), falls within a range of –3% to +6% for all GHGs combined. N<sub>2</sub>O exhibits the highest uncertainty range in the national inventory, with a range of –8% to +80%, followed by HFCs, with a range of –22% to +58%. The largest contributor to the inventory, CO<sub>2</sub>, exhibits an uncertainty of –4% to 0% (ICF Consulting 2005). Canada's inventory uncertainty estimate falls within the range of uncertainty reported by other Annex I countries.

Although the study of uncertainty was performed on the 2003 NIR data, the level uncertainties assessed are assumed to be representative of the current inventory uncertainty for the majority of cases. Explanation of drivers of uncertainty for various categories and the inventory analysts' interpretation of the results from the study are provided within sector-specific chapters. Also provided in those chapters are updates to selected uncertainty estimates for various source categories.

As a short-term objective, Canada plans to update its uncertainty analysis and develop additional in-house expertise to allow uncertainty updates to be performed on a regular basis.

### ***1.8 Completeness Assessment***

The national GHG inventory, for the most part, is a complete inventory of the six GHGs required under the UNFCCC. The exclusion of some emissions typically relates to the unavailability of comprehensive activity data for certain subcategories of a source that are minor by nature. In some cases, lack of appropriate and cost-effective methodologies has been the reason for exclusion of a minor source.

In the NIR submission of 2006, Canada included a substantial number of new sources, such as emissions from use of ethanol in fuel mixtures, use of magnesite (carbonate) in magnesium production, and SF<sub>6</sub> emissions from semiconductor manufacturing. These improved the completeness of the national GHG inventory of 2006, which underwent an in-country review performed by the expert review team (ERT) from the UNFCCC.

The in-country review, carried out in November of 2007 as part of the review of Canada's initial report, identified additional minor sources that were not included in the inventory. Examples of such sources were use of waste tires and other wastes as fuel in cement kilns, biodiesel in road transportation, and HCFC-22 production.

In the Energy Sector, completeness improvements can be further achieved through study of non-conventional fuels used in the manufacturing industry. In the Industrial Processes Sector, GHG emissions from HCFC-22 production have been added to this inventory. Further research may provide better information as to the potential CH<sub>4</sub> emissions from manufacturing processes. In the LULUCF Sector, significant improvements have been implemented starting in 2006, but completeness has not yet been fully met as a result of data limitations.

## 1 INTRODUCTION

As part of the NIR improvement plans, efforts are continuously being made to identify and assess relevant new sources and sinks for which cost-effective estimation methods are available. Further details on the completeness of the inventory can be found in annex 5.

## 2 Greenhouse Gas Emission Trends, 1990–2006

### 2.1 Summary of Emission Trends

In 2006, Canada's GHG emissions (excluding the LULUCF Sector) were 721 Mt, which is a 21.7% increase over 1990 emissions. Between 2005 and 2006, emissions decreased by 1.9%.

Since 1990, growth in emissions has resulted primarily from Electricity and Heat Generation and areas such as Fossil Fuel Industries, Mining, Transportation, Consumption of Halocarbons and SF<sub>6</sub>, Enteric Fermentation, and Waste. There have been overall decreases in Manufacturing Industries and Construction, Chemical Industry, and Metal Production.

### 2.2 Emission Trends by Gas

CO<sub>2</sub> is the largest contributor to Canada's GHG emissions. Figure 2-1 shows how the per cent contributions of the six GHGs have changed between 1990 and 2006. CO<sub>2</sub> has changed only slightly in proportion, from 77% of emissions in 1990 to almost 78% in 2006.

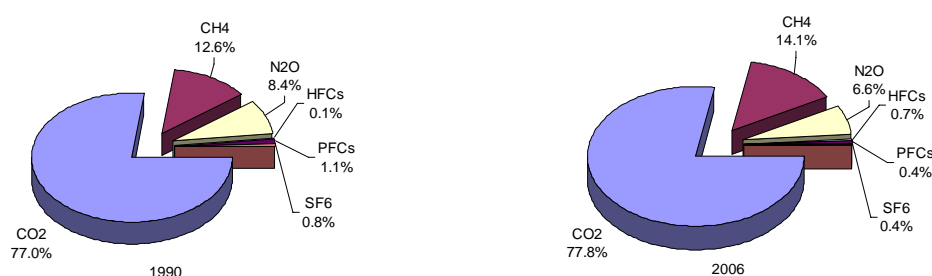


Figure 2-1: Canada's GHG Emissions by Gas, 1990 and 2006 (excluding LULUCF)

### 2.3 Emission Trends by Category

#### 2.3.1 Energy Sector (2006 GHG emissions, 583 Mt)

Energy-related activities are by far the largest source of GHG emissions in Canada. The Energy Sector includes emissions of all GHGs from the production of fuels and their combustion for the primary purpose of delivering energy. Emissions in this sector are classified as either combustion related or fugitive releases. Fugitive emissions are defined as intentional or unintentional releases of GHGs from the production, processing, transmission, storage, and delivery of fossil fuels.

Overall, fuel combustion and fugitive emissions accounted for 81% of total Canadian GHG emissions in 2006 (516 Mt and 66.8 Mt, respectively). Between 1990 and 2006, fuel combustion-related emissions increased 21%, while emissions from fugitive releases rose 57%. Emissions for selected years for both fuel combustion and fugitive emissions between 1990–2006 are provided in Table 2-1.

The Energy Industries, grouped in the Energy Sector, contribute more than any other category to Canada's emissions. These industries (consisting of Fossil Fuel Production and Public Electricity and Heat Production) generate both combustion and fugitive emissions and are presented as "Fuel

Combustion—Energy Industries” and “Fugitive Emissions” in Table 2-1. Altogether, the Energy Industries subsector and the Fugitive Emissions subsector contributed 252 Mt or 35% of Canada’s total and about 43% of the Energy Sector’s emissions in 2006.

**Table 2-1: GHG Emissions from Energy by UNFCCC CRF Sector, 1990–2006**

GHG Sources/Sinks	GHG Emissions (Mt CO <sub>2</sub> eq)				
	1990	1995	2000	2005	2006
1. Energy	470	510	587	596	583
A. Fuel Combustion (Sectoral Approach)	427	453	522	531	516
1. Energy Industries	147	155	199	194	185
2. Manufacturing Industries and Construction	62.9	62.0	64.5	64.2	64.2
3. Transport	145	159	178	193	192
4. Other Sectors	72	76	80	80	75
B. Fugitive Emissions	42.7	57.0	64.7	65.5	66.8
1. Solid Fuels (Coal)	1.9	1.7	0.9	0.7	0.6
2. Oil and Natural Gas	40.7	55.3	63.7	64.8	66.2

Note: Totals may not add up due to rounding.

Table 2-1 divides energy sources by UNFCCC CRF category: Fuel Combustion is categorized separately from Fugitive Emissions. By this breakdown, fuel combustion in the Energy Industries accounted for 185 Mt in 2006, while fugitive emissions were responsible for 66.8 Mt. In terms of relative growth, fugitive emissions from Oil and Natural Gas (including production, processing, transmission, and distribution activities) have increased more rapidly than any other category in the Energy Sector. Between 1990 and 2006, these emissions rose by 57%.

### *2.3.1.1 Emissions from Fuel Combustion (2006 GHG emissions, 516 Mt)*

GHG emissions from fuel combustion rose from 427 Mt in 1990 to 516 Mt in 2006, a 21% increase. Fuel combustion emissions are divided into the following subsectors: Energy Industries, Manufacturing Industries and Construction, Transport, and Other Sectors. The Other Sectors subsector comprises emissions from the residential and commercial categories, as well as minor contributions of stationary fuel combustion emissions from the agriculture and forestry category.

### **Energy Industries (2006 GHG emissions, 185 Mt)**

The Energy Industries subsector accounts for the largest portion of Canada’s fuel combustion emissions (26% of Canada’s total). Emissions included in this subsector are from stationary sources producing, processing, and refining energy. This source category includes Public Electricity and Heat Production, Petroleum Refining, and Manufacture of Solid Fuels and Other Energy Industries. In 2006, combustion emissions from the Energy Industries category totalled 185 Mt, an increase of 26% from the 1990 level of 147 Mt.

***Public Electricity and Heat Production<sup>22</sup> (2006 GHG emissions, 117 Mt)***

This category accounted for 16% (117 Mt) of Canada's 2006 GHG emissions (Table 2-2) and was responsible for 17% of the total emission growth between 1990 and 2006. Overall emissions from this category increased 23% (22 Mt) since 1990.

**Table 2-2: GHG Emissions from Public Electricity and Heat Production, 1990–2006**

GHG Source Category	GHG Emissions (Mt CO <sub>2</sub> eq)					Increase (%)
	1990	1995	2000	2005	2006	1990–2006
Electricity Generation	95	100	131	123	116	22
Heat Generation	1.25	1.84	1.99	1.88	1.48	18
<b>Total</b>	<b>95.4</b>	<b>101.0</b>	<b>132.4</b>	<b>124.7</b>	<b>117.0</b>	<b>23</b>

Note: Totals may not add up due to rounding.

Public Electricity and Heat Production, a constituent of the Energy Industries subsector, has seen a large increase in emissions since 1990. Rising demand for electricity, exacerbated by the increasing use of fossil fuels in the generation mix, drove GHG emissions up 22 Mt between 1990 and 2006; comparatively, electricity demand was 95 TWh higher in 2006 than in 1990 (Statistics Canada #57-601). Although this long term increase in demand was supplied in part by greater hydroelectric and nuclear generation, fossil fuel generation rose even more. The result was that by 2006, hydropower's share of the generation mix had fallen from 63% to 59% (Statistic Canada #57-003), whereas fossil fuels' share had risen from 22% to 26%, worsening the average GHG intensity of production. This meant that from 1990 to 2006, fossil fuel generation rose 40%, and GHG emissions increased 23%.

Over the short term, GHG emissions from the Public Electricity and Heat Production category decreased by almost 8 Mt from 2005, 10 Mt from 2004, and 18 Mt from the peak in 2003. Since electricity is generated to meet an instantaneous demand, decreased GHG emissions are a result of lower demand, which can occur via conservation measures, warmer winters, and economic factors like plant closures. Emissions can also be reduced by increasing nuclear generation and higher water levels behind hydroelectric dams, both of which reduce fossil-fuel-based generation requirements. Warmer winters and cooler summers also help to reduce heating and cooling loads.

Of note in these trends is that the GHG emissions associated with coal-fired electricity generation, which had been increasing since the mid-1990s, have begun to decrease since peaking in 2001. Part of the decrease is due to overall fuel switching and usage of less GHG-intensive coal, while increases in interprovincial and international trade have also played a role. However, fuel costs, economic factors, and the regulatory environment continue to play a major role in determining whether coal-fired generation and the associated GHG emissions will be reduced further in the future. The impact of other renewables such as wind will begin to play a greater role in the coming years, as the installed wind capacity in Canada more than doubled in 2006.

The growth in emissions from 1990 to 2006 is directly related to rising demand for power from end users and the increased use of fossil fuels (coal, oil, and natural gas) in the generation mix. While increasing use of natural gas has helped mitigate the rate of emission growth, the shift

22. The Public Electricity and Heat Production category includes emissions from utilities and industrial generation.

away from non-GHG-emitting sources (nuclear and hydro) in the latter part of the 1990s has resulted in large absolute increases. For more information on electricity generation and trends, see Annex 9 – Electricity Intensity Tables. Trends and analysis on a provincial/territorial level are discussed in Annex 10 – Provincial/Territorial Analysis.

***Petroleum Refining and Manufacture of Solid Fuels and Other Energy Industries<sup>23</sup>***  
***(2006 GHG emissions, 68 Mt)***

The Petroleum Refining category includes mainly emissions from the combustion of fossil fuels during the production of refined petroleum products (RPPs), whereas the Manufacture of Solid Fuels and Other Energy Industries category encompasses fuel combustion emissions associated with the upstream oil and gas (UOG) industry. The majority of combustion emissions from the upgrading of heavy oil and bitumen to produce synthetic crude oil are included in the Manufacture of Solid Fuels and Other Energy Industries category. As shown in Table 2-3, between 1990 and 2006, emissions from these two categories increased by about 16 Mt, or 31%. This growth is due to increases in oil and natural gas production, largely for export.

**Table 2-3: GHG Emissions from Petroleum Refining and Manufacture of Solid Fuels and Other Energy Industries, 1990–2006**

GHG Source Category	GHG Emissions (Mt CO <sub>2</sub> eq)					Increase (%) 1990–2006
	1990	1995	2000	2005	2006	
Petroleum Refining	16	14	14	17	16	3
Manufacture of Solid Fuels and Other Energy Industries	36	40	53	52	52	44
<b>Total</b>	<b>52</b>	<b>54</b>	<b>67</b>	<b>69</b>	<b>68</b>	<b>31</b>

Note: Totals may not add up due to rounding.

**Manufacturing Industries, Construction, and Mining (2006 GHG emissions, 64 Mt)**

Emissions from the Manufacturing Industries and Construction subsector include the combustion of fossil fuels by the iron and steel, non-ferrous metals, chemicals, cement, pulp, paper, and print, construction, mining, and all other manufacturing industries.<sup>24</sup> In 2006, GHG emissions were 64 Mt (Table 2-4). Overall, this subsector was responsible for 8.9% of Canada's total GHG emissions in 2006, up 1.2 Mt from 1990.

23. In the NIR, the Fossil Fuel Industries category encompasses both the Petroleum Refining and Upgrading and Fossil Fuel Production (also known as Manufacture of Solid Fuels and Other Energy Industries) subsectors.

24. The NIR categories that constitute this UNFCCC sector are Manufacturing Industries, Construction, and Mining (refer to Tables S-2 and S-3).



**Table 2-4: GHG Emissions from Manufacturing, Construction, and Mining, 1990–2006**

GHG Source Category	GHG Emissions (Mt CO <sub>2</sub> eq)					Increase (%) 1990–2006
	1990	1995	2000	2005	2006	
Iron and Steel	6.50	7.05	7.19	6.48	6.38	–2
Non-Ferrous Metals	3.19	3.09	3.19	3.27	3.05	–4
Chemicals	7.10	8.45	7.86	6.34	6.49	–9
Cement	3.69	3.67	3.89	4.59	4.85	31
Construction	1.87	1.17	1.07	1.36	1.30	–30
Mining	6.19	7.86	10.40	15.56	16.54	167
Pulp, Paper, and Print	13.7	11.7	11.0	7.2	6.0	–57
Other Manufacturing	20.7	19.0	19.9	19.4	19.6	–5
<b>Total</b>	<b>62.9</b>	<b>62.0</b>	<b>64.5</b>	<b>64.2</b>	<b>64.2</b>	<b>2</b>

Note: Totals may not add up due to rounding.

Between 1990 and 2006, there were changes in both directions in the emissions produced by the various categories within the Manufacturing Industries and Construction subsector. The majority of the overall increase can be attributed to the Mining category, which saw 167% growth since 1990, whereas the largest decrease was in the Pulp, Paper, and Print category. The Mining category includes oil sands mining, as well as mining of metals and minerals. The significant growth in emissions from this category and the small increase in the Cement category can be attributed to strong demand both domestically and internationally. The remaining categories have all shown long-term decreases, from -57% in the Pulp, Paper, and Print category to -2% in the Iron and Steel category. These decreases can be attributed to decreased demand, fuel switching, and changes in manufacturing operations.

The most notable short-term decrease of 17% (or 1.2 Mt) was also observed in the Pulp, Paper, and Print category, and reflects the economic difficulties being felt by this sector. The Mining and Cement categories both exhibit growth of 6% in GHG emissions between 2005 and 2006 that reflects the continued demand for these products. Trends and analysis on a provincial/territorial level are discussed in Annex 10 – Provincial/Territorial Analysis.

### **Transport (2006 GHG emissions, 190 Mt)**

Transport is a large and diverse subsector, accounting for almost 27% of Canada's GHG emissions in 2006. This subsector includes emissions from fuel combustion for the transport of passengers and freight in five distinct subcategories:

- Road Transportation;
- Civil Aviation (Domestic Aviation);
- Navigation (Domestic Marine);
- Railways; and
- Other Transportation (Off-Road and Pipelines).

From 1990 to 2006, GHG emissions from transport, driven primarily by energy used for personal transportation, rose 32%, or 47 Mt. Overall, transport was the second largest emission-producing category in 2006, contributing 190 Mt and accounting for 36% of Canada's emission growth from 1990 to 2006.

Emissions from LDGTs, the subcategory that includes SUVs, pickups, and vans, increased 116% between 1990 and 2006 (from 20.7 Mt in 1990 to 44.8 Mt in 2006), while emissions from cars (LDGVs) decreased 15% (from 45.8 Mt in 1990 to 38.9 Mt in 2006) (Table 2-5).

**Table 2-5: GHG Emissions from Transport, 1990–2006**

GHG Source Category	GHG Emissions (Mt CO <sub>2</sub> eq)		
	1990	2005	2006
Transport (Total)	150	190	190
Civil Aviation (Domestic Aviation)	6.4	8.6	8.4
Light-Duty Gasoline Vehicles	45.8	39.9	38.9
Light-Duty Gasoline Trucks	20.7	43.1	44.8
Heavy-Duty Gasoline Vehicles	7.81	6.30	6.28
Motorcycles	0.146	0.251	0.259
Light-Duty Diesel Vehicles	0.355	0.432	0.433
Light-Duty Diesel Trucks	0.707	2.13	2.33
Heavy-Duty Diesel Vehicles	20.7	37.9	39.4
Propane & Natural Gas Vehicles	2.2	0.72	0.80
Railways	7	6	6
Navigation (Domestic Marine)	5.0	6.4	5.8
Off-Road Gasoline	7	7	7
Off-Road Diesel	20	20	20
Pipelines	6.90	10.1	9.66

Note: For full details of all years, please refer to Annex 8.

As shown in Table 2-5, the growth in road transport emissions is due not only to the 37% increase in the total vehicle fleet, but also to a shift in light-duty vehicle purchases from cars (LDGVs) to trucks (LDGTs), which, on average, emit 40% more GHGs per kilometre.

Over the period 1990–2006, the increase of 24 Mt and 19 Mt for LDGTs and HDDVs, respectively, reflects the trend towards increasing use of SUVs, vans, and pickups for personal transportation and heavy-duty trucks for freight transport (Table 2-6).

**Table 2-6: Trends in Vehicle Populations for Canada, 1990–2006**

Year	Number of vehicles (000s)							Total
	LDGVs	LDGTs	HDGVs	MCs	LDDVs	LDDTs	HDDVs	
1990	10 646	3 308	518	261	109	112	402	15 356
1991	10 677	3 496	463	255	110	117	394	15 512
1992	10 674	3 712	432	248	109	126	397	15 698
1993	10 761	4 019	425	247	111	145	442	16 149
1994	10 694	4 305	428	234	108	165	487	16 421
1995	10 590	4 395	387	226	104	183	513	16 398
1996	10 273	4 517	383	213	99	174	498	16 157
1997	10 420	4 939	388	225	101	188	537	16 797
1998	10 250	5 347	395	263	107	204	629	17 195
1999	10 696	5 787	349	257	114	205	616	18 024
2000	10 863	6 065	376	288	123	224	649	18 587
2001	10 969	6 266	407	327	131	231	713	19 045
2002	10 929	6 421	394	359	138	234	724	19 200
2003	10 940	6 688	410	390	142	243	742	19 554
2004	10 931	6 959	429	417	153	254	801	19 944
2005	10 961	7 386	435	437	159	277	856	20 510
2006	10 989	7 823	438	455	163	300	908	21 077

HDDVs = Heavy-Duty Diesel Vehicles; HDGVs = Heavy-Duty Gasoline Vehicles; LDDTs = Light-Duty Diesel Trucks; LDDVs = Light-Duty Diesel Vehicles; LDGTs = Light-Duty Gasoline Trucks; LDGVs = Light-Duty Gasoline Vehicles; MCs = Motorcycles

In 2006, emissions from HDDVs contributed 39 Mt to Canada's total GHG emissions (an increase of 91% from 1990 emissions). Emissions from heavy-duty gasoline vehicles (HDGVs) were substantially lower, at 6.3 Mt for 2006; this figure represents a decrease of 20% over the 1990 level. While there are difficulties in obtaining accurate and complete data for the freight transport mode, the trends in data from major for-hire truck haulers in Canada show conclusively that freight hauling by truck has increased substantially and that this activity is the primary task performed by HDGVs and HDDVs.

Off-road fuel combustion emissions<sup>25</sup> in the Other Transportation subsector increased by 32% between 1990 and 2006, when the contribution from pipelines is not included.

The pipeline emissions included in the Other Transportation subsector are combustion emissions primarily from natural gas transport. Owing to increasing activity in the Energy Sector, these emissions rose 40%, from 6.9 Mt in 1990 to 9.7 Mt in 2006.

25. Off-road emissions include those from the combustion of diesel and gasoline in a variety of widely divergent activities. Examples include the use of heavy mobile equipment in the construction, mining, and logging sectors, recreational vehicles such as snowmobiles and all-terrain vehicles (ATVs), and residential equipment such as lawnmowers and trimmers.

## Other Sectors (2006 GHG emissions, 81 Mt)

The Other Sectors subsector comprises fuel combustion emissions from the residential and commercial categories, as well as stationary fuel combustion emissions from the agriculture and forestry category.<sup>26</sup> Overall, this subsector exhibited increases in GHG emissions of 5% from 1990 to 2006, while individual subcategories within it demonstrated a variety of changes.

### *Residential and Commercial*

Emissions in these categories arise primarily from the combustion of fuel to heat residential and commercial buildings. Fuel combustion in the residential and commercial/institutional categories<sup>27</sup> accounted for 5.5% (40 Mt) and 4.6% (33 Mt), respectively, of all GHG emissions in 2006.

As shown in Figure 2-2, residential emissions fluctuate on an annual basis and, overall, decreased 3.7 Mt or 8.5% between 1990 and 2006. Over the short term, emissions decreased by 2 Mt from 2005, 3.1 Mt from 2004, and 5.2 Mt from 2003. Commercial/Institutional emissions increased 7.7 Mt or 30% between 1990 and 2006 and show a trend similar to that illustrated by the residential sector. Combined, the two categories exhibited an overall increase of 4 Mt or 6% between 1990 and 2006.

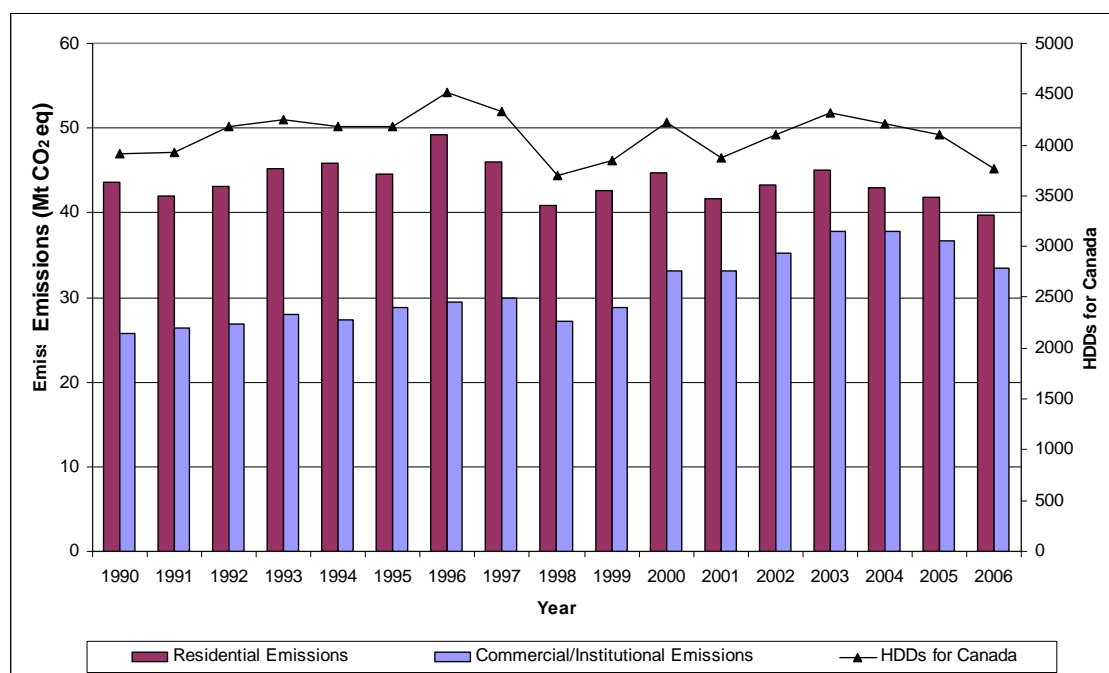


Figure 2-2: GHG Emissions and HDDs from Residential and Commercial Sectors, 1990–2006

26. The UNFCCC Other Sectors category comprises the following NIR sectors: Residential, Commercial, and Institutional; and Agriculture and Forestry (listed under Energy, Stationary Combustion Sources in Annex 8).
27. Commercial sector emissions are based on fuel use as reported in the RESD (Statistics Canada #57-003) for commercial and other institutional and public administration categories. The former is a catch-all category that includes fuel used by service industries related to mining, wholesale and retail trade, financial and business services, education, health and social services, and other industries that are not explicitly included elsewhere.

GHG emissions, particularly in the residential sector, track HDDs<sup>28</sup> closely (as shown in Figure 2-2). This close tracking indicates the important influence weather can have on space heating requirements and therefore on the demand for natural gas, home heating oil, and biomass fuels.

Floor space in both the residential and commercial categories increased significantly and consistently over the same period. In the commercial category, there has been a change in the mix of building types, with a reduction in warehouse-type buildings and an increase in office floor space. The increase in office floor space has also led to increased demand for space cooling and heating and an increase in the number of appliances in homes and auxiliary equipment in offices (NRCan 2005). This upward trend in floor space and equipment was counteracted by fuel substitution away from petroleum products, improvements in end-use efficiency, and improvements in the thermal envelope of houses.

In the residential sector, even though the number of homes has increased by about 2 million since 1990 (Statistics Canada 2007), emissions have decreased — likely as a result of better construction methods, increased insulation, and higher efficiency heating systems. Residential home improvement incentive programs such as the EnerGuide for Homes (replaced by the ecoENERGY Retrofit program in 2007) also played an important role in identifying efficiency improvements and thus lowering emissions for heating purposes.

### ***Agriculture and Forestry***

Stationary fuel combustion related emissions from the agriculture and forestry category amounted to 1.9 Mt in 2006, a decrease of 20% since 1990. Emissions from these categories contributed less than 0.3% of the total for 2006.

#### ***2.3.1.2 Fugitive Emissions from Fuels (2006 GHG emissions, 66.8 Mt)***

As stated above, fugitive emissions from fossil fuels are the intentional or unintentional releases of GHGs from the production, processing, transmission, storage, and delivery of fossil fuels. Released gases that are combusted before disposal (e.g. flaring of natural gases at oil and gas production and processing facilities) are also considered fugitive emissions. Fugitive emissions have two sources: coal mining and handling, and activities related to the oil and natural gas industry. They constituted 9.3% of Canada's total GHG emissions for 2006 and contributed 19% to the growth in emissions between 1990 and 2006.

Table 2-7 summarizes the changes in fugitive emissions from the solid fuel and the Oil and Natural Gas category. In total, fugitive emissions grew by about 57% between 1990 and 2006, from 42.7 to 66.8 Mt, with emissions from the Oil and Natural Gas category contributing 99% of the total fugitive emissions in 2006, far overshadowing the 1% contribution from Coal Mining. Although fugitive releases from the solid fuels category (i.e. coal mining) decreased by 1.3 Mt (67%) between 1990 and 2006 as a result of the closing of many mines in eastern Canada, emissions from oil and natural gas increased 59% during the same period.

This rise in emissions is a result of the increased production of natural gas and heavy oil since 1990, largely for export to the United States. Since 1990, there has been a very large increase in

---

28. HDDs are calculated by determining the average, cross-Canada number of days below 18.0°C and multiplying this value by the corresponding number of degrees below 18.0°C.

the net energy exported from Canada (refer to section ES.4.1 of the executive summary for a discussion of emissions associated with export of oil and natural gas), accompanied by a 219% increase in GHG emissions associated with those net energy exports.

Although overall fugitive emissions associated with oil and gas production have increased substantially since 1990, the overall emissions intensity (emissions per unit energy production), of upstream oil and gas production has only increased 5% (see Table 2-7). However, the fugitive emission intensity of different upstream oil and gas categories has changed substantially. The most notable changes are an approximately 24% increase in conventional oil production intensity and a 17% decline in oil sands intensity (see Table 2-7). Recent Alberta government regulations to control venting emissions and the increased use of solution gas have contributed to some of the observed decreased in fugitive emission intensity in the oil sands industry.

**Table 2-7: Fugitive GHG Emissions Intensity of Oil and Gas Production by Category, Selected Years**

	1990	1995	2000	2005	2006
<b>UPSTREAM PRODUCTION</b>					
Emissions (Mt CO <sub>2</sub> eq) (Total)	39.0	53.5	60.3	60.8	62.1
Change since 1990 (%)	NA	37	54	56	59
Production (PJ)	9 580	12 331	13 489	14 219	14 489
Change since 1990 (%)	NA	29	41	48	51
Intensity (kt CO <sub>2</sub> eq/PJ)	4.08	4.34	4.47	4.27	4.28
Change since 1990 (%)	NA	6.5	9.6	4.8	5.1
<b>Conventional Oil Production</b>					
Emissions (Mt CO <sub>2</sub> eq)	16.2	21.8	25.4	23.1	23.1
Change since 1990 (%)	NA	34	56	42	42
Production (PJ)	2 955	3 441	3 555	3 423	3 401
Change since 1990 (%)	NA	16	20	1%	15
Intensity (kt CO <sub>2</sub> eq/PJ)	5.49	6.33	7.14	6.75	6.79
Change since 1990 (%)	NA	15	30	23	24
<b>Oil Sands Mining, Extraction, and Upgrading</b>					
Emissions (Mt CO <sub>2</sub> eq)	2.5	4.8	4.7	5.9	6.7
Change since 1990 (%)	NA	94	94	143	173
Production (PJ)	768	960	1,362	2,203	2,528
Change since 1990 (%)	NA	25	77	187	229
Intensity (kt CO <sub>2</sub> eq/PJ)	3.19	4.95	3.48	2.70	2.64
Change since 1990 (%)	NA	55	9.1	-15	-17
<b>Natural Gas Production and Processing</b>					
Emissions (Mt CO <sub>2</sub> eq)	14.2	20.1	23.6	25.3	26.0
Change since 1990 (%)	NA	42	67	79	83
Production (PJ)	4 184	6 129	7 062	7 192	7 220
Change since 1990 (%)	NA	47	69	72	73
Intensity (kt CO <sub>2</sub> eq/PJ)	3.39	3.29	3.34	3.52	3.60
Change since 1990 (%)	NA	-2.9	-1.2	4.0	6.3
<b>Oil and Natural Gas Transmission</b>					
Emissions (Mt CO <sub>2</sub> eq)	4.3	5.1	5.6	5.7	5.7
Change since 1990 (%)	NA	19	29	32	32
Pipeline Length (km)	64 222	75 466	81 340	83 195	83 195
Change since 1990 (%)	NA	18	27	30	30
Intensity (kt CO <sub>2</sub> eq/km)	0.067	0.068	0.068	0.068	0.068

	1990	1995	2000	2005	2006
Change since 1990 (%)	NA	1.7	2.1	1.7	1.7
<b>DOWNSTREAM PRODUCTION</b>					
Emissions (Mt CO <sub>2</sub> eq) (Total)	3.6	3.5	4.4	4.7	4.7
Change since 1990 (%)	NA	-3.0	23	31	31
Production (PJ)	3 889	3 873	4 324	4 724	4 676
Change since 1990 (%)	NA	-0.4	11.2	21.5	20.3
Intensity (kt CO <sub>2</sub> eq/PJ)	0.93	0.90	1.03	1.00	1.01
Change since 1990 (%)	NA	-2.6	10.7	7.9	8.7
<b>Petroleum Refining</b>					
Emissions (Mt CO <sub>2</sub> eq)	0.9	0.5	1.1	1.2	1.2
Change since 1990 (%)	NA	-37	34	39	38
Production (PJ)	3 889	3 873	4 324	4 724	4 676
Change since 1990 (%)	NA	-0.4	11	21	20
Intensity (kt CO <sub>2</sub> eq/PJ)	0.22	0.14	0.27	0.25	0.25
Change since 1990 (%)	NA	-37.1	21	14	14
<b>Natural Gas Distribution</b>					
Emissions (Mt CO <sub>2</sub> eq)	2.8	3.0	3.3	3.5	3.5
Change since 1990 (%)	NA	7.6	20	29	29
Pipeline Length (km)	168 813	189 494	210 677	226 515	226 515
Change since 1990 (%)	NA	12	25	34	34
Intensity (kt CO <sub>2</sub> eq/km)	0.016	0.016	0.016	0.016	0.016
Change since 1990 (%)	NA	-4.1	-4.1	-4.1	-4.1

Notes: NA = Not applicable.

### 2.3.2 Industrial Processes Sector (2006 GHG emissions, 54.4 Mt)

The Industrial Processes Sector includes GHG emissions that are direct by-products of processes, including Mineral Products, Chemical Industry, Metal Production, Production and Consumption of Halocarbons and SF<sub>6</sub>, and Other and Undifferentiated Production. GHG emissions from the Industrial Processes sector contributed 54.4 Mt to the 2006 national GHG inventory, compared with 54.8 Mt in 1990. Figure 2-3 illustrates the changes in each of the subsectors over the period 1990–2006, and Table 2-8 provides an emission breakdown by category for selected years.

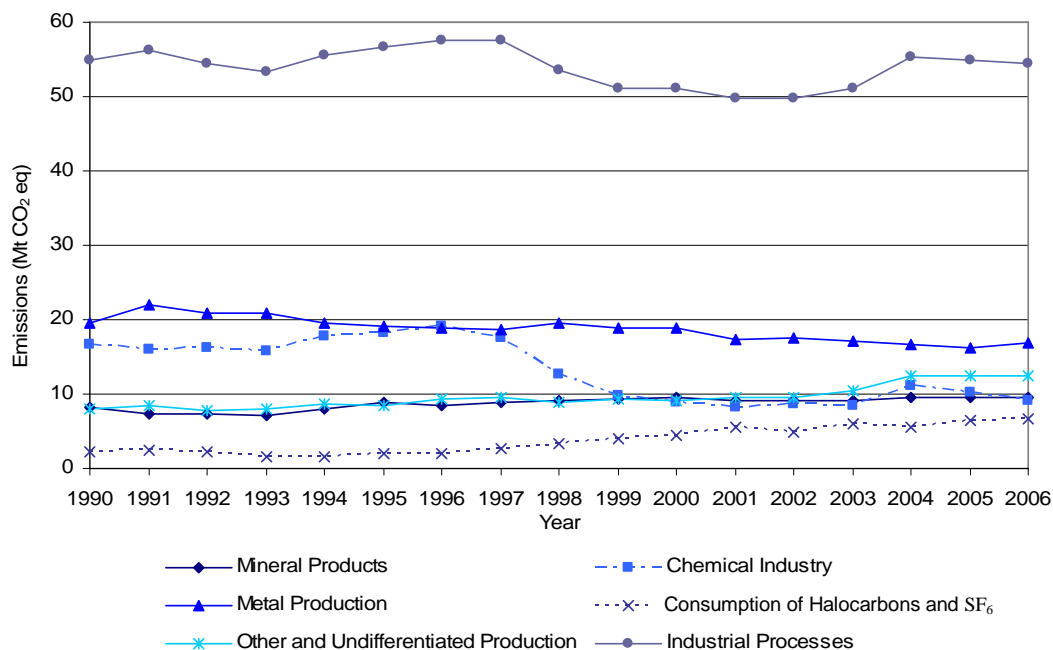


Figure 2-3: GHG Emissions from Industrial Processes by Category, 1990–2006

Table 2-8: GHG Emissions from Industrial Processes by Category, Selected Years

GHG Source Category	GHG Emissions (Mt CO <sub>2</sub> eq)				
	1990	1995	2000	2005	2006
Industrial Processes (Total)	54.8	56.6	51.1	54.8	54.4
Mineral Products	8.3	8.8	9.6	9.5	9.6
Cement Production	5.4	6.1	6.7	7.2	7.3
Lime Production	1.7	1.8	1.9	1.7	1.6
Limestone and Dolomite Use	0.7	0.5	0.6	0.3	0.2
Soda Ash Use	0.2	0.2	0.2	0.2	0.2
Magnesite Use	0.1	0.1	0.2	0.2	0.2
Chemical Industry	16.7	18.3	8.9	10.2	9.0
Ammonia Production	5.0	6.5	6.8	6.3	6.6
Nitric Acid Production	1.0	1.0	1.2	1.3	1.2
Adipic Acid Production	10.7	10.7	0.9	2.6	1.2
Metal Production	19.5	19.2	18.9	16.2	16.8
Iron and Steel Production	7.1	7.9	7.9	7.0	7.8
Aluminium Production	9.3	9.1	8.2	7.9	7.6
Magnesium Production	2.9	1.9	2.3	1.1	1.2
Magnesium Casting	0.2	0.2	0.5	0.2	0.2
Production and Consumption of Halocarbons	0.7	0.5	3.0	5.2	5.3
SF <sub>6</sub> Use in Electric Utilities and Semiconductors	1.5	1.5	1.5	1.2	1.3
Other and Undifferentiated Production	8.0	8.3	9.2	12.4	12.5

Note: Totals may not add up due to rounding.



Between 1990 and 2006, the overall sector emissions decreased by approximately 0.4 Mt (0.7%). This minor change could be explained by significant emission reductions in the adipic acid production (N<sub>2</sub>O), aluminium production (PFCs), magnesium production (SF<sub>6</sub>), and limestone and dolomite use (CO<sub>2</sub>), which were offset by growths in emissions from consumption of HFCs, other and undifferentiated production (CO<sub>2</sub>)<sup>29</sup>, aluminium production (CO<sub>2</sub>), cement production (CO<sub>2</sub>), and ammonia production (CO<sub>2</sub>).

Between 1990 and 2006, significant emission reductions of 89% (9.5 Mt CO<sub>2</sub> eq) were noted in the category adipic acid production. This resulted from the installation of an emission abatement system at Canada's only adipic acid facility in 1997. According to the plant's environmental manager, since the abatement unit has been implemented, emissions are to a large degree dependent on the efficiency of the abatement system and the site's success in maximizing the uptime of the system (e-mail from S. Lauridsen, 2007).<sup>30</sup> The aluminium industry also succeeded in bringing down its PFC emissions by 60% (3.9 Mt CO<sub>2</sub> eq), while increasing the production by 86% (1.3 Mt).<sup>31</sup> The PFC reductions have been achieved through incorporation of computerized sensors and automated alumina feeders, which helped avoid the occurrence of anode effects. The category of magnesium production also showed significant emission diminutions because of progressive replacement of SF<sub>6</sub> with alternatives used as cover gas. Between 1990 and 2005, magnesium production has increased by 78% or 20 kt<sup>32</sup> (NRCan 2005). Hence, it was believed that, as was the case for adipic acid production and aluminium production (PFCs), the level of SF<sub>6</sub> emissions from magnesium production was not so much driven by the production level, but rather by how often alternative gases were used. The decline in emissions from limestone and dolomite use resulted from the downward trend (-66%, or -1.1 Mt, compared to the 1990 level) in the use of the minerals in various industry sectors, for example, iron and steel, glass manufacturing, and pulp and paper industries. The decrease in use was partially due to the increasing acquisition of lime directly from lime manufacturers by the pulp and paper industry.

While emissions have dropped for some metal, chemical, and mineral categories, other categories have shown an upward emission trend between 1990 and 2006. For instance, there has been an emission growth of 1000% (4.8 Mt CO<sub>2</sub> eq) for consumption of halocarbons since 1995. This could be explained by the fact that more ozone-depleting substances (ODSs) were replaced by the HFCs within the refrigeration and air conditioning (AC) markets, when the Montreal Protocol came into effect in 1996. The effect of the Montreal Protocol was also reflected in the upward trend in imported bulk quantities of HFCs since 1995. Although a 1990 value is shown for production and consumption of halocarbons in Table 2-8, this value represents only HFC-23 emissions from the production of HCFC-22, because emissions from consumption of halocarbons were considered negligible in 1990. The 1995, 2000, 2005, and 2006 values in Table 2-8 account for emissions coming from consumption of halocarbons (PFCs and HFCs) only, because the last HCFC-23 producing plant was shut down in 1993. The non-energy (feedstock) use of fuels in the petrochemical industry has considerably increased over the years. For example, the non-energy use of butane has grown by 196% and that of ethane by 129% since 1990, reflecting the increases in the production of natural gas in Canada and extraction of natural gas liquids (NGL) for

29. Other and undifferentiated production is an emission category composed mainly of petrochemical production that uses hydrocarbons as feedstock.

30. E-mail to M. Abdul (Environment Canada) from S. Lauriden (Invista) on Oct 30, 2007. This e-mail explains the 2006 emission estimate and confirms the 2005 estimate.

31. The percent production increase was calculated based on 1990 and 2005 values, since the 2006 value was not available. However, the growth in production between 1990 and 2006 would be even greater, as more production capacity has been added during 2005.

32. The corresponding 2006 statistics for magnesium production were not available when the inventory report was prepared.

petrochemical uses. In addition, an augmentation of 588% was noticed in the non-energy use of other products, like waxes and paraffin. Altogether, these increases in non-energy fuel use have contributed to the emission growth of 55% (4.4 Mt CO<sub>2</sub> eq) for the category of other and undifferentiated production. The increase in aluminium production by 86% (1.3 Mt) mentioned above gave rise to the growth in CO<sub>2</sub> emissions (84% or 2.3 Mt CO<sub>2</sub> eq), since CO<sub>2</sub> comes from the reduction of alumina with carbon anodes, an essential reaction in the production. For cement production, the emission increase of 35% (1.9 Mt CO<sub>2</sub> eq) resulted from the growth in clinker production (35% or 3.6 Mt), which in turn was associated with the increases in the domestic and international demand for cement and clinker. The Canadian exports of Portland cement and clinker were primarily made to U.S. markets. Since there have been very few imports of clinker over the years, the bulk of the clinker used to manufacture cement for the Canadian market came from domestic production, resulting in CO<sub>2</sub> emissions. Between 1990 and 2006, export of Portland cement has increased by 108%. There has also been a rise in the domestic demand for cement due to an increase in construction activities in Alberta and, to a lesser extent, in British Columbia (NRCan 2006). In the case of ammonia production, emissions have gone up 32% (1.6 Mt CO<sub>2</sub> eq), because of an overall 32% growth in production of ammonia relying on steam methane reforming.

Between 2005 and 2006, the total emissions for the Industrial Processes Sector slightly decreased by 0.7% (0.36 Mt CO<sub>2</sub> eq). This overall diminution was driven mainly by emission reductions in the adipic acid production (-54%, or -1.4 Mt CO<sub>2</sub> eq) and aluminium production – PFCs (-14%, or -0.45 Mt CO<sub>2</sub> eq). However, this was counterbalanced by the increase in emissions from iron and steel production (+10%, or +0.73 Mt CO<sub>2</sub> eq), ammonia production (+4%, or +0.25 Mt CO<sub>2</sub> eq), and to a lesser extent, cement production (+2%, or 0.14 Mt CO<sub>2</sub> eq). The year 2006 was good (compared to 2005) in terms of the abatement operations of the adipic acid plant. The abatement unit functioned during the entire year of 2006, except in January (e-mail from S. Lauridsen, 2007).<sup>33</sup> Between 2005 and 2006, the aluminium industry continued to do well in reducing PFC emissions. The Alouette plant at Sept-Iles completed its expansion in May 2005, allowing greater reliance on more modern facilities. Finally, higher demand for iron and steel, as reflected in higher world market prices for steel, and higher demand for ammonia and fertilizer products, caused increases in emissions from the corresponding categories.

### **2.3.3 Solvent and Other Product Use Sector (2006 GHG emissions, 0.32 Mt)**

The Solvent and Other Product Use Sector accounts for emissions related to the use of N<sub>2</sub>O as an anaesthetic in medical applications and as a propellant in aerosol products. It contributed 322 kt CO<sub>2</sub> eq to the 2006 national GHG inventory, compared with 170 kt CO<sub>2</sub> eq in 1990. The emission trends, either long term (between 1990 and 2006) or short term (between 2005 and 2006), were primarily driven by the domestic demand for N<sub>2</sub>O for anaesthetic or propellant purposes, although exports of N<sub>2</sub>O saw increases between 2005 and 2006.

### **2.3.4 Agriculture Sector (2006 GHG emissions, 62 Mt)**

Canada's Agriculture Sector is composed of approximately 250 000 farms, 98% of which are family owned. Agricultural emissions accounted for 62 Mt or 8.6% of total 2006 GHG emissions for Canada, an increase of 12 Mt since 1990. All these emissions are from non-energy sources; N<sub>2</sub>O accounts for about 56% of sectoral 2006 emissions and CH<sub>4</sub> for about 44%.

---

33. E-mail received by M. Abdul (Environment Canada) from S. Lauriden (Invista) on Oct 30, 2007. This e-mail contains explanations of the 2006 emission estimate and a confirmation of the 2005 estimate.

The processes and activities that produce GHG emissions in the Agriculture Sector are enteric fermentation by domestic animals, manure management, fertilizer application, and crop production (Figure 2-4).

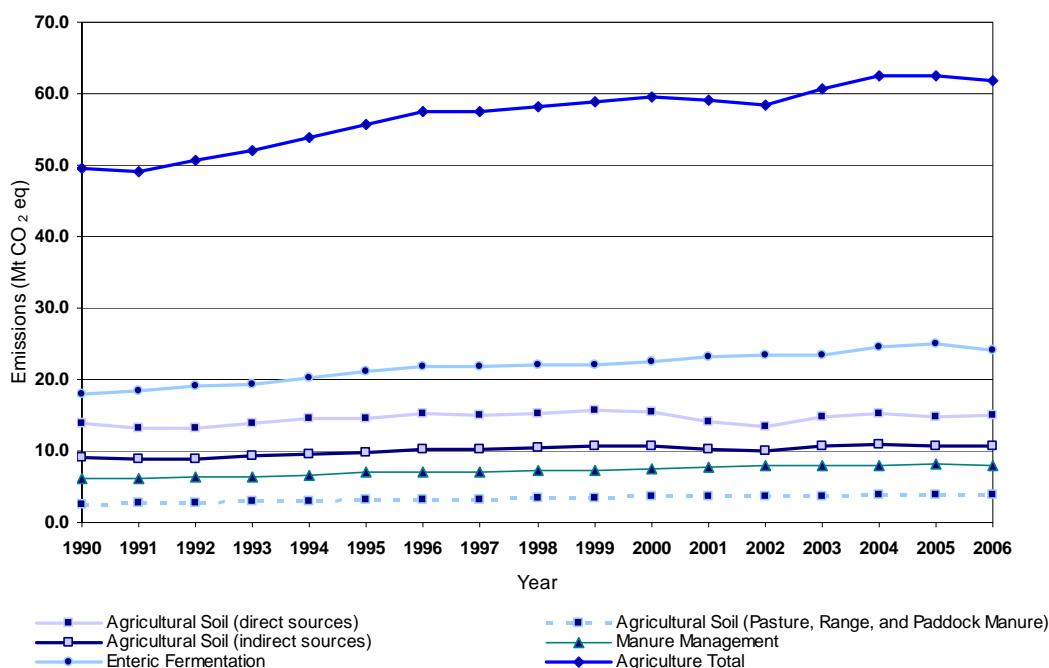


Figure 2-4: GHG Emissions from Agriculture, 1990–2006

Livestock emissions consist of enteric fermentation from domestic animals (i.e. dairy and beef cattle, swine, sheep, goats, horses, poultry, etc.) and manure management. These emissions accounted for 52% of the Agriculture Sector's total GHG emissions in 2006.

Agricultural soil emissions consist of direct N<sub>2</sub>O emissions from synthetic nitrogen fertilizers, animal manure applied to cropland, crop residue decomposition, summerfallow, tillage practices, irrigation, and cultivation of organic soils; indirect N<sub>2</sub>O emissions from volatilization and leaching of fertilizer, manure and crop residue nitrogen; and N<sub>2</sub>O emissions from manure on pasture, range, and paddock. These sources accounted for about 48% of the Agriculture Sector's total GHG emissions in 2006.

In the period from 1990 to 2006, CH<sub>4</sub> emissions from enteric fermentation increased by approximately 34%, emissions from manure management systems 32%, and soil N<sub>2</sub>O emissions by approximately 17%. These increases result mainly from the expansion of the beef cattle, swine and poultry industries combined with an increase in the consumption of synthetic nitrogen fertilizer.

Between 2005 and 2006, there was a slight decrease in agricultural emissions, attributed to the stabilization of beef cattle populations and thus of emissions from manure management and enteric fermentation.

### 2.3.5 Land Use, Land-Use Change, and Forestry Sector (2006 net GHG emissions, 31 Mt, not included in national totals)

The LULUCF Sector reports GHG fluxes between the atmosphere and Canada's managed lands, as well as those associated with land-use changes.

The net LULUCF flux, calculated as the sum of CO<sub>2</sub> emissions and removals and non-CO<sub>2</sub> emissions, displays high interannual variability over the reporting period. In 2006, this net flux amounted to emissions of 31 Mt (Figure 2-5).

All emissions and removals in the LULUCF Sector are excluded from the national totals. In 2006, the estimated 31 Mt would, if included, have increased the total Canadian GHG emissions by about 4%.

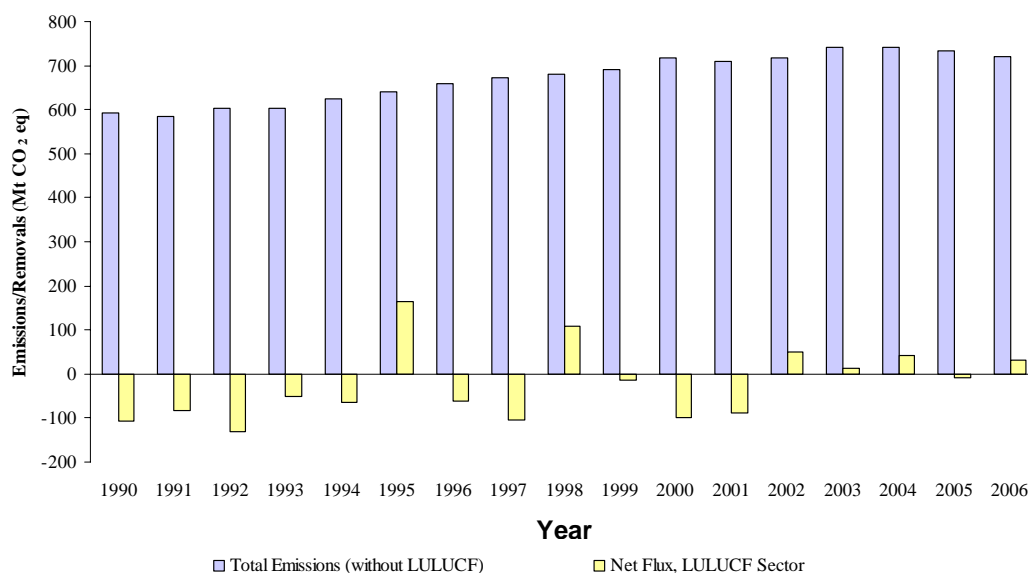


Figure 2-5: GHG Emissions from LULUCF Relative to Total Canadian Emissions, 1990–2006

GHG emissions from sources and removals by sinks are estimated and reported for four categories of managed lands: Forest Land, Cropland, Wetlands, and Settlements.

The Forest Land category includes GHG emissions from and removals by Canada's managed forests and modest CO<sub>2</sub> removals by forest plantations. Managed forests display the highest interannual variability of all categories and exert an overriding influence on the net sectoral GHG balance and trend. The net GHG flux reflects the difference between carbon uptake by tree growth and emissions due to anthropogenic and natural disturbances, specifically forest management activities, wildfires, and insect infestations. The high variability in the net flux from managed forests is associated with the immediate impact of wildfires, which alone accounted for annual emissions between 11 and 290 Mt over the period from 1990 to 2006 (Figure 2-6). Both short- and long-term trends should therefore be interpreted with caution, given that the sector as a whole retains the important interannual variability resulting from large fluctuations in the severity of the fire season, with an additional random effect due to the location of fires with respect to managed forests (as opposed to non-managed). The largest carbon fluxes to and from managed

forests consist of carbon uptake by growing trees and its release due to the decay of organic matter (2 939 and 2 077 Mt in 2006, respectively). Over the last 10 years forest management activities, namely harvesting, account for annual average emissions of 155 Mt, a 54% increase since 1990 levels; note that the current default approach ignores long-term carbon storage in wood products.

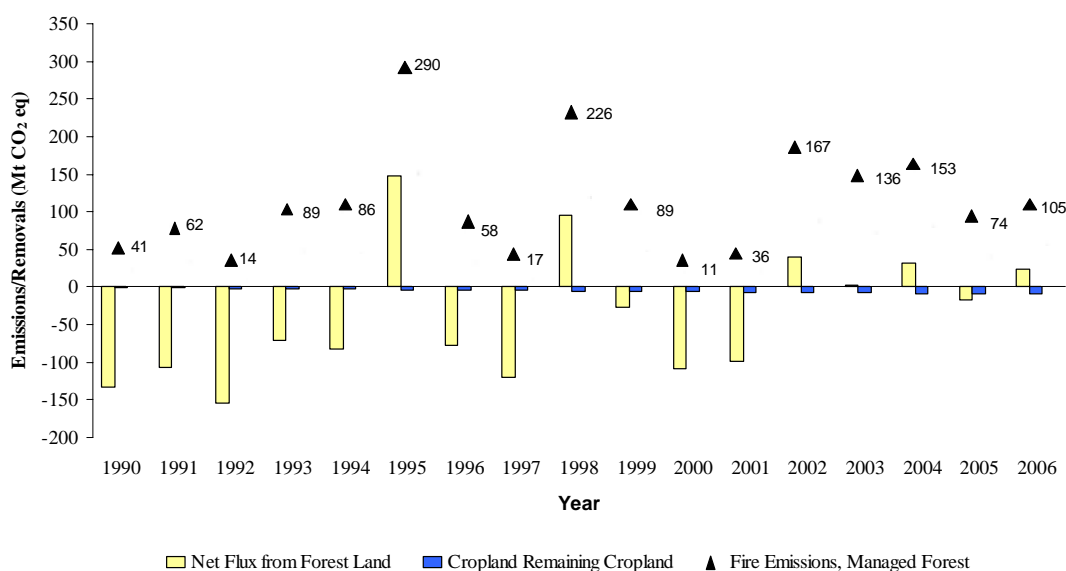


Figure 2-6: Selected GHG Emissions and Removals in LULUCF, 1990–2006

The Cropland subcategory includes the effect of agricultural practices on CO<sub>2</sub> emissions from and removals by arable soils and the GHG impact associated with forest and grassland conversion to cropland. In 2006, the net GHG balance of the Cropland subcategory amounted to net removals of 1.4 Mt. The continued adoption of no-till (NT) and reduced tillage (RT) practices and the reduction of summerfallow have resulted in a steady trend of increasing removals in cultivated soils, which, in 2006, offset the emissions due to land conversion to agriculture.

CO<sub>2</sub> emissions from peatlands managed for peat extraction and from land flooding are reported under the Wetlands category. Emissions from managed peatlands have more than doubled since 1990, reaching almost 0.6 Mt in 2006. Land conversion to flooded lands (reservoirs) accounted for 4 Mt in 1990, decreasing to 1.6 Mt in 2006. Note that reservoirs flooded for more than 10 years are excluded from the accounting (IPCC 2003).

Estimates reported under the Settlements subcategory (8 Mt in 2006) represent the effect of the conversion of forest and other vegetated lands to built-up lands, including urban and recreation, transport infrastructure, and resource extraction. The contribution of urban forests is minimal.

Forest losses to cropland, wetlands, and settlements amounted to emissions of about 19 Mt in 2006, down from 27 Mt in 1990. This reduction is accounted for by declines of 7 Mt in emissions from forests converted to cropland, and nearly 2 Mt in emissions from each of forests converted to wetlands and to settlements. The reader is referred to additional information in Chapter 7 and Section A3.4 of the present report.

### 2.3.6 Waste Sector (2006 GHG emissions, 21 Mt)

From 1990 to 2006, GHG emissions from the Waste Sector increased 15%, only slightly less than the population growth of 18%, while over the same period total national GHG emissions grew by 22% (Figure 2-7). In 2006, these emissions represented 2.9% of the total national GHG emissions, compared with a 3.1% contribution in 1990. Of the 21 Mt total emissions from this sector in 2006, solid waste disposal on land, which includes municipal solid waste (MSW) landfills and wood waste landfills, accounted for 20 Mt. CH<sub>4</sub> emissions produced by the decomposition of biomass in MSW were responsible for 81% of the emissions from this sector. Emissions from municipal wastewater treatment and incineration of waste (excluding emissions from incineration of biomass material) contributed 0.93 Mt and 0.24 Mt, respectively, to the total from the Waste Sector (Table 2-9). Figure 2-7 presents the emission trends for each of the three subsectors compared with the total emissions for the Waste Sector between 1990 and 2006. The tables in Annex 8 summarize this information nationally by CO<sub>2</sub> equivalent and by category (i.e. individual gas and source).

**Table 2-9: GHG Emissions from Waste, Selected Years**

GHG Source Category	GHG Emissions (Mt CO <sub>2</sub> eq)				
	1990	1995	2000	2005	2006
Waste Sector (Total)	18	19	20	21	21
a. Solid Waste Disposal on Land	17	18	19	19	20
b. Wastewater Handling	0.78	0.82	0.88	0.94	0.93
c. Waste Incineration	0.40	0.35	0.25	0.24	0.24

Note: Totals may not add up due to rounding.

CH<sub>4</sub> emissions from MSW landfills increased by 18% between 1990 and 2006, despite an increase in landfill gas capture and combustion of 50% over the same period. Approximately 314 kt of CH<sub>4</sub> (or 6 594 kt CO<sub>2</sub> eq) were captured by the 52 landfill gas collection systems operating in Canada (Environment Canada 2007).<sup>34</sup> Of the total amount of CH<sub>4</sub> collected, 51% (159 kt) was utilized for various energy purposes and 49% (155 kt) was flared. Eight sites utilized the captured CH<sub>4</sub>, 31 sites flared the captured CH<sub>4</sub>, and 13 sites utilized and flared the captured CH<sub>4</sub>.

34. Five landfill gas capture facilities did not provide data for the 2005 landfill gas inventory by February 2007. Thus, for the purposes of the 1990–2006 NIR, these facilities were included in the total number of active facilities collecting landfill gas, and it was assumed that the data provided by these facilities for the 2003 landfill gas inventory were constant for 2004, 2005, and 2006.

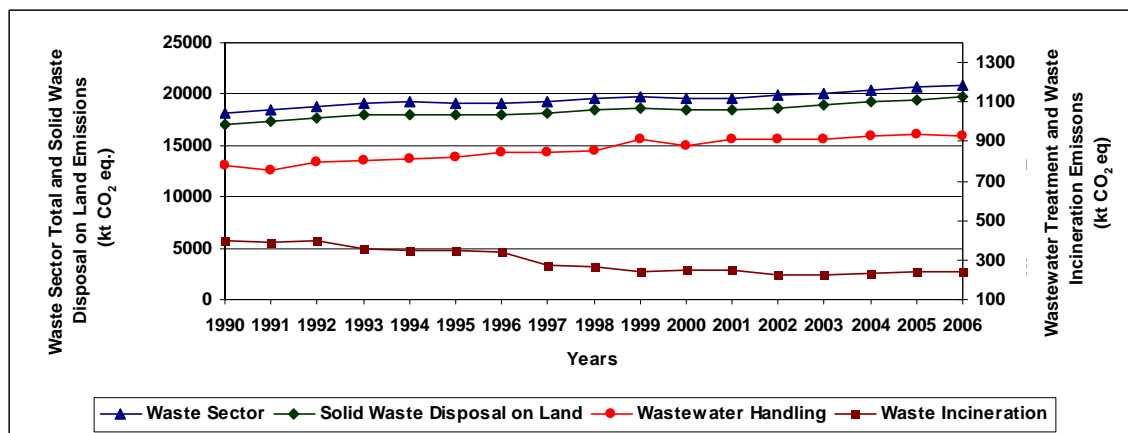


Figure 2-7: GHG Emissions from Waste, 1990–2006

GHG emissions from landfills were estimated for two solid waste types: MSW and wood waste landfills, both of which produce CH<sub>4</sub> anaerobically.<sup>35</sup> The CH<sub>4</sub> production rate at a landfill is a function of several factors, including the mass and composition of biomass being landfilled, the landfill temperature, and the moisture entering the site from rainfall.

CH<sub>4</sub> capture and waste diversion programs at landfills have made significant contributions to reductions in emissions during this period. The quantity of CH<sub>4</sub> captured at MSW landfills for flaring or combustion for energy recovery purposes in 2006 amounted to 28% of the total generated emissions from this source as compared to 22% in 1990. Per capita emissions from the Waste Sector decreased by 2.3% from 1990 to 2006 owing primarily to the increasing quantities of CH<sub>4</sub> captured at landfill sites (Figure 2-8). The amount of CH<sub>4</sub> captured increased by 63% from 1990 to 2006, and the amount of waste diverted as a percentage of the waste generated has fluctuated from 21% to 25% over the period between 1998 and 2004. Although the quantity of waste placed in MSW landfills increased by 24% from 1990 to 2006, the landfilled quantity per capita increased by only 5.8% (Statistics Canada 2000, 2003, 2004, 2007). The amount of waste exported from Canada to the United States for the years 1998 and 2004 were 560 kt and 2 590 kt, respectively, giving a 363% increase in the amount of waste exported over this period. However, emissions from MSW landfills are expected to increase in subsequent years as a result of restrictions on the exportation of solid waste. The main contributors to the export of waste from Canada have committed to the elimination of shipments of residential waste to the United States by the end of 2010. Within this time frame, there will be a 20% reduction by 2007 and a further 20% reduction by the end of 2008 (Ontario Ministry of the Environment 2006).

The population growth trend (18%) slightly exceeds that of sector emissions (15%), partially due to the delayed effect on emissions caused by material landfilled in past decades that is still contributing to CH<sub>4</sub> production. The decline in the growth of emissions per capita observed in the

35. When waste consists of biomass, the CO<sub>2</sub> produced from burning or aerobic decomposition is not accounted for in the Waste Sector. This is because, in the case of agricultural biomass, it is deemed to be a sustainable cycle (carbon in CO<sub>2</sub> will be sequestered when the biomass regenerates in crop reproduction). In the case of biomass from forest products, the emissions of CO<sub>2</sub> are accounted for as part of the LULUCF Sector (forest harvests). However, waste that decomposes anaerobically produces CH<sub>4</sub>, which is not used photosynthetically and therefore does not sequester carbon in biomass regeneration and is not accounted for in forest harvest estimates. The production and release of unburned CH<sub>4</sub> from waste are therefore accounted for in GHG inventories.

mid-1990s, shown in Figure 2-8, is directly attributable to CH<sub>4</sub> capture at landfills and waste diversion programs. However, from 1997 to 1999, there was a reduction in the quantities of landfill gas captured, followed by an increase. These changes have an inversely proportional influence on the emissions per capita, which is apparent in Figure 2-8.

In terms of emissions per capita compared with 1990 emissions per capita for the other waste subsectors, GHG emissions from wastewater handling remained fairly constant, whereas waste incineration showed a significant decrease in GHG emissions over the 1990–2006 time series (Figure 2-8). Total incineration emissions per capita decreased by 49% over the time series, with the greatest decline in emissions per capita for incineration occurring between 1992 and 1997, due mainly to the closure of aging incinerators.

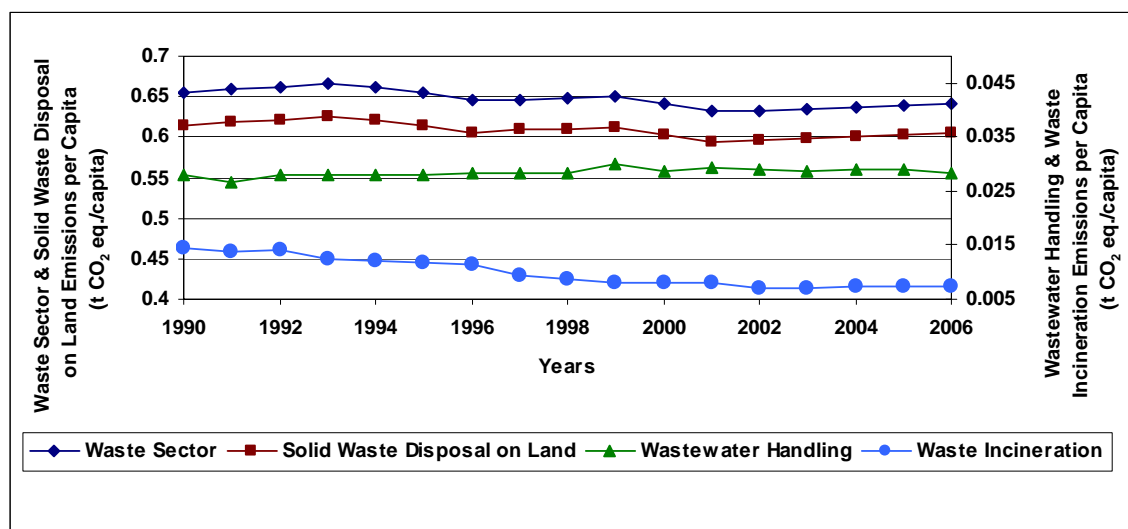


Figure 2-8: Per Capita GHG Emission Trend for Waste, 1990–2006

## 2.4 Emission Trends for Ozone and Aerosol Precursors

Emissions of ozone and aerosol precursors fell over the 1990–2006 period. Emissions of CO fell by 39.1%, NO<sub>x</sub> emissions were down 1.8%, NMVOC emissions declined 17.6%, and SO<sub>x</sub> emissions were reduced by 36.9% (see Annex 14 for data tables).



## 3 Energy (CRF Sector 1)

### 3.1 Overview

Overall, the Energy Sector contributed about 81% (or 583 Mt) of Canada's total GHG emissions in 2006 (Table 3-1). The Energy Sector accounts for all GHG (CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O) emissions from stationary and transport fuel combustion activities as well as fugitive emissions from the fossil fuel industry. Fugitive emissions associated with the fossil fuel industry are the intentional or unintentional (e.g. leaks, accidents) releases of GHGs that may result from production, processing, transmission, and storage activities. Emissions from flaring activities by the oil and gas industry are reported in the fugitive category, since their purpose is not to produce heat or to generate mechanical work (IPCC/OECD/IEA 1997).

Emissions resulting from stationary fuel combustion include, for example, the use of fossil fuels by the electricity generating industry, the oil and gas industry, the manufacturing and construction industry, and the residential and commercial sector. Only CH<sub>4</sub> and N<sub>2</sub>O emissions resulting from the combustion of biomass fuels by the pulp and paper industry and by the residential sector are accounted for in the Energy Sector, whereas CO<sub>2</sub> emissions resulting from the use of biomass are reported as a memo item in the CRF tables.

GHG emissions from the combustion (and evaporation) of fuel for all transport activities, such as Civil Aviation (Domestic Aviation), Road Transportation, Railways, Navigation (Domestic Marine), and Other Transportation (Off-Road and Pipelines), are included in the Transport subsector. Usage of transport fuels (such as gasoline and diesel) by the mining industry, by the oil and gas extraction industry, and by agriculture and forestry is also included under Other Transportation. Emissions from international bunker activities (only in regards to aviation and marine) are reported as a memo item in the CRF tables.

**Table 3-1: GHG Emissions from Energy, Selected Years**

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)		
	1990	2005	2006
<b>Energy Sector</b>	<b>470 000</b>	<b>596 000</b>	<b>583 000</b>
<b>Fuel Combustion (1.A)</b>	<b>427 000</b>	<b>531 000</b>	<b>516 000</b>
Energy Industries (1.A.1)	147 000	194 000	185 000
Manufacturing Industries and Construction (1.A.2)	62 900	64 200	64 200
Transport (1.A.3)	150 000	190 000	190 000
Other Sectors (1.A.4)	71 600	80 500	75 200
<b>Fugitive Emissions from Fuels (1.B)</b>	<b>42 700</b>	<b>65 500</b>	<b>66 800</b>

Note: Totals may not add up due to rounding.

### 3.2 Fuel Combustion (CRF Category 1.A)

Fuel combustion sources include all emissions from the combustion of fossil fuels. Major subsectors include Energy Industries, Manufacturing Industries and Construction, Transport, and Other Sectors (which include the residential and commercial categories). Methods used to calculate emissions from fuel combustion are consistent throughout and are presented in Annex 2: Methodology and Data for Estimating Emissions from Fossil Fuel Combustion; the estimation

methodologies are consistent with the Revised 1996 IPCC Tier 2 approach, with country-specific emission factors and parameters.

In 2006, about 516 Mt (or 72%) of Canada's GHG emissions were from the combustion of fossil fuels (Table 3-1). The overall GHG emissions from fuel combustion activities have increased by 21% since 1990 and decreased by 3% since 2005. Between 1990 and 2006, combustion-related emissions from the Energy Industries and from the Transport category increased by about 15% and 32%, respectively (Figure 3-1).

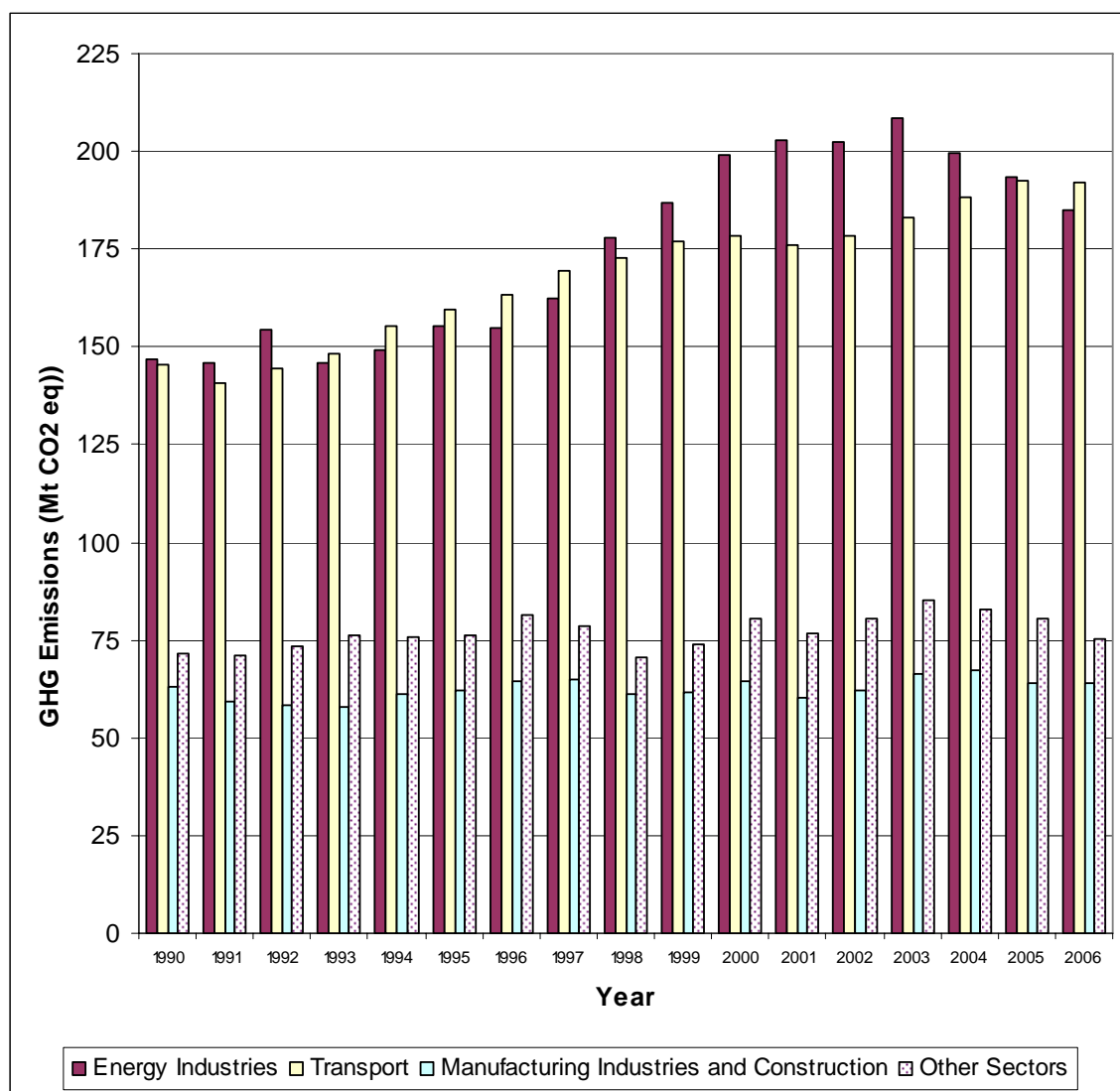


Figure 3-1: GHG Emissions from Fuel Combustion, 1990–2006

### 3.2.1 Energy Industries (CRF Category 1.A.1)

#### 3.2.1.1 Source Category Description

The Energy Industries subsector is divided into the following three categories: Public Electricity and Heat Production, Petroleum Refining, and Manufacture of Solid Fuels and Other Energy Industries (which consists primarily of crude oil, coal, natural gas, bitumen, and synthetic crude oil production).

In 2006, the Energy Industries subsector accounted for 185 Mt (or about 26%) of Canada's total GHG emissions, with an overall increase of about 26% since 1990. About 63% (or 117 Mt) of the subsector's GHG emissions are from Public Electricity and Heat Production, whereas Petroleum Refining and the Manufacture of Solid Fuels and Other Energy Industries contributed 9% (16 Mt) and 28% (52 Mt), respectively (Table 3-2). Additional discussions on trends in emissions from the Energy Industries are to be found in the Emission Trends chapter (Chapter 2).

**Table 3-2: Energy Industries GHG Contribution**

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)		
	1990	2005	2006
<b>Energy Industries TOTAL (1.A.1)</b>	<b>147 000</b>	<b>194 000</b>	<b>185 000</b>
<b>Public Electricity and Heat Production</b>	<b>95 400</b>	<b>124 700</b>	<b>117 000</b>
Electricity Generation—Utilities	92 500	118 800	110 500
Electricity Generation—Industry	2 200	4 500	5 400
Heat/Steam Generation	700	1 400	1 000
<b>Petroleum Refining</b>	<b>16 000</b>	<b>17 000</b>	<b>16 000</b>
<b>Manufacture of Solid Fuels and Other Energy Industries</b>	<b>36 000</b>	<b>52 000</b>	<b>52 000</b>

Note: Totals may not add up due to rounding.

The Energy Industries subsector includes all emissions from stationary fuel combustion sources in the electricity generation industry and the production, processing, and refining of fossil fuels. All of the emissions associated with the fossil fuel industry are estimates, although a portion of emissions from coal mining and from oil and gas extraction associated with the Petroleum Refining and the Manufacture of Solid Fuels and Other Energy Industries have been allocated to the Manufacturing Industries and Construction–Mining and the Transport–Other subsectors, because fuel consumption data at a lower level of disaggregation are not available. Combustion emissions associated with the pipeline transmission of oil and natural gas are included under Other Transportation according to the revised 1996 IPCC guidelines (IPCC/OECD/IEA 1997).

Although actually associated with the Energy Industries, emissions from venting and flaring activities related to the production, processing, and refining of fossil fuels are reported as fugitive emissions (refer to Section 3.3).

#### Public Electricity and Heat Production (CRF Category 1.A.1.a)

The Public Electricity and Heat Production category includes emissions associated with the production of electricity and heat from the combustion of fuel in thermal power plants in both the public and private sectors. The electric supply grid in Canada includes thermal combustion–derived electricity as well as hydro, nuclear, wind, and tidal power. Total power generated from wind, tidal, and solar resources is relatively small compared with that from Canada's significant hydro and nuclear installations. Nuclear, hydro, wind, solar, and tidal electricity generators are

not direct emitters of GHGs; therefore, GHG estimates reflect emissions from combustion-derived electricity only.

Two systems are used to generate electricity using thermal combustion:

- steam generation; and
- internal combustion (turbine and reciprocating) engines.

Steam turbine boilers are fired with coal, heavy fuel oil, natural gas, or biomass. For turbine engines, the initial heat may be generated from natural gas and RPPs (e.g. light fuel oil or diesel fuel). Reciprocating engines can use natural gas and/or a combination of RPPs, whereas gas turbines are also fired with natural gas or RPPs.

Emissions of CH<sub>4</sub> and N<sub>2</sub>O from the combustion of landfill gas (LFG) for heat, steam, and electricity generation are included, while CO<sub>2</sub> emissions are excluded from totals but reported separately in the UNFCCC CRF tables as a memo item.

### **Petroleum Refining (CRF Category 1.A.1.b)**

The Petroleum Refining category includes direct emissions from the production of petroleum products from a raw feedstock. Conventional or synthetic crude oil is refined by distillation and other processes into petroleum products such as heavy fuel oil, residential fuel oil, jet fuel, gasoline, and diesel oil. The heat required for these processes is created by combusting either internally generated fuels (such as refinery fuel gas) or purchased fuels (such as natural gas). CO<sub>2</sub> generated as a by-product during the production of hydrogen in the steam reforming of natural gas is reported in the fugitive category (Section 3.3).

The Petroleum Refining category also includes a small portion of combustion emissions that result from the upgrading of heavy oil from oil sands mining and *in situ* extraction to produce synthetic crude oil and/or other refined products such as diesel oil for sale. Also, owing to the level of aggregation of the fuel consumption data and the assumptions used to report the emissions associated with the downstream (petroleum refining) and the upstream (consisting of solid, oil, and gas production) industry, a small portion of emissions associated with Petroleum Refining (such as CH<sub>4</sub>) are included in the Manufacture of Solid Fuels and Other Energy Industries (and vice versa for a portion of the emissions associated with bitumen upgrading in the oil sands industry). Refer to Annex 2 for additional details on the method used to disaggregate the activity data.

### **Manufacture of Solid Fuels and Other Energy Industries (CRF Category 1.A.1.c)**

The Manufacture of Solid Fuels and Other Energy Industries category comprises fuel combustion emissions associated with the crude oil, natural gas, oil sands mining, bitumen extraction and upgrading, and coal mining industries. A portion of emissions associated with coal mining and with the oil and gas mining and extraction component of the fossil fuel industry are reported in the Manufacturing Industries and Construction–Mining category, whereas emissions associated with pipeline transmission and with the use of transport fuels (such as gasoline and diesel oil) in the mining and the oil and gas mining and extraction industry are reported under Other Transportation, since the fuel data cannot be further disaggregated in the national energy balance as compiled by Statistics Canada.

Upgrading facilities are responsible for producing synthetic crude oil based on a feedstock of bitumen produced by oil sands mining, extraction, and *in situ* recovery activities (e.g. thermal extraction). The synthetic (or upgraded) crude oil has a hydrocarbon composition similar to that of conventional crude oil, which can be refined to produce RPPs such as gasoline and diesel oil. Upgrading facilities also rely on internally generated fuels such as process gas and natural gas for their operation, which result in both combustion- and fugitive-related emissions.

### 3.2.1.2 *Methodological Issues*

Emissions for all source categories are calculated following the methodology described in Annex 2 and are based on national fuel consumption statistics reported in the RESD (Statistics Canada, #57-003), with the exception of LFG utilization estimates, which are provided by the Waste sector. The method is consistent with the IPCC Tier 2 approach, with country-specific emission factors.

#### **Public Electricity and Heat Production (CRF Category 1.A.1.a)**

The revised 1996 IPCC guidelines (IPCC/OECD/IEA 1997) require the Public Electricity and Heat Production sector to include only emissions generated by public utilities. Emissions associated with industrial generation should be allocated to the industry that produces the energy under the appropriate industrial category within the Energy Sector, regardless of whether the energy is for sale or for internal use. The rationale for this is that the IPCC recognizes that it is difficult to disaggregate emissions in cogeneration facilities (i.e. to separate the electricity component from the heat component of fuel use). Statistics Canada fuel-use data in the RESD do distinguish industrial electricity generation data, but aggregate the data into one category titled industrial electricity generation. As a result, the GHG inventory cannot allocate industrial electricity generation emissions to specific industrial categories; rather, these emissions are lumped together and reported with Public Electricity and Heat Production.

Overall, emissions associated with electricity generated by industry made up 2.3% of the Public Electricity and Heat Production sector's emissions in 1990 and 4.7% in 2006.

#### **Petroleum Refining (CRF Category 1.A.1.b)**

Emissions for this category are calculated using all fuel use attributed to the petroleum refining industry and include all petroleum products (including still gas, petroleum coke, and diesel) reported as producer consumed as well as purchases of natural gas for fuel use by refineries. The fuel-use data in the RESD include volumes of flared fuels; however, flaring emissions are calculated and reported separately in the fugitive category. The fuel-use and emission data associated with flaring are subtracted to avoid double-counting.

#### **Manufacture of Solid Fuels and Other Energy Industries (CRF Category 1.A.1.c)**

Emissions for this category are calculated using all fuel use attributed to fossil fuel producers (including petroleum coke, still gas, natural gas, natural gas liquids [NGLs], and coal data). The fuel-use data in the RESD include volumes of flared fuels; however, flaring emissions are calculated and reported separately in the fugitive category. The fuel-use and emission data associated with flaring are subtracted to avoid double-counting.

### 3.2.1.3 *Uncertainties and Time-Series Consistency*

The estimated uncertainty for the Energy Industries subsector ranges from –4% to +6% for all gases and from –6% to +2% for CO<sub>2</sub> alone. Refer to the Uncertainty annex (Annex 7) for additional discussion on the ICF Consulting (2004) uncertainty study and additional uncertainty values for the Energy Industries subsector.

The uncertainties for the Energy Industries subsector are largely dependent on the collection procedures used for the underlying activity data as well as on the representativeness of the emission factors for specific fuel properties. Commercial fuel volumes and properties are generally well-known, whereas there is greater uncertainty surrounding both the reported quantities and properties of non-marketable fuels (e.g. *in situ* use of natural gas from the producing wells and the use of refinery fuel gas). For example, in the Petroleum Refining category, the CO<sub>2</sub> emission factors for non-marketable fuels as consumed, such as refinery still gas, petroleum coke, and catalytic coke, have a greater influence on the uncertainty estimate than the CO<sub>2</sub> factors for commercial fuels.

For the Public Electricity and Heat Production category, the uncertainty associated with industrial electricity generation is higher than that associated with utility-generated electricity owing to a lack of disaggregated information.

Over 83% of the 2006 emissions from the Manufacture of Solid Fuels and Other Energy Industries category are associated with natural gas production and processing. The uncertainty for this category is influenced by the CO<sub>2</sub> emission factors (±6%) and CH<sub>4</sub> emission factors (0% to +240%) for the consumption of unprocessed natural gas. A national weighted emission factor was used to estimate emissions for the natural gas industry due to a lack of plant-level information, such as the physical composition of unprocessed natural gas (which will vary from plant to plant). Thus, the overall uncertainty estimate is based on a rather broad assumption as well.

The estimated uncertainty for CH<sub>4</sub> (+1% to +230%) and N<sub>2</sub>O (–23% to +800%) emissions for the Energy Industries subsector is influenced by the uncertainty associated with the emission factors. Additional expert elicitation is required to improve the CH<sub>4</sub> and N<sub>2</sub>O uncertainty estimates for some of the emission factor uncertainty ranges and probability density functions developed by ICF Consulting (2004), since insufficient time was available to have these assumptions reviewed by industry experts.

The estimates for the Energy Industries subsector are consistent over time and calculated using the same methodology.

### 3.2.1.4 *QA/QC and Verification*

QC checks were done in a form consistent with IPCC Good Practice Guidance (IPCC 2000). Elements of a Tier 1 QC check include a review of the estimation model, activity data, emission factors, time-series consistency, transcription errors, reference material, conversion factors, and unit labelling, as well as sample emission calculations.

Activity data errors involving primarily historical data were identified during the review and corrected. No mathematical or reference errors were found during the QC checks, whereas only minor labelling issues were revealed. A small amount of fugitive emissions associated with the fossil fuel industries was found to have been double-counted in the past, and this has been

corrected. The data, methodologies, and changes related to the QC activities are documented and archived in both paper and electronic form.

#### *3.2.1.5 Recalculations*

Refer to Chapter 9 for a detailed discussion on sectoral recalculations.

#### *3.2.1.6 Planned Improvements*

A review of coal emission factors for the entire time series is planned based on detailed data analysis for coal mined in Canada. This potential multi-year review may result in revised and updated emission factors for all years and provinces. The energy industries are the major consumers of coal and any revisions will have the greatest impact in these categories.

### **3.2.2 Manufacturing Industries and Construction (CRF Category 1.A.2)**

#### *3.2.2.1 Source Category Description*

This subsector is composed of emissions from the combustion of fossil fuels by all mining, manufacturing, and construction industries. The UNFCCC has assigned six categories under the Manufacturing Industries and Construction subsector, and these are presented separately in the following subsections.

In 2006, the Manufacturing Industries and Construction subsector accounted for 64.2 Mt (or 9%) of Canada's total GHG emissions, with a small 2% (1.2 Mt) increase in overall emissions since 1990 (refer to Table 3-3 for more details). Within the Manufacturing Industries and Construction subsector, more than 42 Mt (or 66%) of the GHG emissions are from the Others category, followed by (in order of decreasing contributions) the Chemical industries, Iron and Steel, Pulp, Paper, and Print, and Non-Ferrous Metals categories, at 6.5 Mt (or 10%), 6.4 Mt (or 10%), 6.0 Mt (or 9.3%), and 3.0 Mt (or 4.7%), respectively. Emissions from Food Processing, Beverages, and Tobacco are included in the Other Manufacturing subcategory due to fuel-use data not being available at the appropriate level of disaggregation.

The Others category is made up of Cement, Mining, Construction, and Other Manufacturing activities. Emissions from mining activities (which includes oil sands mining) increased by 167% between 1990 and 2006.

Industrial emissions resulting from fuel combustion for the generation of electricity or steam for sale are assigned to the Energy Industries subsector (under Public Electricity and Heat Production). This allocation is contrary to the recommendations of the revised 1996 IPCC guidelines (IPCC/OECD/IEA, 1997), which state that emissions associated with the production of electricity or heat by industries are to be allocated to the industries generating the emissions. Unfortunately, at present, this is not possible, because fuel-use data at the appropriate level of disaggregation are not available (see Section 3.2.1).

Emissions generated from the use of fossil fuels as feedstocks or chemical reagents such as for use as metallurgical coke during the reduction of iron ore are reported under the Industrial Processes Sector to ensure that the emissions are not double-counted.

**Table 3-3: Manufacturing Industries and Construction GHG Contribution**

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)		
	1990	2005	2006
<b>Manufacturing Industries and Construction TOTAL (1.A.2)</b>	<b>62 900</b>	<b>64 200</b>	<b>64 200</b>
<b>Iron and Steel</b>	6 500	6 480	6 380
<b>Non-Ferrous Metals</b>	3 190	3 270	3 050
<b>Chemicals</b>	7 100	6 340	6 490
<b>Pulp, Paper, and Print</b>	13 700	7 180	5 950
<b>Food Processing, Beverages, and Tobacco<sup>1</sup></b>	IE	IE	IE
<b>Others</b>	32 400	41 000	42 300
<i>Cement</i>	3 690	4 590	4 850
<i>Mining</i>	6 200	15 600	16 500
<i>Construction</i>	1 870	1 360	1 300
<i>Other Manufacturing</i>	20 700	19 400	19 600

Notes:

1. Note that Food Processing, Beverages, and Tobacco emissions are included under Other Manufacturing.

IE = included elsewhere.

Totals may not add up due to rounding.

### 3.2.2.2 Methodological Issues

Fuel combustion emissions for each category within the Manufacturing Industries and Construction subsector are calculated using the methodology described in Annex 2, which is consistent with an IPCC Tier 2 approach. Emissions generated from the use of transportation fuels (e.g. diesel and gasoline) are reported under the Transport subsector (Section 3.2.3). Methodological issues specific to each manufacturing category are identified below.

#### **Iron and Steel (CRF Category 1.A.2.a)**

Emissions associated with the use of metallurgical coke as a reagent for the reduction of iron ore in blast furnaces have been allocated to the Industrial Processes Sector.

#### **Non-Ferrous Metals (CRF Category 1.A.2.b)**

All fuel-use data for this category were obtained from the RESD (Statistics Canada, #57-003).

#### **Chemicals (CRF Category 1.A.2.c)**

Emissions resulting from fuels used as feedstocks are reported under the Industrial Processes Sector.

#### **Pulp, Paper, and Print (CRF Category 1.A.2.d)**

Fuel-use data include industrial wood wastes and spent pulping liquors combusted for energy purposes. Emissions of CH<sub>4</sub> and N<sub>2</sub>O from the combustion of biomass are included in the pulp and paper industrial category. CO<sub>2</sub> emissions from biomass combustion are not included in totals but are reported separately in the UNFCCC CRF tables as a memo item.

#### **Others (Other Manufacturing and Construction) (CRF Category 1.A.2.f)**

This category includes the remainder of industrial sector emissions, including construction, cement, vehicle manufacturing, textiles, mining, food, beverage, and tobacco sectors.



Consumption of diesel fuels associated with on-site off-road vehicles in mining (which also includes oil and gas mining and extraction use of diesel) have been allocated to the Other Transportation category.

### 3.2.2.3 *Uncertainties and Time-Series Consistency*

The estimated uncertainty for the Manufacturing Industries and Construction subsector ranges from  $-3\%$  to  $+6\%$  for all gases and from  $-3\%$  to  $+2\%$  for  $\text{CO}_2$ . Refer to the Uncertainty annex (Annex 7) for a detailed discussion on the ICF (2004) uncertainty study and additional uncertainty values for the Manufacturing Industries and Construction subsector.

The underlying fuel quantities and  $\text{CO}_2$  emission factors have low uncertainty because they are predominantly commercial fuels, which have consistent properties and a more accurate tracking of quantity purchased for consumption.

As stated in the Energy Industries subsector uncertainty discussion, additional expert elicitation is required to improve the  $\text{CH}_4$  and  $\text{N}_2\text{O}$  uncertainty estimates for some of the emission factor uncertainty ranges and probability density functions developed by the ICF (2004) study, since these assumptions were not reviewed by industry experts, owing to a lack of available time in the study's preparation.

The estimates for the Manufacturing Industries and Construction subsector have been prepared in a consistent manner over time using the same methodology.

### 3.2.2.4 *QA/QC and Verification*

Tier 1 QC checks were completed on the entire stationary combustion GHG estimation model, which included checks of emission factors, activity data, and  $\text{CO}_2$ ,  $\text{CH}_4$ , and  $\text{N}_2\text{O}$  estimates for the entire time series.

QC checks were done in a form consistent with IPCC good practice guidance (IPCC 2000). Elements of a Tier 1 QC check include a review of the estimation model, activity data, emission factors, time-series consistency, transcription errors, reference material, conversion factors, and unit labelling, as well as sample emission calculations.

No mathematical or reference errors were found during the QC checks, and only minor labelling issues were revealed. The data, methodologies, and changes related to the QC activities are documented and archived in both paper and electronic form.

### 3.2.2.5 *Recalculations*

Refer to Chapter 9 for a detailed discussion on sectoral recalculations.

### 3.2.2.6 *Planned Improvements*

The use of waste fuels in the cement industry is being studied to ensure all GHG emissions are being accounted for. It is anticipated that waste fuel GHG emissions will be incorporated into future inventories, assuming good quality, reliable data is available. As a continuous improvement activity, Environment Canada, NRCan, and Statistics Canada are working jointly to improve the underlying quality of the national energy balance and to further disaggregate fuel-use information.

### 3.2.3 Transport (CRF Category 1.A.3)

Transport-related emissions account for 27% of Canada's total GHG emissions. The greatest emission growth since 1990 has been observed in LDGTs and HDDVs; this growth amounts to 116% (24.1 Mt) for LDGTs and 91% (18.8 Mt) for HDDVs. A long-term decrease in some Transport subsectors has also been registered: specifically, reductions in emissions from LDGVs (cars), Propane and Natural Gas Vehicles, and HDGVs, for a combined decrease of 9.9 Mt since 1990. Generally, emissions from the Transport subsector have increased 32% and have contributed the equivalent of 36% of the total overall growth in emissions observed in Canada (see Table 3-4).

**Table 3-4: Transport GHG Contribution**

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)		
	1990	2005	2006
<b>Transport TOTAL (1.A.3.)</b>	<b>150 000</b>	<b>190 000</b>	<b>190 000</b>
<b>Civil Aviation (Domestic Aviation)</b>	<b>6 400</b>	<b>8 600</b>	<b>8 400</b>
<b>Road Transportation</b>	<b>98 400</b>	<b>131 000</b>	<b>133 000</b>
<i>Light-Duty Gasoline Vehicles</i>	45 800	39 900	38 900
<i>Light-Duty Gasoline Trucks</i>	20 700	43 100	44 800
<i>Heavy-Duty Gasoline Vehicles</i>	7 810	6 300	6 280
<i>Motorcycles</i>	146	251	259
<i>Light-Duty Diesel Vehicles</i>	355	432	433
<i>Light-Duty Diesel Trucks</i>	707	2 130	2 330
<i>Heavy-Duty Diesel Vehicles</i>	20 700	37 900	39 400
<i>Propane and Natural Gas Vehicles</i>	2 200	720	800
<b>Railways</b>	<b>7 000</b>	<b>6 000</b>	<b>6 000</b>
<b>Navigation (Domestic Marine)</b>	<b>5 000</b>	<b>6 400</b>	<b>5 800</b>
<b>Other Transportation</b>	<b>30 000</b>	<b>40 000</b>	<b>40 000</b>
<i>Off-Road Gasoline</i>	7 000	7 000	7 000
<i>Off-Road Diesel</i>	20 000	20 000	20 000
<i>Pipelines</i>	6 900	10 100	9 660

Note: Totals may not add up due to rounding.

#### 3.2.3.1 Source Category Description

This subsector comprises the combustion of fuel by all forms of transportation in Canada. The subsector has been divided into five distinct categories:

- Civil Aviation (Domestic Aviation);
- Road Transportation;
- Railways;
- Navigation (Domestic Marine); and
- Other Transportation (Off-Road and Pipelines).

#### 3.2.3.2 Methodological Issues

Fuel combustion emissions associated with the Transport subsector are calculated using various adaptations of Equation A2-1 in Annex 2. However, because of the many different types of

vehicles, activities, and fuels, the emission factors are numerous and complex. In order to cope with the complexity, transport emissions are calculated using Canada's Mobile Greenhouse Gas Emission Model (MGEM). This model incorporates a version of the IPCC-recommended methodology for vehicle modelling (IPCC/OECD/IEA 1997) and is used to calculate all transport emissions with the exception of those associated with pipelines (energy necessary to propel oil or natural gas).

### **Civil Aviation (Domestic Aviation) (CRF Category 1.A.3.a)**

This category includes all GHG emissions from domestic air transport (commercial, private, military, agricultural, etc.). Although the revised 1996 IPCC guidelines (IPCC/OECD/IEA, 1997) call for military air transportation emissions to be reported in the Other subsector (CRF Category 1.A.5), they have been included here. Emissions from transport fuels used at airports for ground transport and stationary combustion applications are reported under Other Transportation. Emissions arising from fuel sold to foreign airlines and fuel sold to domestic carriers but consumed during international flights are considered to be international bunkers and are reported separately under memo items (CRF Category 1.C.1.a).

The methodologies for Civil Aviation follow a modified IPCC Tier 1 sectoral approach. Emission estimates are performed within MGEM and are calculated based upon the reported quantities of aviation gasoline and turbo fuel consumed (IPCC/OECD/IEA 1997), as published in the RESD (Statistics Canada #57-003). Fuel consumption is reported separately for Canadian airlines, foreign airlines, public administration, and commercial and other institutional (refer to Annex 2 for a description of the methodology).

### **Road Transportation (CRF Category 1.A.3.b)**

The methodology used to evaluate road transportation GHG emissions follows a detailed IPCC Tier 3 method (except for Propane and Natural Gas Vehicles, for which a modified IPCC Tier 1 method is followed), as outlined in IPCC/OECD/IEA (1997). MGEM disaggregates vehicle data and calculates emissions of CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O from all mobile sources except pipelines (refer to Annex 2 for a description of the methodology).

### **Railways (CRF Category 1.A.3.c)**

The methodology used to evaluate railways is considered to be a modified IPCC Tier 1 (IPCC/OECD/IEA 1997) methodology. Emission estimates are performed within MGEM. Fuel consumption data from the RESD (Statistics Canada #57-003), reported under railways, are multiplied by fuel-specific emission factors (refer to Annex 2 for a description of the methodology).

### **Navigation (Domestic Marine) (CRF Category 1.A.3.d)**

This category includes all GHG emissions from domestic marine transport. Emissions arising from fuel sold to foreign marine are considered to be international bunkers and are reported separately under memo items (CRF Category 1.C.1.b).

The emission calculation methodology is considered to be a modified IPCC Tier 1 approach (IPCC/OECD/IEA 1997), and emission estimates are performed within MGEM. Fuel consumption data from the RESD (Statistics Canada #57-003), reported as domestic marine, are multiplied by fuel-specific emission factors (refer to Annex 2 for a description of the methodology).

### **Other Transportation (CRF Category 1.A.3.e)**

This subsector comprises vehicles that are not licensed to operate on roads or highways and the emissions from the combustion of fuel used to propel products in long-distance pipelines.

#### ***Off-Road Transport***

Non-road or off-road transport<sup>36</sup> (ground, non-rail vehicles) includes emissions from both gasoline and diesel fuel combustion. Vehicles in this category include farm tractors, logging skidders, tracked construction vehicles, and mobile mining vehicles.

Industry uses a considerable amount of diesel fuel in non-road vehicles. The mining (including coal, oil, and gas mining and extraction activities) and construction industries both operate significant numbers of heavy non-road vehicles and are the largest diesel fuel users in the group.

Off-road vehicles are handled by a modified IPCC Tier 1 approach (IPCC/OECD/IEA 1997). For these estimates, emissions are based on fuel-specific emission factors and total fuel consumed (refer to Annex 2 for a description of the methodology).

#### ***Pipeline Transport***

Pipelines<sup>37</sup> represent the only non-vehicular transport in this sector. They use fossil-fuelled combustion engines to power motive compressors that propel their contents. The fuel used is primarily natural gas in the case of natural gas pipelines, but some refined petroleum, such as diesel fuel, is also used. Oil pipelines tend to use electric motors to operate pumping equipment.

The methodology employed is considered an IPCC Tier 2 sectoral approach, with country-specific emission factors. Fuel consumption data from the RESD (Statistics Canada #57-003), reported as pipelines, are multiplied by fuel-specific emission factors (refer to Annex 2 for a description of the methodology).

#### ***3.2.3.3 Uncertainties and Time-Series Consistency***

The following individual sector explanations are based on the results reported in *Quantitative Assessment of Uncertainty in Canada's National GHG Inventory Estimates for 2001* (ICF Consulting 2004). Within each specific subsector described below, it is indicated if the method evaluated during the study has been modified; only in those cases will the uncertainty not be representative of the current process. For an overarching description of the uncertainty study, please refer to Annex 7 on Uncertainty.

### **Transport Subsector Fossil Fuel Combustion**

The Transport subsector comprises 1) the mobile sources of transport, including on-road and off-road vehicles, railways, civil aviation, and navigation; and 2) pipeline transport. The uncertainty in the 2001 estimates for CO<sub>2</sub> emissions from fossil fuel combustion in mobile sources was estimated at -4% to 0%, indicating that the inventory GHG values are likely overestimates.

---

36. Referred to as non-road or off-road vehicles. The terms “non-road” and “off-road” are used interchangeably.

37. Consisting of both oil and gas types.

Similar to the stationary fuel combustion sources, the uncertainty ranges of approximately a factor of 4 or more for the 2003 submission (2001 inventory year) for the CH<sub>4</sub> and N<sub>2</sub>O emissions from Transport subsector fossil fuel combustion were attributable to the large uncertainty ranges for several CH<sub>4</sub> and N<sub>2</sub>O emission factors.

The uncertainty associated with the total GHG emissions (all gases) from the mobile source category for the 2003 submission was estimated to be within the range of -3% to +19%, which reflected the predominance of CO<sub>2</sub> in the total GHG emissions from the mobile sources of transport and its relatively low uncertainty estimate.

### **CO<sub>2</sub> Emissions from Civil Aviation (Domestic Aviation)**

The uncertainty associated with the CO<sub>2</sub> emission estimates from Civil Aviation reported in ICF Consulting (2004) is no longer applicable. Since the study was completed, a new method to enhance resolution on the use of fuel purchased in Canada by Canadian airlines has been employed. This has affected the previous historic emissions reported as domestic and reduced them between 40% and 55% annually (from the 2003 submission). The study's reported uncertainty reflects the low uncertainty range associated with the CO<sub>2</sub> emission factor and the fuel consumption estimate for aviation turbo fuel, which accounted for 97% of the total CO<sub>2</sub> emissions from Civil Aviation in 2006. It has been suggested that the expert polled for his opinion on the uncertainty of the activity data (Apparent Consumption of Aviation Fuels) was misled by the configuration of the questions asked. This would have resulted in a lower-than-actual uncertainty estimate.

### **CO<sub>2</sub> Emissions from Road Transportation**

The uncertainty associated with CO<sub>2</sub> emissions from on-road vehicles was estimated to be within the range of -8% to -3% relative to the 2003 submission estimate for this source category. This implied that the 2003 submission value for this source category was likely an overestimate. The upward bias in the 2003 submission estimate values for this key source category was related to estimated uncertainties for 1) the amount of fuel consumed by motor gasoline and diesel on-road vehicles and 2) the CO<sub>2</sub> emission factors for motor gasoline. The 95% confidence interval uncertainty range for the CO<sub>2</sub> motor gasoline emission factor was estimated to be -3% to -1% by McCann (2000). For the 2008 submission, MGEM employed a higher disaggregation of activity data; this resulted in an increased confidence in the on-road portion of the model, prompting a modification of the fuel balance algorithm and thereby transferring fuel from the on-road to the off-road category. With this improvement, the uncertainties for both on-road and off-road vehicles should be lower than when they were evaluated for the 2003 submission.

### **CO<sub>2</sub> Emissions from Railways**

The uncertainty associated with CO<sub>2</sub> emissions from rail transport was estimated to be within the range of -5% to +3%. In terms of the contribution to the uncertainty in the inventory estimate of this key source category for the 2003 submission, it seemed that the input variables diesel consumption (with an uncertainty of ±3%) and CO<sub>2</sub> emission factor for diesel (with an uncertainty range of -4% to +2%) were equally responsible.

### **CO<sub>2</sub> Emissions from Other Transportation (Off-Road)**

The off-road transport category includes both off-road gasoline and off-road diesel consumption. The uncertainty associated with the off-road mobile transport sources was estimated to be within the range of +4% to +45%, indicating that the 2003 submission estimates likely underestimated

the CO<sub>2</sub> emissions from this source category. The CO<sub>2</sub> emissions from off-road diesel vehicles accounted for nearly 77% of the total CO<sub>2</sub> emissions from the off-road category in 2006. The main sources of uncertainty for this source category are the uncertainty associated with the fuel consumption estimates for off-road gasoline and off-road diesel. Consistent with the inventory estimation methodology for this source category, the off-road diesel fuel consumption is calculated from the on-road diesel fuel consumption residual, and the off-road gasoline consumption is calculated from the on-road gasoline consumption residual. The uncertainty developed for this source category is no longer applicable. Please see “CO<sub>2</sub> Emissions from Road Transportation” in this section (2.2.3.3) for a complete explanation.

### Summary

Generally, for the Transport subsector, the ICF Consulting (2004) study merely incorporated previous studies’ reported values for the estimated uncertainty surrounding the CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O emission factors (McCann 2000; SGA Energy Ltd. 2000). ICF Consulting (2004) included these reports’ values along with a limited expert elicitation addressing the uncertainty of the activity data contributing to the Transport subsector estimates within its Monte Carlo analysis.

Additionally, it should be noted that the overestimate of the on-road emissions (–8% to –3%) offsets the underestimate of off-road emissions (+4% to +45%) to achieve a composite uncertainty (–4% to 0%) better than either of the individual components.

Some of the weaker portions of the uncertainty surround the acquisition of expert opinions on non-fuel-quantity-type activity estimates (e.g. vehicle populations, kilometres travelled, motorcycle numbers). Although it was suggested that the vehicle population data supplied by an outside consultant to Environment Canada are 100% accurate, there are indications that the underlying data may be compiled incorrectly. This will introduce only marginal errors in a fuel-constrained model, but it has considerable impact on the attribution of that fuel to specific vehicle types.

#### 3.2.3.4 QA/QC and Verification

Tier 1 QC checks as elaborated in the framework for the QA/QC plan (see Annex 6) were performed on all key categories in Transport. No significant mathematical errors were found. The QC activities are documented and archived in paper and electronic form.

In addition, certain verification steps were performed during the model preparation stage. Since MGEM uses national fuel data defined by type and region combined with country-specific emission factors, primary scrutiny is applied to the vehicle population profile, as this dictates the fuel demand per vehicle category and, hence, emission rates and quantities. Recently, interdepartmental partnerships have been developed among Environment Canada, Transport Canada, and NRCan to facilitate the sharing of not only raw data but also derived information such as vehicle populations, fuel consumption ratios (FCRs), and vehicle kilometres travelled (VKTs). This broader perspective fosters a better understanding of actual vehicle use and subsequently should promote better modelling and emission estimating. With support from Transport Canada, Statistics Canada publishes the *Canadian Vehicle Survey* (CVS), a quarterly report that provides both vehicle population and VKTs in aggregated regional classes. It provides alternative interpretation of provincial registration files and can therefore corroborate the commercially available data sets mentioned above. Unfortunately, the resolution necessary for emission modelling is unavailable from the CVS, and therefore it cannot replace the annually purchased data sets.

### 3.2.3.5 *Recalculations*

Refer to Chapter 9 for a detailed discussion on sectoral recalculations.

### 3.2.3.6 *Planned Improvements*

The transportation model (MGEM) was upgraded in 2007–2008 and continuously evolves to take advantage of the power of the relational database to accommodate an increasing number of higher-resolution data sets being made available through partnerships and reporting.

Future improvements will concentrate on:

- developing a Tier 3a model to estimate aircraft emissions based on origin–destination data and aircraft-specific emission factors; the new aviation model will allow a more accurate disaggregation of emissions between civil aviation (domestic aviation) and aviation bunkers (international aviation);
- developing region- and time-specific fuel carbon characteristics; and
- acquiring historic biodiesel consumption data.

## 3.2.4 **Other Sectors (CRF Category 1.A.4)**

### 3.2.4.1 *Source Category Description*

The Other Sectors subsector consists of three categories: commercial/institutional, residential, and agriculture/forestry/fisheries. Emissions consist primarily of fuel combustion related to space and water heating. Emissions from the use of transportation fuels in these categories are allocated to Transport (Section 3.2.3).

Biomass<sup>38</sup> combustion is a significant source of emissions in the residential sector, and CH<sub>4</sub> and N<sub>2</sub>O emissions are included in the subsector estimates. However, CO<sub>2</sub> emissions from biomass combustion are reported separately in the CRF tables as memo items and are not included in Energy Sector totals. This method is consistent with the treatment of biomass in the Pulp, Paper, and Print subsector.

In 2006, the Other Sectors subsector contributed about 75.2 Mt (or 10%) of Canada's total GHG emissions, with an overall growth of about 5% since 1990. Within the Other Sectors category, residential emissions contributed about 39.8 Mt (or 53%), followed by a 33.4 Mt (or 44%) contribution from the Commercial/Institutional category, which also includes emissions from the public administration sector (i.e. federal, provincial, and municipal establishments). Since 1990, GHG emissions have grown by about 30% in the Commercial and Institutional sector, while Residential GHG emissions have decreased by 3.7 Mt (or 8.5%). Refer to Table 3-5 for additional details. Additional trend discussion for the Other Sectors subsector is presented in the Emission Trends chapter (Chapter 2).

---

38. Typically firewood.

**Table 3-5: Other Sectors GHG Contribution**

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)		
	1990	2005	2006
<b>Other Sectors TOTAL (1.A.4)</b>	<b>71 600</b>	<b>80 500</b>	<b>75 200</b>
<b>Commercial/Institutional</b>	<b>25 700</b>	<b>36 700</b>	<b>33 400</b>
<i>Commercial and Other Institutional</i>	23 700	34 600	31 600
<i>Public Administration</i>	1 980	2 050	1 820
<b>Residential</b>	<b>43 500</b>	<b>41 800</b>	<b>39 800</b>
<b>Agriculture/Forestry/Fisheries</b>	<b>2 400</b>	<b>2 000</b>	<b>1 900</b>
<i>Forestry</i>	50	120	100
<i>Agriculture</i>	2 300	1 900	1 800

Note: Totals may not add up due to rounding.

### 3.2.4.2 Methodological Issues

Emissions from these source categories are calculated consistently according to the methodology described in Annex 2, which is considered to be an IPCC Tier 2 approach, with country-specific emission factors. Methodological issues specific to each category are described below. Emissions from the combustion of transportation fuels (e.g. diesel and gasoline) are all allocated to the Transport subsector.

#### Commercial/Institutional (CRF Category 1.A.4.a)

Emissions are based on fuel-use data reported as commercial and public administration in the RESD (Statistics Canada #57-003).

#### Residential (CRF Category 1.A.4.b)

Emissions are based on fuel-use data reported as residential in the RESD (Statistics Canada #57-003). The methodology for biomass combustion from residential firewood is detailed in the CO<sub>2</sub> Emissions from Biomass section (Section 3.4.2); although CO<sub>2</sub> emissions are not accounted for in the national residential GHG total, the CH<sub>4</sub> and N<sub>2</sub>O emissions are reported here.

#### Agriculture/Forestry/Fisheries (CRF Category 1.A.4.c)

This source category includes emissions from stationary fuel combustion in the agricultural and forestry industries. However, emission estimates are included for the agriculture and forestry portion only. Fishery emissions are reported typically under either the Transportation or Other Manufacturing (i.e. food processing) category. Mobile emissions associated with this category were not disaggregated and are included as off-road or marine emissions reported under Transport (Section 3.2.3). Emissions from on-site machinery operation and heating are based on fuel-use data reported as agriculture and forestry in the RESD (Statistics Canada #57-003).

### 3.2.4.3 Uncertainties and Time-Series Consistency

The estimated uncertainty for the Other Sectors subsector ranges from –4% to +41% for all gases and from –3% to +2% for CO<sub>2</sub>. Refer to the Uncertainty annex (Annex 7) for a detailed discussion on the ICF Consulting (2004) uncertainty study and additional uncertainty values for the Other Sectors subsector.



The underlying fuel quantities and CO<sub>2</sub> emission factors have low uncertainties, since they are predominantly commercial fuels, which have consistent properties and accurate tracking. Although the non-CO<sub>2</sub> emissions from biomass combustion contributed only 5% to the total Residential category, its CH<sub>4</sub> (–90% to +1500%) and N<sub>2</sub>O (–65% to +1000%) uncertainties are high due to the uncertainty associated with their emission factors. As stated in the Energy Industries subsector, additional expert elicitation is required to improve the CH<sub>4</sub> and N<sub>2</sub>O uncertainty estimates for some of the emission factor uncertainty ranges and probability density functions developed by the ICF Consulting (2004) study, since insufficient time was available to have these assumptions reviewed by industry experts.

These estimates are consistent over the time series.

#### *3.2.4.4 QA/QC and Verification*

The Other Sectors subsector was identified as a key category for both CH<sub>4</sub> and CO<sub>2</sub> emissions and underwent Tier 1 QC checks in a manner consistent with IPCC Good Practice Guidance (IPCC 2000). No mathematical or referencing errors were observed during the QC checks, and only minor labelling issues were revealed. Activity data errors involving historical values were identified during the review and corrected.

The data, methodologies, and changes related to the QC activities are documented and archived in both paper and electronic form.

#### *3.2.4.5 Recalculations*

Refer to Chapter 9 for a detailed discussion on sectoral recalculations.

#### *3.2.4.6 Planned Improvements*

Future improvement plans for the Other Sectors subsector include a review of the residential biomass model and a review of industrial fuelwood characteristics in order to substantiate existing assumptions of moisture and energy content.

### **3.2.5 Other: Energy—Fuel Combustion Activities (CRF Category 1.A.5)**

The UNFCCC reporting guidelines assign military fuel combustion to this subsector. However, emissions related to military vehicles have been included in the Transport subsector, whereas stationary military fuel use has been included under the Commercial/Institutional category (Section 3.2.4) due to fuel data allocation in the RESD (Statistics Canada #57-003). This is a small source of emissions.

### **3.3 Fugitive Emissions (CRF Category 1.B)**

Fugitive emissions from fossil fuels are intentional or unintentional releases of GHGs from the production, processing, transmission, storage, and delivery of fossil fuels.

Released gas that is combusted before disposal (e.g. flaring of natural gases at oil and gas production facilities) is considered a fugitive emission. However, if the heat generated during combustion is captured for use (e.g. heating) or sale, then the related emissions are considered fuel combustion emissions.

The two categories considered in the inventory are fugitive releases associated with solid fuels (coal mining and handling) and releases from activities related to the oil and natural gas industry.

In 2006, the Fugitives category accounted for about 66.8 Mt (or 8.8%) of Canada's total GHG emissions, with about a 57% growth in emissions since 1990. Between 1990 and 2006, fugitive emissions from oil and natural gas increased 62% to 66.2 Mt, and those from coal decreased by about 1 Mt from 2 Mt in 1990. The oil and gas production, processing, transmission, and distribution activities contributed 99% of the fugitive emissions. Refer to Table 3-6 for more detail.

**Table 3-6: Fugitive GHG Contribution**

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)		
	1990	2005	2006
<b>Fugitive Emissions from Fuels (1.B)</b>	<b>42 700</b>	<b>65 500</b>	<b>66 800</b>
<b>Solid Fuels—Coal Mining (1.B.1)</b>	<b>2 000</b>	<b>1 000</b>	<b>1 000</b>
<b>Oil and Natural Gas (1.B.2)</b>	<b>40 700</b>	<b>64 800</b>	<b>66 200</b>
<i>a. Oil<sup>1</sup></i>	4 200	5 600	5 700
<i>b. Natural Gas<sup>1</sup></i>	12 900	20 800	21 300
<i>c. Venting and Flaring<sup>2</sup></i>	23 700	38 300	39 100
<i>Venting</i>	19 300	32 800	33 100
<i>Flaring</i>	4 400	5 500	6 000

Notes:

1. All other fugitives except venting and flaring.

2. Both oil and gas activities.

Totals may not add up due to rounding.

### 3.3.1 Solid Fuels (CRF Category 1.B.1)

#### 3.3.1.1 Source Category Description

Coal in its natural state contains varying amounts of CH<sub>4</sub>. In coal deposits, CH<sub>4</sub> is either trapped under pressure in porous void spaces within the coal formation or adsorbed to the coal. The pressure and amount of CH<sub>4</sub> in the deposit vary depending on the grade, the depth, and the surrounding geology of the coal seam. During coal mining, post-mining activities, and coal-handling activities, the natural geological formations are disturbed, and pathways are created that release the pressurized CH<sub>4</sub> to the atmosphere. As the pressure on the coal is lowered, the adsorbed CH<sub>4</sub> is released until the CH<sub>4</sub> in the coal has reached equilibrium with the surrounding atmospheric conditions.

Mining activity emission sources are from the exposed coal surfaces, coal rubble, and the venting of CH<sub>4</sub> from within the deposit. Post-mining activities such as preparation, transportation, storage, or final processing prior to combustion also release CH<sub>4</sub>.

Fugitive emissions from solid fuel transformation (e.g. fugitive losses from the opening of metallurgical coking oven doors) are not estimated owing to a lack of data. Other sources of solid fuel transformation emissions are not known. These sources are thought to be insignificant.

#### 3.3.1.2 Methodological Issues

In the early 1990s, King (1994) developed an inventory of fugitive emissions from coal mining operations, which is the basis for the coal mining fugitive emissions estimated. The emission

factors currently used were calculated by dividing the emission estimates in the above inventory by the appropriate coal production data.

The method used by King (1994) to estimate emission rates from coal mining (emission factors in Annex 12) was based on a modified procedure from the Coal Industry Advisory Board. It consists of a hybrid of IPCC Tier 3– and Tier 2–type methodologies, depending on the availability of mine-specific data. Underground mining activity emissions and surface mining activity emissions were separated, and both include post-mining activity emissions. A detailed description of the methodology is located in Annex 3: Additional Methodologies.

### *3.3.1.3 Uncertainties and Time-Series Consistency*

The CH<sub>4</sub> uncertainty estimate for fugitive emissions from coal mining is estimated to be in the range of –30% to +130% (ICF, 2004). The production data are known to a high degree of certainty ( $\pm 2\%$ ). On the other hand, a very significant uncertainty (–50% to +200%) was estimated for the emission factors. It is our view that further expert elicitation is required to validate assumptions made by the study in the development of the probability density functions and uncertainty ranges of emission factors and activity data from surface and underground mining activities. IPCC default uncertainty values were assumed for Canada's country-specific emission factors, and these will need to be reviewed. The use of IPCC default values will not result in a representative uncertainty estimate when country-specific information is used. Refer to the Uncertainty annex (Annex 7) for more details on the study.

### *3.3.1.4 QA/QC and Verification*

The CH<sub>4</sub> emissions from coal mining were identified as a key category and underwent Tier 1 QC checks in a manner consistent with IPCC Good Practice Guidance (IPCC 2000). Checks included a review of activity data, time-series consistency, emission factors, reference material, conversion factors, and units labelling, as well as sample emission calculations. No mathematical errors were found during the QC checks, although some issues with labelling and references were revealed. The data and methods related to the QC activities are documented and archived in paper and electronic form.

### *3.3.1.5 Recalculations*

Refer to Chapter 9 for specific recalculation explanations.

### *3.3.1.6 Planned Improvements*

No improvements are planned for this category.

## **3.3.2 Oil and Natural Gas (CRF Category 1.B.2)**

### *3.3.2.1 Source Category Description*

The Oil and Natural Gas subsector of fugitive emissions includes emissions from oil and gas production, processing, oil sands mining, bitumen extraction, heavy oil/bitumen upgrading, natural gas transmission, and natural gas distribution. Fuel combustion emissions from facilities in the oil and gas industry (when used for energy) are included under the Petroleum Refining and the Manufacture of Solid Fuels and Other Energy Industries categories (Section 3.2.1).

The Oil and Natural Gas source category has three main components: Conventional Oil and Gas Production, Unconventional Oil Production, and Natural Gas Distribution.

### **Conventional Oil and Gas Production**

Conventional oil and gas production includes all fugitive emissions from exploration, production, processing, and transmission of oil and natural gas. Emissions may be the result of designed equipment leakage (bleed valves, fuel gas-operated pneumatic equipment), imperfect seals on equipment (flanges and valves), use of natural gas to produce hydrogen, accidents, spills, and deliberate vents.

The sources of emissions from the conventional oil and gas industry have been divided into major categories:

*Oil and Gas Well Drilling and Associated Testing:* Oil and gas well drilling is a minor emission source. The emissions are from drill stem tests, release of entrained gas in drilling fluids, and volatilization of invert drilling fluids.

*Oil and Gas Well Servicing and Associated Testing:* Well servicing is also a minor emission source. The emissions are mainly from venting, flaring, and fuel combustion, which are included in the Stationary Combustion Sources sector. Venting results from conventional service work, such as the release of solution gas from mud tanks and blow down treatment for natural gas wells. It is assumed that there is no significant potential for fugitive emissions from leaking equipment. Fugitive emissions from absolute open flow tests are assumed to be negligible.

*Natural Gas Production:* Natural gas is produced exclusively at gas wells or in combination with conventional oil, heavy oil, and crude bitumen production wells with gas conservation schemes. The emission sources associated with natural gas production are wells, gathering systems, field facilities, and gas batteries. The majority of emissions result from equipment leaks, such as leaks from seals; however, venting from the use of fuel gas to operate pneumatic equipment and line-cleaning operations are also significant sources.

*Light/Medium Oil Production:* This type of production is defined by wells producing light- or medium-density crude oils (i.e. density  $<900 \text{ kg/m}^3$ ). The emissions are from the wells, flow lines, and batteries (single, satellite, and central). The largest sources of emissions are the venting of solution gas and evaporative losses from storage facilities.

*Heavy Oil Production:* Heavy oil is defined as having a density above  $900 \text{ kg/m}^3$ . Production of this viscous liquid requires a special infrastructure. There are generally two types of heavy oil production systems: primary and thermal. The emission sources from both types are wells, flow lines, batteries (single and satellite), and cleaning plants. The largest source is venting of casing and solution gas.

*Crude Bitumen Production:* Crude bitumen is a highly viscous, dense liquid that cannot be removed from a well using primary production means. Enhanced heavy oil recovery is required to recover the hydrocarbons from the formation. The sources of emissions are wells, flow lines, satellite batteries, and cleaning plants. The main source of emissions is the venting of casing gas.

*Gas Processing:* Natural gas is processed before entering transmission pipelines to remove water vapour, contaminants, and condensable hydrocarbons. There are four different types of plants: sweet plants, sour plants that flare waste gas, sour plants that extract elemental sulphur, and

straddle plants. Straddle plants are located on transmission lines and recover residual hydrocarbons. They have a similar structure and function and so are considered in conjunction with gas processing. The largest source of emissions is equipment leaks.

*Natural Gas Transmission:* Virtually all of the natural gas produced in Canada is transported from the processing plants to the gate of the local distribution systems by pipelines. The volumes transported by truck are insignificant and assumed to be negligible. The gas transmission system emission sources are from equipment leaks and process vents. Process vents include activities such as compressor start-up and purging of lines during maintenance. The largest source of emissions is equipment leaks.

*Liquid Product Transfer:* The transport of liquid products from field processing facilities to refineries or distributors produces emissions from the loading and unloading of tankers, storage losses, equipment leaks, and process vents. The transport systems included are liquefied petroleum gas (LPG) (by both surface transport and high-vapour-pressure pipeline systems), pentane-plus systems (by both surface transport and low-vapour-pressure pipeline systems), and crude oil pipeline systems.

*Accidents and Equipment Failures:* Fugitive emissions can result from human error or extraordinary equipment failures in all segments of the conventional UOG industry. The major sources are emissions from pipeline ruptures, well blowouts, and spills. Emissions from the disposal and land treatment of spills are not included owing to insufficient data.

*Surface Casing Vent Blows and Gas Migration:* At some wells, fluids will flow into the surface casing from the surrounding formation. Depending on the well, the fluids will be collected, sealed in the casing, flared, or vented. The vented emissions are estimated in this section. At some wells, particularly in the Lloydminster (Alberta) region, gas may migrate outside of the well, either from a leak in the production string or from a gas-bearing zone that was penetrated but not produced. The emissions from the gas flowing to the surface through the surrounding strata have been estimated.

*Refining:* There are three main sources of fugitive emissions from refineries: process, fugitive, and flare. Process emissions result from the production of hydrogen as well as from process vents. Fugitive emissions are a result of equipment leaks, wastewater treatment, cooling towers, storage tanks, and loading operations. Emissions from flaring are a result of the combustion of hazardous waste gas streams (such as acid gas) and fuel gas (or natural gas). GHG emissions from the combustion of fuel for energy purposes are reported under the Energy Industries.

## **Unconventional Oil Production**

This category includes emissions from oil sand open pit mining operations, *in situ* bitumen extraction, and heavy oil/bitumen upgrading to produce bitumen, synthetic crude oil, and other derived products for sale. Fugitive emissions are primarily from hydrogen production, flue gas desulfurization (FGD), venting and flaring activities, storage and handling losses, fugitive equipment leaks, and CH<sub>4</sub> from the open mine surfaces and from methanogenic bacteria in the mine tailings settling ponds.

Emissions related to methanogenic bacteria in the tailings ponds continue to be studied by the operators. It is believed that with the planned implementation of new bitumen recovery techniques, the lighter hydrocarbons in the waste streams of the current processes will be reduced, and the emissions will be correspondingly lowered.

## Natural Gas Distribution

The natural gas distribution system receives high-pressure gas from the gate of the transmission system and distributes this through local pipelines to the end user. The major emission source is station vents during maintenance, which account for about half the emissions.

### 3.3.2.2 Methodological Issues

## Conventional Oil and Gas Production

### *Upstream Oil and Gas Production*

Fugitive emission estimates from the conventional upstream oil and gas (UOG) industry are based on the Canadian Association of Petroleum Producers' (CAPP) study of the industry: *A National Inventory of Greenhouse Gas (GHG), Criteria Air Contaminant (CAC) and Hydrogen Sulphide (H<sub>2</sub>S) Emissions by the Upstream Oil and Gas Industry* (CAPP 2005a). The complete methodology is presented in volumes 1, 3, and 5 of the report.

For the year 2000, emissions were identified at a facility level for over 5000 facilities. These estimates were then extrapolated to approximately 370 000 primary sources from flaring, venting, equipment leaks, formation CO<sub>2</sub> venting, storage losses, loading/unloading losses, and accidental releases. Natural gas systems, gas production, and gas processing are considered to be part of the upstream petroleum industry, and the emissions for these sections were included.

A multitude of data were collected and used in the study. These included activity data from the facilities, such as process and equipment data. Emission factors were obtained from a variety of sources: published reports, such as EPA (1995a, 1995b), equipment manufacturers' data, observed industry values, measured vent rates, simulation programs, and other industry studies. A list of data and emission factors can be found in Volume 5 of the UOG report (CAPP 2005a).

The 1990–1999 and 2001–2005 fugitive emissions were extrapolated using annual industry activity data from conventional UOG production and the 2000 emission results. The 1990–1999 estimates and method are presented in Volume 1 of the UOG report. A consistent extrapolation model for 2001 and onward was developed by Clearstone Engineering Ltd. for use in estimating annual national- and provincial-level GHG estimates. The emissions for both time spans were extrapolated using emission data from the year 2000 together with the annual production and activity data for the relevant years. A detailed description of the methodology can be found in the UOG report (CAPP 2005a) and the extrapolation report (CAPP 2005b).

### *Natural Gas Transmission*

Fugitive emissions from natural gas transmission for 1990–1996 are from the conventional UOG industry study, *CH<sub>4</sub> and VOC Emissions from the Canadian Upstream Oil and Gas Industry* (CAPP 1999). This study is considered to follow a rigorous IPCC Tier 3 approach in estimating GHG emissions. Fugitive emission estimates for 1997 onward were extrapolated based on length of natural gas pipeline and leakage rates, as developed based on the results from the original study. The extrapolation methodology can be found in Annex 3.

### *Downstream Oil and Gas Production*

Fugitive emissions from refineries are based on the Canadian Petroleum Products Institute (CPPI) study, *Economic and Environmental Impacts of Removing Sulphur from Canadian Gasoline and*

*Distillate Production*, as prepared by Purvin & Gertz Inc. in association with Levelton Consultants Ltd. (CPPI 2004). Refer to the CPPI report for full details on the study. Historical fuel, energy, and emission data were gathered from the Canadian Industrial Energy End-Use Data Analysis Centre (CIEEDAC) and directly from refineries for the years 1990 and 1994–2002. Fugitive, venting, and flaring emissions for the years 1991–1993 were interpolated, whereas the emissions for 2003–2005 were extrapolated using the respective data in the report and the petroleum refinery energy consumption data from the RESD as published by Statistics Canada (#57-003). A detailed description of the methodology used to estimate emissions from 1991 to 1993 and from 2003 onward can be found in Annex 3 of this report.

## Unconventional Oil Production

Sources of GHG emissions from unconventional oil production include oil sands mining, heavy oil/bitumen extraction and heavy oil upgraders, and integrated cogeneration facilities. Fugitive emissions for the oil sands mining and heavy oil upgrading industries are from the bitumen study, *An Inventory of GHGs, CACs, and H<sub>2</sub>S Emissions by the Canadian Bitumen Industry: 1990 to 2003*, prepared for CAPP by Clearstone Engineering Ltd. (CAPP 2006). The bitumen study is a compilation of GHG emissions from the following companies: Suncor Energy Inc., Syncrude Canada Ltd., Shell Canada Ltd., Husky Energy Inc. Methods used to estimate fugitive emissions from *in situ* oil sands extraction to produce heavy oil/bitumen for sale and for upgrading to synthetic oil and other products are from CAPP's UOG study (CAPP 2005a).

Facilities' inventories were reviewed by Clearstone Engineering Ltd. to ensure that each facility's estimates were complete, accurate, and transparent. Issues were corrected by facilities, and the final bitumen inventory was compiled by Clearstone Engineering Ltd. In general, the IPCC Tier 3 approach was used by each operator to develop a bottom-up approach in estimating GHG emissions. Where gaps existed, estimates were prepared by Clearstone Engineering Ltd. and provided to each operator for review. QA/QC and an uncertainty analysis following the IPCC good practice guidance (IPCC 2000) was also included in the study.

An extrapolation model was developed to allow annual updating of fugitive emissions from oil sands mining and heavy oil upgrading activities from 2004 onwards. The extrapolation model was developed based on relevant parameters and results from the original bitumen study along with annual activity data. The activity data as used by the model are published in the following publications: *Mineable Alberta Oil Sands Annual Statistics ST43* from the Energy Resources Conservation Board (previously known as the Alberta Energy and Utilities Board) and the National Energy Board's (1998–2008) online statistics: *Estimated Production of Canadian Crude Oil and Equivalent*. These data are updated annually for use in estimating GHG emissions. Refer to both the bitumen study (CAPP 2006) and the bitumen extrapolation model (Environment Canada 2007) for a detailed description of the methodology.

## Natural Gas Distribution

The emission estimates were derived from a study prepared for the Canadian Gas Association (CGA) by Radian International (Canadian Gas Association 1997). The study estimated the emissions from the Canadian gas pipeline industry for the years 1990 and 1995.

Emissions in the study were calculated based upon emission factors from the U.S. EPA, other published sources, and engineering estimates.

The activity data in the study were obtained from published sources and from specialized surveys of gas distribution system companies. The surveys obtained information on schedules of equipment, operation parameters of equipment, pipeline lengths used in the Canadian distribution system, etc.

General emission factors were developed for the distribution system based on the study data (Canadian Gas Association 1997) and gas distribution pipeline distances published by Statistics Canada (#57-205).

The original study method is a rigorous IPCC Tier 3 approach.

### 3.3.2.3 *Uncertainties and Time-Series Consistency*

#### **Conventional Oil and Gas Production**

##### ***Upstream Oil and Gas Production***

The UOG fugitive emissions for 2000 are taken directly from CAPP's UOG study (CAPP 2005a). The emissions from 1990 to 1999 and from 2001 to 2006 have been extrapolated using the 2000 data, along with other factors discussed above. The uncertainty for the overall 2000 emissions is  $\pm 1.5\%$ . The uncertainties for the 2000 emissions for the oil and natural gas industries are listed in Table 3-7 and Table 3-8, respectively. The detailed uncertainties for each gas can be found in the UOG report (CAPP 2005a).

**Table 3-7: Uncertainty in Oil Production Industry Fugitive Emissions**

GHG Source Category	Uncertainty (%)		
	Oil Exploration	Oil Production	Oil Transportation
Flaring	$\pm 4.2$	$\pm 2.3$	$\pm 24.0$
Fugitive	-8.9 to +8.3	$\pm 7.4$	-20.9 to +21.0
Venting	-38.4 to +30.4	-3.7 to +3.4	—
<b>Total</b>	<b>-2.3 to +2.1</b>	<b><math>\pm 3.1</math></b>	<b>-16.7 to +16.8</b>

**Table 3-8: Uncertainty in Natural Gas Production Industry Fugitive Emissions**

GHG Source Category	Uncertainty (%)
	Gas Production/Processing
Flaring	-2.6 to +2.2
Fugitive	-0.6 to +1.1
Other	$\pm 1.7$
Venting	-4.0 to +3.5
<b>Total</b>	<b><math>\pm 0.7</math></b>

Source: CAPP (2005b).

The uncertainties were determined using the Tier 1 uncertainty approach presented in the IPCC Good Practice Guidance (IPCC 2000). According to IPCC (2000), there are three sources of uncertainties: definitions, natural variability of the process that produces the emissions, and the assessment of the process or quantity. Only the last two sources of uncertainty were considered in the analysis: it was assumed that the uncertainties from the definitions were negligible, as they were adequately controlled through QA/QC procedures. The uncertainty in the extrapolated emissions would be greater than the uncertainty of the 2000 UOG emission estimates.



### ***Downstream Oil and Gas Production***

The emission data used in the inventory for fugitive emissions from refineries for 1990 and for 1994–2002 are directly from the CPPI (2004) study. The data for 1991–1993 and 2003–2006 are based on an extrapolation of the emissions from that study. The uncertainty for the extrapolated data is greater due to the available level of disaggregation for the activity. Tier 1 and Tier 2 uncertainty analyses were performed, for comparison purposes, of the emission factors and activity data, for an overall CO<sub>2</sub> uncertainty in the 2002 data (CPPI 2004).

The results of these analyses are as follows: For the Tier 1 analysis, the overall uncertainty was  $\pm 8.3\%$ . The Tier 2 analysis determined that the overall uncertainty was  $\pm 14\%$ . The difference between the Tier 1 and Tier 2 uncertainties may be due to the high level of variability in some of the emission factors. The uncertainty results can be found in Table 3-9.

**Table 3-9: Uncertainty in Oil Refining Fugitive Emissions**

	Uncertainty (%)			
	Overall	Excluding Refinery Fuel Gas	Excluding Flare Gas	Excluding Refinery Fuel and Flare Gas
Tier 1	$\pm 8.3$	$\pm 4.3$	$\pm 8.3$	$\pm 8.3$
Tier 2	$\pm 14$	$\pm 5$	$\pm 14$	$\pm 14$

### **Unconventional Oil Production**

Only facility-level uncertainty estimates are currently available. Clearstone Engineering Ltd. conducted an IPCC Good Practice Guidance Tier 1 uncertainty assessment for each facility and full details of the assessment can be found in the bitumen study (CAPP, 2006) and the bitumen extrapolation model (Environment Canada 2007). Development of an overall uncertainty range for this industry will be part of the uncertainty analysis improvement plan.

#### ***3.3.2.4 QA/QC and Verification***

To ensure that the results were correct in the UOG study (CAPP 2005a), Clearstone Engineering Ltd. performed the following QA/QC procedures. First, all results were reviewed internally by senior personnel to ensure that there were no errors, omissions, or double-counting. The report was also reviewed by individual companies for comment. A second level of review was performed by the project steering committee and nominated experts. Furthermore, where possible, results were compared with previous baseline data and other corporate, industrial, and national inventories. Any anomalies were verified through examination of activity levels, changes in regulations, and voluntary industry initiatives.

Tier 1 QC checks consistent with IPCC Good Practice Guidance (IPCC 2000) were performed on the CO<sub>2</sub> and CH<sub>4</sub> estimates for the following key subcategories:

- Oil and Natural Gas Industries; and
- Oil and Natural Gas Venting and Flaring.

No significant mathematical errors were found during the QC checks; however, some labelling and referencing problems were identified. Small changes to the spreadsheet model to correct these issues will assist the future production of accurate and error-free inventories. The data, methodologies, and changes related to the QC activities are documented and archived in both paper and electronic form.

#### 3.3.2.5 *Recalculations*

Refer to Chapter 9 for specific recalculation explanations.

#### 3.3.2.6 *Planned Improvements*

Environment Canada plans to conduct a review and an assessment of improvements to the fugitive model and methodology for the petroleum refining industry and pipeline transmission sources.

### 3.4 *Memo Items (CRF Category 1.C)*

#### 3.4.1 **International Bunker Fuels (CRF Category 1.C1)**

According to the revised 1996 IPCC guidelines (IPCC/OECD/IEA 1997), emissions resulting from fuels sold for international marine and aviation transportation should not be included in national inventory totals, but should be reported separately as emissions from “bunkers” or “international bunkers.” Historically, in the Canadian inventory, any fuel reported by Statistics Canada as having been sold to foreign-registered marine or aviation carriers was excluded from national inventory emission totals.

However, it has not been clear whether all of the fuel sold to foreign-registered carriers in Canada is used for international transport. More importantly, it has become apparent that not all of the fuels sold to domestically registered carriers are consumed within the country. The UNFCCC and the IPCC are currently developing clearer guidelines for bunkers, and modified statistical procedures may be required to track bunker fuels more accurately.

##### 3.4.1.1 *Aviation (CRF Category 1.C1.A)*

Emissions (Table 3-10) have been calculated using the same methods listed in the section Civil Aviation (Domestic Aviation) (see Section 3.2.3.2). Fuel-use data are reported as foreign airlines in the RESD (Statistics Canada, #57-003). As mentioned previously, a method developed to estimate the portion of fuel sold to domestic airlines and used for international flights was adopted to allow a further disaggregation of the fuel sold to domestic carriers. This additional quantity augments that sold directly to foreign airlines, and the sum represents the total fuel allocated to international aviation.

The adopted method uses data that report total tonne-kilometres flown by all Canadian airlines globally and stratifies the tonne-kilometres as either international or domestic. This was chosen as a proxy of fuel consumption owing to its acceptable correlation (high  $R^2$  coefficient: 93.5%) when both the fuel consumption and tonne-kilometres are known. An assumption that 69% of the international tonne-kilometres are flown using domestically purchased fuel achieves maximum corroboration with both SAGE and AERO2K, flight path models operated by the United States and the United Kingdom, respectively.

**Table 3-10: GHG Emissions from Domestic and International Aviation, 1990–2006**

	GHG Emissions (Mt CO <sub>2</sub> eq)																
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Aviation Bunkers (International)	7.1	6.4	6.9	6.6	7.1	7.6	8.9	9.1	9.4	10.0	10.2	9.1	9.2	8.5	9.5	9.5	9.4
Civil Aviation (Domestic)	6.4	5.6	5.5	5.2	5.4	5.9	6.2	6.3	6.4	6.6	6.5	6.1	6.7	7.2	7.8	8.6	8.4
<b>Total</b>	<b>13.4</b>	<b>12.0</b>	<b>12.4</b>	<b>11.9</b>	<b>12.5</b>	<b>13.4</b>	<b>15.0</b>	<b>15.4</b>	<b>15.8</b>	<b>16.6</b>	<b>16.7</b>	<b>15.3</b>	<b>15.9</b>	<b>15.7</b>	<b>17.4</b>	<b>18.1</b>	<b>17.8</b>

Note: Totals may not add up due to rounding.

### 3.4.1.2 Marine (CRF Category 1.C.1.B)

Emissions (Table 3-11) have been calculated using the same methods listed in the Navigation (Domestic Marine) section (see Section 3.2.3.2). Fuel-use data are reported as foreign marine in the RESD (Statistics Canada #57-003).

**Table 3-11: GHG Emissions from Domestic and International Navigation, 1990–2006**

	GHG Emissions (Mt CO <sub>2</sub> eq)																
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Marine Bunkers (International)	3.1	3.2	3.3	2.9	3.3	3.4	3.2	3.1	3.9	3.5	3.6	3.8	2.9	1.7	2.0	2.0	1.8
Navigation (Domestic)	5.0	5.2	5.1	4.5	4.7	4.4	4.5	4.5	5.1	5.0	5.1	5.5	5.5	6.1	6.6	6.4	5.8
<b>Total</b>	<b>8.2</b>	<b>8.5</b>	<b>8.4</b>	<b>7.4</b>	<b>8.0</b>	<b>7.8</b>	<b>7.7</b>	<b>7.7</b>	<b>9.0</b>	<b>8.5</b>	<b>8.7</b>	<b>9.3</b>	<b>8.4</b>	<b>7.8</b>	<b>8.7</b>	<b>8.4</b>	<b>7.6</b>

Note: Totals may not add up due to rounding.

## 3.4.2 CO<sub>2</sub> Emissions from Biomass

As per the UNFCCC reporting guidelines, CO<sub>2</sub> emissions from the combustion of biomass used to produce energy are not included in the Energy Sector totals but are reported separately as memo items. They are accounted for in the LULUCF Sector and are recorded as a loss of biomass (forest) stocks. CH<sub>4</sub> and N<sub>2</sub>O emissions from the combustion of biomass fuels for energy are reported in the fuel combustion section in the appropriate categories.

Biomass emissions have been grouped into three main sources: residential firewood, industrial wood wastes, and fuel ethanol used in transportation.

### 3.4.2.1 Residential Firewood

Firewood is used as a primary or supplementary heating source for many Canadian homes. Combustion of firewood results in CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O emissions.

The calculation of GHG emissions from the combustion of residential firewood is based on estimated fuel use and technology-specific emission factors. Fuel-use data are based on the criteria air contaminant (CAC) inventory (Environment Canada 1999). Residential fuel-use data from Statistics Canada and NRCAN were not used, since they appear to greatly underestimate firewood consumption (as a significant portion of firewood consumed in Canada is not from commercial sources).

Firewood consumption data were collected through a survey of residential wood use for the year 1995 (Canadian Facts 1997). These data were collected by province and grouped into five major appliance-type categories:

1. Conventional stoves
  - non- airtight
  - airtight, non-advanced technology
  - masonry heaters
2. Stove/fireplace inserts with advanced technology or catalyst control
  - advanced-technology fireplaces
  - advanced-technology stoves
  - catalytic fireplaces
  - catalytic stoves
3. Conventional fireplaces
  - without glass doors
  - with non- airtight glass doors
  - with airtight glass doors
4. Furnaces
  - wood-burning fireplaces
5. Other equipment
  - other wood-burning equipment

The firewood consumption data for the other years were extrapolated based on the number of houses in each province using wood as a principal or supplementary heat source (from Statistics Canada 1995) in relation to 1995. The emission factors for CO<sub>2</sub> are from an Environment Canada study (ORTECH Corporation 1994). The N<sub>2</sub>O and CH<sub>4</sub> emission factors for different wood-burning appliances are from the U.S. Environmental Protection Agency's *AP 42, Supplement B* (EPA 1996). These emissions are included in the fuel combustion sector of the inventory.

GHG emissions were calculated by multiplying the amount of wood burned in each appliance by the emission factors.

#### 3.4.2.2 Industrial Wood Wastes

A limited number of data for industrial firewood and spent pulping liquor are available in the RESD (Statistics Canada #57-003). The Statistics Canada data for 1990 and 1991 were combined for the Atlantic provinces, as were the data for the Prairie provinces. Individual provincial data were delineated by employing a data comparison with the 1992 RESD data. For 1992, the data for Newfoundland and Nova Scotia were also combined, and there were no comparable data to allow separation of these provinces. Emissions are listed under Nova Scotia.

Industrial firewood CO<sub>2</sub> and CH<sub>4</sub> emission factors are those assigned by the U.S. EPA to wood fuel/wood waste (EPA 1996). For CH<sub>4</sub>, emission factors were given for three different types of boilers; the emission factor used in the Canadian inventory is an average of the three.

Industrial firewood N<sub>2</sub>O emission factors are those assigned to wood fuel and to wood waste (Rosland and Steen 1990; Radke et al. 1991) (see Annex 12).

The emission factor for CO<sub>2</sub> from spent pulping liquor combustion was developed based on two assumptions:

1. The carbon content of spent pulping liquor is 41% by weight.
2. There is a 95% conversion of the carbon to CO<sub>2</sub>.

The emission factor (EF) for CO<sub>2</sub> is therefore calculated as follows (Jaques 1992):

$$\begin{aligned}\text{EF} &= 0.41 \times 0.95 \times (44 \text{ g/mol} / 12 \text{ g/mol}) \\ &= 1.428 \text{ t CO}_2/\text{t spent pulping liquor}\end{aligned}$$

Emissions are calculated by applying emission factors to the quantities of biomass combusted. The CH<sub>4</sub> and N<sub>2</sub>O emissions are included in the manufacturing sector of the inventory.

### 3.4.2.3 Fuel Ethanol

For the 2008 submission, fuel ethanol used in transportation for 1990–2006 was included (Table 3-12). Ethanol properties were developed according to chemistry and resulted in a higher heating value (HHV) (gross calorific value, or GCV) of 24.12 TJ/ML, 52.14% carbon content, and 789.2 kg/m<sup>3</sup> density.

**Table 3-12: Ethanol Used for Transport in Canada, 1990–2006**

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Ethanol Consumed (ML)	28	28	28	28	28	28	28	28	163	163	163	163	240	270	280	290	483

Fuel ethanol was introduced and modelled as if it were mixed into the total gasoline for the region(s). Total fuel available per province was allocated to each mode (on/off-road, and vehicle technology class) as per the percentage of total gasoline calculated traditionally with MGEM. In lieu of reviewed emission factors for CH<sub>4</sub> and N<sub>2</sub>O for ethanol, the representative gasoline emission factor was applied as per mode and technology class. CO<sub>2</sub> emission factors used are those based upon true chemical characteristics mentioned previously and a 99% oxidation rate.

## 3.5 Other Issues

### 3.5.1 Comparison of Sectoral and Reference Approaches

Results from the reference approach (RA) were compared with those from the sectoral approach (SA) as a check of energy consumed and CO<sub>2</sub> emissions from the combustion of fossil fuels (refer to Table 3-13). The check was performed for all years from 1990 to 2006 and is an integral part of reporting to the UNFCCC. Additional details on the RA are located in Annex 4.

When results from the RA are directly compared with those from the SA, the comparison produces a significant discrepancy, since the combustion total of the SA does not include fossil fuel-derived CO<sub>2</sub> emissions from the non-energy use of fossil fuels and feedstocks. When the RA and SA are directly compared, there is a 6.65 – 9.04% variation in emissions and an 8.75 – 10.04% variation in energy use. To ensure that energy information is comparable with that from the SA, the apparent energy consumption output excluding non-energy use and feedstock should be used.

In Canada, a significant amount of fossil fuel is used for feedstock in industrial processes, such as aluminium production, ammonia production, ethylene production, and iron and steel production. The emissions resulting from these processes are reported under the industrial processes, whereas CO<sub>2</sub> emissions resulting from flaring activities in the production and processing of oil and gas are reported in the fugitive oil and gas section of Energy. Owing to these discrepancies, the predefined comparison of emissions used in CRF Table 1.A.(c) is not appropriate for Canada, since this table is not comparing similar emission sources.

When the RA energy amount is corrected to exclude non-energy feedstock use of fuels, the variation between the SA and adjusted RA ranges between -3.64 and -1.72%, and the emission totals match within -0.78 and 1.91%. A reconciliation of the adjusted RA and SA is shown in Table 3-13.

**Table 3-13: Reconciliation of Reference Approach and Sectoral Approach for Canada**

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
<b>Overall Energy Comparison</b>																	
Reference Approach (PJ)	7,153	7,017	7,228	7,265	7,485	7,668	7,919	8,090	8,137	8,431	8,757	8,704	8,819	9,129	9,136	8,979	8,843
Sectoral Approach (PJ)	6,508	6,368	6,605	6,614	6,834	6,998	7,192	7,326	7,441	7,699	8,054	7,919	8,085	8,369	8,281	8,191	8,011
Percentage Difference without Adjustment (%)	9.9	10.2	9.4	9.8	9.5	9.6	10.1	10.4	9.4	9.5	8.7	9.9	9.1	9.1	10.3	9.6	10.4
Reference Approach with Non-Energy Use of Fossil Fuels and Feedstock Adjustment (PJ)	6,396	6,241	6,436	6,467	6,689	6,851	7,032	7,172	7,239	7,515	7,882	7,763	7,849	8,151	8,031	7,923	7,719
Percentage Difference with Adjustment - 100% x (RA-SA)/SA	-1.72	-1.99	-2.55	-2.22	-2.12	-2.11	-2.23	-2.11	-2.71	-2.39	-2.13	-1.97	-2.92	-2.60	-3.02	-3.27	-3.64
<b>Non-Energy Use of Fossil Fuels and Feedstocks</b>																	
Non-Energy Use of Liquid Fuels (PJ)	427	403	416	415	418	433	494	525	500	510	504	540	571	576	680	665	706
Non-Energy Use of Solid Fuels (PJ)	125	139	140	138	134	138	137	132	135	142	148	141	139	142	146	152	156
Non-Energy Use of Gaseous Fuels (PJ)	207	233	235	244	244	246	256	261	263	263	222	260	260	259	279	239	262
<b>Overall Emission Comparison</b>																	
Reference Approach (Gg CO <sub>2</sub> )	449,657	440,528	451,014	449,888	462,114	474,046	487,992	501,100	505,120	521,837	544,990	539,843	541,618	564,399	560,527	550,564	535,763
Sectoral Approach (Gg CO <sub>2</sub> )	414,098	403,996	417,476	414,504	427,105	438,375	449,779	460,795	467,677	483,888	506,429	500,623	507,836	527,403	522,635	515,686	501,499
Percentage Difference without Adjustment (%)	8.59	9.04	8.03	8.54	8.20	8.14	8.50	8.75	8.01	7.84	7.61	7.83	6.65	7.01	7.25	6.76	6.83
Reference Approach with Non-Energy Use of Fossil Fuels and Feedstock Adjustment (Gg CO <sub>2</sub> )	422,012	410,973	421,387	419,036	431,143	442,123	454,864	467,427	470,479	488,111	511,322	507,087	508,465	530,053	523,708	514,038	497,564
Percentage Difference with Adjustment - 100% x (RA-SA)/SA	1.91	1.73	0.94	1.09	0.95	0.85	1.13	1.44	0.60	0.87	0.97	1.29	0.12	0.50	0.21	-0.32	-0.78
<b>Carbon dioxide emissions from non-energy use of fossil fuel and feedstocks</b>																	
Liquid (Gg CO <sub>2</sub> )	8,636	8,434	8,579	9,307	9,505	10,069	11,092	11,740	12,772	11,129	11,241	11,427	12,402	12,951	14,664	14,465	15,588
Solid (Gg CO <sub>2</sub> )	11,314	12,631	12,758	12,593	12,383	12,598	12,527	12,049	12,285	13,024	13,653	13,101	12,947	13,382	13,676	14,299	14,592
Gaseous (Gg CO <sub>2</sub> )	7,695	8,490	8,290	8,951	9,083	9,256	9,509	9,884	9,584	9,573	8,774	8,228	7,805	8,013	8,478	7,762	8,020

### 3.5.2 Feedstocks and Non-Energy Use of Fuels

Emissions from fuel use in the Energy Sector are those related to the combustion of the fuels for the purpose of generating heat or work. In addition to being combusted for energy production, fossil fuels are also consumed for non-energy purposes. Non-energy uses of fossil fuels include application as waxes, solvents, lubricants, and feedstocks (including the manufacturing of fertilizers, rubber, plastics,

and synthetic fibres). Emissions from the non-energy use of fossil fuels have been included in the Industrial Processes Sector, whereas emissions from the use of fossil fuels associated with flaring activities by the oil and gas industry are included in the fugitive section.

Refer to the Industrial Processes chapter (Chapter 4) for a discussion of the use of feedstocks and the non-energy use of fossil fuels and the methodological issues associated with calculating emissions from this source.

### 3.5.3 CO<sub>2</sub> Capture and Storage

CO<sub>2</sub> is used in the Canadian petroleum industry as a means of enhancing oil recovery from depleted oil reservoirs. It is also disposed of with hydrogen sulphide in geological reservoirs as part of some gas processing operations. These are normal operational activities in the upstream industry. The quantities are not known or accounted for in the inventory. However, current inventory procedures are designed to estimate the net CO<sub>2</sub> actually emitted to the atmosphere from all energy production sources within Canada.

### 3.5.4 Country-Specific Issues: Emissions Associated with the Export of Fossil Fuels

Canada exports a great deal of its produced fossil resources, mostly to the United States. In 2006, Canada exported over approximately 60% (energy equivalent) of its gross or 43% of its net natural gas and crude oil production. The GHGs associated with this production have historically been estimated using a 1997 Environment Canada study as the basis. *Fossil Fuel Energy Trade & Greenhouse Gas Emissions*, prepared for Environment Canada by T.J. McCann and Associates (McCann 1997), integrates the authors' expert perspective and national energy data to achieve a reasonable estimate of GHG emissions associated with natural gas and crude oil production in Canada for the years 1990–1995.

Using the emission results presented in the study, an empirical relationship was established between emissions and the net exported energy associated with the volumes of crude oil and natural gas, as recorded by Statistics Canada. This trend was then applied to the actual 1996–2006 exports to develop the emission estimates (see Section ES.4.1 for further details).

The emissions/sectors included within the two main fuel stream estimates are:

- *Natural Gas*: This category accounts for GHG emissions specific to the production, gathering, processing, and transmission of natural gas. It includes emissions from gas conservation systems at oil batteries (i.e. dehydrators, compressors, and related piping) and excludes emissions that may be attributed to the handling, processing (e.g. stabilization, treating, and/or fractionation), or storage of NGLs at gas facilities. Basically, only those sources that exist for the primary purpose of producing natural gas for sale are considered. Gas distribution systems and end-use emissions are specifically excluded, since they pertain to domestic gas consumption rather than gas imports and exports.
- *Crude Oil*: Similarly, this category considers emissions related to the production, treatment, storage, and transport of crude oils. Emissions from venting and flaring of associated or solution gas at these facilities are allocated to this category. Any gas equipment that is dedicated to servicing on-site fuel needs is part of the oil system. Gas conservation systems that collect emissions in a gas-gathering system are allocated to the natural gas system.

It must be noted that the absolute emission estimates provided here have a high level of uncertainty, as great as 40% or more. On the other hand, the trend estimates are more accurate and can be considered to be representative.

## 4 Industrial Processes (CRF Sector 2)

### 4.1 Overview

Greenhouse gas emissions are produced from a variety of industrial activities that are not related to energy. The main emission sources are industrial production processes that chemically or physically transform materials. During these processes, many different greenhouse gases, including CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, and PFCs, can be released (IPCC/OECD/IEA 1997). Certain halocarbons (HFCs and PFCs) and SF<sub>6</sub> are also consumed in industrial processes or used as alternatives to ozone depleting substances (ODS) in various applications; these emissions are also included in the Industrial Processes Sector.

GHG emissions from fuel combustion that supplies energy to industrial activities are generally assigned to the Energy Sector. In some cases, such as when natural gas is used to produce ammonia, it is difficult to differentiate between emissions associated with energy and those produced by industrial process use of fuel. In such cases, and where predominance is with the industrial process use of fuel, the emissions are allocated to the Industrial Processes Sector. Emissions associated with the use of natural gas as feedstock in the upstream and downstream oil industries, to produce hydrogen, are assigned to the Energy Sector.

The processes addressed in this sector include production and use of mineral products, ammonia production, nitric acid production, adipic acid production, ferrous metal production, aluminium production, magnesium production and casting, production and consumption of halocarbons, consumption of SF<sub>6</sub>, and other and undifferentiated production.

CO<sub>2</sub> emissions resulting from the use of fossil fuels as feedstock for the production of chemical products other than ammonia, nitric acid, and adipic acid are reported under other and undifferentiated production (Section 4.16).

Indirect GHG emissions and SO<sub>2</sub> emissions from industrial process activities including asphalt roofing, road paving with asphalt, pulp and paper production, and production of food and drink have not been estimated. These emissions along with the indirect GHG emissions associated with energy activities are reported under Annex 14 of this National Inventory Report.

As shown in Table 4-1, the GHG emissions from the Industrial Processes Sector contributed 54.4 Mt to the 2006 national GHG inventory, compared with 54.8 Mt in 1990. These emissions represented 7.6% of the total Canadian GHG emissions in 2006. The overall slight change of -0.7% (compared with the 1990 level) in this sector could be explained by significant emission reductions in the adipic acid production, aluminium production (PFCs), magnesium production, and limestone and dolomite use, which were offset by growth in emissions from consumption of HFCs, other and undifferentiated production, aluminium production (CO<sub>2</sub>), cement production, and ammonia production. In the case of iron and steel production, the emission increase seen between 1990 and 2006 was not representative of the actual situation, because the 1990 estimate for this industry was lower than it would usually be due to a strike. There has been, in fact, an overall emission decrease since 1991.

Between 1990 and 2006, emissions from adipic acid production, aluminium production (PFCs), magnesium smelters, and limestone and dolomite use dropped by 89% (9 500 kt CO<sub>2</sub> eq), 60% (3900 kt CO<sub>2</sub> eq), 58% (1 670 kt CO<sub>2</sub> eq), and 66% (480 kt CO<sub>2</sub> eq), respectively. These categories contributed to the bulk of the overall emission decrease observed between 1990 and



2006. A reduction of 78% was also seen in SF<sub>6</sub> emissions from aluminium production, but the drop in physical units (46 kt CO<sub>2</sub> eq) was insignificant when compared to the categories mentioned previously. The use of an emission abatement system since 1997 by Invista's plant in Maitland, Ontario, explained the considerable N<sub>2</sub>O emission reduction observed in the adipic acid industry. Aluminium producers have reduced their PFC emissions by means of emission control technologies, while increasing their production volume. The drop in emissions from magnesium production was due to the progressive replacement of SF<sub>6</sub> used as cover gas with alternatives. The decline in emissions from limestone and dolomite use resulted from the downward trend in the use of these minerals in various industry sectors, for example, iron and steel, glass manufacturing, and pulp and paper industries. The use decrease of 66% (compared to the 1990 value) was partially due to the increasing acquisition of lime directly from lime manufacturers by the pulp and paper industry.

The categories of consumption of HFCs, other and undifferentiated production, aluminium production (CO<sub>2</sub>), cement production, and ammonia production all showed considerable increases in emissions between 1990 and 2006. An emission growth of 1000% (4 800 kt CO<sub>2</sub> eq) for consumption of halocarbons since 1995 could be explained by the progressive replacement of chlorofluorocarbons (CFCs) by HFCs when the Montreal Protocol came into effect in 1996. The non-energy (feedstock) use of fuels, such as butane and ethane, in the petrochemical industry has noticeably increased over the years. In addition, an augmentation was noticed in the non-energy use of other products, like waxes and paraffin. Altogether, these increases in non-energy fuel uses have played a role in the emission growth of 55% (4 400 kt CO<sub>2</sub> eq) for the category of other and undifferentiated production, which primarily includes emissions from petrochemical production. Increasing aluminium production gave rise to the growth in CO<sub>2</sub> emissions (84% or 2 300 kt CO<sub>2</sub> eq), since CO<sub>2</sub> comes from the reduction of alumina with carbon anodes, an essential reaction in the production process for which emissions cannot be easily controlled. For cement production, the emission increase was explained by an increase in cement production associated with a higher international demand (mainly from the U.S.) between 1990 and 2006. In the case of ammonia production, emissions have gone up by 32% (1 600 kt CO<sub>2</sub> eq) due to an overall growth in production of ammonia relying on steam methane reforming (SMR).

Between 2005 and 2006, the total emissions for the Industrial Processes Sector slightly decreased by 0.7%. This overall diminution was driven mainly by emission reductions in adipic acid production (54% or 1 400 kt CO<sub>2</sub> eq) and aluminium production – PFCs (14% or 450 kt CO<sub>2</sub> eq). However, this was mainly counterbalanced by the increase in emissions from iron and steel production (10% or 733 kt CO<sub>2</sub> eq), ammonia production (4% or 250 kt CO<sub>2</sub> eq), and to a lesser extent, cement production (2% or 140 kt CO<sub>2</sub> eq). According to a representative from Canada's only adipic acid plant, 2006 (compared to 2005) was a good year for abatement operations; the abatement unit functioned during the entire year of 2006, except in January. At the beginning of 2005, the abatement equipment did not operate due to a failure of the catalyst. In addition, following a nearly 6-month idle period due to a strike, the site experienced again problems with the abatement unit when the equipment was re-started (2007 e-mail from S. Lauridsen).<sup>39</sup> Between 2005 and 2006, the aluminium industry continued to do well in reducing PFC emissions. This could be attributed to greater reliance on more modern facilities. Finally, the growth in CO<sub>2</sub> emissions corresponded to higher iron and steel production, and production of ammonia (which is primarily used in the manufacture of fertilizers for use in the Agriculture Sector).

---

39. E-mail to M. Abdul (Environment Canada) from S. Lauriden (Invista) on Oct 30, 2007. This e-mail explains the 2006 emission estimate and confirms the 2005 estimate.

**Table 4-1: GHG Emissions from the Industrial Processes Sector, Selected Years**

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)		
	1990	2005	2006
<b>Industrial Processes TOTAL</b>	<b>54 800</b>	<b>54 800</b>	<b>54 400</b>
<b>a. Mineral Products</b>	<b>8 300</b>	<b>9 500</b>	<b>9 500</b>
<i>Cement Production</i>	5 400	7 200	7 300
<i>Lime Production</i>	1 700	1 700	1 600
<i>Limestone and Dolomite Use</i>	730	250	250
<i>Soda Ash Use</i>	210	160	170
<i>Magnesite Use</i>	147	176	179
<b>b. Chemical Industry</b>	<b>17 000</b>	<b>10 000</b>	<b>9 000</b>
<i>Ammonia Production</i>	5 000	6 300	6 600
<i>Nitric Acid Production</i>	1 010	1 250	1 230
<i>Adipic Acid Production</i>	11 000	2 600	1 200
<b>c. Metal Production</b>	<b>19 500</b>	<b>16 200</b>	<b>16 800</b>
<i>Iron and Steel Production</i>	7 060	7 020	7 760
<i>Aluminium Production</i>	9 300	7 900	7 600
<i>Magnesium Production</i>	2 870	1 090	1 200
<i>Magnesium Casting</i>	236	201	190
<b>d. Production and Consumption of Halocarbons (HFCs &amp; PFCs)</b>	<b>770</b>	<b>5 200</b>	<b>5 300</b>
<b>e. SF<sub>6</sub> Use in Electric Utilities and Semiconductors</b>	<b>1 500</b>	<b>1 200</b>	<b>1 300</b>
<b>f. Other and Undifferentiated Production</b>	<b>8 000</b>	<b>12 000</b>	<b>12 000</b>

Note: Totals may not add up due to rounding. Also, because of number rounding, some slight emission decreases or increases discussed in the paragraphs above may not be reflected in Table 4-1.

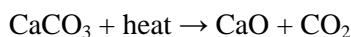
The uncertainty in the 2001 total GHG emission estimate (excluding halocarbon consumption) for this sector was estimated to be within the range of –7% to +5% (ICF Consulting 2004). Improvements have been made to some categories since the completion of the ICF Consulting study; thus, the overall sectoral uncertainty range is considered to be conservative for the current emission estimate.

To ensure that the inventory was correctly prepared, the key, new, and updated categories of this sector have all undergone Tier 1–level QC checks.

## **4.2 Cement Production (CRF Category 2.A.1)**

### **4.2.1 Source Category Description**

CO<sub>2</sub> is generated during the production of clinker, an intermediate product from which cement is made. Calcium carbonate (CaCO<sub>3</sub>) from limestone, chalk, or other calcium-rich materials and other raw ingredients, such as silicates, are heated in a high-temperature kiln, forming lime (CaO) and CO<sub>2</sub>. This process is called calcination or calcining. It occurs in the lower-temperature section of the kiln (800–900°C) and can be represented as follows:



The lime is then combined with silica-containing materials in the higher-temperature section of the kiln (1350–1450°C) to produce clinker (greyish-black pellets about the size of 12 mm diameter marbles). The clinker is removed from the kiln, cooled, and pulverized, and gypsum is added to produce Portland cement. Almost all of the cement produced in Canada is of the

Portland cement type (ORTECH Corporation 1994), which contains 60–67% lime by weight. Other specialty cements are lower in lime, but are typically used in small quantities.

CO<sub>2</sub> emissions from cement production are essentially directly proportional to lime content. The emissions resulting from the combustion of fossil fuels to generate the heat to drive the reaction in the kiln fall under the Energy Sector and are not considered here.

#### 4.2.2 Methodological Issues

To estimate national CO<sub>2</sub> emissions from cement production, the equation recommended in the IPCC good practice guidance (IPCC 2000), as shown below, was used:

##### Equation 4-1:

$$\text{CO}_2 \text{ emissions} = \text{EF}_{\text{clinker}} \times \text{Clinker Production} \times \text{CKD Correction Factor}$$

where:

EF <sub>clinker</sub>	=	emission factor based on clinker production, kt CO <sub>2</sub> /kt clinker
Clinker Production	=	clinker production data, kt
CKD Correction Factor	=	factor that corrects for the loss of cement kiln dust (CKD), fraction

The IPCC default EF<sub>clinker</sub> of 0.5071 kt CO<sub>2</sub>/kt clinker produced was applied. This factor was developed based on an average lime percentage of 64.6% and the molecular weight ratio of CO<sub>2</sub> to CaO in the raw material, which is 0.785 (IPCC/OECD/IEA 1997). The IPCC good practice guidance (IPCC 2000) suggests 1.02 (i.e. adding 2% to the CO<sub>2</sub> calculated for clinker) as the default CKD Correction Factor.

Clinker production data for 1990–1996 were obtained from *A Review of Energy Consumption and Related Data: Canadian Cement Manufacturing Industry, 1990 to 2004* (CIEEDAC 2007). Clinker production data for 1997–2004 were obtained from Statistics Canada (#44-001) and for 2005 and 2006 from CANSIM Table 303-0060 (Statistics Canada 2007). Applying Equation 4-1 above to the clinker production data is considered a Tier 2–type approach.

To estimate CO<sub>2</sub> provincial/territorial emissions, data on clinker capacity of cement plants across Canada were used. The source of data was the *Canadian Minerals Yearbook* (NRCan). These data were used to derive the percentage of total national clinker capacity attributed to each province/territory. CO<sub>2</sub> emissions on a provincial/territorial level were estimated by multiplying the percentage attributed to each province/territory by the national emission estimate.

In the most recent (2006) *Canadian Minerals Yearbook* (NRCan), only 2005 capacity data are provided. Therefore, it is assumed that there was no change in clinker production capacity from 2005 to 2006.

#### 4.2.3 Uncertainties and Time-Series Consistency

A new Tier 1 uncertainty has been developed based on the IPCC (2006) default uncertainty values provided for various parameters in the equation for CO<sub>2</sub> emissions. Also, considered is the error associated with the non-response rate of the Statistics Canada's survey which collects clinker production data. The Tier 1 uncertainty associated with cement production is ±33%. The main contributor to the uncertainty is the use of IPCC default uncertainty for the correction factor

related to the cement kiln dust. The assessment of uncertainty here has been made using a Tier 1 method. A Tier 2 assessment of uncertainty should produce a lower uncertainty value.

Equation 3.1 of the IPCC good practice guidance (IPCC 2000) has been consistently applied over the time series. The activity data sources are described in Section 4.2.2.

#### **4.2.4 Category-Specific QA/QC and Verification**

This key category in the Industrial Processes Sector has undergone Tier 1 QC checks as elaborated in the QA/QC plan (see Annex 6). The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC good practice guidance (IPCC 2000). No issues of importance were detected from the Tier 1 QC process.

For this submission, a Tier 2 QC process has been performed. From this QC, it has been noted that having country-specific information for cement kiln dust and Canadian-specific CaO content in clinker would improve the estimates.

A QA has been initiated with the Cement Association of Canada. Results of this QA are expected to be available for submission in 2009.

#### **4.2.5 Category-Specific Recalculations**

This category has undergone minor recalculations since the submission of 2006. For a more detailed discussion, please refer to Chapter 9.

#### **4.2.6 Category-Specific Planned Improvements**

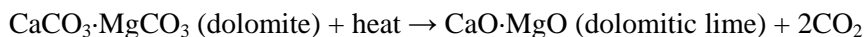
A QA review is planned to be conducted, with the participation of Cement Association of Canada, in order to identify potential improvements in the methodology, emission factors, and uncertainty for this category.

### **4.3 Lime Production (CRF Category 2.A.2)**

#### **4.3.1 Source Category Description**

Calcined limestone (quicklime or CaO) is formed by heating limestone to decompose carbonates. As with cement production, this is usually done at high temperatures in a rotary kiln, and the calcination process releases CO<sub>2</sub>. Primarily high-calcium limestone (calcite) is processed in this manner from quarried limestone to produce quicklime in accordance with the same reaction discussed in Section 4.2.1 on cement production.

Dolomitic limestone, which is a mix of calcite and magnesite (MgCO<sub>3</sub>), may also be processed at high temperature to obtain dolomitic lime (and release CO<sub>2</sub>) in accordance with the following reaction:



Emissions from the regeneration of lime from spent pulping liquors at pulp mills are not accounted for in the Industrial Processes Sector. Since this CO<sub>2</sub> is biogenic in origin, it is recorded as a change in forest stock in the LULUCF Sector. The CO<sub>2</sub> associated with the use of natural limestone for producing lime in the pulp and paper industry is accountable and is included in the category Limestone and Dolomite Use (section 4.4).

### 4.3.2 Methodological Issues

CO<sub>2</sub> emissions from lime production were estimated using an emission factor of 750 g CO<sub>2</sub>/kg high-calcium lime (or quicklime) and an emission factor of 860 g CO<sub>2</sub>/kg dolomitic lime. These IPCC default emission factors are based on the associated calcination reaction stoichiometry and IPCC default values for the lime content of the two types of lime (IPCC 2000).

Total lime production and lime plant calcining capacity data were obtained from the *Canadian Minerals Yearbook* (NRCan). For any given year, the most recent lime production numbers provided are preliminary and are subject to revision in subsequent publications. The lime production data were corrected for the proportion of hydrated lime using national hydrated lime production data and the IPCC default water content of 28% (IPCC 2000). Furthermore, the IPCC default ratio of high-calcium lime to dolomitic lime, 85/15, was applied to the lime production data to estimate the quantity of each type of lime. National CO<sub>2</sub> emissions were calculated by applying the above-noted emission factors to the estimated yearly national lime production data, by lime type.

Data on calcining capacities of lime production facilities across Canada also came from the *Canadian Minerals Yearbook* (NRCan). These data were used to derive the percentage of total national calcining capacity attributed to each province/territory. It should be noted that the same 85/15 split was applied to the calcining capacities of those facilities known to produce both lime types. CO<sub>2</sub> emissions on a provincial/territorial level were estimated by multiplying the capacity percentage attributed to each province/territory by the national emission estimate.

Since this estimation technique accounts for hydrated lime and the production of different lime types, it is considered to be an improved Tier 1-type methodology.

### 4.3.3 Uncertainties and Time-Series Consistency

The Tier 1 uncertainty for CO<sub>2</sub> emissions from lime production is  $\pm 21\%$  based on the IPCC (2000) default uncertainty value and information received from NRCan (2006 e-mail from D. Panagapko).<sup>40</sup> The IPCC default ratio of high-calcium lime to dolomitic lime, 85/15, can be a source of uncertainty, since it may not be absolutely true in a Canadian context.

The data source and estimation technique used are consistent over the time series.

### 4.3.4 Category-Specific QA/QC and Verification

This key category in the Industrial Processes Sector has undergone Tier 1 QC checks as elaborated in the QA/QC plan (see Annex 6). The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC 2000). No anomalies were observed.

---

40. E-mail received by L. Van de Mosselaer (Environment Canada) from D. Panagapko (Natural Resources Canada) on December 15, 2006. This e-mail contains uncertainty information for lime production.

### 4.3.5 Category-Specific Recalculations

Over the last two years, recalculations have occurred in this category as a result of updated 2004–2005 activity data. These recalculations slightly affected estimates of 2004 and 2005. Details of these recalculations and their impact are found in Chapter 9.

### 4.3.6 Category-Specific Planned Improvements

There are currently no improvements planned specifically for estimating CO<sub>2</sub> emissions from lime production.

## 4.4 Limestone and Dolomite Use (CRF Category 2.A.3)

### 4.4.1 Source Category Description

Limestone is a basic raw material used in a number of industries. In addition to its consumption in the production of cement and lime for resale, limestone is used as a raw material in glass factories. As well, significant amounts of limestone are used as flux stone in iron and steel furnaces and in non-ferrous smelters. Dolomite may also be used in the iron and steel furnaces. The proportion of limestone to dolomite used in the iron and steel industry varies depending on the character of iron ore and how the resulting slag is used. Since limestone at high temperatures is calcined to lime in these industries, CO<sub>2</sub> is produced by the same reaction described in Section 4.2.1 on cement production.

In addition, other areas in which limestone is consumed include pulp and paper mills (used for makeup lime), flue gas desulphurisation (FGD), and wastewater treatment/neutralization.

### 4.4.2 Methodological Issues

CO<sub>2</sub> emissions from limestone and dolomite were calculated separately using two different emission factors.

Based on the process stoichiometry, it was determined that 440 g of CO<sub>2</sub> could be emitted per kilogram of pure limestone used. However, since there was no pure limestone used in the Canadian industry, a purity fraction of 95% was applied, to come up with the overall emission factor of 418 g CO<sub>2</sub>/kg of limestone used (AMEC 2006). The purity fraction of 95% came from a report prepared by the Ministry of Northern Development and Mines (1989) for the Ontario Ministry of Natural Resources.

Dolomite consists of both limestone (CaCO<sub>3</sub>) and magnesite (MgCO<sub>3</sub>). A major Canadian producer of dolomite reported the composition of its dolomite to range from 56% to 58% CaCO<sub>3</sub> and from 38% to 41% MgCO<sub>3</sub> (Limestone Industries of Ontario 1989). An overall emission factor of 468 g CO<sub>2</sub>/kg of dolomite used was derived based on the emission factors for pure limestone (440 kg CO<sub>2</sub>/tonne) and magnesite (522 kg CO<sub>2</sub>/tonne), and the assumption that dolomite is composed of 58% CaCO<sub>3</sub> and 41% MgCO<sub>3</sub> (AMEC 2006).

Data on raw stone use in iron and steel furnaces, non-ferrous smelters, glass factories, pulp and paper mills, and other chemical uses were obtained from the *Canadian Minerals Yearbook* (NRCan). Data on consumption of stone as flux in iron and steel furnaces were disaggregated into limestone and dolomite use based on a 70/30 split (AMEC 2006). National CO<sub>2</sub> emissions were estimated by multiplying the quantities of limestone/dolomite consumed by the corresponding emission factors. The most recent activity data, stone use, for each of the sectors published by

NRCan were for 2005; only a national consumption value of stone was available for 2006. The national stone consumption in 2006 was compared with the national consumption in 2005. The change from 2005 to 2006 was then used to determine stone sectoral use by assuming that stone use in each sector increased by that amount; the consumption of stone in each of the sectors was assumed to be proportional to that for 2005. An appropriate method for estimating limestone use emissions on a provincial/territorial basis has not yet been developed.

This technique is considered to be a Tier 2-type method. National consumption data and national purity factors are used in the calculations of the CO<sub>2</sub> emissions for dolomite and limestone use. A 70/30 split on the consumption of limestone and dolomite was used. Methodological issues for calculating CO<sub>2</sub> emissions from limestone and dolomite use are addressed in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006).

#### **4.4.3 Uncertainties and Time-Series Consistency**

The overall uncertainties associated with CO<sub>2</sub> emissions from limestone and dolomite use in the whole time series were estimated to vary from  $\pm 16\%$  to  $\pm 19\%$ . The uncertainties are mostly associated with the activity data: quantities of limestone used as flux in iron and steel furnaces and other chemical uses (AMEC 2006). Additional uncertainties in this category come from the 70/30 limestone/dolomite split applied to disaggregate the amount of raw stone used as flux in iron and steel furnaces.

#### **4.4.4 Category-Specific QA/QC and Verification**

This key category in the Industrial Processes Sector has undergone Tier 1 QC checks as elaborated in the QA/QC plan (see Annex 6). The checks performed are consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC good practice guidance (IPCC 2000). No anomalies were observed.

#### **4.4.5 Category-Specific Recalculations**

Over the last two years, recalculations have occurred in this category due to revisions in activity data. These have moderately affected estimates of the whole time series of this category. More details on these recalculations are provided in Chapter 9.

#### **4.4.6 Category-Specific Planned Improvements**

The emissive portion of the subcategory Other chemical uses published in the *Canadian Minerals Yearbook* (NRCan), was estimated based on U.S. activity data. There is a plan to improve or refine this estimate by using Canadian activity data.

### **4.5 Soda Ash Production and Use (CRF Category 2.A.4)**

#### **4.5.1 Source Category Description**

Soda ash (sodium carbonate, Na<sub>2</sub>CO<sub>3</sub>) is a white crystalline solid that is used as a raw material in a large number of industries, including glass manufacture, chemical production, soap and detergents, pulp and paper manufacture, FGD, and wastewater treatment (AMEC 2006). Based on use data supplied in a study prepared for Environment Canada (AMEC 2006) and the *Non-Metallic Mineral Products Industries* (Statistics Canada #44-250) publication, it appears that soda ash in Canada is used mainly in the glass products manufacturing industry. CO<sub>2</sub> is emitted as the soda ash decomposes at high temperatures in a glass manufacturing furnace.

CO<sub>2</sub> is also emitted during the Solvay process that is used to produce soda ash. However, as the CO<sub>2</sub> is a necessary component in the carbonation stage of the production process, it is usually recovered and recycled for use.

#### 4.5.2 Methodological Issues

Soda ash in Canada is used in glass manufacturing and for other purposes, such as chemical production, pulp and paper mills, and FGD, resulting in CO<sub>2</sub> emissions (AMEC 2006).

For each mole of soda ash used, 1 mole CO<sub>2</sub> is emitted. The emission factor (EF) for the mass of CO<sub>2</sub> emitted is estimated from the stoichiometry of the chemical process as follows:

**Equation 4-2:**

$$\begin{aligned} \text{EF} &= (1000 \text{ g/kg}) \times (44.01 \text{ g CO}_2/\text{mole}) / (105.99 \text{ g Na}_2\text{CO}_3/\text{mole}) \\ &= 415 \text{ g CO}_2/\text{kg Na}_2\text{CO}_3 \end{aligned}$$

National CO<sub>2</sub> emissions were calculated by applying the emission factor of 415 g CO<sub>2</sub>/kg to the national data on soda ash consumption. Quantities of soda ash used were estimated based on soda ash production, import, and export data. Production data was assumed to be equal to the capacity of the only facility that has produced soda ash in Canada. Import and export data was obtained from the Global Trade Information Services (GTIS 1995–2006). It should be noted that since GTIS did not report trade data before 1995, it was assumed that the trade data for the years 1990–1994 were the average of the 1995–2000 trade data.

This method is considered to be Tier 1–type, as it is based on the use of national consumption data and an emission factor derived from the stoichiometry of the process. An appropriate method for estimating soda ash use emissions on a provincial/territorial basis has not yet been developed. Methodological issues for calculating CO<sub>2</sub> emissions from soda ash use are not addressed specifically in the IPCC good practice guidance (IPCC 2000).

There is currently no soda ash production in Canada. The only soda ash producing plant, which produced soda ash using the Solvay process, closed in 2001. Although most CO<sub>2</sub> that was emitted from this facility was recovered for reuse (as mentioned in Section 4.5.1), some CO<sub>2</sub> may have been released from vents on absorbers, scrubbers, and distillation units. However, the amount of net CO<sub>2</sub> emissions from soda ash production in Canada is assumed to be minimal (AMEC 2006).

#### 4.5.3 Uncertainties and Time-Series Consistency

The uncertainties associated with emissions from soda ash use stem mostly from activity data, and they were higher for the years 1990–1994. The soda ash import and export data were available only from GTIS from 1995 onwards. The uncertainties associated with import and export data before 1995 were estimated to be ±23% and ±27%, respectively; for 1995 and later, the uncertainty of both the import and export data was estimated to be ±2.0% (AMEC 2006). The overall uncertainty values associated with CO<sub>2</sub> emissions from soda ash use in the whole time series vary from ±10% to ±14%.

#### 4.5.4 Category-Specific QA/QC and Verification

CO<sub>2</sub> from soda ash use was not a key category; however, Tier 1 QC checks as elaborated in the QA/QC plan (see Annex 6) were performed. The checks performed were consistent with the Tier



1 General Inventory Level QC Procedures outlined in the IPCC good practice guidance (IPCC 2000). No anomalies were observed.

#### 4.5.5 Category-Specific Recalculations

The 2004 emission estimate of this category has been recalculated. More details on the revision made are provided in Chapter 9.

#### 4.5.6 Category-Specific Planned Improvements

There are currently no improvements planned specifically for estimating CO<sub>2</sub> emissions from soda ash production and use.

### 4.6 Magnesite Use (CRF Category 2.A.7.2)

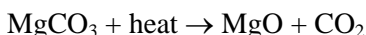
#### 4.6.1 Source Category Description

Magnesite, or magnesium carbonate (MgCO<sub>3</sub>), is a silver-white solid that is used as a raw material in the making of a variety of products, including magnesium metal (Mg) and magnesia (MgO).

CO<sub>2</sub> is emitted when magnesite is used during the leaching step of the magnesium production process, as shown below:



Magnesite can also be processed to become lighter-fired caustic magnesia and sintered magnesia, which are then used in refractory manufacturing (AMEC 2006). CO<sub>2</sub> is generated along with magnesia when magnesium carbonate decomposes at high temperatures:



#### 4.6.2 Methodological Issues

In calculating the CO<sub>2</sub> emissions from the use of magnesite, an emission factor was developed based on the process stoichiometry and, as the commercial magnesite is not 100% pure, on a 97% fractional purity (AMEC 2006). During 1990–2006, three facilities in Canada have reported use of magnesite as a raw material, but one of them has shown no use of magnesite use since 1992. In the *5th Strategic Diversification Newsletter* (SIDEX 2004), one of these facilities reported that the purity fraction of the magnesite it used was 97%, and this magnesite was mined by the facility's parent company. It was assumed that all three of the facilities used magnesite with the purity fraction of 97%. Taking the purity of magnesite into account, an overall emission factor of 506 g CO<sub>2</sub>/kg was used in estimating CO<sub>2</sub> emissions from magnesite use.

The 1990–2005 facility-specific magnesite use data came from British Columbia's Ministry of Energy, Mines and Petroleum Resources (2006) and Environment Canada, Quebec Region, Environmental Protection Branch (2006 e-mail from J. Banville).<sup>41</sup> For 2006, to estimate the use of magnesite at one of the plants for which data could not be obtained, some assumptions were

---

41. E-mail received from J. Banville, Environment Canada, Environmental Protection Branch, Québec region, on March 3, 2006. Provided in this e-mail were the 1990–2005 magnesite use data for one of the plants.

made. First, the ratio of magnesite use to magnesium production was calculated for each year of the period 1990–2005 (2007 e-mail from J. Banville).<sup>42</sup> The average of the calculated (magnesite use/magnesium production) ratios was then taken. Finally, it was multiplied by the plant's 2006 production to yield the 2006 magnesite use. For the other plant for which 2006 data was again not available, it was assumed that the 2006 use of magnesite stayed at the 2005 level. Multiplying the consumption data (either actual or estimated, depending on the years) by the above-mentioned emission factor gives the national emission estimates for this subsector.

This method is considered to be Tier 1–type, as it is based on the use of national consumption data and an emission factor derived from the stoichiometry of the process.

#### **4.6.3 Uncertainties and Time-Series Consistency**

The uncertainties associated with CO<sub>2</sub> emissions from magnesite use in the whole time series vary from  $\pm 5\%$  to  $\pm 6\%$ . The main sources of uncertainty for magnesite are the assumed purity fraction of magnesite for two of the three plants and the activity data (AMEC 2006).

#### **4.6.4 Category-Specific QA/QC and Verification**

Informal QC checks were performed on the category of magnesite use (a non-key category). Some of these QC checks include double-checking calculations in the model, comparing emission estimates developed this year with those developed last year, and checking for transcription errors throughout the NIR production steps. No issues of importance were detected from the checks.

#### **4.6.5 Category-Specific Recalculations**

For this category, there were recalculations only between submission 2007 and 2008 due to the acquisition of new activity data for 2004 and 2005. These recalculations resulted in lower 2004 and 2005 emission estimates (-2.7% and -5.5%, respectively).

#### **4.6.6 Category-Specific Planned Improvements**

There are currently no improvements planned specifically for estimating CO<sub>2</sub> emissions from magnesite use.

### **4.7 Ammonia Production (CRF Category 2.B.1)**

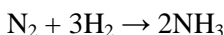
#### **4.7.1 Source Category Description**

Ammonia (NH<sub>3</sub>) is gaseous at standard temperature and pressure. It is toxic and corrosive and has a pungent odour. Commercially used ammonia is referred to as “anhydrous ammonia,” which must be stored under pressure or at low temperature to remain a liquid. It is used mainly in the production of fertilizers, explosives, and polymers.

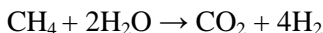
---

42. E-mail received from J. Banville, Environment Canada, Environmental Protection Branch, Québec region, on October 4, 2007. Provided in this e-mail were the estimated 1990–2006 magnesium production data for a magnesium plant.

To produce anhydrous ammonia, nitrogen ( $\text{N}_2$ ) and hydrogen ( $\text{H}_2$ ) react together in the Haber-Bosch process. The reaction (as shown below) occurs at high temperature in the presence of a catalyst:

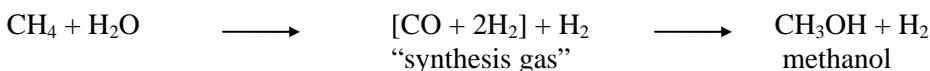


The nitrogen required is obtained from air. The typical source of hydrogen for ammonia plants is the catalytic steam reforming of CH<sub>4</sub> (and minor amounts of other hydrocarbons) contained in natural gas. CO<sub>2</sub> is also generated, as a by-product gas, during the steam methane reforming (SMR) process:



CO<sub>2</sub> is then removed from the process gas by absorption, usually with a solution of monoethanolamine or potassium carbonate (K<sub>2</sub>CO<sub>3</sub>). The primary release of CO<sub>2</sub> occurs during the regeneration (for reuse) of the CO<sub>2</sub>-rich absorption solution by steam stripping or boiling. The stripping gas, which contains CO<sub>2</sub> and other impurities, is then vented to the atmosphere. Alternatively, it can be directed to a neighbouring urea plant, where the CO<sub>2</sub> is recovered and utilized as a feedstock gas. Since the carbon will only be stored for a short, no account should be taken for intermediate binding of CO<sub>2</sub> in downstream manufacturing processes and products (IPCC/OECD/IEA 1997).

For most Canadian ammonia production facilities, SMR plants are essential units for the operations, because they can generate hydrogen in sufficient quantities to support large-scale ammonia production. However, some plants may use by-product hydrogen to feed into the Haber-Bosch reaction, thereby eliminating release of CO<sub>2</sub> from the ammonia production process. In other words, the hydrogen needed for producing ammonia can also be obtained in ways that do not involve an on-site SMR operation. For instance, at methanol plants, a synthesis gas (or “syn gas”) consisting of one part CO and two parts hydrogen is prepared by using a variation of the SMR reaction. The reaction (as depicted below) produces an excess of hydrogen that is more than what is required for methanol production:



This excess of hydrogen is often purged from the methanol plant and used at neighbouring ammonia plants. Also, ethylene plants generate hydrogen as a co-product from cracking furnaces in making ethylene and other chemicals (e.g. propylene, butadiene). This hydrogen stream can be used at the nearby ammonia plants as well (Cheminfo Services 2006).

### 4.7.2 Methodological Issues

Emissions from ammonia production were estimated by multiplying CO<sub>2</sub>-related ammonia production by an emission factor of 1.56 t CO<sub>2</sub>/t NH<sub>3</sub> produced. The emission factor was developed based on typical energy and material requirements for ammonia production in Canada (Jaques 1992). Data on CO<sub>2</sub>-related production used in the calculation were either directly collected from ammonia plants or estimated. For plants that had used SMR (i.e. releasing CO<sub>2</sub>), but whose data were not available, estimation of production was done based on the reported production and capacity data of other plants and national ammonia production statistics. Data on production and production capacity for 1990–2004, when available, were gathered in a study conducted by Cheminfo Services (2006); those for 2005–2006 were collected by Environment

Canada's GHG Division through a voluntary data submission process. Data on national ammonia production were found in Statistics Canada's publication #46-002.

The estimation technique (emissions = production of ammonia  $\times$  emission factor) is one of the default methods suggested in the revised 1996 IPCC guidelines (IPCC/OECD/IEA 1997). However, it should be noted that the emission factor of 1.56 t CO<sub>2</sub>/t NH<sub>3</sub> produced is a national average value and that plant-specific production data were used whenever possible. Methodological issues for calculating CO<sub>2</sub> emissions from ammonia production are not addressed specifically in the IPCC good practice guidance (IPCC 2000).

Finally, the quantity of natural gas used to produce hydrogen for ammonia production was also recorded by Statistics Canada with all other non-energy uses of natural gas. Therefore, to avoid double-counting, the CO<sub>2</sub> emissions from ammonia production were subtracted from the total non-energy fossil fuel use CO<sub>2</sub> emissions.

Further details with respect to the calculation method used are provided in Annex 3.

### **4.7.3 Uncertainties and Time-Series Consistency**

The ICF Consulting (2004) report shows an uncertainty range of -23% to +55% for the CO<sub>2</sub> emission estimate for ammonia production. The provided uncertainty value is considered as conservative for this year's estimate because of the calculation improvement made since the completion of the uncertainty study. For instance, the values of ammonia production not involving SMR have been updated for all years. It is expected that the uncertainty associated with this category will be lowered as a result of this. A sensitivity analysis needs to be conducted to determine the relative contribution of the activity data and emission factor to the uncertainty associated with this category.

The data sources and methodology used are consistent over the time series.

### **4.7.4 Category-Specific QA/QC and Verification**

Ammonia production was a key category that has undergone Tier 1 QC checks as developed in the QA/QC plan (see Annex 6). The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC 2000). No issues of importance were detected from the Tier 1 QC process.

### **4.7.5 Category-Specific Recalculations**

Over the last two years, recalculations for the whole time series have occurred in this category as a result of an update in activity data and a methodological change. These changes considerably affected estimates for the entire time series. A more detailed discussion of these recalculations and their impact is provided in Chapter 9.

### **4.7.6 Category-Specific Planned Improvements**

Efforts will be made to determine the amounts of natural gas used as feedstock and as fuel during ammonia production over the years.

## 4.8 Nitric Acid Production (CRF Category 2.B.2)

### 4.8.1 Source Category Description

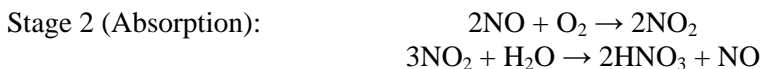
Nitric acid ( $\text{HNO}_3$ ) is a highly corrosive and toxic inorganic compound that is used mainly as a raw material in the manufacture of synthetic commercial fertilizer. It can also be used in the production of adipic acid and explosives, in metal etching, and in the processing of ferrous metals (IPCC/OECD/IEA 1997).

The production of nitric acid is a two-stage process involving catalytic oxidation of ammonia ( $\text{NH}_3$ ) to nitrogen dioxide ( $\text{NO}_2$ ) and then subsequent formation of nitric acid by addition of water ( $\text{H}_2\text{O}$ ) to  $\text{NO}_2$ . As shown below, the first stage is the reaction of ammonia gas with oxygen ( $\text{O}_2$ ) (from air) at high temperatures:



The hot gases pass through many sheets of wire gauze catalyst. These are usually made from (platinum, palladium, gold, or rhodium) alloy wire knitted into a fine mesh surface. The reaction products are a mixture of nitric oxide ( $\text{NO}$ ),  $\text{NO}_2$ , and water vapour, with trace amounts of  $\text{N}_2\text{O}$  and nitrogen ( $\text{N}_2$ ) (Cheminform Services 2006). An excess of oxygen may drive the  $\text{NO}$  to be converted to  $\text{NO}_2$ . Nitrogen oxidation steps under reducing conditions are sources of  $\text{N}_2\text{O}$ . More specifically,  $\text{NO}$ , an intermediate in the production of nitric acid, can readily decompose to  $\text{N}_2\text{O}$  and  $\text{NO}_2$  at high pressures and at a temperature range of 30–50°C (IPCC/OECD/IEA 1997).

During the second stage of the production process, water is added at the top of an absorber tower to hydrate the  $\text{NO}_2$  and to scrub the gases. As shown below, hydration of cooled  $\text{NO}_2$  with water forms a 60–65% solution of nitric acid, leaving the bottom of the tower. Moreover, to complete the conversion of  $\text{NO}$  to  $\text{NO}_2$ , excess air (oxygen) is introduced at the bottom tray of the absorber tower. The  $\text{NO}_2$  formed is also absorbed.



Since the hydration reaction is exothermic, the absorber towers require cooling, and some of them have a cooling circuit on each tower tray. The typical conversion yield to nitric acid is 93% if a fresh reaction catalyst is used. As the catalyst ages and degrades, conversion can fall to about 90%. The tail gases that leave the absorber tower consist mostly of nitrogen, a small concentration of oxygen, and trace quantities of  $\text{N}_2\text{O}$ ,  $\text{NO}$ ,  $\text{NO}_2$ , and other  $\text{NO}_x$ . The concentration of  $\text{N}_2\text{O}$  in the exhaust gases depends on the type of plant and its emission controls (Cheminform Services 2006).

There exist two basic types of nitric acid production technology: high pressure and dual pressure. *High-pressure* designs, commonly used in North America, apply a single pressure throughout the reaction and absorption stages. The second type of nitric acid production technology design, *dual pressure*, was developed in Europe. This older technology uses low pressure for the reaction stage and higher pressure for a more efficient absorption stage (Cheminform Services 2006).

The two types of production process described above can be found in Canadian nitric acid plants. The high-pressure process plants function with non-selective catalytic reduction (NSCR) systems. The emission abatement systems are “non-selective” because natural gas is used as reductant, and it reduces all  $\text{NO}_x$ . In contrast, “selective” catalytic reduction (SCR) uses ammonia, which selectively reacts only with  $\text{NO}$  and  $\text{NO}_2$  gases, not with  $\text{N}_2\text{O}$ . Dual-pressure plants also exist in

Canada. They operate either with extended absorption tower (also referred to as “absorption Type 1”) or with double absorption (also referred to as “absorption Type 2”).

#### 4.8.2 Methodological Issues

Data supporting the estimation of N<sub>2</sub>O emissions from nitric acid production for 1990–2004 were gathered through a study conducted for Environment Canada (Cheminfo Services 2006) and those for 2005–2006 were obtained by the department’s GHG Division from industry through a voluntary data submission process. The collected data led to the adoption of a country-specific hybrid emission estimation methodology. This output-based method relied on:

1. plant-specific production data and plant-specific emission factors (i.e. Tier 3–type method) when these were available from companies; or
2. plant-specific production data and production technology–specific emission factors that are national average values (i.e. Tier 2–type method) when plant-specific emission factors were not available; or
3. estimated production data and national average technology-specific emission factors (i.e. Tier 1–type method) when limited or no plant-specific data were available.

In all three scenarios, the equation applied was as follows:

##### Equation 4-3:

$$\text{N}_2\text{O Emissions (t)} = \text{Production-Based Emission Factor (kg N}_2\text{O/t HNO}_3\text{)} \times \text{Production (kt HNO}_3\text{)}$$

To estimate emissions in scenarios 2 and 3, the types of production process and emission control technology of a plant were first determined. The reported or estimated production was then multiplied by the corresponding emission factor. The industry-typical emission factors used had been obtained from the Canadian Fertilizer Institute in the early 1990s (1992 letter from G. Collis).<sup>43</sup> These were confirmed again, as being applicable, by industry representatives during the recent study. In addition, another industry-typical emission factor is provided in the IPCC good practice guidance (IPCC 2000), and it was confirmed through the same study (Cheminfo Services 2006). Table 4-2 summarizes the industry-typical emission factors by process and control types.

---

43. Letter received from G. Collis on March 23, 1992. This letter contains industry-typical emission factors for different types of nitric acid plants.

**Table 4-2: Nitric Acid Industry—Typical Emission Factors**

Type of Production Process Technology	Type of Emission Control Technology	Emission Factor (kg N <sub>2</sub> O/t HNO <sub>3</sub> )	Data Source
Dual Pressure	Extended Absorption “Type 1”	9.4	(1992 letter from G. Collis) <sup>44</sup>
Dual Pressure	Extended Absorption “Type 2”	12	(1992 letter from G. Collis) <sup>45</sup>
High Pressure	NSCR	0.66	(1992 letter from G. Collis) <sup>46</sup>
High Pressure	SCR	8.5	IPCC (2000)

For plants that did not have production data available, production were estimated based on the national production data from Statistics Canada (# 46-002), and the reported production data and the production capacity data of other plants. More specifically, the sum of all production reported by companies was deducted from the national total production (Statistics Canada # 46-002) to give the national *unreported* nitric acid production. The latter was then allocated based on the capacities of the non-reporting plants to give the estimated production values for the non-reporting plants. The *estimated* production was multiplied by what was believed to be the most appropriate industry-typical emission factor to estimate emissions coming from plants for which no or few data were available. For 1990–2004, the raw activity data and plant-specific emission factors (when available) used to develop emission estimates were collected through the 2006 Cheminfo study (Cheminfo Services 2006). For 2005–2006, the data used were reported by companies to the Greenhouse Gas Division on a voluntary basis.

Finally, the estimates of N<sub>2</sub>O emissions (by plant) were summed either all together to yield the national emission estimate or by province to give the provincial emission estimate.

### 4.8.3 Uncertainties and Time-Series Consistency

The uncertainty range provided in the ICF Consulting (2004) study for this category is no longer applicable, because the emission estimation methodology was revised in the Cheminfo Services (2006) study. The updated data and information collected from that study and the voluntary data submission process have helped reduce the uncertainty related to this category. According to the Tier 1 uncertainty assessment (performed by Cheminfo Services for 1990–2004 data and by the GHG Division for 2005–2006 data), the uncertainty was  $\pm 8\%$  for the 1990–1998 estimates and  $\pm 7\%$  for the 1999–2006 estimates.

The data sources and methodology used are consistent over the time series.

### 4.8.4 Category-Specific QA/QC and Verification

Informal checks (such as data transcription checks, calculation checks, and unit conversion checks) were done on the category of nitric acid production. No issues of importance were detected.

44. See footnote 5

45. See footnote 5

46. See footnote 5

### 4.8.5 Category-Specific Recalculations

Over the last two years, recalculations have occurred in this category as a result of the update in activity data. The update moderately affected the estimates for the entire time series. Details of these recalculations are provided in Chapter 9.

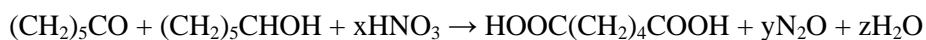
### 4.8.6 Category-Specific Planned Improvements

There are currently no improvements planned for this category.

## 4.9 Adipic Acid Production (CRF Category 2.B.3)

### 4.9.1 Source Category Description

Adipic acid ( $\text{HOOC}(\text{CH}_2)_4\text{COOH}$ ) is a dicarboxylic acid used primarily in the production of Nylon 66, resins, and plasticizers. It is produced via a two-stage oxidation process. The first step involves the oxidation of cyclohexane to form a cyclohexanone ( $(\text{CH}_2)_5\text{CO}$ ) / cyclohexanol ( $(\text{CH}_2)_5\text{CHOH}$ ) mixture. The mixture is then oxidized by a 50–60% nitric acid solution in the presence of a catalyst (e.g. vanadium or copper) to form adipic acid.  $\text{N}_2\text{O}$  is generated as a by-product in the second oxidation reaction, as shown below:



Emissions of  $\text{N}_2\text{O}$  from this manufacturing process depend on both the amount generated and the amount that can potentially be destroyed in any subsequent abatement process. When emission abatement equipment is not installed at a facility, the  $\text{N}_2\text{O}$  generated is generally vented to the atmosphere in a waste gas stream. Adipic acid production also results in emissions of NMVOCs, CO, and  $\text{NO}_x$  (IPCC/OECD/IEA 1997). Emissions of these indirect GHGs are not covered in this section. Annex 14 provides details on indirect GHG emissions.

Invista Canada, formerly Dupont Canada, located in Maitland, Ontario, has been operating the only adipic acid production facility in Canada. It has significantly reduced its  $\text{N}_2\text{O}$  emissions since 1997, when a catalytic  $\text{N}_2\text{O}$  abatement system with emission monitoring system was started up.

### 4.9.2 Methodological Issues

The emission estimates for adipic acid production have always been provided by Invista. For the period 1990–1996, when no emission controls were in place, the reported emission estimates were calculated by simply multiplying the annual adipic acid production by the IPCC default generation factor of 0.3 kg  $\text{N}_2\text{O}$ /kg adipic acid.

As mentioned above, in 1997, Invista installed a  $\text{N}_2\text{O}$  abatement system with a continuous emission monitor on the controlled off-gas stream at the abatement system outlet. Since then, the emission estimation method applied by Invista has become the following:

#### Equation 4-4:

**Total Emissions (t) =  $\text{N}_2\text{O}$  Emissions (t) with abator + Unabated  $\text{N}_2\text{O}$  Emissions (t) without abator**



The first term accounts for emissions that occur when the abator is operating, and the second for emissions that occur when the abator is *not* operating because of maintenance or technical problems.

N<sub>2</sub>O Emissions with Abator:

**Equation 4-5:**

$$\text{N}_2\text{O Emissions (t) with Abator} = \text{Production (t)} \times 0.3 \text{ t N}_2\text{O/t adipic acid} \times (1 - \text{Destruction Efficiency}) \times \text{Abatement Utilization Ratio}$$

where:

Destruction Efficiency is determined based on the difference between the amount of N<sub>2</sub>O entering the abatement unit and that leaving the unit. It is a monthly average calculated using values recorded by analyzers, which are located at the inlet and outlet of the abator. The targeted instantaneous destruction efficiency is 97%.

Abatement Utilization Ratio is the number of hours during which N<sub>2</sub>O goes through the abator divided by the total operating time.

N<sub>2</sub>O Emissions without Abator:

**Equation 4-6:**

$$\text{N}_2\text{O Emissions (t) without Abator} = \text{Production (t)} \times 0.3 \text{ t N}_2\text{O/t adipic acid} \times (1 - \text{Abatement Utilization Ratio})$$

It is important to note that the in-line continuous emission monitor has never been used to directly monitor net N<sub>2</sub>O emissions. This is because the analyzer is limited to accurately measuring relatively low concentrations of N<sub>2</sub>O only when the reactor is online and abating N<sub>2</sub>O gas. The analyzer is not capable of measuring the full range of N<sub>2</sub>O concentrations that could potentially exist in the stack. The N<sub>2</sub>O concentration can vary from a low nominal level of 0.3% when the stream leaves the abator to a high nominal level of 35–39% N<sub>2</sub>O in the unabated stream. When the abatement reactor is bypassed, there is no N<sub>2</sub>O abatement occurring, and the analyzer will not record N<sub>2</sub>O stack emissions (Cheminfo Services 2006).

The calculation techniques used to estimate emissions for the periods 1990–1997 and 1998–2006 are basically the same as the default methods presented in the IPCC good practice guidance (IPCC 2000) and the revised 1996 IPCC guidelines (IPCC/OECD/IEA 1997).

### 4.9.3 Uncertainties and Time-Series Consistency

According to the ICF Consulting (2004) report, the 2001 N<sub>2</sub>O emission estimate for adipic acid production had an uncertainty of ±2%, reflecting the random component of the uncertainty related to monitoring and reporting of emissions. The results of the ICF Consulting Tier 2 uncertainty assessment are applicable to the 2005 estimate for this category. During the Cheminfo Services (2006) study, a Tier 1 uncertainty assessment was also performed.

The data source remains consistent over the time series, but the methodology has evolved over the years, as mentioned in the methodological issues section.

#### **4.9.4 Category-Specific QA/QC and Verification**

Adipic acid production was a key category that has undergone Tier 1 QC checks as developed in the QA/QC plan (see Annex 6). The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC good practice guidance (IPCC 2000). No issues of importance were detected from the Tier 1 QC process.

#### **4.9.5 Category-Specific Recalculations**

There were no recalculations of N<sub>2</sub>O emissions related to adipic acid production.

#### **4.9.6 Category-Specific Planned Improvements**

There are currently no improvements planned specifically for this category.

### ***4.10 Iron and Steel Production (CRF Category 2.C.1)***

#### **4.10.1 Source Category Description**

Crude (pig) iron is produced in a blast furnace through the reduction of iron oxide (ore), with the carbon in coke or charcoal as the reducing agent. In most iron furnaces, the process is aided by the use of limestone fluxes (IPCC 2000). Steel can be made in electric arc furnaces (EAFs), basic oxygen furnaces, or cupola furnaces. Low-carbon steel is produced in basic oxygen furnaces, where a mixture of pig iron and iron scrap is remelted in the presence of pure oxygen, which oxidizes the dissolved carbon to CO or CO<sub>2</sub>. Carbon and alloy steels are produced in EAFs, refractory-lined pots that utilize electric heating through graphite electrodes, which are consumed in the process (IPCC/OECD/IEA 1997).

In the production of pig iron, carbon plays the dual role of fuel and reductant. Emissions from the combustion of fuels such as coke oven gas are not reported in this category, but rather under the appropriate industrial category in the Energy Sector. CO<sub>2</sub> emissions from carbon oxidation, which occurs when iron ore is reduced to pig iron, are included in this category. Also accounted for in this category are emissions during steel production, which occur to a much lesser extent. These come from the oxidation of carbon in crude iron and electrode consumption. Additional CO<sub>2</sub> given off by limestone flux in the blast furnace is covered under Limestone and Dolomite Use (Section 4.4.1).

#### **4.10.2 Methodological Issues**

To estimate CO<sub>2</sub> emissions from iron and steel production at a national level, the Tier 2 method, as described in the IPCC good practice guidance (IPCC 2000), was used. With this methodology, the fate of carbon was tracked throughout the production process, and emissions from iron production and steel production were calculated separately. The following equation was used to estimate emissions from pig iron production:

**Equation 4-7:**

$$\text{Emissions}_{\text{pig iron}} = (\text{Emission Factor}_{\text{reductant}} \times \text{mass of reductant}) + (\text{mass of carbon in the ore} - \text{mass of carbon in pig iron}) \times 44/12$$

where:

Emissions <sub>Pig Iron</sub>	=	Emissions from pig iron production, kt
Emission Factor <sub>reductant</sub>	=	2.479 kt CO <sub>2</sub> /kt of coke used (Jaques 1992)
mass of reductant	=	mass of metallurgical coke used in the process, kt
mass of carbon in the ore	=	zero; according to the IPCC (2000), kt
mass of carbon in pig iron	=	total pig iron production, kt × carbon content in pig iron, 4%
44/12	=	ratio of the molecular weight of CO <sub>2</sub> to the molecular weight of carbon

Reducing agents used to produce crude iron from iron ore can be coke, coal, charcoal, heavy fuel oil, or petroleum coke. However, for the purposes of this category's emission estimates, it was assumed that the reductant used in the Canadian industry is 100% metallurgical coke. The carbon content in pig iron is about 4% (IPCC 2006) and the carbon content in ore is almost zero (IPCC 2000). The GHG emissions associated with the use of reductants other than metallurgical coke, are estimated in the Other and Undifferentiated source category.

The data source for the use of metallurgical coke was the RESD (Statistics Canada #57-003). Data on total pig iron production in Canada came from Statistics Canada (for 1990–2003: #41-001; and for 2004–2006: #41-019).

Emissions from steel production were estimated using the following equation:

**Equation 4-8:**

$$\text{Emissions}_{\text{crude steel}} = [(\text{mass of carbon in pig iron used for crude steel} - \text{mass of carbon in crude steel}) \times 44/12] + (\text{Emission Factor}_{\text{EAF}} \times \text{steel produced in EAFs})$$

where:

Emissions <sub>crude steel</sub>	=	Emissions from crude steel production, kt
mass of carbon in pig iron used for crude steel	=	total pig iron charged to steel furnaces, kt × carbon content of pig iron, 4%
mass of carbon in crude steel	=	total steel production, kt × carbon content in crude steel, 1.25%
44/12	=	ratio of the molecular weight of CO <sub>2</sub> to the molecular weight of carbon
Emission Factor <sub>EAF</sub>	=	emission factor for steel produced in EAFs, 0.005 kt CO <sub>2</sub> /kt steel
steel produced in EAFs	=	the amount of steel produced in EAFs, kt

According to Equation 4-8, the amount of CO<sub>2</sub> emitted from steel production is estimated based on the difference between the amount of carbon in the iron used to make steel and that in the steel produced. It should be noted that the amount of pig iron fed to steel furnaces (used in Equation 4-8) does not equal the amount of total pig iron production (used in Equation 4-7). The quantity charged to steel furnaces is usually higher than the quantity produced.

Data on the total pig iron charged to steel furnaces, on total steel production, and on the amount of steel produced in EAFs were obtained from Statistics Canada (for 1990–2003: #41-001 and for 2004–2006: #41-019). The value of the carbon content in crude steel applied in the equation was 1.25%, and it was also the midpoint of the IPCC default range (0.5–2%). The emission factor for steel produced in EAFs of 5 kg CO<sub>2</sub>/t steel (or 0.005 kt CO<sub>2</sub> kt steel) was the default value shown in the IPCC good practice guidance (IPCC 2000).

The total emissions from the sector of iron and steel production is the sum of Equation 4-7 and Equation 4-8 above.

Data on metallurgical coke use at provincial/territorial levels from the RESD (Statistics Canada #57-003) were used to derive the percentage of total reductant consumption attributed to each province and territory. CO<sub>2</sub> emissions at provincial/territorial levels were then estimated by multiplying the percentage derived by the national emission estimate.

It should be noted that RESD data (Statistics Canada #57-003) published for any given year are preliminary and subject to revision in subsequent publications.

The method described above does not account for additional CO<sub>2</sub> given off by the use of limestone as flux in blast furnaces, since the limestone-consumption-related emissions are included in the subsector of Limestone and Dolomite Use.

The use of petroleum coke in EAF electrodes is reported by Statistics Canada with all other non-energy uses of petroleum coke. To avoid double-counting, the CO<sub>2</sub> emissions from the consumption of electrodes in the steel production process in EAFs are therefore subtracted from the total non-energy emissions. It is assumed that there are no imported electrodes used for steel production in EAFs in Canada. If there is import of electrodes, then the portion of CO<sub>2</sub> generated by the imported electrodes will need to be subtracted from the emissions from electrode consumption before being subtracted from the total non-energy emissions.

#### **4.10.3 Uncertainties and Time-Series Consistency**

The uncertainty in the 2001 inventory's CO<sub>2</sub> emission estimate for iron and steel production is ±5% (ICF Consulting 2004). It should be noted that this represents a conservative uncertainty value for the 2006 inventory emission estimates because the methodology for calculating CO<sub>2</sub> emissions has improved since the 1990–2002 inventory. The shift from a Tier 1 to a Tier 2 approach is expected to lower the uncertainty. However, an updated analysis would be needed to fully assess the uncertainty in the emission estimates calculated using a Tier 2-type technique.

The data sources and methodology used are consistent over the time series.

#### **4.10.4 Category-Specific QA/QC and Verification**

Iron and steel production is a key category that has undergone Tier 1 QC checks as developed in the QA/QC plan (see Annex 6). The checks performed are consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC 2000). No issues of importance were detected from the Tier 1 QC process.

A Tier 2 QC was done for this category for submission 2008.

#### 4.10.5 Category-Specific Recalculations

Over the last two years, recalculations have occurred in this category as a result of revisions in the 2004–2005 metallurgical coke consumption data. These recalculations moderately affected the 2004–2005 estimates. Details of these recalculations can be found in Chapter 9.

#### 4.10.6 Category-Specific Planned Improvements

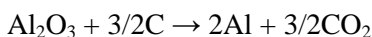
Efforts will be made to rectify the assumption made regarding the agent used to reduce iron ore. In the current estimation methodology, it is assumed that the reductant used by industry is 100% metallurgical coke. However, it is known that there are other reductants, such as natural gas and coal, that have been used by the iron and steel industry over the years. Hence, part of the CO<sub>2</sub> emissions coming from non-energy use of fossil fuels, currently reported under the category of Other and Undifferentiated Production and also those reported under the Energy Sector, may be reallocated to the category of Iron and Steel Production. Obtaining country-specific carbon contents of steel and of pig iron is also part of the planned improvements.

### 4.11 Aluminium Production (CRF Category 2.C.3)

#### 4.11.1 Source Category Description

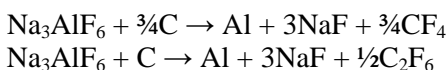
Primary aluminium is produced in two steps. In the first stage, bauxite ore is ground, purified, and calcined to produce alumina (Al<sub>2</sub>O<sub>3</sub>). The latter is then, in the second stage, electrically reduced to aluminium by smelting in large pots with carbon-based anodes. The pot itself (a shallow steel container) forms the cathode, whereas the anode consists of one or more carbon blocks suspended within it. Inside the pot, alumina is dissolved in a cryolite (Na<sub>3</sub>AlF<sub>6</sub>) bath. Passing a current through the resistance of the cell causes the heating effect, which maintains the contents in a liquid state. The aluminium forms at the cathode and gathers on the bottom of the pot.

As the anode is consumed, CO<sub>2</sub> is formed in the following reaction, provided that enough alumina is present at the anode surface:



Although most of the CO<sub>2</sub> forms from the electrolysis reaction of the carbon anode with alumina as shown above, other sources, namely the baking of prebaked anodes, can contribute to some (usually less than 10%) of the total non-energy related CO<sub>2</sub> emissions. Emissions from the combustion of fossil fuels used in the production of baked anodes are covered in the Energy section, but emissions arising specifically from the combustion of volatile matter released during the baking operation and from the combustion of baking furnace packing material are accounted for under the Industrial Processes section (IPCC 2006).

In addition to CO<sub>2</sub> emissions, primary aluminium smelting is a major source of carbon tetrafluoride (CF<sub>4</sub>) and carbon hexafluoride (C<sub>2</sub>F<sub>6</sub>). When alumina levels are too low, these PFCs are formed during an occurrence known as the “anode effect” or “anode event.” In theory, when an anode event occurs, the cell resistance increases very suddenly (within a 50th of a second). As a result, the voltage rises and the temperature goes up, forcing the molten fluorine salts in the cell to chemically combine with the carbon anode (Laval University 1994). During the anode event, competing reactions shown below occur to produce CF<sub>4</sub>, and C<sub>2</sub>F<sub>6</sub>.



PFC emissions can be controlled by computerized alumina feeders. Sensors measure the alumina concentration and automatically feed more to the pot when levels become low. In this way, anode events can be controlled. The computers can be programmed to detect the onset of anode events as well, providing additional warning for the system to take counteractive measures. “Point” feeders, as opposed to “centre-break” types, also tend to reduce emissions (Øye and Huglen, 1990).

Besides CO<sub>2</sub>, CF<sub>4</sub>, and C<sub>2</sub>F<sub>6</sub>, a small amount of SF<sub>6</sub> is also emitted from its use as cover gas at some aluminium plants that produce high magnesium-aluminium alloys (2007 e-mail from P. Chaput).<sup>47</sup>

Aluminium plants are characterized by the type of anode technology employed. In general, older plants with Söderberg technology have higher emissions than newer plants, which usually use pre-baked anodes. The trend in the Canadian aluminium industry has been towards modernizing facilities, since production efficiency has improved. In some cases, this has meant taking old lines out of production as new ones are installed to meet increasing demand.

Finally, even though aluminium production consumes extremely large quantities of electrical energy, currently estimated to be 13.5 kWh/kg of aluminium (AIA 1993), GHG emissions associated with its electricity consumption are not necessarily high in a Canadian context. All of Canada’s primary aluminium smelters are located in Quebec and British Columbia, where almost all (95%) of the electricity generated is produced by hydraulic generators; these are believed to emit a negligible amount of GHGs compared with conventional fossil fuel-based electricity generators.

#### 4.11.2 Methodological Issues

Process-related emission estimates for aluminium production were directly obtained from companies via the AAC. In addition to the smelter-specific emission estimates, information on the methodologies used by the aluminium producers to calculate CO<sub>2</sub>, PFC, and SF<sub>6</sub> emissions was obtained from the AAC. The estimation techniques applied may be Tier 3–, Tier 2–, or Tier 1–type, as described below, depending on data availability; a Tier 3–type technique has mostly been applied for estimating emissions for recent years.

Calculating CO<sub>2</sub> emissions:

Typically, the equations used by smelters to estimate CO<sub>2</sub> emissions from the reaction of the carbon anode with alumina are (AAC 2002b):

---

47. E-mail received from P. Chaput, AAC, on October 12, 2007. This e-mail contains a response from Alcan (in MS Word format) to a set of questions asked by the GHG Division.

**Equation 4-9 for pre-baked anode consumption:**

$$\text{CO}_2 \text{ Emissions (t)} = [\text{CC} \times \text{MP} \times (100 - \%S_a - \%Ash_a - \%Imp_a)/100] \times 44/12$$

where:

CC	=	baked anode consumption per tonne of aluminium (t C/t Al)
MP	=	total aluminium production (t)
S <sub>a</sub>	=	sulphur content in baked anodes (wt %)
Ash <sub>a</sub>	=	ash content in baked anodes (wt %)
Imp <sub>a</sub>	=	fluorine and other impurities (wt %)*
44/12	=	ratio of the molecular weight of CO <sub>2</sub> to the molecular weight of carbon

\* The weight percentage of fluorine and other impurities may not be a parameter considered by all the smelters.

**Equation 4-10 for Söderberg anode consumption:**

$$\text{CO}_2 \text{ Emissions (t)} = \left\{ (\text{PC} \times \text{MP}) - (\text{BSM} \times \text{MP}/1000) - [\%BC/100 \times \text{PC} \times \text{MP} \times (\%S_p + \%Ash_p + \%H_2) / 100] - [(100 - \%BC)/100 \times \text{PC} \times \text{MP} \times (\%S_c + \%Ash_c)/100] \right\} \times 44/12$$

where:

PC	=	paste consumption (t paste/t Al)
MP	=	total aluminium production (t)
BSM	=	emissions of benzene-soluble matter (kg/t Al)
BC	=	average binder content in paste (wt %)
S <sub>p</sub>	=	sulphur content in pitch (wt %)
Ash <sub>p</sub>	=	ash content in pitch (wt %)
H <sub>2</sub>	=	hydrogen content in pitch (wt %)
S <sub>c</sub>	=	sulphur content in calcinated coke (wt %)
Ash <sub>c</sub>	=	ash content in calcinated coke (wt %)
44/12	=	ratio of the molecular weight of CO <sub>2</sub> to the molecular weight of carbon

The use of the above equations with actual plant-specific data is considered a Tier 3-type methodology. A Tier 2-type technique involves the application of some measured data in combination with industry-typical values to these equations. Shown in Table 4-3 are Tier 2 industry-typical values that can be applied by facilities.

**Table 4-3: Default Tier 2 Parameter Values for the Estimation of CO<sub>2</sub> Emissions from Anode Consumption**

Parameter	Industry Typical Value	Source
<b>For Prebaked Anode Consumption:</b>		
sulphur content in baked anodes (wt %) - $S_a$	2%	IAI, 2006
ash content in baked anodes (wt %) - $Ash_a$	0.4%	IAI, 2006
fluorine and other impurities (wt %) - $Imp_a$	0.4%	AAC, 2002b
<b>For Søderberg Anode Consumption:</b>		
Parameter	Industry Typical Value	Source
emissions of benzene-soluble matter (kg/t Al) - BSM	For HSS: 4.0 kg/ t Al For VSS: 0.5 kg/ t Al	IAI, 2006
average binder content in paste (wt %) - BC	Dry Paste: 24% Wet Paste: 27%	IAI, 2006
sulphur content in pitch (wt %) - $S_p$	0.6 %	IAI, 2006
ash content in pitch (wt %) - $Ash_p$	0.2%	IAI, 2006
hydrogen content in pitch (wt %) - $H_2$	3.3%	IAI, 2006
sulphur content in calcinated coke (wt %) - $S_c$	1.9%	IAI, 2006
ash content in calcinated coke (wt %) - $Ash_c$	0.2%	IAI, 2006

When no process data other than aluminium production are available, emission factors for a Tier 1 method (as shown below) can be used. These factors depart slightly from the IPCC default ones, because the IPCC Tier 1 default factors reflect 1990 emissions and would produce considerable errors if applied to current production. The factors below reflect the considerable progress that has been made over the period from 1990 to 2001 (AAC 2002b and IAI 2006):

Søderberg: EF = 1.7 t CO<sub>2</sub>/t Al produced; and

Pre-baked: EF = 1.6 t CO<sub>2</sub>/t Al produced.

To calculate CO<sub>2</sub> emissions resulting from anode baking (i.e., pitch volatiles combustion and combustion of baking furnace packing material), the following equations are used (AAC 2002a):

**Equation 4-11 for Pitch Volatiles Combustion:**

$$\text{CO}_2 \text{ Emissions (t)} = [\text{GAW} - \text{BAP} - \text{HW} - \text{RT}] * 44/12$$

where:

GAW	=	green anode weight (t)
BAP	=	baked anode production (t)
HW	=	weight of hydrogen from pitch (t) = %H <sub>2</sub> / 100 * PC / 100 * GAW
H <sub>2</sub>	=	hydrogen content in pitch (wt%)
PC	=	average pitch content in green anode (wt%)
RT	=	waste tar collected (t)
44/12	=	ratio of the molecular weight of CO <sub>2</sub> to the molecular weight of carbon



**Equation 4-12 for Packing Coke:**

$$\text{CO}_2 \text{ Emissions (t)} = [\text{PCC} * \text{BAP} * (100 - S_{pc} - \text{Ash}_{pc}) / 100] * 44/12$$

where:

PCC	=	packing coke consumed (t coke/ t of baked anode)
BAP	=	baked anode production (t)
$S_{pc}$	=	sulphur content in packing coke (wt%)
$\text{Ash}_{pc}$	=	ash content in packing coke (wt%)
44/12	=	ratio of the molecular weight of CO <sub>2</sub> to the molecular weight of carbon

Like in the case of anode consumption, the use of the equations 4-11 and 4-12 with actual plant-specific data is considered a Tier 3-type methodology. A Tier 2-type technique involves the application of some measured data in combination with industry-typical values to these equations. Shown in Table 4-4 are Tier 2 industry-typical values that can be applied by facilities to estimate CO<sub>2</sub> emissions arising from anode baking.

**Table 4-4: Default Tier 2 Parameter Values for the Estimation of CO<sub>2</sub> Emissions from Anode Baking**

Parameter	Industry Typical Value	Source
<b>For Pitch Volatiles Combustion:</b>		
hydrogen content in pitch (wt%) - %H <sub>2</sub>	0.5%	IAI 2006
waste tar collected (t) - RT	For Riedhammer furnaces only; all others are insignificant	IAI 2006
<b>For Packing Coke:</b>		
packing coke consumed (t coke/ t of baked anode) – PCC	0.015 t/ t	IAI 2006
sulphur content in packing coke (wt%) - $S_{pc}$	2%	IAI 2006
ash content in packing coke (wt%) - $\text{Ash}_{pc}$	2.5%	IAI 2006

According to recent communication with representatives of the Canadian aluminium industry (2007 e-mails from P. Chaput and C. Dubois),<sup>48</sup> one of the three aluminium companies has only relied on plant-specific values to develop its process CO<sub>2</sub> estimates (Tier 3), whereas the other two companies have used for estimates of some years default parameter values shown in Tables 4-3 and 4-4 above.

It should be noted that the use of petroleum coke in anodes for the production of aluminium was also reported by Statistics Canada with all other non-energy uses of petroleum coke. To avoid double-counting, the CO<sub>2</sub> emissions from the consumption of anodes in the aluminium smelting process were therefore subtracted from the total non-energy emissions associated with the consumption of petroleum coke.

48. E-mails received from P. Chaput, AAC and C. Dubois, Alcoa, on October 12, 2007. These e-mails contain responses from aluminium companies (in MS Word format) to a set of questions asked by the GHG Division.

## Calculating PFC Emissions:

CF<sub>4</sub> and C<sub>2</sub>F<sub>6</sub> emitted during anode effects can be calculated by smelters using either the Slope Method or the Pechiney Overvoltage Method, depending on the smelter technology (AAC 2002a):

**Equation 4-13 for Slope Method:**

$$\text{PFC Emissions (t CO}_2\text{ eq)} = \text{slope} \times \text{AEF} \times \text{AED} \times \text{MP} \times \text{GWP} / 1000$$

where:

slope	=	slope (for CF <sub>4</sub> or C <sub>2</sub> F <sub>6</sub> ) of the emission relationship ([kg PFC/t Al]/[AE-minutes/cell-day])
AEF	=	number of anode effects per pot per day (AE/cell-day)
AED	=	anode effect duration (minutes)
MP	=	total aluminium production (t)
GWP	=	global warming potential for CF <sub>4</sub> or C <sub>2</sub> F <sub>6</sub>

**Equation 4-14 for Pechiney Overvoltage Method:**

$$\text{PFC Emissions (t CO}_2\text{ eq)} = \text{overvoltage coefficient} \times \text{AEO} / \text{CE} \times \text{GWP} \times \text{MP} / 1000$$

where:

overvoltage coefficient	=	([kg PFC/t Al]/[mV/cell-day])
AEO	=	anode effect overvoltage (mV/cell-day)
CE	=	aluminium production process current efficiency expressed as a fraction
GWP	=	global warming potential for CF <sub>4</sub> or C <sub>2</sub> F <sub>6</sub>
MP	=	total aluminium production (t)

The use of the above equations with actual process data to estimate PFC emissions is considered a Tier 3–type methodology. The estimation technique is considered as Tier 2–type when the default coefficients shown in Table 4-5 (IAI 2006) are used together with smelter-specific operating parameters. In a Tier 2 approach, one would first estimate emissions of CF<sub>4</sub> using the slope or overvoltage coefficients as per equations 4–13 and 4–14. Emissions of C<sub>2</sub>F<sub>6</sub> are then calculated by multiplying the CF<sub>4</sub> estimates by the CF<sub>4</sub>/C<sub>2</sub>F<sub>6</sub> weight fraction.

**Table 4-5: Tier 2 Default Slope and Overvoltage Coefficients (IAI 2006)**

Type of Cell	Slope Coefficients for CF <sub>4</sub>	Overvoltage Coefficients for CF <sub>4</sub>	Weight Fraction
	([kg PFC/t Al]/[AE-minutes/cell-day])	([kg PFC/t Al]/[mV/cell-day])	CF <sub>4</sub> / C <sub>2</sub> F <sub>6</sub>
Centre Worked Pre-Baked	0.143	1.16	0.121
Side Worked Pre-Baked	0.272	3.65	0.252
Vertical Stud Söderberg	0.092	NA	0.053
Horizontal Stud Söderberg	0.099	NA	0.085

Note: NA = not applicable

If only production statistics are available (i.e. no data on anode effect frequency, anode effect duration, or anode effect overvoltage), the Tier 1 emission factors shown in Table 4-6 can be used by smelters (IAI 2006).

**Table 4-6: PFC Emission Factors**

Type of Cell	Emission Factors (kg PFC/t Al)	
	CF <sub>4</sub>	C <sub>2</sub> F <sub>6</sub>
Centre Worked Pre-Baked	0.4	0.04
Side Worked Pre-Baked	1.6	0.4
Vertical Stud Søderberg	0.8	0.04
Horizontal Stud Søderberg	0.4	0.03

Based on recent information provided by the Canadian aluminium industry (2007 e-mail from P. Chaput),<sup>49</sup> one of the three aluminium companies has solely relied on plant-specific values to develop its process PFC estimates (Tier 3), whereas the other two companies have used for estimates of some years default parameter values shown in Tables 4-5 and 4-6 above.

Calculating SF<sub>6</sub> Emissions:

According to the methodology documents supplied by the AAC, SF<sub>6</sub> emissions are equal to consumption in the aluminium industry. This method is consistent with the revised 1996 IPCC guidelines (IPCC/OECD/IEA 1997).

#### 4.11.3 Uncertainties and Time-Series Consistency

The uncertainties in CO<sub>2</sub> and PFC emission estimates for aluminium production provided in the ICF Consulting (2004) report are not applicable to the 2006 inventory year estimates because of the change in methodology from Tier 1, at the time when the ICF study was conducted, to Tier 3, for recent years of the time series. Emission data obtained via the AAC, which are included in this year's submission, are believed to be significantly more accurate than the estimates shown in the 1990–2001 inventory report. Moreover, as estimates of SF<sub>6</sub> emissions from aluminium production were not included in the 1990–2001 inventory, uncertainties around these were not examined by ICF Consulting (2004). However, uncertainty estimates for the default parameter values shown in the methodology section can be found in the *Aluminium Sector Greenhouse Gas Protocol* published by the International Aluminium Institute (IAI 2006). The protocol also provides uncertainty values around some of the Tier 3 facility-level data. Hence, for future inventories, a Tier 1 uncertainty analysis can potentially be conducted using the uncertainty values suggested in the IAI protocol and additional inputs to be obtained from the aluminium industry.

The AAC has consistently been used as the data source of estimates shown in this inventory over the time series. The methodology applied by smelters may be Tier 3–, Tier 2–, or Tier 1–type, depending on data availability. However, for recent years, a Tier 3–type technique has been applied by all smelters for estimating emissions.

49. E-mail received from P. Chaput (of AAC) on October 12, 2007. This e-mail contains the response prepared by an aluminium company (in MS Word format) for a set of questions asked by the GHG Division.

#### 4.11.4 Category-Specific QA/QC and Verification

CO<sub>2</sub> and PFC emissions from aluminium production were key categories that have undergone Tier 1 QC checks as elaborated in the QA/QC plan (see Annex 6). The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC good practice guidance (IPCC 2000). No issues of importance were detected from the Tier 1 QC process.

#### 4.11.5 Category-Specific Recalculations

Over the last two years, updates in the 1990–2004 SF<sub>6</sub> emission estimates and in the 2004–2005 PFC emission estimates were provided by the aluminium industry. As a result of this data acquisition, the total GHG emissions coming from this sector were slightly recalculated. A more detailed discussion on these recalculations and their impact is provided in Chapter 9.

#### 4.11.6 Category-Specific Planned Improvements

There are currently no improvements planned specifically for estimating CO<sub>2</sub>, PFC, and SF<sub>6</sub> emissions from aluminium production in Canada. However, efforts will be made to update the uncertainty analysis. Efforts will also be made to acquire more information on the QC procedures followed by member companies when estimates were developed and ensure that adequate QC was undertaken.

### 4.12 Magnesium Metal Production and Casting (CRF Categories 2.C.5.1 & 2.C.4.2)

#### 4.12.1 Source Category Description

SF<sub>6</sub> is emitted during magnesium production and casting, where it is used as a cover gas to prevent oxidation of the molten metals. Although emitted in relatively small quantities, SF<sub>6</sub> is an extremely potent GHG, with a 100-year GWP of 23 900. SF<sub>6</sub> is not manufactured in Canada. All SF<sub>6</sub> is imported.

During the period 1990–2006, there were two major magnesium producers in Canada: Norsk Hydro and Timminco Metals. Another magnesium producer, Métallurgie Magnola, existed between 2000 and 2003, but has been shut down since April 2003. Between 1990 and 2004, Norsk Hydro had invested in research and development projects having as objectives finding a substitute for SF<sub>6</sub> and eventually eliminating the use of SF<sub>6</sub> as cover gas at its plant (2004 e-mail from J. Laperrière).<sup>50</sup> This research and use of substitute gas mixtures produced significant reductions in SF<sub>6</sub> emissions in the mid- to late 1990s. For the years 2005–2006, Norsk Hydro's SF<sub>6</sub> emissions were significantly reduced as a result of production reduction.

There were in total 11 magnesium casting facilities in operation during the period 1990–2004 (Cheminfo Services 2005b). Only a few of them had used SF<sub>6</sub> every year during the entire period. Some casters started using SF<sub>6</sub> towards the mid- or late 1990s, whereas others replaced it with an alternative gas, such as SO<sub>2</sub>. Two facilities have ceased their casting operations over the last few years. In 2005–2006, only seven facilities were in operation and still used SF<sub>6</sub>.

---

50. E-mail received by A. Au (Environment Canada) from J. Laperrière, Norsk Hydro, on October 27, 2004. This e-mail provides explanations on the research project done by Norsk Hydro over the years to find an alternative to SF<sub>6</sub>, and the alternative gas used by Norsk Hydro.

#### 4.12.2 Methodological Issues

For SF<sub>6</sub> emissions from magnesium production, data for 1999–2005 were directly reported by the companies (Norsk Hydro, Timminco Metals, and Métallurgie Magnola Inc.) through a mandatory emissions reporting program known as the National Pollutant Release Inventory (NPRI).

Emission estimates used in this report were obtained from the NPRI's online database ([http://www.ec.gc.ca/pdb/querysite/query\\_e.cfm](http://www.ec.gc.ca/pdb/querysite/query_e.cfm)). For previous years (i.e. 1990–1998), the data were provided voluntarily by the producers to the GHG Division over the telephone.

Representatives from both Norsk Hydro and Timminco were contacted in 2006, so that the methodology they have applied to estimate SF<sub>6</sub> emissions could be understood. Both companies reported that they used the IPCC default method (Emissions of SF<sub>6</sub> = Consumption of SF<sub>6</sub>), as recommended in the IPCC good practice guidance (IPCC 2000). However, they have used different ways for estimating their SF<sub>6</sub> consumption. Norsk Hydro confirmed the use of the weight difference method (2006 e-mail from J. Laperrière).<sup>51</sup> This method is based on measuring the weight of gas cylinders used at the facility at the time when these were purchased and when these were returned to suppliers at the end of the usage. The accounting method was reported as being used by Timminco for estimating its SF<sub>6</sub> use (2006 e-mails from Katan).<sup>52</sup> In this method, accounting of delivered purchases and inventory changes of SF<sub>6</sub> used are recorded. The purchases must be the actual volumes received in the calendar period; therefore, beginning-of-year and end-of-year inventories are taken into account.

The technique applied to estimate emissions from magnesium production is considered to be a Tier 3–type method, as it is based on the reporting of facility-specific emission data.

For calculating SF<sub>6</sub> emissions from casters, the revised 1996 IPCC guidelines (IPCC/OECD/IEA 1997) provide one general equation that assumes that all SF<sub>6</sub> used as a cover gas is emitted to the atmosphere. To estimate SF<sub>6</sub> emissions for 1990–2004 using this equation, attempts had been made, through a study (Cheminfo Services 2005b) in 2005, to collect data on SF<sub>6</sub> consumption from casting facilities. A couple of facilities indicated that they did not hold any historical records of their past SF<sub>6</sub> consumption. Therefore, to estimate SF<sub>6</sub> use for the entire time series, results of a previous study (Cheminfo Services 2002) were used in combination with the data received from the Cheminfo Services (2005b) study and some assumptions. For casters that had SF<sub>6</sub> data for only a year, it was assumed that their SF<sub>6</sub> use stayed constant, during the other operating years, at the level of the year for which the actual SF<sub>6</sub> data were obtained. For casters that had data for more than one year, linear interpolation between two data points was applied to estimate SF<sub>6</sub> consumption for the other years.

For 2005–2006, consumption data were provided by all seven operating casting facilities in a voluntary data submission process. They were used for the calculation of emissions.

The technique applied to estimate emissions from magnesium casting for 1990–2004 is considered to be a modified Tier 3–type method, as it is based on the reporting of facility-specific emission data and some assumptions. For 2005–2006, the method used is considered as a Tier 3–type.

51. E-mail received by A. Au (Environment Canada) from J. Laperrière, Norsk Hydro, on October 4, 2006. This e-mail contains explanations on the method used by Norsk Hydro to estimate its SF<sub>6</sub> emissions/consumption.

52. E-mails received by A. Au (Environment Canada) from R. Katan, Timminco, on March 16–22, 2006. These e-mails contain details on the method used by Timminco to estimate its SF<sub>6</sub> emissions/consumption.

### 4.12.3 Uncertainties and Time-Series Consistency

The uncertainty in the SF<sub>6</sub> emission estimate for magnesium production, provided in the ICF Consulting (2004) report, was evaluated at  $\pm 1\%$ . It is applicable to the 2006 estimate because there has been no change in the data source since the ICF Consulting study was completed.

For the subsector of magnesium production, the methodology and data sources remain consistent over the time series. Emissions from two primary magnesium smelters, Norsk Hydro and Timminco, were reported directly to Environment Canada between 1990 and 1998. Estimates of SF<sub>6</sub> emissions from all three smelters, including Magnola, which started up in 2000 and shut down in 2003, have been submitted to the NPRI since 1999.

According to the Cheminfo Services (2005b) study, the SF<sub>6</sub> emission estimate for magnesium casters has an uncertainty of 4%. This is a weighted average, depending on each company's consumption of SF<sub>6</sub> and the overall data availability. The uncertainty estimate is applicable to the 2006 estimate because there has been no change in the data source since the Cheminfo study was completed.

The data source remains consistent over the time series. The methodology, which is equating consumption of SF<sub>6</sub> as a cover gas by magnesium casters to emissions of SF<sub>6</sub>, is applied over the time series with some assumptions for some historical years, as discussed in the methodology section.

### 4.12.4 Category-Specific QA/QC and Verification

Magnesium production was a key category that has undergone Tier 1 QC checks as elaborated in the QA/QC plan (see Annex 6). The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC good practice guidance (IPCC 2000). No issues of importance were detected from the Tier 1 QC process.

Magnesium casting was a non-key category that has undergone Tier 1 QC checks as per the GHG Division's QA/QC schedule. No issues of importance were detected from the Tier 1 QC process..

### 4.12.5 Category-Specific Recalculations

Over the last two years, recalculations have occurred in the category of magnesium production due to acquisition of updated 1999–2001 data (data with higher resolution). Revisions were done to the 1991–2005 SF<sub>6</sub> emission estimates for magnesium casting to correct transcription errors and to include updated data provided by companies.

### 4.12.6 Category-Specific Planned Improvements

There are currently no improvements planned specifically for estimating SF<sub>6</sub> emissions from magnesium production and casting in Canada.

## 4.13 Production of Halocarbons (CRF Category 2.E)

### 4.13.1 Source Category Description

Chlorodifluoromethane (HCFC-22 or CHClF<sub>2</sub>) is produced when reacting chloroform (CHCl<sub>3</sub>) with hydrogen fluoride (HF), in the presence of antimony pentachloride (SbCl<sub>5</sub>) as catalyst.

During the manufacture of HCFC-22, trifluoromethane (HFC-23 or CHF<sub>3</sub>) is generated as a by-product (IPCC 2002).

The reaction is carried out in a continuous flow reactor, usually under high pressure (up to 500 psig) and temperatures in the order of 45 to 200°C. Although the reaction is exothermic, heat is added to increase the flow of vapours leaving the reactor. The vapour stream contains HCFC-22 (CHClF<sub>2</sub>), HFCF-21 (CHCl<sub>2</sub>F), HFC-23 (CHF<sub>3</sub>), HCl, excess CHCl<sub>3</sub>, HF and some entrained catalyst. Subsequent processing of the vapour stream involves several separations to remove/recover by-products and to purify HCFC-22. Unreacted chloroform, entrained catalyst and underfluorinated intermediates (i.e. HCFC-21) from the vapour stream are condensed and returned to the reactor. The major emission point for HFC-23 is the condenser vent, where HFC-23 is discharged into the atmosphere after being separated from HCFC-22 (IPCC 2002).

Two HCFC-22 producers (Dupont Canada and Allied-Signal) operated in Canada during the years 1980s and early 1990s. They ceased their HCFC-22 production between 1990 and 1993. According to the data records transferred from the Chemical Controls Division of Environment Canada to the GHG Division, Dupont Canada produced some HCFC-22 in 1989, but none in the years 1990 and after. Allied-Signal only submitted its 1990–1992 production data to UPCIS because it stopped its operation in 1993 (2007 e-mail from Y. Bovet).<sup>53</sup>

HCFC-22 can be used as refrigerant, as a blend component in foam blowing and as a chemical feedstock for manufacturing synthetic polymers (IPCC 2002). However, due to its ozone depleting properties, developed countries have scheduled the phase-out of HCFC-22 for the coming years. In Canada, there should be no more manufacturing or import of HCFC-22-containing equipment as of Jan. 1, 2010 (HRAI 2008).

#### 4.13.2 Methodological Issues

To estimate HFC-23 emissions from HCFC-22 production, the total HCFC-22 production was multiplied by the IPCC Tier 1 default emission factor of 0.04 t HFC-23/ t HCFC-22 produced (IPCC/OECD/IEA 1997). It was assumed that destruction (through thermal oxidation) or transformation of HFC-23 was not practiced in Canada. The 1990–1992 production data were collected by the Chemical Controls Division from HCFC-producers (2007 e-mail from Y. Bovet).<sup>54</sup>

#### 4.13.3 Uncertainties and Time-Series Consistency

Uncertainty in the HFC-23 emission estimates has not been assessed. However, it was believed that the production data reported by HCFC-22 producers were reasonably accurate. The major source of uncertainty could be the Tier 1 default emission factor, because the correlation between the quantity of HFC-23 emitted and the HCFC-22 production rate can vary with plant infrastructure and operating conditions (IPCC 2002).

53. E-mail received by A. Au (Environment Canada) from Y. Bovet, Environment Canada, Chemical Controls Division, on November 8, 2007. The e-mail contains HCFC-22 production data and other information related to the HCFC-22 production.

54. See footnote 7.

#### 4.13.4 Category-Specific QA/QC and Verification

Informal checks (such as data transcription checks, calculation checks, and unit conversion checks) were done on the category of HCFC-22 production. No issues of importance were detected.

#### 4.13.5 Category-Specific Recalculations

There were no recalculations for this category. The category of HFC-23 emissions from HCFC-22 production was first introduced in the 2006 inventory resubmission (in 2007) to address a comment made by the expert review team during the in-country review.

#### 4.13.6 Category-Specific Planned Improvements

There are currently no improvements planned for this category.

### 4.14 Consumption of Halocarbons (CRF Category 2.F)

Hydrofluorocarbons (HFCs) and, to a very limited extent, perfluorocarbons (PFCs) are serving as alternatives to ozone depleting substances being phased out under the Montreal Protocol. Application areas of HFCs and PFCs include: refrigeration and air conditioning; fire suppression; aerosols; solvent cleaning; foam blowing; and other applications (such as semiconductor manufacturing in the case of PFCs).

Before the ban on the production and use of CFCs came into effect in 1996, as a result of the Montreal Protocol, very few HFCs were produced and used. The only HFCs produced were HFC-152a, a component of the refrigerant blend R-500, and HFC-23, a by-product of HCFC-22 production (discussed in the previous section). As such, emissions from HFC consumption were considered negligible for the period 1990–1994. HFC-134a entered in production in 1991 and a variety of other HFCs are now being produced (IPCC/OECD/IEA 1997). All HFCs consumed in Canada are imported in bulk or in products (e.g. refrigerators). There is no known production of HFCs in Canada.

PFCs have been primarily used as cooling/heating agents in specialized market segments and in electronic safety testing. However, emissions from the consumption of PFCs are minor relative to the by-product emissions of PFCs from aluminium production (discussed in the section on aluminium production). Like HFCs, all PFCs consumed in Canada are imported in bulk or in products. There is no known PFC manufacturing in Canada.

#### 4.14.1 Methodological Issues

HFC emission estimates for 1995 were based on data gathered from an initial HFC survey conducted by the Chemical Controls Division of Environment Canada in 1996. Environment Canada has revised subsequent surveys to obtain more detailed activity data. The 1998, 1999, 2001, and 2005 HFC surveys were the source of activity data for emission estimates for the years 1996–2000 and 2004 (2004–2006 e-mails from Y. Bovet and Y. Guilbault).<sup>55</sup> In some cases, one

---

55. E-mails received by A. Au (Environment Canada) from Y. Bovet and Y. Guilbault, Environment Canada, Chemical Controls Division, over the years 2004–2006. These e-mails contain the 1999–2000 and 2004 HFC data (compiled in MS Excel format) collected by the Chemical Controls Division.



survey was done to collect data for two years. HFC sales data for 2001–2003 were also collected in 2005 from major HFC importers in Canada (Cheminfo Services 2005c). These data were provided by market segment, such that the total quantity used for each type of application could be determined. HFC import and sales data for 2005–2006 were collected by the GHG Division through a voluntary data submission process. In this process, requests for data were sent to the main importers of bulk HFCs and to companies that import/export HFC-containing products. Around 85% of the companies to which a request was sent were able to provide their data. In the cases where data were not available from companies, it was assumed that their 2005 import quantities (i.e. the quantities they reported to the Chemical Controls Division) stayed at 2004 levels.

In addition, data on the quantities of HFCs contained in imported and exported products, except imported and exported vehicles, were not available for the years 1995 and 1999–2003. The 1999 and 2000 amounts of HFCs found in imported and exported vehicles were provided by the Chemical Controls Division. For 1995, HFC quantities in imported and exported products were assumed to be zero. For 1999–2003, these quantities were assumed to stay at 1998 levels and at the 2000 level for imported/exported vehicles.

Since detailed 1995 HFC data were not available, the IPCC Tier 2 method could not be applied. Instead, a modified Tier 1 methodology was used to obtain a representative estimate of the actual 1995 HFC emissions for the following groups: Aerosols; Foams; Air Conditioning Original Equipment Manufacture (AC OEM); AC Service; Refrigeration; and Total Flooding System. To estimate 1996–2006 HFC emissions, an IPCC Tier 2 methodology was applied. A more detailed description of the Tier 1 and Tier 2 methods used is provided in the following subsections.

The IPCC Tier 2 methodology was used to estimate emissions from the consumption of PFCs for the years 1995–2006. Details of the method are found in the following subsections. The 1995–2000 activity data were obtained through the 1998 and 2001 PFC surveys conducted by Environment Canada. As 2001–2006 data were unavailable, emission estimates were developed based on the assumption that the use quantities in various applications stayed constant since 2000.

#### *4.14.1.1 1995 HFC Emission Estimates*

The following subsections provide explanations on the emission factors used and the assumptions made to develop 1995 HFC emission estimates for: AC OEM; AC service; refrigeration; foam blowing; aerosol products; and total flooding systems.

#### **Air Conditioning Original Equipment Manufacture (AC OEM)**

To estimate emissions from AC OEM, the revised 1996 IPCC guidelines (IPCC/OECD/IEA 1997) suggest a 2–5% loss rate. For Canada, a rate of 4% was assumed.

#### **AC Service**

Since it was assumed that most AC-related use of HFCs was due to the replacement of operating losses, a loss rate of 100% was applied.

#### **Refrigeration**

It was assumed that all refrigeration in Canada falls under the IPCC other (i.e. commercial and industrial) category, since this was the dominant emission source. It was also assumed that

refrigeration HFCs represented those used for initial and subsequent recharging of equipment. Therefore:

**Equation 4-15:**

$$\text{HFC (refrig)} = \text{Charge} + \text{Operating Loss}$$

The IPCC considers that operating loss is approximately 0.17(charge) (IPCC/OECD/IEA 1997). Therefore, assuming the total charge remains constant for the short term:

$$\text{HFC (refrig)} = \text{Charge} + 0.17(\text{Charge}) = 1.17(\text{Charge})$$

or

$$\text{Charge} = \text{HFC (refrig)}/1.17$$

Assuming assembly leakage was minimal:

$$\text{Emissions} = \text{Operating Loss} = 0.17(\text{Charge})$$

Thus,

**Equation 4-16:**

$$\text{Emissions} = 0.17 \{[\text{HFC (refrig)}]/1.17\}$$

**Foam Blowing**

For 1995, it was assumed that all foam blowing was of open cell type. In other words, it was assumed that 100% of the HFCs used were emitted (IPCC/OECD/IEA 1997).

**Aerosol Products**

For aerosol products, the IPCC good practice guidance (IPCC 2000) suggests a default EF of 50% of the initial charge per year. It was assumed that 1994 production was 50% of that of 1995. Hence, emissions from aerosol products manufactured in 1994, occurring in 1995, would be equivalent to approximately 25% of the 1995 consumption level. Therefore, a factor of 80% was applied to the 1995 consumption to estimate HFC emissions from aerosol products in 1995.

**Fire Suppression – Total Flooding Systems**

For 1995, it was assumed that all fire suppression equipment to which HFCs were introduced was of total flooding type. Hence, a factor of 35% (IPCC/OECD/IEA 1997) was applied to estimate HFC emissions from fire suppression.

*4.14.1.2 1996–2006 HFC and 1995–2006 PFC Emission Estimates*

The following subsections provide explanations on the emission factors used and the assumptions made to develop 1996–2006 HFC and 1995–2006 PFC emission estimates.

**Refrigeration and AC System Assembly**

The equation below, found in the revised 1996 IPCC guidelines (IPCC/OECD/IEA 1997), was used to estimate emissions during system assembly for residential refrigeration, commercial refrigeration, stationary AC, and mobile AC:

**Equation 4-17:**

$$E_{\text{assembly}, t} = \text{Charge}_t \times k$$

where:

$E_{\text{assembly}, t}$	=	emissions during system manufacture and assembly in year t
$\text{Charge}_t$	=	quantity of refrigerant charged into new systems in year t
k	=	assembly losses in percentage of the quantity charged

The k value was chosen from a range of values that were provided for each equipment category in the revised 1996 IPCC guidelines (IPCC/OECD/IEA 1997) (see Table 4-7).

**Table 4-7: Percentage of Losses during Assembly (k) for Various Applications**

For HFC estimates		For PFC estimates	
Application Type	k Values (%)	Application Type	k Values (%)
Residential Refrigeration	2.0	Refrigeration (including ultra low temperature refrigeration)	3.5
Commercial Refrigeration	3.5	Stationary AC	3.5
Stationary AC	3.5	Mobile	4.5
Mobile AC	4.5		

### Annual Leakage

The equation below, given in the revised 1996 IPCC guidelines (IPCC/OECD/IEA 1997), was used to calculate HFC and PFC emissions from leakage:

**Equation 4-18:**

$$E_{\text{operation}, t} = \text{Stock}_t \times x$$

where:

$E_{\text{operation}, t}$	=	quantity of HFCs/PFCs emitted during system operations in year t
$\text{Stock}_t$	=	quantity of HFCs/PFCs stocked in existing systems in year t
x	=	annual leakage rate in percentage of total HFC/PFC charge in the stock

The amount of HFCs/PFCs stocked in existing systems includes the HFCs/PFCs in equipment manufactured in Canada, the amount of HFCs/PFCs in imported equipment, and the amount of HFCs used for servicing equipment and excludes the amount of HFCs/PFCs in exported equipment. It was assumed that no leakage occurred in the year of manufacturing or conversion. The revised 1996 IPCC guidelines (IPCC/OECD/IEA 1997) give a range of values for the annual leakage rate (x) for each of the different equipment categories. The annual leakage rate chosen for each category is shown in Table 4-8.

**Table 4-8: Annual Leakage Rates (x) for Various Applications**

For HFC estimates:		For PFC estimates:	
Application Type	x Values (%)	Application Type	x Values (%)
Residential Refrigeration	1.0	Refrigeration (including ultra low temperature refrigeration)	17.0
Commercial Refrigeration	17.0	Stationary AC	17.0
Stationary AC	17.0	Mobile AC	30.0
Mobile AC	15.0		

### System Disposal

It was assumed that there were no HFC/PFC emissions from system disposal during 1995–2006, since refrigeration and AC systems have a lifetime of 12–15 years and HFC use began only in 1995.

### Foam Blowing

The IPCC Tier 2 methodology presented in the revised 1996 IPCC guidelines (IPCC/OECD/IEA 1997) was used to estimate HFC (1996–2006) and PFC (1995–2006) emissions from foam blowing. Foams are grouped into two main categories: open cell and closed cell.

#### *Open Cell Foam Blowing*

In the production of open cell foam, 100% of the HFCs used are emitted (IPCC/OECD/IEA 1997). There has been no known PFC use in open cell foam blowing. Open cell foam production categories that release HFC emissions include:

- Cushioning—Automobiles;
- Cushioning—Others;
- Packaging—Food;
- Packaging—Others; and
- Other Foam Uses.

#### *Closed Cell Foam Blowing*

During the production of closed cell foam, approximately 10% of the HFCs/PFCs used are emitted (IPCC/OECD/IEA 1997). The remaining quantity of HFCs/PFCs is trapped in the foam and is emitted slowly over a period of approximately 20 years. The IPCC Tier 2 equation (as shown below) was used to calculate emissions from closed cell foam:

#### **Equation 4-19:**

$$E_{\text{foam}, t} = 10\% \times \text{Qty}_{\text{manufacturing}, t} + 4.5\% \times \text{Orig. Charge}$$

where:

- $E_{\text{foam}, t}$  = emissions from closed cell foam in year t
- $\text{Qty}_{\text{manufacturing}, t}$  = quantity of HFCs/PFCs used in manufacturing closed cell foam in year t
- Orig. Charge = original charge blown into the foam

The following are closed cell foam production categories that emit HFC emissions:

- Thermal Insulation—Home and Building;
- Thermal Insulation—Pipe;
- Thermal Insulation—Refrigerator and Freezer; and
- Thermal Insulation—Other.

### **Fire Extinguishers**

The IPCC Tier 2 methodology of the revised 1996 IPCC guidelines (IPCC/OECD/IEA 1997) was used to calculate HFC emissions from portable fire extinguishers and total flooding systems from 1996 onward. There has been no known PFC use in fire-extinguishing equipment.

#### ***Portable Fire-Extinguishing Equipment***

The IPCC Tier 2 methodology in the revised 1996 IPCC guidelines (IPCC/OECD/IEA 1997) estimated emissions as 60% of HFCs used in newly installed equipment.

#### ***Total Flooding Systems***

The IPCC Tier 2 methodology provided in the revised 1996 IPCC guidelines (IPCC/OECD/IEA 1997) estimated emissions from total flooding systems as 35% of the HFCs used in newly installed fire-extinguishing systems.

### **Aerosols/Metered Dose Inhalers**

The IPCC Tier 2 methodology presented in the revised 1996 IPCC guidelines (IPCC/OECD/IEA 1997) was used to calculate HFC emissions from aerosols from 1996 onward. The emission estimate for the current year is equal to half of the HFCs used in aerosols in the current year plus half of the HFCs used in aerosols in the previous year. The amount of HFCs used each year is equal to the amount of HFCs used to produce aerosols and the amount of HFCs in imported aerosol products and excludes the amount of HFCs in exported aerosol products.

Since no data on PFCs used in aerosols were gathered from Environment Canada's PFC surveys, it was assumed that PFC emissions coming from its use in aerosols were negligible.

### **Solvents**

The IPCC Tier 2 methodology presented in the revised 1996 IPCC guidelines (IPCC/OECD/IEA 1997) was used to estimate HFC and PFC emissions from solvents. The emission estimate for the current year is equal to half of the HFCs/PFCs used as solvents in the current year plus half of the HFCs/PFCs used as solvents in the previous year. The amount of HFCs/PFCs used each year is equal to the amount of HFCs/PFCs produced and imported as solvents and excludes the amount of HFCs/PFCs exported as solvents. HFCs/PFCs used as solvents include the following categories:

- electronics industries;
- laboratory solvents; and
- general cleaning.

## Semiconductor Manufacture

There are two main uses of PFCs in the semiconductor manufacturing industry: plasma etching of silicon wafers and plasma cleaning of chemical vapour deposition chambers.

IPCC Tier 2b methodology, as shown below, was used to estimate PFC emissions from the semiconductor manufacturing industry:

### Equation 4-20:

$$E_{SC} = E_{FC} + E_{CF_4}$$

where:

- $E_{SC}$  = total PFC emissions from semiconductor
- $E_{FC}$  = emissions resulting from the use of PFCs (see Equation 4-21 below)
- $E_{CF_4}$  =  $CF_4$  emitted as a by-product during the use of PFCs (see Equation 4-22 below)

### Equation 4-21:

$$E_{FC} = (1 - h) \times \sum_p [FC_{i,p} \times (1 - C_{i,p}) \times (1 - a_{i,p} \times d_{i,p})]$$

where:

- $h$  = fraction of fluorocarbon remaining in shipping container (heel) after use
- $p$  = process type (plasma etching or chemical vapour deposition chamber cleaning)
- $FC_{i,p}$  = quantity of fluorocarbon  $i$  fed into the process type  $p$
- $C_{i,p}$  = use rate (fraction destroyed or transformed) for each fluorocarbon  $i$  and process type  $p$
- $a_{i,p}$  = fraction of gas volume  $i$  fed into the process  $p$  with emission control technologies
- $d_{i,p}$  = fraction of fluorocarbon  $i$  destroyed in the process  $p$  by the emission control technologies

### Equation 4-22:

$$E_{CF_4} = (1 - h) \times \sum_p [B_{i,p} \times FC_{i,p} \times (1 - a_{i,p} \times d_{i,p})]$$

where:

- $B_{i,p}$  = fraction of gas  $i$  transformed into  $CF_4$  for each process type  $p$

and other terms are as defined above.

Default values for variables used in the above equations are shown in Table 4-9 (IPCC 2000).

**Table 4-9: PFC Emission Rates<sup>1</sup>**

Process	IPCC Default Emission Fractions			
	CF <sub>4</sub>	C <sub>2</sub> F <sub>6</sub>	C <sub>3</sub> F <sub>8</sub>	c-C <sub>4</sub> F <sub>8</sub>
(1-C) Plasma Etching	0.7	0.4	0.4	0.3
(1-C) Chemical Vapour Deposition Chamber	0.8	0.7	0.4	ND
B Plasma Etching	NA	0.1	ND	NA
B Chemical Vapour Deposition Chamber	NA	0.1	0.2	NA

Notes:

1. Tier 2b, from IPCC (2000).

ND = no data available.

NA = not applicable.

As no information on emission control technologies for these processes was available,  $a_{i,p}$  was assumed to equal to 0 and  $d_{i,p}$  to 1. Also,  $h$  was assumed to equal 0.1, as suggested in IPCC (2000).

### Other Sources

Minor amounts of PFC emissions have been identified as related to its use in the electronics industry for emissive applications, including reliability testing (inert liquids), coolants (direct evaporative cooling for electric and electronic apparatuses and indirect coolants in closed-circuit electronic apparatuses), and precision cleaning (IPCC 2000). These emissions can be classified into two types of sources: *emissive* and *contained*.

*Emissive* sources include the following:

- electrical environmental testing;
- gross leak testing; and
- thermal shock testing.

Unidentified and miscellaneous PFC uses reported in the PFC survey were also considered as part of *emissive* sources. According to the IPCC Tier 2 methodology, 50% of PFCs used for the above purposes would be released during the first year and the remaining 50% released in the following year.

*Contained* sources consist of PFC use as an electronic insulator and a dielectric coolant for heat transfer in the electronics industry. The IPCC Tier 2 emission factors (IPCC 2000) are applied to the PFC use data obtained from the PFC survey to estimate PFC emissions from contained sources, as follows:

**Equation 4-23:**

$$E_{\text{contained}, t} = (k \times Qty_t) + (x \times Stock_t) + (d \times Qty_t)$$

where:

$E_{\text{contained}, t}$	=	emissions from contained sources
$Qty_t$	=	quantity of PFC sale for use or manufacturing of contained sources in year t
$Stock_t$	=	quantity of PFCs in stock in year t
k	=	manufacturing emission rate (1% of annual sales)
x	=	leakage rate (2% of stock)
d	=	disposal emission factor (5% of annual sales)

**4.14.2 Uncertainties and Time-Series Consistency**

The uncertainty in the 2001 HFC emission estimate, provided in the ICF Consulting (2004) report, was estimated to be within the range of -21% to +55%. The ICF Consulting (2004) report stated that since the uncertainty models for consumption of halocarbons as well as the uncertainty assessment of input data were done with several assumptions, the uncertainty estimates developed for this subsector should be considered preliminary.

By and large, the uncertainty range corresponds to a highly conservative estimate for the total 2006 HFC emissions. Improvements made for estimating “stock” of HFCs and acquisition of more recent consumption data are believed to have brought down the uncertainty around the HFC emission estimate. To assess the quantitative impact of these changes on the uncertainty range, an updated detailed analysis needs to be conducted. Possible sources of uncertainty for this category are 1) the IPCC default emission rates, which may not be totally applicable to a Canadian context, and 2) data on HFC quantities found in imported/exported products.

An uncertainty range of -28% to +70% was reported in the ICF Consulting (2004) study for the 2001 PFC emission estimate. This uncertainty range is considered to be conservative for the 2006 emission estimate because this estimate was developed based on more recent consumption data.

For both HFC and PFC emissions from this subsector, the IPCC default emission rates have been consistently applied over the time series. The source for PFC consumption data was surveys conducted by the Chemical Controls Division of Environment Canada. Surveys conducted by the Chemical Controls Division, by Cheminfo Services on behalf of the GHG Division (Cheminfo Services 2005c) and by the GHG Division were data sources for HFC emission estimates.

**4.14.3 Category-Specific QA/QC and Verification**

Consumption of halocarbons resulting in HFC emissions was a key category that has undergone, for this submission, Tier 1 QC checks as developed in the QA/QC plan (see Annex 6). The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC good practice guidance (IPCC 2000). No issues of importance were detected from the Tier 1 QC process.

Informal QC measures have been taken for the PFC emission estimates.



#### 4.14.4 Category-Specific Recalculations

Over the last two years, recalculations have occurred in the category of HFC consumption as a result of acquisition of new 2005 data and minor revisions in calculating the “stock” values for 1996–2004. These recalculations slightly affected estimates for 1996–2005. Details of these recalculations and their impact can be found in Chapter 9.

#### 4.14.5 Category-Specific Planned Improvements

Efforts will be made to improve on the established voluntary HFC data submission mechanism. For example, the format of the response template will be modified. Acquisition of country-specific emission rates is also part of the planned improvements for the category of HFC consumption.

### 4.15 *Production and Consumption of SF<sub>6</sub> (CRF Categories 2.E & 2.F)*

#### 4.15.1 Source Category Description

In addition to magnesium production and casting, electrical equipment in electric utilities and semiconductor manufacturing are known sources of SF<sub>6</sub> emissions. In electric utilities, SF<sub>6</sub> is used as an insulating and arc-quenching medium in high-tension electrical equipment, such as electrical switchgear, stand-alone circuit breakers, and gas-insulated substations.

There is currently no production of SF<sub>6</sub> in Canada; therefore, all Canadian supply of SF<sub>6</sub> is obtained through imports. From 1990 to 1996, more than 95% of total SF<sub>6</sub> imports came from the United States; however, in recent years, this percentage has declined, with an increase in SF<sub>6</sub> imports from Germany (Cheminform Services 2002).

#### 4.15.2 Methodological Issues

The method used for estimating SF<sub>6</sub> emissions from electrical equipment in utilities was a top-down approach, assuming that all SF<sub>6</sub> purchased from gas distributors replaces SF<sub>6</sub> lost through leakage.

In a study conducted by Cheminform Services (2002) to review and assess potential SF<sub>6</sub> emission sources in Canada, several Canadian utilities reported that new equipment is typically delivered with a few cylinders of SF<sub>6</sub> supplied for charging by the original equipment manufacturer (OEM). This implies that the amount of SF<sub>6</sub> purchased from OEMs can be small compared with the quantity bought from gas distributors. Hence, it is assumed that 100% of the SF<sub>6</sub> sales from gas distributors to utilities are used to refill leaking equipment and that SF<sub>6</sub> supplied by OEMs is added to new stock and not emitted.

This method is considered a modified Tier 1 method because it follows the Tier 1 logic in assuming that all of the SF<sub>6</sub> purchased from gas distributors goes to replace SF<sub>6</sub> lost through leakage. It is considered as “modified” because it focuses only on gas distributor SF<sub>6</sub> sales (Cheminform Services 2005a).

Gas distributors have been requested by the Greenhouse Gas Division to submit their annual SF<sub>6</sub> sales data by market segment so that this modified Tier 1 method can be applied. However, comprehensive sets of sales data were collected only for 1995–2000 inclusively. Alternative approaches were applied to estimate SF<sub>6</sub> sales for the other years of the time series. For example, 1990–1994 sales estimates were assumed to be the same as in 1995. The 2001–2006 sales

estimates were based on data on imports obtained from Statistics Canada and the use of SF<sub>6</sub> in other sectors (such as primary magnesium production and magnesium product casting). The 2004–2006 sales data from some major gas distributors were collected by the GHG Division. These were used to determine the SF<sub>6</sub> sales distribution (in %) by market segment. The distribution percentages were then multiplied by the total import values to estimate the sales to smaller SF<sub>6</sub> users from which data could not be collected. The method applied to estimate SF<sub>6</sub> emissions from semiconductor manufacturing was similar to the one used for calculating PFC emissions. However, as there is no by-product CF<sub>4</sub> created during the use of SF<sub>6</sub> in the process, Equation 4-22 is not needed. Hence,

#### Equation 4-24:

$$\text{SF}_6 \text{ Emissions} = (1 - h) \times [\text{FC} \times (1 - C) \times (1 - a \times d)]$$

where:

h	=	fraction of SF <sub>6</sub> remaining in shipping container (heel) after use (%)
FC	=	quantity of SF <sub>6</sub> fed into the process (or sales) (t)
C	=	use rate (fraction destroyed or transformed) (%)
a	=	fraction of gas volume fed into the process with emission control technologies
d	=	fraction of SF <sub>6</sub> destroyed in the process by the emission control technologies

The value of h provided and confirmed by two major SF<sub>6</sub> gas distributors, Air Liquide and Praxair, was 12% (2006 e-mails from H. Rahal and A. Tardif).<sup>56</sup> The IPCC default value of 0.5 for (1 – C) was used. As it was assumed that there has been no emission control technology applied by this industry, the values of “a” and “d” were 0 and 1, respectively. The estimation technique is considered as Tier 2–type.

Since only 1995–2000 sales data were obtained from major Canadian gas suppliers through a study conducted in 2005 (Cheminfo Services 2005a), it was assumed that the quantity sold per year during 1990–1994 was at the 1995 level. The sales per year for 2001–2003 were assumed to be the average value between 1995 and 2000. The total quantities of SF<sub>6</sub> sold to semiconductor manufacturers in 2004 and 2005 were estimated based on SF<sub>6</sub> import data purchased from Statistics Canada’s international merchandise trade database ([http://www.statcan.ca/trade/scripts/trade\\_search.cgi](http://www.statcan.ca/trade/scripts/trade_search.cgi)) and sales data by market segment provided by some of the major SF<sub>6</sub> gas distributors. For 2006, it was assumed that emissions stayed constant at the 2005 level.

### 4.15.3 Uncertainties and Time-Series Consistency

The 2005 Cheminfo Services study (Cheminfo Services 2005a) provides an uncertainty range of –50% to +19% for the SF<sub>6</sub> emission estimate for electrical equipment. The uncertainty can generally be explained by the drawbacks that the current methodology may have. For example, not all SF<sub>6</sub> purchased from a gas distributor is used in its entirety, and oversupplied SF<sub>6</sub> cylinders could be returned to the distributors (Cheminfo Services 2005a). Nevertheless, it is recognized that given the current lack of electricity release data, this approach would be the simplest method for estimating SF<sub>6</sub> emissions until SF<sub>6</sub> emission data reported by utilities, through the CEA’s

56. E-mails received from H. Rahal (Praxair) and A. Tardif (Air Liquide) on November 22, 2006 and November 13, 2006, respectively. These e-mails contain explanations on the h value.

Environmental Commitment and Responsibility Program, become available to the Greenhouse Gas Division.

Uncertainty in the SF<sub>6</sub> emission estimate for semiconductor manufacturing has not been assessed.

The data source and methodology used (for both electrical equipment and semiconductor manufacturing) are generally consistent over the time series.

#### **4.15.4 Category-Specific QA/QC and Verification**

SF<sub>6</sub> consumption in electrical equipment was a key category that has undergone Tier 1 QC checks as developed in the QA/QC plan (see Annex 6). The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC good practice guidance (IPCC 2000). No issues of importance were detected from the Tier 1 QC process.

#### **4.15.5 Category-Specific Recalculations**

Over the last two years, recalculations have occurred in the category of SF<sub>6</sub> consumption as a result of revisions in the methodologies used. These moderately affected SF<sub>6</sub> estimates for the entire time series. A more detailed discussion of the recalculations and their impact is provided in Chapter 9.

#### **4.15.6 Category-Specific Planned Improvements**

Collection of SF<sub>6</sub> emission estimates directly from utilities for inclusion in future GHG inventories is a planned improvement for the category of SF<sub>6</sub> emissions from electrical equipment. The estimates will be prepared and reported by utilities to the GHG Division according to the SF<sub>6</sub> emission estimation and reporting protocol recently developed by the GHG Division and the CEA.

### ***4.16 Other and Undifferentiated Production (CRF Category 2.G)***

#### **4.16.1 Source Category Description**

Emissions from this subsector are from the non-energy use of fossil fuels and are not accounted for under any of the other subsectors of Industrial Processes. Examples of fuels in non-energy applications are the use of natural gas liquids (NGLs) and feedstocks in the chemical industry and the use of lubricants. All of them result in varying degrees of oxidation of the fuel, producing CO<sub>2</sub> emissions.

The use of fossil fuels as feedstock or for other non-energy uses is reported in an aggregated manner by Statistics Canada (#57-003) under “Non-Energy Use” for each individual fuel. In the event that CO<sub>2</sub> emissions resulting from non-energy fuel use are allocated to another category of the Industrial Processes Sector (as is the case for ammonia production, iron and steel production, and aluminium production), those emissions are subtracted from the total non-energy emissions to avoid double-counting.

#### **4.16.2 Methodological Issues**

Emission rates for non-energy use of fuels were developed based on the total potential CO<sub>2</sub> emission rates and the IPCC default percentages of carbon stored in products. The total potential

CO<sub>2</sub> emission rates were derived from the carbon emission factors shown in Jaques (1992), McCann (2000) and CIEEDAC (2006).

Fuel quantity data for non-energy fuel usage were reported by the RESD (Statistics Canada #57-003). It should be noted that the RESD data for any given year are preliminary and subject to revisions in subsequent publications. These data were multiplied by the emission rates shown in Annex 3 to estimate CO<sub>2</sub> emissions for this subsector.

This technique is considered to be a Tier 1-type method, as it is based on the use of national consumption data and average national emission factors. Methodological issues for calculating CO<sub>2</sub> emissions from the non-energy use of fossil fuels are not addressed specifically in the IPCC Good Practice Guidance (IPCC 2000).

Further details with respect to the calculation method used are provided in Annex 3.

#### **4.16.3 Uncertainties and Time-Series Consistency**

An uncertainty range of -40% to +1% reported in the ICF Consulting (2004) study for estimates of CO<sub>2</sub> emissions from non-energy use of fuels is generally applicable to the 2006 estimate, because there has been no change in the methodology and data source used since the ICF study was completed. The uncertainty range implies that emissions from this category are likely to be overestimated. It also seems to reflect the predominant influence of the uncertainty associated with 1) the emission factor for petroleum coke and 2) the CO<sub>2</sub> emissions from ammonia production (ICF Consulting 2004).

The data sources and methodology used are consistent over the time series.

#### **4.16.4 Category-Specific QA/QC and Verification**

Other and Undifferentiated Production was a key category that has undergone Tier 1 QC checks as developed in the QA/QC plan (see Annex 6). The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC good practice guidance (IPCC 2000). No issues of importance were detected from the Tier 1 QC process.

#### **4.16.5 Category-Specific Recalculations**

Over the last two years, recalculations have occurred in this category as a result of minor methodological change and update in activity data. These slightly affected estimates for the whole time series. A more detailed discussion on these recalculations and their impact is provided in Chapter 9.

#### **4.16.6 Category-Specific Planned Improvements**

It is planned to allocate emissions from petroleum products used as feedstock in the petrochemical industry into a new category, petrochemical production, which will be included under the chemical subsector.

## 5 Solvent and Other Product Use (CRF Sector 3)

### 5.1 Overview

Although the revised 1996 IPCC guidelines (IPCC/OECD/IEA 1997) mention that solvents and related compounds can be significant sources of emissions of NMVOCs, the Solvent and Other Product Use Sector accounts only for direct GHG emissions. Annex 14 of the NIR provides details on emissions of NMVOCs and other indirect GHG emissions.

This sector specifically includes emissions that are related to the use of N<sub>2</sub>O as an anaesthetic and propellant. Emissions from use of solvents in dry cleaning, printing, metal degreasing, and a variety of industrial applications as well as household use are not estimated because, according to the revised 1996 IPCC guidelines, GHGs are not emitted in significant amounts from these types of uses (IPCC/OECD/IEA 1997).

As shown in Table 5-1, the GHG emissions from the Solvent and Other Product Use Sector contributed 320 kt CO<sub>2</sub> eq to the 2006 national GHG inventory, compared with 170 kt CO<sub>2</sub> eq in 1990. These emissions represented 0.04% of the total Canadian GHG emissions in 2006. The emission trends, either long term (between 1990 and 2006), or short term (between 2005 and 2006), were driven mainly by the domestic demand for N<sub>2</sub>O for anaesthetic or propellant purposes. In the long term, the N<sub>2</sub>O emissions exhibit a growth rate of 188%. Most of the growth relate to the short-term rate of 178%. The sharp growth observed between 2005 and 2006 is attributable to the increases in the domestic demand for N<sub>2</sub>O. However, according to the plant manager of Nitrous Oxide of Canada,<sup>57</sup> the historical activity data provided to the GHGD through a study in 2006 (Cheminfo 2006) could possibly be underestimated. This implies that the emission growth rate, either on a long-term or short-term basis, could be lower. The GHGD is in the process of developing an improvement plan to examine this issue further.

The second major application of N<sub>2</sub>O, after its use as an anaesthetic, is as a propellant in pressure and aerosol products, with the largest application being pressure-packaged whipped cream. Demand for N<sub>2</sub>O in Canada for manufacturing this food product has been relatively stable since 1995 (Cheminfo Services 2006).

**Table 5-1: Solvent and Other Product Use Sector GHG Emission Summary, Selected Years**

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)		
	1990	2005	2006
<b>Solvent and Other Product Use TOTAL</b>	<b>170</b>	<b>180</b>	<b>320</b>
<i>Use of N<sub>2</sub>O as Anaesthetic</i>	150	150	270
<i>Use of N<sub>2</sub>O as Propellant</i>	27	28	51

To ensure the correctness of the estimates, this sector has undergone Tier 1 QC checks. Further details on QA/QC and uncertainty assessment can be found in Section 5.1.4 and Section 5.1.3, respectively.

---

57. Phone conversation between the GHGD and Nitrous Oxide Canada on March 5, 2008.

### 5.1.1 Source Category Description

N<sub>2</sub>O is a clear, colourless, oxidizing liquefied gas with a slightly sweet odour, which is stable and inert at room temperature. In a low-pressure and low-temperature reaction that decomposes ammonium nitrate (NH<sub>4</sub>NO<sub>3</sub>), steam (H<sub>2</sub>O) and N<sub>2</sub>O are formed. While the steam is condensed out, the “crude” N<sub>2</sub>O is further purified, compressed, dried, and liquefied for storage and distribution. Nitrous Oxide of Canada in Maitland, Ontario, is the only known producer of compressed N<sub>2</sub>O for commercial sale in Canada. It supplies N<sub>2</sub>O to two of the three primary N<sub>2</sub>O gas distributors that essentially account for the total commercial market in Canada. These companies sell cylinders of N<sub>2</sub>O to a relatively large number of sub-distributors. It is estimated that there can be 9 000 to 12 000 final end-use customers for N<sub>2</sub>O in Canada, including dental offices, clinics, hospitals, and laboratories (Cheminfo Services 2006).

N<sub>2</sub>O is used in a limited number of applications, with anaesthetic use representing the vast majority of consumption in Canada. Use as a propellant in food products is the second largest type of end use in Canada. Other areas where N<sub>2</sub>O can be used include production of sodium azide<sup>58</sup> (a chemical that was used to inflate automobile airbags), atomic absorption spectrometry, and semiconductor manufacturing. According to the distributors that were surveyed during the recent study, approximately 82% of their N<sub>2</sub>O sales volume goes to dentistry/medical applications, 15% to food processing propellant, and only 3% to the other uses (Cheminfo Services 2006).

It is important to note that among all applications in which N<sub>2</sub>O can be used, only the two major types are emissive. When used as an anaesthetic, approximately 97.5% of the N<sub>2</sub>O is not metabolized and quickly leaves the body in exhaled breath (i.e. emitted) as a result of its poor solubility in blood and other tissues. In the case of N<sub>2</sub>O used as a propellant, only emissions coming from N<sub>2</sub>O use in whipped cream are estimated, because the amounts of N<sub>2</sub>O employed in other food products and in non-food products are considered negligible, according to the food industry and the gas producer and distributors. When the cream escapes from the can, the N<sub>2</sub>O gas expands and whips the cream into foam form. As none of the N<sub>2</sub>O is reacted during the process, it is all emitted to the atmosphere (Cheminfo Services 2006).

### 5.1.2 Methodological Issues

Estimation of N<sub>2</sub>O emissions from this sector was done based on sales data, following the consumption-based approach presented in the revised 1996 IPCC guidelines (IPCC/OECD/IEA 1997). Because it was virtually impossible to collect data from all end users, it was assumed that domestic sales equal domestic consumption.

Attempts were made to collect sales data, instead of purchase or consumption data, for all years. To obtain the sales volumes by end-use type, for 1990–2005, Canada’s single N<sub>2</sub>O producer and the three major N<sub>2</sub>O gas distributors were surveyed through a study (Cheminfo Services 2006). Nitrous Oxide of Canada (NOC) was contacted to obtain its annual production and domestic sales data, but it was able to provide only rough estimates of historical data. Also, a questionnaire requesting sales volumes by market segment was sent to each of the N<sub>2</sub>O distributors. However, these companies did not provide the full set of historical data that was requested. For the 2006 data, requests for data were sent to NOC and the gas distributions directly by the GHG Division.

---

58. N<sub>2</sub>O was used by ICI Chemicals between 1990 and 1997 as a reactant for producing sodium azide. However, it has been replaced by a different raw material since 1998.

As a complete set of sales data, covering 1990–2006, could not be gathered, the domestic sales of Canadian production data provided by Nitrous Oxide of Canada and N<sub>2</sub>O import data purchased from Statistics Canada's merchandise trade database<sup>59</sup> were used to estimate the total domestic sales volumes (or consumption) of N<sub>2</sub>O for 1990–2006. The sales data by market segment and qualitative information gathered from the producer and distributors were used to develop the patterns of sales by application for all years between 1990 and 2006. To calculate the amounts of N<sub>2</sub>O sold for anaesthetic and propellant purposes, the total domestic sales volume was multiplied by the percentage of each of these provided in the sales patterns.

To estimate emissions coming from usage of anaesthetic at the national level, the amount of N<sub>2</sub>O sold for anaesthetic purposes was multiplied by a factor of 97.5%. The latter factor was used for the reason mentioned in the source category description, which is that approximately 97.5% of the N<sub>2</sub>O is not metabolized and is emitted in exhaled breath. The same factor is also applied by the U.S. EPA.

To estimate emissions coming from N<sub>2</sub>O use in food products (i.e. whipped cream cans) at the national level, it was assumed that 100% of the quantity used in the whipped cream manufacturing was emitted, as explained previously in the source category description section. The same assumption was also made by the U.S. EPA.

Summing the emission estimates for anaesthetic and propellant would give the national emission totals for the Solvent and Other Product Use Sector.

The national emission estimates were divided by the national total population to yield an emissions per capita factor. This factor was then multiplied by the population in each province and territory to estimate emissions at provincial/territorial levels. The 1990–2002 annual population statistics were obtained from Statistics Canada (#91-213) and 2003–2006 data from Statistics Canada (#91-215).

The IPCC Good Practice Guidance (IPCC 2000) does not provide any recommendations on the estimation of N<sub>2</sub>O emissions.

### 5.1.3 Uncertainties and Time-Series Consistency

In 2004, ICF Consulting performed a Tier 2 uncertainty assessment on the 2001 emission estimate of the Solvent and Other Product Use Sector. Because the study was conducted based on estimates from the inventory submitted in 2003, the results are no longer applicable to the current estimates of this sector. An updated uncertainty assessment is needed to determine the actual uncertainty around the current emission estimates, but the 2006 Cheminfo report provided some ideas of the uncertainty range. For example, as historical sales data were not available from the N<sub>2</sub>O gas distributors and were estimated, they have an uncertainty range of approximately  $\pm 30\%$ . For more recent years, the uncertainty related to the total Canadian sales for each application is around  $\pm 10\%$ , because more data were gathered from the distributors (Cheminfo Services 2006).

The data sources and methodology used are generally consistent over the time series.

---

59. Available online at: [http://www.statcan.ca/trade/scripts/trade\\_search.cgi](http://www.statcan.ca/trade/scripts/trade_search.cgi)

#### **5.1.4 QA/QC and Verification**

This sector was a key category which has undergone Tier 1 QC checks as developed in the QA/QC plan (see Annex 6). The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC good practice guidance (IPCC 2000). No issues of importance were detected from the Tier 1 QC process.

#### **5.1.5 Recalculations**

Over the last two years, recalculations have occurred in this sector as a result of update of activity data (i.e. N<sub>2</sub>O sales data) obtained during the Cheminfo study in 2006 (Cheminfo Services 2006). There were also updates in the population data for 2003–2005, which resulted in recalculations at provincial levels for estimates of these years.

#### **5.1.6 Planned Improvements**

NOC will be contacted to verify the historical N<sub>2</sub>O production data. It is also planned to review the use patterns of N<sub>2</sub>O based on data and inputs to be supplied by gas distributors.



## 6 Agriculture (CRF Sector 4)

### 6.1 Overview

Emission sources from agriculture include animal production—namely, enteric fermentation ( $\text{CH}_4$ ) and manure management ( $\text{N}_2\text{O}$  and  $\text{CH}_4$ )—and agricultural soils ( $\text{N}_2\text{O}$ ).  $\text{CO}_2$  emissions and removals by cropland are reported under the LULUCF Sector under the Cropland Remaining Cropland category (see Chapter 7).

Total GHG emissions from the Canadian Agriculture Sector were 49 Mt  $\text{CO}_2$  eq in 1990, 63 Mt  $\text{CO}_2$  eq in 2005 and 62 Mt  $\text{CO}_2$  eq in 2006 (Table 6-1). This represents an increase of 25% between 1990 and 2006, mainly resulting from the expansion of the beef cattle industry (29% since 1990), of the swine industry (47% since 1990), as well as an increase in synthetic nitrogen fertilizer consumption.

The stabilization of emissions between 2005 and 2006 reflects a 3.6% decrease in beef cattle population, likely attributed to the BSE (“mad cow”) outbreak in 2003.

In this submission, changes in inventory methodologies for the Agriculture Sector focus mainly on:

- implementing recommendations from the UNFCCC expert review team that reviewed the inventory in 2007 (see Chapter 9)
- carrying out regular annual inventory improvements, concentrating on updates of activity data and parameters as well as inventory methodologies.

The recent release of the *2006 Census of Agriculture* (Statistics Canada 2006) provided updated population counts of major and minor animal types, which were incorporated in the inventory. In addition, llamas is a required reporting animal category in the CRF tables and is now included. The changes listed above triggered recalculations, resulting in an overall upward change that varied from 0.8 Mt  $\text{CO}_2$  eq (1%) up to 1.8 Mt  $\text{CO}_2$  eq (3%) for the Agriculture Sector for the 1990–2006 inventory years.

Biological nitrogen fixation by the legume–rhizobium association is reported as not occurring. This decision is supported by Rochette and Janzen (2005) (and reflected in the IPCC 2006 Guidelines), who concluded that there is no evidence that measurable amounts of  $\text{N}_2\text{O}$  are produced during the nitrogen fixation process.  $\text{CH}_4$  emissions from rice production in Canada are considered to be negligible and are not inventoried. Field burning of agricultural residues is not inventoried due to lack of consistent time-series activity data. Prescribed burning of savannas is not a relevant practice in Canada. Finally, emissions of GHG from on-farm fuel combustion are included in the Energy Sector (Chapter 3).

For each emission source category, a brief introduction and a brief description of methodological issues, uncertainties and time-series consistency, QA/QC and verification, recalculations, and planned improvements are provided in this chapter. The detailed inventory methodologies and sources of activity data are described in Section A3.3, while recalculation details are included in Chapter 9.

**Table 6-1: Short- and Long-Term Changes in GHG Emissions from the Agriculture Sector**

GHG Source Category		GHG Emissions (kt CO <sub>2</sub> eq)		
		1990	2005	2006
<b>Agriculture TOTAL</b>		<b>49 000</b>	<b>63 000</b>	<b>62 000</b>
<i>Enteric Fermentation</i>		<i>18 000</i>	<i>25 000</i>	<i>24 000</i>
—CH <sub>4</sub>	Dairy Cattle	3 300	2900	2900
	Beef Cattle	14 000	21 000	20 000
	Others	610	1 000	1 000
<i>Manure Management</i>		<i>6 100</i>	<i>8 200</i>	<i>8 000</i>
—CH <sub>4</sub>	Dairy Cattle	740	640	630
	Beef Cattle	710	940	910
	Swine	1 100	1 600	1 600
	Poultry	70	90	90
	Others	20	40	40
—N <sub>2</sub> O	All Animal Types	3 500	4 900	4 800
<i>Agricultural Soils (N<sub>2</sub>O)</i>		<i>26 000</i>	<i>30 000</i>	<i>30 000</i>
Direct Sources		14 000	15 000	15 000
	Synthetic Nitrogen Fertilizers	5 900	7 000	7 100
	Manure Applied as Fertilizers	1 800	2 300	2 300
	Crop Residue Decomposition	4 800	5 200	5 500
	Cultivation of Organic Soils	60	60	60
	Conservation Tillage <sup>1</sup>	–300	–910	–840
	Summerfallow	1 300	730	690
	Irrigation	320	370	360
Pasture, Range, and Paddock Manure		2 600	3 900	3 800
Indirect Sources		9 000	11 000	11 000

Notes:

1. The negative values reflect a reduced N<sub>2</sub>O emission due to the adoption of conservation tillage.

Totals may not add up due to rounding.

## 6.2 Enteric Fermentation (CRF Category 4.A)

### 6.2.1 Source Category Description

Large quantities of CH<sub>4</sub> are produced from herbivores through enteric fermentation. During the normal digestive process, microorganisms break down carbohydrates into simple molecules for absorption and CH<sub>4</sub> is produced as a by-product. This process results in CH<sub>4</sub> in the rumen, which is emitted by eructation and exhalation. Some CH<sub>4</sub> is released later in the digestive process by flatulation. Ruminant animals, such as cattle, generate the most CH<sub>4</sub>.

### 6.2.2 Methodological Issues

CH<sub>4</sub> emissions are calculated for each animal category/subcategory, for each province, by multiplying the animal population of a given category/sub-category by its corresponding emission factor.

CH<sub>4</sub> enteric fermentation emission factors of cattle are estimated using the IPCC Tier 2 methodology, following the guidance provided by IPCC good practice guidance and based on a study by Boadi et al. (2004) that characterized cattle population in Canada by animal type, physiological status, age, sex, weight, rate of weight gain, level of activity and production environment. Much of this information was obtained by surveying beef and dairy cattle specialists across the country. In addition, milk productivity and milk fat data were factored into the method to derive a time series of emission factors for dairy cows, reflecting the fact that CH<sub>4</sub> production increases with milk productivity. Further more, for non-dairy cattle, carcass weight data over time were used as an indicator of change in live body weights, resulting in an emission factor time series.

For non-cattle animal categories, CH<sub>4</sub> emissions from enteric fermentation continue to be estimated using the IPCC Tier 1 methodology. Poultry are excluded from enteric fermentation estimates, since no emission factors are available.

Activity data consist of domestic animal population for each animal category/subcategory, by province, and is obtained from Statistics Canada (Table 6-2). The data is based on the *Census of Agriculture*, which is conducted every 5 years, and on semi-annual or quarterly surveys for important animal categories; semi-annual or quarterly data is averaged to result in yearly populations. CANSIM is Statistics Canada's on-line database that stores the most up-to-date statistics available in Canada.

**Table 6-2: Animal Categories and Sources of Population Data**

Category	Sources/Notes
<b>Cattle</b>	Data downloaded from CANSIM in January 2008
—Dairy Cattle	Dairy cows
—Non-Dairy Cattle	All other cattle
<b>Buffaloes</b>	Statistics Canada (2008), Alternative Livestock on Canadian Farms: Census years 1981, 1986, 1991, 1996, 2001 and 2006 (Catalogue # 23-502-X)
<b>Sheep and Lambs</b>	Data downloaded from CANSIM in January 2008
<b>Goats and Horses</b>	Statistics Canada (2008), Alternative Livestock on Canadian Farms: Census years 1981, 1986, 1991, 1996, 2001 and 2006 (Catalogue # 23-502-X)
<b>Llamas and Alpacas</b>	Statistics Canada (2008), Alternative Livestock on Canadian Farms: Census years 1981, 1986, 1991, 1996, 2001 and 2006 (Catalogue # 23-502-X)
<b>Mules and Asses</b>	Considered a negligible source in Canada
<b>Swine</b>	All pigs Data downloaded from CANSIM in January 2008
<b>Poultry</b>	Agricultural perspectives from seven censuses, Canada and provinces: census years 1976 to 2006 (Table 2.16 and section 4.6 of publication #95-632 from Statistics Canada) (Statistics Canada 2007a) Farm data and farm operator data tables (section 6.5 of publication #95-629 from Statistics Canada) (Statistics Canada 2007b)

### 6.2.3 Uncertainties and Time-Series Consistency

The uncertainty associated with CH<sub>4</sub> emissions from enteric fermentation was determined using the Monte Carlo technique based on the IPCC Tier 2 methodology (Hutchinson et al. 2007). Uncertainties associated with animal populations are estimated as relatively low, ranging from  $\pm 1\%$  for poultry,  $\pm 2\%$  for sheep and lambs,  $\pm 3\%$  for dairy cattle,  $\pm 5\%$  for non-dairy cattle,  $\pm 10\%$  for swine, and  $\pm 15\%$  for horses, goats, and llamas. Uncertainties associated with the IPCC Tier 2

emission factors for cattle vary from  $\pm 5\%$  for dairy cows to  $\pm 17\%$  for steers (Boadi et al. 2004). Uncertainties associated with emission factors taken from the IPCC Tier 1 defaults for non beef-cattle categories were estimated to be  $\pm 20\%$  (IPCC/OECD/IEA 1997). The overall level and trend uncertainties for emission estimates from 1990 to 2006 were estimated to be  $\pm 11\%$  and  $\pm 10\%$ , respectively (Hutchinson et al. 2007). Uncertainty estimates reported here for the Agriculture Sector sources have been updated since the 2004 study by ICF Consulting (2004), reported in Annex 7.

The same methodology and data sources are used for the entire time series of emission estimates (1990–2006).

#### **6.2.4 QA/QC and Verification**

Enteric fermentation, as a key category, has undergone Tier 1–level QC checks as elaborated in the QA/QC plan (Annex 6) in a manner consistent with IPCC 2000 good practice guidance. In addition, the activity data, methodologies, and changes are documented and archived in both paper and electronic forms. The IPCC Tier 2 emission factors for cattle, derived from Boadi et al. (2004), have been reviewed by independent experts (T. McAllister, Agriculture and Agri-Food Canada; J. Basarab, Alberta Agriculture, Food and Rural Development).

Direct measurements of CH<sub>4</sub> emissions from enteric fermentation in Canada are recent and data are still scarce. Over the last few years, a number of Canadian researchers have adopted a tracer technique for measuring CH<sub>4</sub> emissions from grazing cattle using SF<sub>6</sub> (McCaughy et al. 1997, 1999; Boadi and Wittenberg 2002; Boadi et al. 2002a, 2002b; McGinn et al. 2004, 2006; Beauchemin and McGinn 2005). CH<sub>4</sub> measurements in the scientific literature are currently being compiled by the Greenhouse Gas Division for purposes of future comparison and verification.

#### **6.2.5 Recalculations**

Over the last two years (2005 and 2006), recalculations have occurred in this category as a result of updates in animal population data (the release of the *2006 Census of Agriculture* triggered intercensal data revisions), inclusion of llamas and alpacas, and methodological improvements, notably the incorporation of annual live body weights in the derivation of time-series emission factors for non-dairy cattle categories. These recalculations moderately affected estimates for the entire time series. A more detailed discussion of these recalculations and their impact is provided in Chapter 9.

#### **6.2.6 Planned Improvements**

In the current methodology, the value for digestible energy (DE) for beef and dairy cattle is constant over time, based on 2001 feed rations. Updates to the emission factor to account for changes in feed ration digestibility over time are being investigated.

In addition, the live weight of calves, a non-dairy cattle sub-category, is set constant to its 2001 value cited in Boadi et al. (2004) due to the lack of the data on potential variation of their live weight. A thorough investigation and analysis of data that might suggest a variation in calves' live weights will be made.

It is also recognized that the current method for deriving the IPCC Tier-2 enteric fermentation CH<sub>4</sub> emission factors is approximately three years old. An attempt to upgrade and simplify the model will be made.

### **6.3 Manure Management (CRF Category 4.B)**

In Canada, the four major types of animal waste management systems (AWMS) typically used are 1) liquid, 2) solid storage and drylot, 3) pasture and paddock, and 4) other systems such as composters and biodigestors. It is assumed that no manure is burned as fuel.

CH<sub>4</sub> and N<sub>2</sub>O are emitted during the handling and storage of livestock manure. The magnitude of the emissions depends upon the quantity of manure handled, its characteristics, and the type of manure management systems. Generally, poorly aerated manure management systems generate more CH<sub>4</sub> than N<sub>2</sub>O, whereas well-aerated systems generate little CH<sub>4</sub> but more N<sub>2</sub>O.

#### **6.3.1 CH<sub>4</sub> Emissions from Manure Management (CRF Category 4.B (a))**

##### *6.3.1.1 Source Category Description*

Shortly after manure is excreted, the decomposition process begins. If little oxygen is present, the decomposition is mainly anaerobic and produces CH<sub>4</sub>. The quantity of CH<sub>4</sub> produced depends on the manure characteristics linked to animal types and diets and on the type of manure management system.

##### *6.3.1.2 Methodological Issues*

CH<sub>4</sub> emissions from manure management were calculated for each animal category/subcategory by multiplying its population by the corresponding weighted average emission factor (see Annex 3.3 for more details on the methodology). The animal population data are the same as those used for the enteric fermentation emission estimates (Section 6.2.2).

CH<sub>4</sub> emission factors for manure management are estimated using the IPCC Tier 2 methodology. Emission factors were derived from a study conducted by Marinier et al. (2004), with modifications and updates following the IPCC 2006 Guidelines. Marinier et al. (2004) estimated volatile solids (VS) for non-cattle through expert consultations. For dairy cattle, dry matter intake (DMI), and therefore VS, were estimated using the same characterization as in the enteric fermentation Tier 2 method developed by Boadi et al. (2004). The emission factor time series reflects the increase in milk productivity of dairy cows over time. For non-dairy cattle, VS was estimated with Equation 4.16 of the IPCC 2006 Guidelines based on gross energy (GE) calculated in the enteric fermentation methodology, digestible energy (DE), and ash content. The emission factor time series reflects the increase in live body weights using carcass weight as an indicator.

In addition, maximum CH<sub>4</sub> production potential (B<sub>0</sub>) and methane conversion factor (MCF) have been updated according to the new information in the IPCC 2006 Guidelines.

##### *6.3.1.3 Uncertainties and Time-Series Consistency*

The uncertainty associated with CH<sub>4</sub> emissions from manure management was determined using the Monte Carlo technique based on the IPCC Tier 2 methodology (Hutchinson et al. 2007). Uncertainties associated with animal populations are estimated as relatively low, ranging from ±1% for poultry, ±2% for sheep and lambs, ±3% for dairy cattle, ±5% for non-dairy cattle, ±10% for swine, and ±15% for horses, goats, and llamas.

Uncertainties associated with the gross energy intake for cattle vary from ±5% for dairy cows to ±17% for steers (Boadi et al. 2004). Uncertainty associated to the methane conversion factor

(MCF) and  $B_0$  for various animal categories were taken from the IPCC 2006 defaults, and Marinier et al. (2004) calculated uncertainty related to animal manure distribution systems. The uncertainties associated with the IPCC Tier 2 emission factors varied from  $\pm 26\%$  for beef cows to  $\pm 50\%$  for chickens (Marinier et al. 2004). The overall level and trend uncertainties for emission estimates from 1990 to 2006 were estimated to be  $\pm 29\%$  and  $\pm 23\%$ , respectively (Hutchinson et al. 2007).

The same methodology and data sources are used for the entire time series of emission estimates (1990–2006).

#### 6.3.1.4 *QA/QC and Verification*

CH<sub>4</sub> emissions from manure management have undergone Tier 1–level QC checks as elaborated in the QA/QC plan (Annex 6) in a manner consistent with IPCC good practice guidance. The activity data and methodologies are documented and archived in both paper and electronic form. The IPCC Tier 2 CH<sub>4</sub> emission factors for manure management practices by various animal categories derived from Marinier et al. (2004) have been reviewed by independent experts (N. Patni and R. Desjardins, Agriculture and Agri-Food Canada).

#### 6.3.1.5 *Recalculations*

Over the last two years, recalculations have occurred in this category as a result of updates in animal populations (Section 6.2.5), inclusion of llamas and alpacas, and methodological improvements, notably the incorporation of annual live body weights in the estimation methods of manure CH<sub>4</sub> emission factors for a number of non-dairy cattle categories. These recalculations slightly affected estimates for the entire time series and had no impact on the emission trend. A more detailed discussion of these recalculations and their impact is provided in Chapter 9.

#### 6.3.1.6 *Planned Improvements*

In the current methodology, digestible energy by animal category is static over time based on the 2001 feed rations. Updates to the emission factor to account for changes in feed ration digestibility over time are being investigated. Methane producing potential values ( $B_0$ ) for various animal manures will be reviewed.

### 6.3.2 **N<sub>2</sub>O Emissions from Manure Management (CRF Category 4.B (b))**

#### 6.3.2.1 *Source Category Description*

The production of N<sub>2</sub>O during storage and treatment of animal waste occurs during nitrification and denitrification of nitrogen contained in the manure. Nitrification is the oxidation of ammonium (NH<sub>4</sub><sup>+</sup>) to nitrate (NO<sub>3</sub><sup>-</sup>), and denitrification is the reduction of NO<sub>3</sub><sup>-</sup> to N<sub>2</sub>O or N<sub>2</sub>. In general, the amount of N<sub>2</sub>O produced increases with greater aeration of the manure. Manure from cattle, sheep, lamb, goats, and horses are mainly handled with a solid and drylot system, which is the manure management system that emits the most N<sub>2</sub>O emissions. N<sub>2</sub>O emissions from manure on pasture, range, and paddock by grazing animals are reported separately (refer to Manure on Pasture, Range, and Paddock, Section 6.4.2).

### 6.3.2.2 *Methodological Issues*

N<sub>2</sub>O emissions from manure management are estimated using the IPCC Tier 1 methodology. Emissions are calculated for each animal category by multiplying the animal population of a given category by its related average nitrogen excretion rate and by the fraction of available nitrogen based on the type of animal waste management system (AWMS).

The animal population data are the same as those used for the Enteric Fermentation estimates (Section 6.2) and CH<sub>4</sub> Emissions from Manure Management (Section 6.3.1). The average annual nitrogen excretion rates for domestic animals are taken from the IPCC 2006 Guidelines. The amount of manure nitrogen subject to losses because of leaching and volatilization of NH<sub>3</sub> and NO<sub>x</sub> is adjusted by animal type and manure management system according to the default values provided in the IPCC 2006 Guidelines.

The fraction of nitrogen available for conversion into N<sub>2</sub>O is estimated by applying system-specific emission factors to the manure nitrogen handled by each management system. The IPCC 2006 default emission factors for a developed country with a cool climate are used to estimate manure nitrogen emitted as N<sub>2</sub>O for each type of AWMS.

### 6.3.2.3 *Uncertainties and Time-Series Consistency*

Uncertainties associated with N<sub>2</sub>O emission estimates from manure management result from uncertainties associated with estimates of animal populations from the *Census of Agriculture* and range from  $\pm 1\%$  ~  $\pm 15\%$ , as noted in Sections 6.2.3 and 6.3.1.3. Uncertainties associated with rates of nitrogen excretion are  $\pm 20\%$  (IPCC 2006), with types of AWMS are  $\pm 20\%$  (Marinier et al. 2004), and with the emission factors associated with AWMS are  $\pm 20\%$  (IPCC 2006). The overall level and trend uncertainties associated with this source of emission estimates from 1990 to 2006 were estimated to be  $\pm 25\%$  and  $\pm 21\%$ , respectively (Hutchinson et al. 2007).

The same methodology, emission factors, and data sources are used for the entire time series (1990–2006).

### 6.3.2.4 *QA/QC and Verification*

This category has undergone Tier 1–level QC checks as elaborated in the QA/QC plan (Annex 6) in a manner consistent with IPCC good practice guidance. The activity data, methodology, and changes to methodologies are documented and archived in both paper and electronic form.

### 6.3.2.5 *Recalculations*

Over the last two years, recalculations have occurred in this category as a result of updates in animal population data (Section 6.2.5), updated animal manure N excretion rates, and inclusion of llamas and alpacas. These recalculations modestly affected estimates for the entire time series and had a small impact on the long-term trend. A more detailed discussion of these recalculations and their impact is provided in Chapter 9.

### 6.3.2.6 *Planned Improvements*

Data from direct measurements of N<sub>2</sub>O emissions from manure management in Canada are scarce. Recent scientific advances in analytical techniques allow direct measurements of N<sub>2</sub>O

emissions from point sources. However, it will likely take several years before N<sub>2</sub>O emissions can be reliably measured and verified for various manure management systems in Canada.

#### **6.4 N<sub>2</sub>O Emissions from Agricultural Soils (CRF Category 4.D)**

Emissions of N<sub>2</sub>O from agricultural soils consist of direct and indirect emissions as well as emissions from animal manure on pasture, range, and paddock. The emissions of N<sub>2</sub>O that result from anthropogenic N inputs occur directly from the soils to which the N is added, and also indirectly through two pathways: i) volatilization of N from synthetic fertilizer and manure as NH<sub>3</sub> and NO<sub>x</sub> and its subsequent deposition off-site; and ii) leaching and runoff of N.

##### **6.4.1 Direct N<sub>2</sub>O Emissions from Soils (CRF Category 4.D.1)**

Direct sources of N<sub>2</sub>O from soils include synthetic fertilizers, animal manure applied as fertilizer, crop residue decomposition, modification of tillage practices, summerfallow, irrigation, and cultivation of histosols.

###### **6.4.1.1 Synthetic Nitrogen Fertilizers**

###### **Source Category Description**

Synthetic fertilizers add large quantities of nitrogen to agricultural soils. This added nitrogen undergoes transformations, such as nitrification and denitrification, which release N<sub>2</sub>O. Emission factors associated with fertilizer application depend on many factors, such as the quantity and type of nitrogen fertilizers, crop types, soil types, climate, and other environmental conditions.

###### **Methodological Issues**

As elaborated in detail in Section A3.3, Canada has developed a country-specific, Tier 2–type methodology to estimate N<sub>2</sub>O emissions from synthetic nitrogen fertilizer application on agricultural soils, which takes into account local climate and topographic conditions. Emissions of N<sub>2</sub>O are estimated by ecodistrict, by province, and for the country as a whole. The amount of nitrogen applied is obtained from yearly fertilizer sales data, which are available from regional fertilizer associations (Korol 2003). Since 2003, fertilizer nitrogen data have been obtained from the Canadian Fertilizer Institute.<sup>60</sup> All synthetic nitrogen fertilizers sold by retailers are assumed to be applied for crop production in Canada.

###### **Uncertainties and Time-Series Consistency**

Uncertainties associated with N<sub>2</sub>O emission estimates from synthetic nitrogen fertilizer applications result from uncertainties associated with estimates of nitrogen fertilizer sales ( $\pm 20\%$ ), estimates of EF<sub>BASE</sub> ( $\pm 25\%$ ), and estimates of RF<sub>TEXTURE</sub>, a ratio factor adjusting EF<sub>BASE</sub> for soil texture ( $\pm 30\%$ ). These terms and emission calculations are explained in the methodological Section A3.3. The overall level and trend uncertainties associated with this source of emission estimates from 1990 to 2006 were estimated to be  $\pm 21\%$  and  $\pm 19\%$ , respectively (Hutchinson et al. 2007).

The same methodology and emission factors are used for the entire time series (1990–2006).

---

60. Available online at: [http://www.cfi.ca/Publications/Statistical\\_Documents.asp](http://www.cfi.ca/Publications/Statistical_Documents.asp).



## QA/QC and Verification

This category has undergone Tier 1–level QC checks as elaborated in the QA/QC plan (Annex 6) in a manner consistent with IPCC good practice guidance. The activity data, methodologies, and changes to methodologies are documented and archived in both paper and electronic form.

N<sub>2</sub>O emissions associated with synthetic fertilizer nitrogen applications on agricultural soils in Canada vary widely, but there is a close agreement between the the IPCC default emission factor of 1.25% (IPCC 2006) and the aggregated, measured emission factor of 1.2% in eastern Canada, excluding emissions during the spring-thaw period (Gregorich et al. 2005). .

## Recalculations

Over the last two years, recalculations have occurred in this category as a result of updates in long-term climate normals (monthly precipitation and potential evapotranspiration). These recalculations modestly affected estimates for the entire time series and had a modest impact on the long-term trend. A more detailed discussion of these recalculations and their impact is provided in Chapter 9.

## Planned Improvements

There is no immediate plan in place aimed at improving emission estimates for this source.

### 6.4.1.2 *Manure Applied as Fertilizer*

## Source Category Description

The application of animal manure as fertilizer to agricultural soils can increase the rate of nitrification and denitrification and result in enhanced N<sub>2</sub>O emissions. Emissions from this category include manure managed by drylot, liquid, and other animal waste management system. Manure deposited on grazing land is accounted for in Section 6.4.2, Manure on Pasture, Range, and Paddock.

## Methodological Issues

Similar to the methodology used to estimate emissions from synthetic fertilizer, the methodology used to estimate N<sub>2</sub>O emissions from animal manure applied to agricultural soils is a country-specific IPCC Tier 2–type method that takes into account local climate (long-term monthly precipitation and potential evapotranspiration) and topographic conditions. Emissions are calculated by multiplying the amount of manure nitrogen applied to agricultural soils by the non-volatilized fraction (available for nitrification and denitrification) and by an emission factor, at the ecodistrict, provincial and, finally, national levels. All manure that is handled by Animal Waste Management Systems, except for the manure on pasture, range, and paddock from grazing animals, is assumed to be applied to agricultural soils (see Section 6.4.2).

## Uncertainties and Time-Series Consistency

Uncertainties associated with N<sub>2</sub>O emission estimates from animal manure applied as fertilizers result from uncertainties associated with estimates of manure nitrogen based on types of animal population ( $\pm 1\%$  ~  $\pm 15\%$ ), average animal manure nitrogen excretion rate ( $\pm 20\%$ ), manure nitrogen loss ( $\pm 20\%$ ), RF<sub>TEXTURE</sub> ( $\pm 30\%$ ), and EF<sub>BASE</sub> ( $\pm 25\%$ ). The overall level and trend

uncertainties associated with this source of emission estimates from 1990 to 2006 were estimated to be  $\pm 32\%$  and  $\pm 28\%$ , respectively (Hutchinson et al. 2007).

The same methodology and emission factors are used for the entire time series (1990–2006).

### **QA/QC and Verification**

This category has undergone Tier 1–level QC checks as elaborated in the QA/QC plan (Annex 6) in a manner consistent with IPCC good practice guidance. The activity data, methodologies, and changes to methodologies are documented and archived in both paper and electronic form.

### **Recalculations**

Over the last two years, recalculations have occurred in this category as a result of updates in animal population (Section 6.2.5), long-term climate normals (Section 6.4.1.1), and animal manure N excretion rates. These recalculations slightly affected estimates for the entire time series and had a minimal impact on the long-term trend. A more detailed discussion of these recalculations and their impact is provided in Chapter 9.

### **Planned Improvements**

There is no immediate plan in place aimed at improving emission estimates for this source.

#### *6.4.1.3 Biological Nitrogen Fixation*

##### **Source Category Description**

Until the 2005 submission, biological nitrogen fixation by the legume–rhizobium association was a major source of  $\text{N}_2\text{O}$  emissions in previous national GHG inventories reported by Canada. The decision to exclude this category as an emission source in the IPCC 2006 Guidelines is supported by the findings of Rochette and Janzen (2005) that there is no evidence that measurable amounts of  $\text{N}_2\text{O}$  are produced during the nitrogen fixation process. Therefore, Canada reports this source as “not occurring.” However, the contribution of legume nitrogen to  $\text{N}_2\text{O}$  emissions from crop residue decomposition is still included (see Section 6.4.1.4).

#### *6.4.1.4 Crop Residue Decomposition (CRF Category 4.D.4)*

##### **Source Category Description**

When a crop is harvested, a portion of the crop (crop residue) is left on the field to decompose. The remaining plant matter is a nitrogen source for nitrification and denitrification and thus produces  $\text{N}_2\text{O}$ .

##### **Methodological Issues**

Emissions are estimated using an IPCC Tier 2 approach. Emissions of  $\text{N}_2\text{O}$  are estimated using the amount of nitrogen contained in crop residue multiplied by the emission factor at the ecodistrict level and scaled up to the provincial and national levels. The amount of nitrogen contained in crop residues from both nitrogen-fixing and non-nitrogen-fixing crops is estimated using country-specific crop characteristics (Janzen et al. 2003). Emission factors are determined using the same approach as for synthetic fertilizer nitrogen application, using moisture regimes and topographic conditions.

## Uncertainties and Time-Series Consistency

Uncertainties associated with N<sub>2</sub>O emission estimates from crop residue decomposition result from uncertainties associated with estimates of crop residue nitrogen returned to the soil based on crop production data ( $\pm 15\%$ ), above- and below-ground crop residue nitrogen concentration ( $\pm 15\%$ ), RF<sub>TEXTURE</sub> ( $\pm 30\%$ ), and EF<sub>BASE</sub> ( $\pm 25\%$ ). The overall level and trend uncertainties associated with this source of emission estimates from 1990 to 2006 were estimated to be  $\pm 23\%$  and  $\pm 20\%$ , respectively (Hutchinson et al. 2007).

The same methodology and emission factors are used for the entire time series (1990–2006).

## QA/QC and Verification

This category has undergone Tier 1–level QC checks as elaborated in the QA/QC plan (Annex 6) in a manner consistent with IPCC good practice guidance. The activity data, methodologies, and changes to methodologies are documented and archived in both paper and electronic form.

## Recalculations

Over the last two years, recalculations have occurred in this category as a result of updates in long-term climate normals. These recalculations modestly affected estimates for the entire time series and had a modest impact on the long-term trend. A more detailed discussion of these recalculations and their impact is provided in Chapter 9.

## Planned Improvements

Activity data on the area of crop residue burning are only available from the Farm Environmental Management Survey by Statistics Canada in 2001 and 2006. Efforts will be made to fill in the data gap since 1990 through expert consultations. Emissions of non-CO<sub>2</sub> from crop residue burning will be reported separately, but the amount of N contained in the burned crop residue will be subtracted from crop residue decomposition.

### 6.4.1.5 Cultivation of Organic Soils (Histosols)

#### Source Category Description

Cultivation of organic soils (histosols) for crop production usually involves drainage, lowering the below-ground water table, increasing aeration, and speeding up the decomposition of organic matter. Denitrification and nitrification also take place, releasing N<sub>2</sub>O.

#### Methodological Issues

The IPCC Tier 1 methodology is used to estimate N<sub>2</sub>O emissions from cultivated organic soils. N<sub>2</sub>O emissions are calculated by multiplying the area of cultivated histosols by the IPCC default emission factor.

Areas of cultivated histosols at a provincial level are not covered in the *Census of Agriculture*. Consultations with numerous soil and crop specialists across Canada have resulted in an estimate of cultivated organic soils in Canada to be 16 156 ha, a constant level for the period 1990–2006 (G. Padbury and G. Patterson, Agriculture and Agri-Food Canada, personal communication).

## Uncertainties and Time-Series Consistency

Uncertainties associated with N<sub>2</sub>O emission estimates from cultivation of histosols result from uncertainties associated with area estimates of cultivated histosols ( $\pm 50\%$ ) and emission factors ( $\pm 50\%$ ). The overall level and trend uncertainties associated with this source of emission estimates from 1990 to 2006 were estimated to be  $\pm 67\%$  and  $\pm 65\%$ , respectively (Hutchinson et al. 2007).

The same methodology and emission factors are used for the entire time series (1990–2006).

## QA/QC and Verification

This category has undergone Tier 1–level QC checks as elaborated in the QA/QC plan (Annex 6) in a manner consistent with IPCC good practice guidance. The activity data, methodologies, and changes to methodologies are documented and archived in both paper and electronic form.

## Planned Improvements

There is no immediate plan in place aimed at improving emission estimates from this source.

### 6.4.1.6 N<sub>2</sub>O Emissions or Removals from Adoption of No-Till and Reduced Tillage

## Source Category Description

This category is not derived from additional nitrogen input but rather reflects changes in N<sub>2</sub>O emission rates from fertilizer, manure, and crop residue inputs because of the switch to conservative soil management practices—namely, reduced tillage (RT) and no-tillage (NT).

## Methodological Issues

Compared with conventional or intensive tillage (IT), direct seeding or NT as well as RT affect several factors that influence N<sub>2</sub>O production, including decomposition of soil organic matter, soil carbon and nitrogen availability, soil bulk density, and water content (McConkey et al. 1996, 2003; Liang et al. 2004). As a result, compared with conventional tillage, conservation tillage (i.e. RT and NT) reduced N<sub>2</sub>O emissions for the Prairies, but increased N<sub>2</sub>O emissions for the non-Prairie regions of Canada. The net result across the country amounts to a small reduced source (hence the negative sign in Table 6-1).

Changes in N<sub>2</sub>O emissions resulting from the adoption of NT and RT are estimated through modifications of emission factors for synthetic fertilizers, manure nitrogen applied to cropland, and crop residue nitrogen decomposition. This subcategory is kept separate from the fertilizer and crop residue decomposition source categories to increase the transparency in reporting, which causes negative emissions to be reported (Table 6-1). An empirically derived tillage factor ( $F_{\text{TILL}}$ ), defined as the ratio of mean N<sub>2</sub>O fluxes on NT or RT to mean N<sub>2</sub>O fluxes on IT ( $N_{2O\text{NT}}/N_{2O\text{IT}}$ ), represents the effect of NT or RT on N<sub>2</sub>O emissions (see Section A3.3).

## Uncertainties and Time-Series Consistency

Uncertainties associated with changes in N<sub>2</sub>O emission estimates from adoption of NT and RT result from uncertainties associated with area estimates of NT and RT from the *Census of Agriculture* ( $\pm 15\%$ ),  $F_{\text{TILL}}$  ( $\pm 20\%$ ), and  $EF_{\text{BASE}}$  ( $\pm 25\%$ ). The overall level and trend uncertainties

associated with this source of emission/removal estimates from 1990 to 2006 have not been assessed.

The same methodology and emission factors are used for the entire time series (1990–2006).

### **QA/QC and Verification**

This category has undergone Tier 1–level QC checks as elaborated in the QA/QC plan (Annex 6) in a manner consistent with IPCC good practice guidance. The activity data, methodologies, and changes to methodologies are documented and archived in both paper and electronic form.

### **Recalculations**

Over the last two years, recalculations have occurred in this category as a result of updates in animal populations (Section 6.2.5), animal manure N excretion rates and long-term climate normals, and the inclusion of llamas and alpacas. These recalculations slightly affected estimates for the entire time series and had no impact on the long-term trend. A more detailed discussion of these recalculations and their impact is provided in Chapter 9.

### **Planned Improvements**

There is no immediate plan in place aimed at improving emission estimates from this source.

#### *6.4.1.7 N<sub>2</sub>O Emissions Resulting from Summerfallowing*

### **Source Category Description**

This category is not derived from additional nitrogen input but reflects changes in soil conditions that affect N<sub>2</sub>O emissions. Summerfallow (SF) is a farming practice typically used in the Prairie region to conserve soil moisture by leaving the soil unseeded for an entire growing season in a crop rotation. During the fallow year, several factors may stimulate N<sub>2</sub>O emissions relative to a cropped situation, such as higher soil water content, temperature, and available carbon and nitrogen (Campbell et al. 1990).

### **Methodological Issues**

Experimental studies have shown that N<sub>2</sub>O emissions in fallow fields are not statistically different from emissions on continuously cropped fields (Rochette et al. 2008). The emissions from SF land are therefore calculated through a country-specific method by summing emissions from fertilizer N, manure N application to annual crops and crop residue N for a given ecodistrict and multiplying the sum by the proportion of that ecodistrict area under summerfallow (Rochette et al. 2008).

### **Uncertainties and Time-Series Consistency**

Uncertainties associated with N<sub>2</sub>O emission estimates from summerfallow result from uncertainties associated with area estimates of summerfallow from the *Census of Agriculture* (cropland area: 1.25% ~10%; the fraction of cropland that is under summerfallow (FRAC<sub>FALLOW</sub>): 1.25% ~10%) and EF<sub>BASE</sub>: ±25%. The overall level and trend uncertainties associated with this source of emission estimates from 1990 to 2006 were estimated to be ±24% and ±21%, respectively (Hutchinson et al. 2007).

The same methodology and emission factors are used for the entire time series (1990–2006).

## QA/QC and Verification

This category has undergone Tier 1–level QC checks as elaborated in the QA/QC plan (Annex 6) in a manner consistent with IPCC good practice guidance. The activity data, methodologies, and changes to methodologies are documented and archived in both paper and electronic form.

## Recalculations

Over the last two years, recalculations have occurred in this category as a result of updates in animal populations (Section 6.2.5), animal manure N excretion rates and long-term climate normals, and the inclusion of llamas and alpacas. These recalculations modestly affected estimates for the entire time series and had little impact on the long-term trend. A more detailed discussion of these recalculations and their impact is provided in Chapter 9.

## Planned Improvements

There is no immediate plan in place aimed at improving emission estimates from this source.

### 6.4.1.8 *N<sub>2</sub>O Emissions from Irrigation*

#### Source Category Description

Similar to tillage practices and summerfallow, the effect of irrigation on N<sub>2</sub>O emissions is not derived from additional nitrogen input but reflects changes in soil conditions that affect N<sub>2</sub>O emissions. Higher soil water content under irrigation increases potential N<sub>2</sub>O emissions by increasing biological activity and reducing soil aeration (Jambert et al. 1997).

#### Methodological Issues

The methodology is country specific and is based on the assumptions that 1) the irrigation water stimulates N<sub>2</sub>O production in a way similar to rainfall water and 2) irrigation is applied at rates such that amounts of precipitation plus those of irrigation water are equal to the potential evapotranspiration at the local conditions. Consequently, the effect of irrigation on N<sub>2</sub>O emissions from agricultural soils was estimated using an EF<sub>BASE</sub> estimated at a P/PE = 1 (e.g. EF<sub>BASE</sub> = 0.017 N<sub>2</sub>O-N/kg N) for the irrigated areas of a given ecodistrict.

#### Uncertainties and Time-Series Consistency

Uncertainties associated with N<sub>2</sub>O emission estimates from irrigation result from uncertainties associated with synthetic nitrogen ( $\pm 20\%$ ) and animal manure nitrogen ( $\pm 20\%$ ) inputs, crop residue nitrogen ( $\pm 15\%$ ), area estimates of irrigated cropland from the *Census of Agriculture* (1.25% ~10%), as well as EF<sub>BASE</sub> ( $\pm 25\%$ ). The overall level and trend uncertainties associated with this source of emission estimates have not been assessed at this time.

The same methodology and emission factors are used for the entire time series (1990–2006).

## QA/QC and Verification

This category has undergone Tier 1–level QC checks as elaborated in the QA/QC plan (Annex 6) in a manner consistent with IPCC good practice guidance. The activity data and methodology are documented and archived in both paper and electronic form.

## Recalculations

Over the last two years, recalculations have occurred in this category as a result of updates in animal population data (Section 6.2.5), animal manure N excretion rates, inclusion of llamas and alpacas, and long-term climate normals. These recalculations modestly affected estimates for the entire time series and had little impact on the long-term trend. A more detailed discussion of these recalculations and their impact is provided in Chapter 9.

## Planned Improvements

The level and trend uncertainties associated with this source of emission estimates will be assessed in future.

### 6.4.2 Manure on Pasture, Range, and Paddock (CRF Category 4.D.2)

#### 6.4.2.1 Source Category Description

When manure is excreted on pasture, range, and paddock from grazing animals, nitrogen in the manure undergoes transformations, such as ammonification, nitrification, and denitrification. During these transformation processes,  $\text{N}_2\text{O}$  is produced.

#### 6.4.2.2 Methodological Issues

The emissions from manure excreted by grazing animals are calculated using the IPCC Tier 1 methodology (IPCC/OECD/IEA 1997). Emissions are calculated for each animal category by multiplying the animal population for that category by the appropriate nitrogen excretion rate and by the fraction of manure nitrogen available for conversion to  $\text{N}_2\text{O}$ .

The animal population data are the same as those used in Section 6.2. The nitrogen excretion rates are based on the IPCC 2006 defaults. The fraction of manure nitrogen available for conversion to  $\text{N}_2\text{O}$  is calculated as the percentage of total manure nitrogen produced on pasture, range, and paddock multiplied by the IPCC 2006 default values of 0.02 kg  $\text{N}_2\text{O}$ -N/kg N for cattle, poultry, and swine, and 0.01 kg  $\text{N}_2\text{O}$ -N/kg N for sheep/lamb, goat, and horse, which represents the fraction of excreted manure nitrogen converted to  $\text{N}_2\text{O}$ -N.

#### 6.4.2.3 Uncertainties and Time-Series Consistency

Uncertainties associated with  $\text{N}_2\text{O}$  emission estimates from animal manure on pasture, range, and paddock result from uncertainties associated with animal populations ( $\pm 1\% \sim \pm 15\%$ ), manure nitrogen excretion rate ( $\pm 20\%$ ), fraction of manure nitrogen on pasture, range, and paddock ( $\pm 20\%$ ), as well as emission factors ( $-25\% \sim +150\%$ ). The overall level and trend uncertainties associated with this source of emission estimates from 1990 to 2006 were estimated to be  $\pm 19\%$  and  $\pm 21\%$ , respectively (Hutchinson et al. 2007).

The same methodology and emission factors are used for the entire time series (1990–2006).

#### 6.4.2.4 QA/QC and Verification

The activity data, methodologies, and changes to methodologies are documented and archived in both paper and electronic form. QC checks and cross-checks have been carried out to identify data entry errors and calculation errors. In general, there are very few data available on the

quantity of N<sub>2</sub>O emissions from the manure on pasture, range, and paddock from grazing animals in Canada. Therefore, it is extremely difficult to verify how well the IPCC emission factors reflect Canadian conditions.

#### 6.4.2.5 *Recalculations*

Over the last two years, recalculations have occurred in this category as a result of updates in animal population data because of the release of the *2006 Census of Agriculture* (Statistics Canada 2006) animal manure N excretion rates, and inclusion of llamas and alpacas. These recalculations modestly affected estimates for the entire time series and had some impact on the long-term trend. A more detailed discussion of these recalculations and their impact is provided in Chapter 9.

#### 6.4.2.6 *Planned Improvements*

There is no immediate plan for improvements associated with estimates of N<sub>2</sub>O emissions from animal manure on pasture, range, and paddock.

### 6.4.3 Indirect Emissions of N<sub>2</sub>O from Soils (CRF Category 4.D.3)

A fraction of the nitrogen from both synthetic fertilizer and manure that is applied to agricultural fields is transported off-site through volatilization and subsequent redeposition or leaching, erosion, and runoff. The nitrogen that is transported from the agricultural field in this manner provides additional nitrogen for subsequent nitrification and denitrification to produce N<sub>2</sub>O. The nitrogen leaving an agricultural field may not be available for the process of nitrification and denitrification for many years, particularly in the case of nitrogen leaching into groundwater.

#### 6.4.3.1 *Volatilization and Redeposition of Nitrogen*

##### **Source Category Description**

When synthetic fertilizer or manure is applied on cropland, a portion of the nitrogen is lost through volatilization in the form of NH<sub>3</sub> or NO<sub>x</sub>, which can be redeposited somewhere else and undergo further transformation, thus resulting in N<sub>2</sub>O emissions off-site. The quantity of this volatilized nitrogen depends on a number of factors, such as rates of fertilizer and manure nitrogen application, fertilizer types, methods and time of nitrogen application, soil texture, rainfall, temperature, and soil pH.

##### **Methodological Issues**

The IPCC Tier 1 methodology is used to estimate indirect N<sub>2</sub>O emissions due to volatilization and redeposition of nitrogen from synthetic fertilizer and manure. The portions of volatilized NH<sub>3</sub> or NO<sub>x</sub> from animal manure vary with animal types and manure management systems based on the default values from the IPCC 2006 Guidelines. The amount of synthetic fertilizer and manure nitrogen is multiplied by the fraction of nitrogen that is volatilized as NH<sub>3</sub>-N and NO<sub>x</sub>-N and then by an emission factor. The amount of nitrogen applied is obtained from yearly fertilizer sales data, which are available from the Canadian Fertilizer Institute, and from the amounts excreted by animals (see Section A3.3). The amount of nitrogen that volatilizes is assumed to be 10% of the total amount of synthetic fertilizer applied (IPCC/OECD/IEA 1997) and 20% of the applied manure N to cropland (IPCC 2006). The default IPCC emission factor, 0.01 kg N<sub>2</sub>O-N/kg N, is applied to derive the N<sub>2</sub>O emission estimate (IPCC/OECD/IEA 1997).



## Uncertainties and Time-Series Consistency

Uncertainties associated with N<sub>2</sub>O emission estimates from volatilization of NH<sub>3</sub> and NO<sub>x</sub> due to applications of synthetic and manure nitrogen result from uncertainties associated with estimates of synthetic fertilizer nitrogen consumption ( $\pm 20\%$ ), fraction of volatilized NH<sub>3</sub> and NO<sub>x</sub> from synthetic nitrogen fertilizers ( $\pm 20\%$ ), animal populations ( $\pm 1\% \sim \pm 15\%$ ), manure nitrogen excretion rate ( $\pm 20\%$ ), fraction of volatilized NH<sub>3</sub> + NO<sub>x</sub> from animal manure ( $\pm 20\%$ ), as well as emission factors ( $-50\% \sim +300\%$ ). The overall level and trend uncertainties associated with this source of emission estimates from 1990 to 2006 were estimated to  $\pm 40\%$  and  $\pm 34\%$ , respectively (Hutchinson et al. 2007).

The same methodology and emission factors are used for the entire time series (1990–2006).

## QA/QC and Verification

This category has undergone Tier 1–level QC checks as elaborated in the QA/QC plan (see details and references in Annex 6) in a manner consistent with IPCC good practice guidance. The activity data, methodologies, and changes to methodologies are documented and archived in both paper and electronic form.

## Recalculations

Over the last two years, recalculations have occurred in this category as a result of updates in animal population data (Section 6.2.5), animal manure N excretion rates, and inclusion of llamas and alpacas, as well as methodological improvements, notably in the estimation methods reflecting the change in the equation proposed in the IPCC 2006 Guidelines. These recalculations modestly affected estimates for the entire time series and had some impact on the long-term trend. A more detailed discussion of these recalculations and their impact is provided in Chapter 9.

## Planned Improvements

There is no immediate plan in place aimed at improving emission estimates from this source.

### 6.4.3.2 *Leaching, Erosion, and Runoff*

#### Source Category Description

When synthetic fertilizer or manure nitrogen is applied to cropland, a portion of the nitrogen is lost through leaching, erosion, and runoff. The magnitude of this loss depends on a number of factors, such as application rate and method, crop type, soil texture, rainfall, landscape. This portion of lost nitrogen can further undergo transformations, such as nitrification and denitrification, thus producing N<sub>2</sub>O emissions off-site.

#### Methodological Issues

A modified IPCC Tier 1 methodology is used to estimate indirect N<sub>2</sub>O emissions from leaching, runoff, and erosion of fertilizers, manure, and crop residue nitrogen from agricultural soils. Indirect N<sub>2</sub>O emissions from runoff and leaching of nitrogen at the ecodistrict level are estimated using FRAC<sub>LEACH</sub> multiplied by the amount of synthetic fertilizer nitrogen, non-volatilized manure nitrogen, and crop residue nitrogen and by an emission factor of 0.025 kg N<sub>2</sub>O-N/kg N (IPCC 2000).

The default value for the fraction of nitrogen that is lost through leaching and runoff ( $\text{FRAC}_{\text{LEACH}}$ ) in the Revised 1996 Guidelines was 0.3.  $\text{FRAC}_{\text{LEACH}}$  can reach values as low as 0.05 in regions where rainfall is much lower than potential evapotranspiration (IPCC 2006), such as in the Prairie region of Canada. Accordingly, it was assumed that  $\text{FRAC}_{\text{LEACH}}$  would vary among ecodistricts from a low of 0.05 to a high of 0.3. For ecodistricts with no moisture deficit during the growing season (May through October), the maximum  $\text{FRAC}_{\text{LEACH}}$  value of 0.3 recommended by the IPCC 2006 Guidelines was assigned. The minimum  $\text{FRAC}_{\text{LEACH}}$  value of 0.05 was assigned to ecodistricts with the greatest moisture deficit. For the remaining ecodistricts,  $\text{FRAC}_{\text{LEACH}}$  was estimated by the linear extrapolation of the two “limit situations” described above.

### Uncertainties and Time-Series Consistency

Uncertainties associated with  $\text{N}_2\text{O}$  emission estimates from leaching, runoff, and erosion of nitrogen from synthetic, manure, and crop residue nitrogen result from uncertainties associated with estimates of synthetic fertilizer nitrogen consumption ( $\pm 20\%$ ), manure nitrogen excretion rate ( $\pm 20\%$ ), animal populations ( $\pm 1\% \sim \pm 15\%$ ), crop residue nitrogen ( $\pm 15\%$ ),  $\text{FRAC}_{\text{LEACH}}$  ( $\pm 50\%$ ), as well as the leaching/runoff emission factor  $\text{EF}_{\text{LEACH}}$  ( $-48\% \sim +200\%$ ). The overall level and trend uncertainties associated with this source of emission estimates from 1990 to 2006 were estimated to be  $\pm 32\%$  and  $\pm 29\%$ , respectively (Hutchinson et al. 2007).

The same methodology and emission factors are used for the entire time series (1990–2006).

### QA/QC and Verification

This category has undergone Tier 1–level QC checks as elaborated in the QA/QC plan (refer to details and references in Annex 6) in a manner consistent with IPCC good practice guidance. The activity data, methodologies, and changes to methodologies are documented and archived in both paper and electronic form.

### Recalculations

Over the last two years, recalculations have occurred in this category as a result of updates in animal populations because of the release of the *2006 Census of Agriculture* as noted in Enteric Fermentation (Section 6.2), animal manure N excretion rates and long-term climate normals, and inclusion of llamas and alpacas. These recalculations slightly affected estimates for the entire time series and had little impact on the long-term trend. A more detailed discussion of these recalculations and their impact is provided in Chapter 9.

### Planned Improvements

There is no immediate plan in place aimed at improving emission estimates from this source.

## 7 Land Use, Land-Use Change and Forestry (CRF Sector 5)

### 7.1 Overview

The LULUCF Sector reports GHG fluxes between the atmosphere and Canada's managed lands, as well as those associated with land-use changes. The assessment includes emissions and removals of CO<sub>2</sub>, additional emissions of CH<sub>4</sub>, N<sub>2</sub>O, and CO due to wildfires and controlled burning, and N<sub>2</sub>O released following land conversion to cropland. All emissions from and removals by the LULUCF Sector are excluded from the national totals.

In 2006, the estimated net GHG flux in the LULUCF Sector, calculated as the sum of CO<sub>2</sub><sup>61</sup> emissions and removals and non-CO<sub>2</sub> emissions, amounted to emissions of 31 Mt. If these were included in the national totals, they would reduce the total Canadian GHG emissions by about 4%. Table 7-1 provides the net flux estimates for 1990, 2006, and 2005 in the major LULUCF Sector categories and subcategories.

In view of the high interannual variability displayed by some categories and its effect on the sectoral trends, the reader is cautioned against interpreting the figures in Table 7-1 as trends. The full time series of LULUCF Sector estimates is available in Table 10 of the CRF series.

**Table 7-1: LULUCF Sector Net GHG Flux Estimates, Selected Years**

Sectoral Category	Net GHG Flux (kt CO <sub>2</sub> eq) <sup>4</sup>		
	1990	2005	2006
<b>Land Use, Land-Use Change and Forestry TOTAL<sup>1</sup></b>	<b>-110 000</b>	<b>-8 400</b>	<b>31 300</b>
<b>a. Forest Land</b>	<b>-130 000</b>	<b>-18 000</b>	<b>22 700</b>
Forest Land Remaining Forest Land	-130 000	-17 000	23 800
Land Converted to Forest Land	-1 200	-1 100	-1 100
<b>b. Cropland</b>	<b>13 700</b>	<b>-860</b>	<b>-1 400</b>
Cropland Remaining Cropland	-1 400	-9 000	-9 600
Land Converted to Cropland	15 100	8 170	8 150
<b>c. Grassland</b>	<b>NE</b>	<b>NE</b>	<b>NE</b>
Grassland Remaining Grassland	NE	NE	NE
Land Converted to Grassland	NE	NE	NE
<b>d. Wetlands</b>	<b>4 370</b>	<b>2 330</b>	<b>2 130</b>
Wetlands Remaining Wetlands	707	1 310	1 280
Land Converted to Wetlands	3 660	1 020	851
<b>e. Settlements</b>	<b>9 160</b>	<b>7 830</b>	<b>7 890</b>
Settlements Remaining Settlements	-140	-160	-160
Land Converted to Settlements	9 300	7 990	8 060
Forest conversion (memo item) <sup>2</sup>	26 600	19 900	19 300
Grassland conversion (memo item) <sup>2,3</sup>	1 090	737	723

Notes:

1. Totals may not add up due to rounding. Annex 13 describes the rounding protocol.

2. Already included in land converted to cropland, land converted to wetlands, and land converted to settlements; and in cropland remaining cropland and wetlands remaining wetlands (for residual emissions post-20 years, 10 years for reservoirs).

3. Includes conversion of agricultural grassland to cropland and of tundra to settlement.

4. Negative sign indicates removal of CO<sub>2</sub> from the atmosphere.

NE = Not estimated.

61. Unless otherwise indicated, all emissions and removals are in CO<sub>2</sub> equivalents.

The Forest Land category has the largest influence on sectoral totals. The net fluxes are negative (removals) in 11 of the 17 years of the time series, and positive (emissions) for the remainder. Years with a net positive flux are increasing in frequency in the latter part of the time series. Net emissions are particularly large in years with large areas burned by wildfire. As a consequence, the interannual variability is high, with net category totals fluctuating between –155 Mt (1992) and 146 Mt (1995). These fluctuations are carried over to the LULUCF Sector totals, which vary between net emissions and net removals, depending on the net flux from managed forests.

Over the entire period, the Cropland category displays a steady trend towards decreasing emissions, to a small removal of 1.4 Mt in 2006. The decline of emissions from land converted to cropland and growing removals by cropland remaining cropland equally contribute to the 15 Mt reduction in net emissions over the period 1990–2006.

Net fluxes in the Wetlands category (managed peatlands and flooded lands) fluctuate between 1.9 Mt and 4.4 Mt. Emissions from land converted to wetlands declined from a little less than 4 Mt to 0.9 Mt during the period. Emissions from flooded lands account for over 85% of all emissions in the Wetlands category.

With this submission, Canada continues the implementation of a multi-year effort to substantially improve its estimates for the LULUCF Sector.<sup>62</sup> The contribution of the best Canadian expertise to this and the previous submission occurred within Canada's national, multidisciplinary framework for monitoring, accounting, and reporting emissions and removals in managed lands. This MARS framework provides a means for coordinating, planning, and integrating the activities of many groups of scientists and experts across several government levels and research institutions.

Work within MARS for LULUCF is expected to continue in the next several years. In addition to enhanced collaboration within the framework, planned improvements include the development of formal and documented uncertainty estimates in all LULUCF categories and more complete scientific documentation.

The remainder of this chapter highlights the salient features of each LULUCF Sector category, beginning with key changes since the previous submission (Section 7.1). Section 7.2 gives an overview of the representation of managed lands; each subsequent section provides a short description of a land category (Sections 7.3–7.7). A special section (Section 7.8) is devoted to the cross-category estimates of forest conversion to other lands.

## **7.2 Land Category Definition and Representation of Managed Lands**

In order to harmonize all land-based estimates, a common, definitional framework was elaborated and adopted by all groups involved in estimate preparation. Definitions are consistent with the IPCC (2003) land categories, while remaining relevant to land management practices, prevailing environmental conditions, and available data sources in Canada.

Forest land includes all areas of 1 ha or more where tree formations can reach 25% crown cover and 5 m in height in situ. Not all Canadian forests are under the direct influence of human activities, prompting the non-trivial question of what areas properly embody the “managed

---

62. First described in the 2004 NIR and implemented for the 2006 submission.

forests.” For the purpose of the GHG inventory, managed forests are those potentially subject to harvesting or to measures of fire protection. Section A3.4 provides more detail on the implementation of the “managed forests” definition.

Agricultural land comprises both cropland and agricultural grassland. Cropland includes all lands in annual crops, summerfallow, and perennial crops (mostly forage, but also including berries, grapes, nursery crops, vegetables, and fruit trees and orchards). Agricultural grassland is defined as “unimproved” pasture or rangeland that is used only for grazing domestic livestock. It occurs only in geographical areas where the grassland would not naturally regrow to forest if abandoned: the natural shortgrass prairie in southern Saskatchewan and Alberta and the dry, interior mountain valleys of British Columbia. All agricultural land that is not grassland is de facto classified as cropland, including unimproved pastures where natural vegetation would be forest (eastern Canada and most of British Columbia).

Vegetated areas that do not meet the definition of forest land or cropland are generally classified as grassland: extensive areas of tundra in the Canadian north are considered non-managed grasslands.

Wetlands are areas where permanent or recurrent saturated conditions allow the establishment of vegetation and soil development typical of these conditions and that are not already in forest land, cropland, or agricultural grasslands. A national wetland inventory is under preparation (Hélie et al. 2003). Managed wetlands are those where human interventions have altered the water table—for example, peatlands drained for peat extraction or flooded lands (IPCC 2003).

Settlements include all built-up land: urban, rural residential, land devoted to industrial and recreational use; roads, rights-of-way, and other transportation infrastructure; and resource exploration, extraction, and distribution (mining, oil and gas). The diversity of this category has so far precluded an assessment of its extent in the Canadian landscape; however, it is often involved in land conversion, and the impact of forest land conversion to settlements is assessed in this GHG inventory.

As a consequence of the land categorization scheme, some land-use transitions cannot occur—for example, forest conversion to agricultural grassland, since these by definition exclude areas where forests can grow naturally. Note that in theory the opposite can happen (i.e. grassland conversion to forest), although the direct human-induced conversion of agricultural grassland to forest has not been observed. Since grassland is defined as “native,” creation of grassland is mostly not occurring.

Table 7-2 illustrates the land-use areas (diagonal cells) and cumulative land-use change areas (non-diagonal cells) in 2006. Cumulative land-use change areas are the total land areas converted over the past 20 years (10 years for reservoirs). The grassland diagonal cell refers to the total area of agricultural grasslands, whereas grassland converted to settlements refers to land conversion of non-managed tundra to settlements in northern Canada. Column totals indicate the total land area reported in the CRF for each category.

The MARS land monitoring system includes the conversion of non-managed forests and grasslands to other land categories. Unmanaged land converted to any use always becomes “managed”; once land has become managed, it does not revert to “unmanaged” status, even if management practices are discontinued. Parks and protected areas are included in managed lands.

With a few exceptions (e.g. emissions due to liming), the LULUCF estimates as reported in the CRF tables are spatially attached to “reporting zones” (Figure 7-1). These reporting zones are essentially the same as the terrestrial ecozones (Marshall and Shut 1999), with three exceptions: the Boreal Shield and Taiga Shield ecozones are split into their east and west components to form four reporting zones; and the Prairies ecozone is divided into a semi-arid and a subhumid component. Estimates are reported for 15 of the 18 reporting zones, leaving out the three northernmost ecozones of Canada: Arctic Cordillera, Northern Arctic, and Southern Arctic, where no direct human-induced GHG emissions and removals are detected for this sector. More details on the spatial estimating and reporting framework can be found in Section A3.4.

**Table 7-2: Managed Land Areas (kha) in the 2006 LULUCF Accounting System<sup>1</sup>**

Initial Land Use	Final Land Use					
	Forest	Cropland	Grassland	Wetlands	Settlements	Other
<b>Forest</b>	229 800	658	NO	64	434	NO
<b>Cropland</b>	174	50 140	NO	NE	NE	NO
<b>Grassland</b>	NO	192	NE	NE	1	NO
<b>Wetlands</b>	NO	NE	NO	397 <sup>2</sup>	NE	NE
<b>Settlements</b>	NO	NE	NO	NO	NE	NO
<b>Other</b>	NO	NO	NO	38	NE	NE

Notes:

1. Non-diagonal cells refer to cumulative areas, i.e. total land converted over the last 20 years (10 years for reservoirs).

2. Only includes wetland areas for which emissions are reported in the CRF.

NE = Not estimated.

NO = Not occurring.



**Figure 7-1: Reporting Zones Spatial Framework for LULUCF Estimate Development**

The areas reported in the CRF tables represent those used for annual estimate development, but not always the total land area under a land category or subcategory in a specific inventory year. Hence, areas used for estimate development in the Cropland category represent areas subjected to changes in soil management practices only, as opposed to total Cropland area; areas of land converted to wetlands (reservoirs) represent a fraction of total reservoir areas (those flooded for 10 years or less), not the total area of reservoirs in Canada.

Similarly, the areas of land conversion reported in the CRF tables refer to the cumulative total land area converted over the last 20 years (10 years for reservoirs) and should not be confused with annual rates of land-use change. The trends observed in the land conversion categories of the CRF (e.g. land converted to forest land, land converted to cropland) result from the balance between land area newly converted to a category and the transfer of lands converted more than 20 years ago (10 years for reservoirs) into the “land remaining land” categories.

### **7.3 Forest Land**

Forest and other wooded lands cover 402 Mha of Canadian territory; forest lands alone occupy 310 Mha (NRCan 2001). Managed forests, those under direct human influence, extend over 230 Mha, or 74% of all forests. Four reporting zones account for 68% of managed forests (see Table 7-3).

In 2006, the net GHG balance of managed forest land amounted to emissions of 23 Mt (Table 7-1 above and CRF Table 5). For the purpose of UNFCCC reporting, managed forest lands are divided into forest land remaining forest land (230 Mha, net removals of 24 Mt) and land converted to forest land (10.174 Mha, net removals of 1.1 Mt) in 2006. Both categories include net emissions and removals of CO<sub>2</sub>, as well as N<sub>2</sub>O, CO, and CH<sub>4</sub> emissions from wildfires.

GHG fluxes from and to managed forests are not spatially homogeneous. In 2006, managed forests in the Pacific Maritime and Montane Cordillera reporting zones are two large net sources of GHG, while those in the Taiga Plains are a net sink (Table 7-3). Note that the spatial distribution of emissions and removals is influenced by the occurrence and location of disturbances and would therefore not be constant in successive years.

#### **7.3.1 Forest Land Remaining Forest Land**

##### **7.3.1.1 Methodological Issues**

Vegetation absorbs CO<sub>2</sub> from the atmosphere through photosynthesis, and some of this carbon is sequestered in standing vegetation, dead biomass, and soils. CO<sub>2</sub> is returned to the atmosphere by vegetation respiration and the decay of organic matter in dead biomass and soils. The natural CO<sub>2</sub> exchanges between the atmosphere and biota are large fluxes, recycling on the order of one seventh of the total atmospheric CO<sub>2</sub> content annually. In reality, these large fluxes result from the accumulation of minute processes dispersed over vast land areas.

Human interactions with the land directly alter the size and rate of these natural exchanges of GHGs, in both the immediate and long term. Land-use change and land-use practices in the past still affect current GHG fluxes to and from the terrestrial biosphere. This long-term effect is a unique characteristic of the LULUCF Sector, which makes it very distinct from other sectors, such as Energy.

While the focus is on anthropogenic impacts on the GHG balance, it is recognized that separating human from natural effects in the LULUCF Sector poses a unique challenge. Humans manipulate biological processes in a myriad of ways and intensities. What we observe is typically the outcome of these various manipulations and their combined interactions with an equally varied biophysical environment. Untangling the various cause-and-effect relationships is still the object of complex scientific inquiries.

**Table 7-3: GHG Balance of Managed Forests by Reporting Zone, 2006<sup>1</sup>**

Reporting Zone Number	Reporting Zone Name	Managed Forest Area (kha)	Net GHG Balance (Mt CO <sub>2</sub> eq)
1	Arctic Cordillera	—	NA
2	Northern Arctic	—	NA
3	Southern Arctic	—	NA
4	Taiga Shield East	1 100	1.4
5	Boreal Shield East	55 600	−8.0
6	Atlantic Maritime	15 900	11
7	Mixedwood Plains	2 720	−7.6
8	Hudson Plains	302	−0.96
9	Boreal Shield West	28 800	0.6
10	Boreal Plains	36 200	−1.9
11	Subhumid Prairies	1 820	−1.8
12	Semi-Arid Prairies	24	0
13	Taiga Plains	20 000	−34
14	Montane Cordillera	35 400	40
15	Pacific Maritime	13 200	46
16	Boreal Cordillera	16 600	−20
17	Taiga Cordillera	412	−0.27
18	Taiga Shield West	1 830	−1.9

Notes:

1. Negative sign indicates removal of CO<sub>2</sub> from the atmosphere.

NA = Not applicable.

Canada applies a Tier 3 methodology for estimating GHG emissions and removals in managed forests. Its major features include a model-based approach (Carbon Budget Model of the Canadian Forest Service, CBM-CFS3), which integrates all forest carbon pools; the incorporation of detailed activity data from regional and local forest inventories; spatially referenced data on natural disturbances (fires and insects); and numerous detailed parameters to simulate natural and disturbance-driven carbon transfers among pools and with the atmosphere. The conceptual approach remains that recommended by IPCC (2003), in which net removals or emissions are calculated as the difference between CO<sub>2</sub> uptake by growing trees and emissions from forest management activities (harvesting) and natural disturbances (wildfires, insect infestations). The interested reader will find additional information on estimation methodology in Section A3.4.

Carbon stock changes in managed forests are reported in CRF Table 5A, by reporting zone. These net carbon stock changes include not only exchanges of GHG with the atmosphere, but also the carbon transfers between pools, for example its transfer from living biomass to dead organic matter upon stand mortality. Therefore these carbon stock changes give no indication of the main fluxes between carbon pools in managed forests and the atmosphere. The largest carbon fluxes to



and from managed forests consist of carbon uptake by growing trees and its release due to the decay of organic matter (respectively  $-2\,939$  and  $2\,077$  Mt in 2006 – Figure 7-2). The upward trend in dead organic matter (DOM) decay reflects the long-term, growing effect of past disturbances, especially insect epidemics, leaving substantial quantities of decaying DOM. Over the last three years, insect epidemics have affected a total of over 16 Mha of managed forests. In contrast, much of the interannual variability of the GHG budget of managed forests hinges on the occurrence and severity of fires. During 1990–2006, annual wildfire emissions fluctuated between 11 and 290 Mt. During fires, emissions from DOM consumption account for 81% of immediate emissions; much biomass is killed by forest fires, but is not immediately consumed. Hence, a large amount of the actual fuel load consists of dead wood and litter on the forest floor. On average, 8% of immediate fire emissions in CO<sub>2</sub> equivalents are in the form of CO, 7% as CH<sub>4</sub>, and 4% in the form of N<sub>2</sub>O.

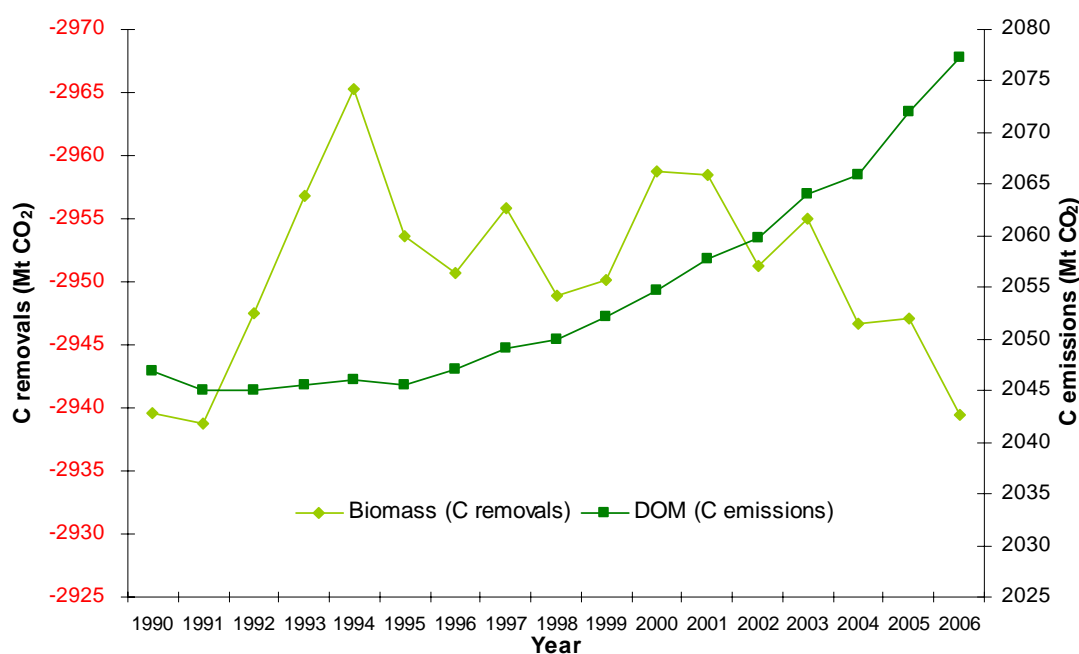


Figure 7-2: Large Annual Carbon Fluxes to and from the Atmosphere in Managed Forests, 1990–2006

In order to avoid double-counting, estimates of C stock changes in CRF Table 5A exclude carbon emissions as CO<sub>2</sub>, CH<sub>4</sub>, and CO due to biomass burning, which are reported in Table 5(V). Emissions and removals are automatically tallied in CRF Table 5.

In keeping with the current IPCC default methodology, emissions from forest management activities comprise all the CO<sub>2</sub> contained in harvested roundwood and harvest residues. All carbon transferred out of managed forests as wood products is deemed an immediate emission. Under this approach, in 2006 the transfer of carbon from forests to harvested wood products (HWPs) from forest management activities accounts for emissions of 164 Mt, an increase of 62% since 1990. Three alternative approaches—atmospheric flow, production, and stock change—have been preliminarily evaluated in Canada to attempt to correctly account for delayed

emissions due to long-term carbon storage in HWPs. These approaches account for the carbon stored in HWPs and emissions from its eventual decay from products harvested, imported (stock change, atmospheric flow), or exported (production) in the current and previous years; they are therefore more spatially and temporally realistic than the current default, which does not account for emissions from HWPs where or when they actually occur. They differ with respect to their allocation of emissions and removals. A breakdown and brief discussion of each of the accounting approaches, along with implications for Canada, are contained in Annex 3.4.

### 7.3.1.2 *Uncertainties and Time-Series Consistency*

Considering the ongoing and important efforts required for the continued implementation of a Tier 3 approach in the managed forests, it was not possible, owing to resource limitations, to develop formal uncertainty estimates for this submission. A discussion of the main uncertainty sources is provided in Annex 3.4. A comprehensive analysis is under preparation (White et al., 2008).

All estimates have been developed in a consistent manner. Estimates for wildfire areas in 2004–2006 were derived from real-time, remotely sensed imagery. Estimates for 1990–2003 were derived from the CFS large fire database. In addition, the available forest inventory data do not span the same periods across the country; Annex 3.4 explains how forest inventory data from various sources were harmonized to provide complete, coherent, and consistent forest data for 1990.

### 7.3.1.3 *QA/QC and Verification*

Tier 2 QC checks, implemented and documented by CFS (White and Dymond 2008), specifically address estimate development in the Forest Land category. Systematic and documented QA/QC procedures are performed in four areas: workflow checks (manual), model checks (automated), benchmark checks (manual), and external reviews. Check results are systematically documented; an issue logging system identifies each issue and facilitates tracking and managing its resolution.

Environment Canada, while maintaining its own QA/QC procedures for estimates developed internally (refer to Annex 6), has implemented new ones for estimates obtained from partners, as well as for all estimates and activity data contained in the LULUCF geodatabase and entered into the CRF reporter. These procedures and their outcome are fully documented in the centralized archives.

### 7.3.1.4 *Recalculations*

Over the last two years very significant recalculations have occurred in this category as a result of changes in the estimated area and delineation of managed forest area. These recalculations have considerably affected estimates in years for which wildfire events previously determined to fall in the managed forest were determined to occur outside of it. Carbon uptake by growing trees was also altered. Other significant changes resulted from the implementation of refined decay rates in fresh and humified aboveground litter, and an annual carbon transfer from this litter pool to the belowground soil pool. A more detailed discussion of these recalculations and their impact is provided in Chapter 9.

### 7.3.1.5 *Planned Improvements*

Highest priorities are given to the development of uncertainty estimates in the Forest Land category and to the publication of scientific, peer-reviewed material. Work is in progress towards an in-depth uncertainty analysis in the CBM-CFS3 modelling framework (White et al. 2008).

## 7.3.2 **Land Converted to Forest Land**

### 7.3.2.1 *Category Description*

This category includes all lands converted to forest land through direct human activity. Post-harvest tree planting is not included, nor is abandoned farmland where natural vegetation is allowed to grow; hence, the category more precisely refers to forest plantations where the previous land use was not forest (typically, abandoned farmland).

In 1990–2002, softwood plantations, especially spruce and pine, accounted for 90% of the area planted (White and Kurz 2005). The total cumulative area of land converted to forest land declined from 220 kha in 1990 to 174 kha in 2005. This trend reflects decreasing rates of forest planting in eastern Canada and the gradual transfer of lands afforested more than 20 years ago to the forest land remaining forest land category.

Net removals consequently declined throughout the period, from 1.2 Mt in 1990 to 1.1 Mt in 2006. Because the activity data are restricted to plantations younger than 20 years, and considering the relatively slow net increment of planted trees in the early years, the subcategory as a whole is not expected to contribute significantly to the net greenhouse gas balance of forest lands.

### 7.3.2.2 *Methodological Issues*

Up to very recently, afforestation records in Canada were not available. The Feasibility Assessment of Afforestation for Carbon Sequestration (FAACS) initiative collected and compiled afforestation records for 1990–2002 (NRCan 2005a); activities for 1970–1989 and 2003–2006 were estimated based on activity rates observed in the FAACS data, complemented with information from the Forest 2020 Plantation Demonstration Assessment (NRCan 2005b) (refer to Section A3.4 for details).

GHG emissions and removals on lands newly converted to forests were estimated using CBM-CFS3, as described in Section A3.4. Changes in soil carbon stocks are highly uncertain, because of difficulties in locating data about the carbon stocks prior to plantation. It was assumed that the ecosystem would generally accumulate soil carbon at a slow rate; the limited time frame of this analysis and the scale of the activity relative to other land use and land-use change activities suggest that the impact of this uncertainty, if any, is minimal.

### 7.3.2.3 *Uncertainties and Time-Series Consistency*

It was not possible, owing to resource limitations, to develop formal uncertainty estimates for this submission. All recalculations were applied to the entire time series of estimates, ensuring that the same approach and methods were consistently applied.

### 7.3.2.4 QA/QC and Verification

Tier 2 QC checks, implemented and documented by CFS (White and Dymond 2008), specifically address estimate development in the Forest Land category. Environment Canada, while maintaining its own QA/QC procedures for estimates developed internally (refer to Annex 6), has implemented new ones for estimates obtained from partners, as well as for all estimates and activity data contained in the LULUCF geodatabase and entered into the CRF reporter.

## 7.4 Cropland

Croplands cover approximately 50 Mha of the Canadian territory. In 2006, the net GHG balance in the Cropland category amounted to removals of 1.4 Mt (Table 7-1 and CRF Table 5). For the purpose of UNFCCC reporting, Cropland is divided into cropland remaining cropland (net removals of about 9.6 Mt in 2006) and land converted to cropland, due to either forest or grassland conversion (net emissions of about 7.7 Mt and 0.45 Mt respectively in 2006). The estimates in land “converted to cropland” include net emissions and removals of CO<sub>2</sub>, as well as N<sub>2</sub>O, CO, and CH<sub>4</sub> emissions.

### 7.4.1 Cropland Remaining Cropland

Cultivated agricultural land in Canada includes areas of field crops, summerfallow, hayland, and tame or seeded pasture. Cropland is found only in the nine southernmost reporting zones. About 83% of Canada’s cropland is in the interior plains of western Canada, made up of the Semi-Arid and Subhumid Prairies and Boreal Plains reporting zones.

Cropland remaining cropland includes CO<sub>2</sub> emissions/removals in mineral soils, CO<sub>2</sub> emissions from agricultural lime application and cultivation of organic soils, and CO<sub>2</sub> emissions/removals resulting from changes in woody biomass from specialty crops. An enhanced Tier 2 approach is used for estimating CO<sub>2</sub> emissions from and removals by mineral soils. Table 7-4 summarizes the trend in emissions and removals for these categories.

**Table 7-4: Base and Recent Year Emissions and Removals Associated with Various Land Management Changes on Cropland remaining Cropland**

Land Management Practice	Land Management Change (LMC)	Emissions/Removals (Gg CO <sub>2</sub> )		
		1990	2005	2006
Change in Crop Mixture	Increase in Perennial	-1 400	-4 000	-4 200
	Increase in Annual	3 700	4 300	4 400
Change in Tillage	CT to RT	-910	- 980	-960
	CT to NT	-570	-3 800	-4 000
	Other Tillage Change	NO	-390	-420
Change in Summerfallow	Increase in Summerfallow	1 600	1 300	1 200
	Decrease in Summerfallow	-4 700	-7 900	-8 000
Land Conversion—Residual Emissions <sup>1</sup>		290	1 800	1 900
<i>Total Mineral Soils</i>		-2 000	-9 700	-10 100
Cultivation of Histosols		300	300	300
Liming		200	290	290
Perennial Woody Crops		36	25	21
<b>Total Cropland Remaining Cropland</b>		<b>-1 400</b>	<b>-9 100</b>	<b>-9 600</b>

Notes:

1. Net residual CO<sub>2</sub> emissions from the conversion of forest land and grassland to cropland that occurred more than 20 years prior to the inventory year.

Negative sign indicates removal of CO<sub>2</sub> from the atmosphere.

NO = Not occurring.

#### 7.4.1.1 *CO<sub>2</sub> Emissions and Removals in Mineral Soils*

Mineral soils constitute the majority of cropland areas. The amount of organic carbon retained in soil is a function of primary production and rate of decomposition of soil organic carbon (SOC). Cultivation and management practices can lead to an increase or decrease in the organic carbon stored in soils. This change in SOC results in a CO<sub>2</sub> emission to or removal from the atmosphere.

In 1990, the management of mineral soils amounted to a net CO<sub>2</sub> removal of about 2.0 Mt (Table 7-4). This net sink steadily increased after 1990 to about 10.1 Mt in 2006, reflecting continuous efforts in reducing summerfallow and increasing conservation tillage (Campbell et al. 1996; Janzen et al. 1998; McConkey et al. 2003). The increase in net sink due to change in areas under summerfallow (from –3.1 Mt in 1990 to –6.8 Mt in 2006) is supported by a 55% decrease in total summerfallow area over 1990–2006. The increase in net sink due to the adoption of conservation tillage practices (from –1.5 Mt in 1990 to –5.0 Mt in 2006) is substantiated by a net total increase of over 10 Mha in areas under NT and RT over the 1990–2006 period. The net increase in areas with perennial crops has had a much more modest impact.

The net increase in sink from the change in management practices over time was partially offset by an increase since 1990 in net residual CO<sub>2</sub> emissions from the decay of dead organic matter and soil organic carbon on land converted to cropland more than 20 years prior to the inventory year (emissions from land converted for less than 20 years are included in the Land Converted to Cropland category). The increase since 1990 in these residual emissions after 20 years is due to an accounting artefact, because deforestation monitoring goes back only to 1970. In the CRF tables, these emissions are split among dead organic matter and soil pools (as opposed to only soil pools).

#### **Methodological Issues**

Following the IPCC good practice guidance for LULUCF (IPCC 2003), the premise is that the changes in soil organic carbon are driven by changes in soil management. Where no change in management is detected, it is assumed that mineral soils are neither sequestering nor losing carbon.

A number of management practices are known to increase soil organic carbon (SOC) in cultivated cropland. They include a reduction in tillage intensity, intensification of cropping systems, adoption of yield-promoting practices, and reestablishment of perennial vegetation (Janzen et al. 1997; Bruce et al. 1999). VandenBygaart et al. (2003) compiled published data from long-term studies in Canada to assess the effect of agricultural management on SOC. This compendium provided the basis for selecting the key management practices and management changes likely to cause changes in soil carbon stocks. The availability of activity data (time series of management practices) from the *Census of Agriculture* was also taken into account.

Estimates of CO<sub>2</sub> changes in mineral soils were derived from the following land management change (LMC) types:

- change in mixture of cropland type;
- change in tillage practices; and
- change in area of summerfallow.

Other land management changes (LMCs), such as changes in irrigation, manure application, and fertilization, are also known to have positive impacts on soil organic carbon. The lack of activity data for these LMCs associated with specific crops is a barrier for inclusion in the inventory at this time. It was assumed that LMCs not considered would not result in large changes in soil carbon stocks in mineral soils.

Carbon emissions and removals were estimated by applying country-specific carbon emission and removal factors multiplied by the relevant area of land that underwent a management change. Calculations were performed at a high degree of spatial disaggregation—namely, by Soil Landscapes of Canada (SLC) polygons (see Section A3.4.1). The carbon emission/removal factors represent the rate of SOC change per year and per unit area that underwent a land management change (LMC). The annual CO<sub>2</sub> emissions/removals by mineral soils undergoing a specific LMC are expressed as:

**Equation 7-1:**

$$\Delta C = F \times A$$

where:

$\Delta C$	=	change in soil carbon stock (Mg C)
F	=	average annual change in SOC subject to LMC (Mg C/ha per year)
A	=	area of LMC (ha)

In theory, a more accurate estimate of soil carbon stock change could be derived by individually considering the cumulative effects of the long-term management history of each piece of land or farm field. However, limits are imposed by the availability of activity data. At this point of development, the inventory relies extensively on the *Census of Agriculture* to estimate the areas of land management change (LMC) involved (i.e. changes in tillage, types of crop, and fallow). Since only the area of each practice is known for each Census year, only the net area of change for each land management practice can be estimated. The area of LMC was determined individually for 3264 SLC polygons having agricultural activities, each one having an area in the order of 1000–100 000 ha. This is the finest possible resolution of activity data, given the limitations imposed by confidentiality requirements of Census data. Estimates of these LMCs are as close to gross area of LMC as is feasible for regional or national analyses.

The validity of “spatializing” Census data relies on two key assumptions: additivity and reversibility of carbon factors. Additivity assumes that the combined effects of different LMCs or LMCs at different times would be the same as the sum of factors for each individual LMC. Reversibility is the assumption that the carbon effects of an LMC in one direction (e.g. converting annual crops to perennial crops) is the opposite of the carbon effects of the LMC in the opposite direction (e.g. converting perennial crops to annual crops).

The various carbon factors associated with each particular situation (in both space and time) were derived using the CENTURY model (Version 4.0) by comparing output for scenarios “with” and “without” the management change in question. In specific instances, empirical data were used to complement the results of the CENTURY runs. More detailed methodologies for determining carbon factors and other key parameters can be found in Section A3.4.

## Uncertainties and Time-Series Consistency

Uncertainty was estimated using analytical uncertainty analysis (Coleman and Steele 1999). The uncertainties associated with estimates of CO<sub>2</sub> emissions or removals involve estimates of uncertainties for area and carbon factors of management changes for fallow, tillage, and annual/perennial crops (McConkey et al. 2007).

The uncertainty of the area in a management practice at any time for an ecodistrict varied inversely with the relative proportion it occupied of the total area of agricultural land in that ecodistrict. The relative uncertainty of the area of management practice (expressed as standard deviation of an assumed normal population) decreased from 10% of the area to 1.25% of the area as the relative area of that practice increased (T. Huffman, personal communication).

The uncertainties associated with carbon change factors for fallow, tillage, and annual/perennial crops were assumed from two main influences: 1) process uncertainty in carbon change due to inaccuracies in predicting carbon change even if the situation of management practice was defined perfectly and 2) situational uncertainty in carbon change due to variation in the situation of the management practice. More details about estimating process and situational uncertainties are presented in Section A3.4. The overall level and trend uncertainty estimates associated with various LMCs were developed by McConkey et al. (2007), and these estimates are assumed representative for this submission even though the mean values associated with emissions/removals may have changed slightly (Table 7-5).

**Table 7-5: Level and Trend Uncertainty Estimates for Various Land Management Changes in Mineral Soils of Cropland Remaining Cropland<sup>1</sup>**

Land Management Practice		Uncertainty Estimates (kt CO <sub>2</sub> eq)			
		Level (2005)		Trend (1990–2005)	
		Lower Limit	Upper Limit	Lower Limit	Upper Limit
Change in Crop Mixture	Increase in Perennial	–6 500	–3 900	–4 600	–1 400
	Increase in Annual	2 800	5 400	–810	2 600
Change in Tillage	CT to RT	–1 200	–760	–390	290
	CT to NT	–4 800	–2 900	–4 200	–2 300
	Other Tillage Change	–590	–200	–630	–170
Change in Summerfallow	Increase in Summerfallow	1 000	1 500	–860	540
	Decrease in Summerfallow	–9 300	–6 500	–4 700	–1 500
Residual Emissions <sup>2</sup>		500	590	350	470
<b>Total Mineral Soils</b>		<b>–15 000</b>	<b>–9 900</b>	<b>–12 000</b>	<b>–5 700</b>

Notes:

1. Negative sign indicates removal of CO<sub>2</sub> from the atmosphere.
2. These net residual CO<sub>2</sub> emissions come from conversion of forest land and grassland to cropland that occurred more than 20 years prior to the inventory year.

Consistency in the CO<sub>2</sub> estimates is ensured through the use of the same methodology for the entire time series of estimates (1990–2006).

## QA/QC and Verification

Tier 1 QC checks, implemented by AAFC, specifically address estimate development in the cropland remaining cropland category. Environment Canada, while maintaining its own QA/QC

procedures for estimates developed internally (see Annex 6), has implemented additional QC checks for estimates obtained from partners, as well as for all estimates and activity data contained in its LULUCF geodatabase and entered into the CRF reporter. In addition, the activity data, methodologies, and changes are documented and archived in both paper and electronic form.

Carbon change factors for LMCs used in the inventory were compared with empirical coefficients in VandenBygaart et al. (2007). This assessment showed that empirical data on carbon change driven by no tillage were highly variable, particularly for Eastern Canada. Nonetheless, the modelled factors were still within the range derived from the empirical data. When considering the switch from annual to perennial cropping, the mean empirical factor was 0.59 Mg C/ha per year, and this compared favourably with the range of 0.46–0.56 Mg C/ha per year in the modelled factors in Western Canadian soil zones. In Eastern Canada, only two empirical change factors were available, but they appeared to be in line with the modelled values (0.60–1.07 Mg C/ha per year empirical versus 0.74–0.77 Mg C/ha per year modelled). For conversion of crop fallow to continuous cropping, the modelled rate of carbon storage obtained (0.33 Mg/ha per year) was more than twice the average rate of  $0.15 \pm 0.06$  Mg/ha per year derived from two independent assessments of the literature. This difference led to the decision to use empirically based factors for changes in summer fallow in the inventory. More details can be found in Section A3.4.

## Recalculations

There were no changes in methodologies or factors associated with emission/removal estimates related to LMCs. The areas of cropland subject to specific changes in management practices have been affected, because the rules for allocating the deforested land to cropland in western Canada have been changed. Chapter 9 provides more detail on the impact of these changes.

## Planned Improvements

Work is ongoing to reduce uncertainties associated with the modelled carbon factors, through general improvements to factor methodologies, validation, and review of assumptions, where possible. Publication of scientific, peer-reviewed material is also under way. Improvements to the CENTURY model and the use of alternative models are also being explored, to improve the simulation of Canadian agricultural conditions.

### 7.4.1.2 *CO<sub>2</sub> Emissions from Lime Application*

In Eastern Canada, limestone and dolomite are often used for certain crops such as alfalfa to neutralize acidic soils, increase the availability of soil nutrients, in particular phosphorus, reduce the toxicity of heavy metals, such as aluminium, and improve the crop growth environment. During this neutralization process, CO<sub>2</sub> is released in bicarbonate equilibrium reactions that take place in the soil:



The rate of release will vary with soil conditions and the compounds applied. In most cases where lime is applied, applications are repeated every few years. For the purposes of the inventory, it was assumed that the rate of lime addition is in near equilibrium with the rate of lime consumed from previous applications.



## Methodological Issues

Emissions associated with the use of lime were calculated from the amount and composition of the lime applied annually—specifically, the respective stoichiometric relationships that describe the breakdown of limestone and dolomite into CO<sub>2</sub> and other minerals. Methods and data sources are outlined in Section A3.4.

## Uncertainties and Time-Series Consistency

The 95% confidence limits associated with annual lime consumption data were estimated to be  $\pm 50\%$  (B. McConkey, personal communication). This uncertainty was assumed to include the uncertainty about lime sales, uncertainty in proportion of dolomite to calcite, uncertainty of when lime sold is actually applied, and uncertainty in the timing of emissions from applied lime. The uncertainty in the emission factor was not considered because the chemical conversion is deemed complete, and the maximum value of the emission factor was used. The overall mean and uncertainties were estimated to be  $0.3 \pm 0.14$  Mt for the level uncertainty and  $0.09 \pm 0.15$  Mt for the trend uncertainty (McConkey et al. 2007).

The same methodology is used for the entire time series of emission estimates (1990–2006).

## QA/QC and Verification

This category has undergone Tier 1 QC checks (see Annex 6) in a manner consistent with IPCC good practice guidance (IPCC 2000). The activity data, methodologies, and changes to methodologies are documented and archived in both paper and electronic form.

## Planned Improvements

There is no immediate plan in place aimed at improving emission estimates for this source.

### 7.4.1.3 CO<sub>2</sub> Emissions from Cultivation of Organic Soils

## Category Description

In Canada, cultivated organic soils are defined as the conversion of organic soils to agriculture for annual crop production, normally accompanied by artificial drainage, cultivation, and liming. Organic soils used for agriculture in Canada include the Peaty Phase of Gleysolic soils, Fibrisols over 60 cm thick, and Mesisols and Humisols over 40 cm thick.

## Methodological Issues

The emissions from the cultivation of organic soils were calculated by multiplying the total area of cultivated histosols by the default emission factor of 5 Mg C/ha per year (IPCC 2006).

Areas of cultivated histosols are not provided by the Census of Agriculture; area estimates were based on the expert opinion of soil and crop specialists across Canada (G. Padbury and G. Patterson, personal communication). The total area of cultivated organic soils in Canada (constant for the period 1990–2006) was estimated to be 16 kha.

## Uncertainties and Time-Series Consistency

The uncertainty associated with emissions from this source is due to the uncertainties associated with the area estimates for the cultivated histosols and with the emission factor. The 95% confidence limits associated with the area estimate of cultivated histosols are assessed to be  $\pm 50\%$  (Hutchinson et al. 2007). The 95% confidence limits of the default emission factor are  $\pm 90\%$  (IPCC 2006). The overall mean and uncertainties associated with this source of emissions were estimated to be  $0.3 \pm 0.09$  Mt for the level uncertainty and  $0 \pm 0.14$  Mt for the trend uncertainty (McConkey et al. 2007).

The same methodology and emission factors are used for the entire time series of emission estimates (1990–2006).

## QA/QC and Verification

This category has undergone Tier 1 QC checks (see Annex 6) in a manner consistent with IPCC good practice guidance (IPCC 2000). The activity data, methodologies, and changes to methodologies are documented and archived in both paper and electronic form.

## Planned Improvements

There is no immediate plan in place aimed at improving emission estimates for this source.

### 7.4.1.4 *CO<sub>2</sub> Emissions and Removals in Woody Biomass*

## Category Description

Perennial woody biomass is found on cropland planted with vineyards, fruit orchards, and Christmas trees. It also accumulates on abandoned cropland allowed to revert to natural vegetation. In the definitional framework adopted in Canada for LULUCF reporting, abandoned cropland is still considered “cropland” until there is evidence of a new land use; however, there is little information on the dynamics of cropland abandonment or recultivation. Owing to these data limitations, only vineyards, fruit orchards, and Christmas trees are considered, and they contribute an insignificant source of about 25 Gg CO<sub>2</sub>; changes in woody biomass from “abandoned cropland” on cropland remaining cropland are excluded.

## Methodological Issues

Vineyards, fruit orchards, and Christmas tree farms are intensively managed for sustained yields. Vineyards and fruit trees are pruned annually, and old plants are replaced on a rotating basis for disease prevention, stock improvement, or introduction of new varieties. For all three crops, it was assumed that, because of rotating practices and the requirements for sustained yield, a uniform age-class distribution is generally found on production farms. Hence, there would be no net increase or decrease in biomass carbon within existing farms, as carbon lost from harvest or replacement would be balanced by gains due to new plant growth. The approach therefore was limited to detecting changes in areas under vineyards, fruit orchards, and Christmas tree plantations and estimating the corresponding carbon stock changes in total biomass. More information on assumptions and parameters can be found in Section A3.4.

## Uncertainties and Time-Series Consistency

Upon a loss of area with perennial woody crops, all carbon in woody biomass is assumed to be immediately released. It is assumed that the uncertainty for carbon loss equals the uncertainty about mass of woody biomass carbon. The default uncertainty of  $\pm 75\%$  (i.e. 95% confidence limits) for woody biomass on cropland from the IPCC good practice guidance (IPCC 2003) was used.

If the loss in area of fruit trees, vineyards, or Christmas trees is estimated to have gone to annual crops, there is also a deemed perennial to annual crop conversion with associated uncertainty that contributes to carbon change uncertainty. For area of gain in area of fruit trees, vineyards, or Christmas trees, the uncertainty of annual carbon change was also assumed to be the default uncertainty of  $\pm 75\%$  (i.e. 95% confidence limits) (IPCC 2003).

The overall mean and uncertainties associated with emissions or removals of carbon from woody specialty crops were estimated to be  $0.025 \pm 0.049$  Mt for the level uncertainty and  $-0.015 \pm 0.075$  Mt for the trend uncertainty (McConkey et al. 2007).

The same methodology was used for the entire time series of emission estimates (1990–2006).

## QA/QC and Verification

This category has undergone Tier 1 QC checks (see Annex 6) in a manner consistent with IPCC good practice guidance (IPCC 2000). The activity data, methodologies, and changes to methodologies are documented and archived in both paper and electronic form.

## Planned Improvements

There is no immediate plan in place aimed at improving emission estimates for this category.

### 7.4.2 Land Converted to Cropland

This section covers the conversion of forest land and grassland to cropland. The methods for area determination and estimate development differ in each case. This section describes estimate development only for soil carbon and soil  $N_2O$  emissions following land conversion to cropland. Estimation approaches for other pools (biomass and DOM upon forest conversion to cropland), including those due to controlled burning, are described in Section 7.8, Forest Conversion.

#### 7.4.2.1 Forest Land Converted to Cropland

Clearing forest for use as agricultural land is an ongoing but declining practice in Canada, although it remains the single most important cause of deforestation. The cumulative area of forest land converted to cropland since 1971 was 1441 kha in 1990; in 2006, the cumulative area converted since 1987 was 767 kha. Apart from biomass and dead organic matter losses, this category includes the net carbon stock change from soils due to the actual land conversion and a very small net  $CO_2$  sink from change in management practices (tillage, etc.) since the cropland was converted, as well as the  $N_2O$  emissions following the conversion. As explained below, patterns of change in SOC after the conversion of forest to cropland clearly differ between eastern and western Canada.

## Methodological Issues

The emissions from forest land conversion to cropland were calculated by multiplying the total area of conversion by the empirically-derived emission factor along with modelling-based SOC dynamics (see Section A3.4). Because of regional difference, the estimation methods for net changes in SOC and N<sub>2</sub>O emissions differ between Eastern and Western Canada.

### *Eastern Canada*

Generally, all land in the eastern part of the country was forested before its conversion to agriculture. Many observations in the scientific literature and the Canadian Soil Information System compare SOC for land under forest with adjacent agricultural land in eastern Canada. The mean loss of carbon is 20% at depths to approximately 20–40 cm (see Section A3.4). Average nitrogen change was –5.2%, equivalent to a loss of approximately 0.4 Mg N/ha. For those comparisons where both nitrogen and carbon losses were determined, the corresponding carbon loss was 19.9 Mg C/ha. Therefore, it was assumed that nitrogen loss was a constant 2% of carbon loss.

The CENTURY model (Version 4.0) is used to estimate the soil organic carbon dynamics from conversion of forest land to cropland in eastern Canada. More details of methodologies for determining the maximal carbon loss and its rate constant associated with the conversion of forest land can be found in Section A3.4.

Following a Tier 2-type methodology, as was done for direct N<sub>2</sub>O emissions from agricultural soils (see Agriculture Sector, Chapter 6), emissions of N<sub>2</sub>O from forest conversion to cropland were estimated by multiplying the amount of carbon loss by the fraction of nitrogen loss per unit of carbon and by an emission factor (EF<sub>BASE</sub>). EF<sub>BASE</sub> was determined for each ecodistrict based on topographic and climate characteristics (see Section A3.3).

### *Western Canada*

Much of the current agricultural land in Western Canada (Prairies and British Columbia) was under grassland in native condition. Hence, deforestation has been primarily of forest that lies on the fringe of former grassland areas.

The Canadian Soil Information System (CanSIS) data provide the most useful comparisons of SOC under forest with that under agriculture. On average, these data suggest that there is no loss of SOC from deforestation and that, in the long term, the balance between carbon input and SOC mineralization under agriculture remains similar to what it was under forest.

It is important to recognize that along the northern fringe of western Canadian agriculture, where most deforestation is occurring, the land is marginal for arable agriculture; pasture and forage crops are the dominant management practices.

For western Canada, no loss of SOC over the long term was assumed from deforestation to cropland managed exclusively for seeded pastures and hayland. The carbon loss from deforestation in western Canada results from the loss of above- and below-ground tree biomass and from loss or decay of other above- and below-ground coarse woody DOM that existed in the forest at the time of deforestation. The average nitrogen change in western Canada for sites at least 50 years from breaking was +52% (see Section A3.4), reflecting substantial added nitrogen in agricultural systems compared with forest management practices. However, recognizing the

uncertainty about actual carbon-nitrogen dynamics for deforestation, loss of forest land to cropland in western Canada was assumed not to be a source of N<sub>2</sub>O.

### **Uncertainties and Time-Series Consistency**

The uncertainty was assessed only for changes in soil organic carbon after forest land conversion to cropland (McConkey et al. 2007); it compounds uncertainties in area and in the carbon change factor.

Uncertainty in area of forest land converted to cropland was estimated based on expert judgement (see Section A3.4). For eastern and western Canada, the uncertainty of the factor for SOC change was estimated differently. More detail on estimation methods is presented in Section A3.4. The overall mean and uncertainty associated with CO<sub>2</sub> emissions due to SOC losses on forest land converted to cropland were estimated to be  $0.28 \pm 0.05$  Mt in 2006. The uncertainty associated with the trend since 1990 has not yet been determined.

The same methodology and emission factors are used for the entire time series of emission estimates (1990–2006).

### **QA/QC and Verification**

This category has undergone Tier 1 QC checks (see Annex 6) in a manner consistent with IPCC Good Practice Guidance (IPCC 2000). Quality checks were also performed externally by AAFC, which derived the estimates of SOC change. The activity data, methodologies, and changes to methodologies are documented and archived in both paper and electronic form.

### **Recalculations**

Changes were made to the assumptions underlying the integration of afforestation and deforestation data to the estimation system, which resulted in modest changes in estimates for the entire time series, but did not affect trends. More information on these recalculations is provided in Chapter 9.

### **Planned Improvements**

Work is ongoing to improve and validate the soil carbon change factors from forest land converted to cropland, and finalize uncertainty estimates.

#### *7.4.2.2 Grassland Converted to Cropland*

Conversion of native grassland to cropland occurs in the Prairie region of the country and generally results in losses of soil organic carbon (SOC) and soil organic nitrogen and emissions of CO<sub>2</sub> and N<sub>2</sub>O to the atmosphere. It is assumed that there is no loss of above-ground or below-ground organic matter or dead organic matter upon conversion. Total emissions in 2006 from soils amounted to 0.45 Mt. This includes the carbon losses and N<sub>2</sub>O emissions from the conversion itself, as well as a small sink from adoption of new practices on the croplands since conversion.

### **Methodological Issues**

A number of studies on changes of SOC and soil organic nitrogen in grassland converted to cropland have been carried out on the Brown, Dark Brown, and Black soil zones of the Canadian

Prairies. The average loss of SOC, weighted for number of locations across landscape positions, was 22%, and the corresponding average change in soil organic nitrogen was 0.06 kg N lost/kg C (see Section A3.4).

The CENTURY model (Version 4.0) is used to estimate the SOC dynamics from breaking of grassland to cropland for the Brown and Dark Brown Chernozemic soils. More details of methodologies for determining the maximal carbon loss and its rate constant associated with the breaking of grassland can be found in Section A3.4.

Similar to N<sub>2</sub>O emissions in forest converted to cropland, emissions of N<sub>2</sub>O in grassland converted to cropland were estimated by a Tier 2 methodology, multiplying the amount of carbon loss by the fraction of nitrogen loss per unit of carbon by a base emission factor (EF<sub>BASE</sub>). EF<sub>BASE</sub> is determined for each ecodistrict based on climate and topographic characteristics (see Section A3.3 of Annex 3).

### Uncertainty and Time-Series Consistency

The conversion from agricultural grassland to cropland is allowed, but the conversion in the other direction is not occurring. Therefore, the uncertainty of the area of this conversion cannot be larger than the uncertainty about the area of cropland or grassland. Hence, the uncertainty of the area of conversion was set to the lower of the uncertainties of the area of either cropland or grassland. The uncertainty of SOC change was estimated similarly with forest land conversion to cropland. The overall mean and uncertainty associated with emissions due to SOC losses on grassland conversion to cropland (excluding N<sub>2</sub>O) were estimated to be  $0.45 \pm 0.19$  Mt in 2006. The uncertainty associated with the trend since 1990 has not yet been determined.

The same methodology and emission factors are used for the entire time series of emission estimates (1990–2006).

### QA/QC and Verification

This category has undergone Tier 1 QC checks (see Annex 6) in a manner consistent with IPCC good practice guidance (IPCC 2000). The activity data, methodologies, and changes to methodologies are documented and archived in both paper and electronic form.

### Planned Improvements

Work is ongoing to improve and validate the soil carbon change factors from grassland conversion and finalize uncertainty estimates.

## 7.5 Grassland

Agricultural grassland is defined under the Canadian LULUCF framework as “unimproved” pasture or rangeland that is used only for grazing domestic livestock. It occurs only in geographical areas where the grassland would not naturally regrow to forest if abandoned: the natural shortgrass prairie in southern Saskatchewan and Alberta and the dry, interior mountain valleys of British Columbia. Agricultural grassland is found in two reporting zones: Semi-Arid Prairies (5 600 kha in 2001) and the Montane Cordillera (160 kha in 2001). As with cropland, the change in management triggers a change in carbon stocks (IPCC 2003). Very little information is available on management practices on Canadian agricultural grassland. It is unknown whether grazed land is improving or degrading. Therefore, Canada reports this grassland remaining grassland category as not estimated. More details on the rationale for not estimating this category

are provided in Section A3.4. The category land converted to grassland, within the current definitional framework as explained in Section 7.2, is reported either as not estimated (wetlands converted to grassland) or as not occurring (Table 7-2).

## **7.6 Wetlands**

In Canada, a wetland is land that is saturated with water long enough to promote anaerobic processes, as indicated by poorly drained soils, hydrophytic vegetation, and various kinds of biological activity that are adapted to a wet environment—in other words, any land area that can keep water long enough to let wetland plants and soils develop. As such, wetlands cover about 14% of the land area of Canada (Environment Canada 2003). The Canadian Wetland Classification System groups wetlands into five broad categories: bogs, fens, marshes, swamps, and shallow water (National Wetlands Working Group 1997).

However, for the purpose of this report and in compliance with land categories as defined in IPCC (2003), the Wetlands category should be restricted to those wetlands that are not already in the forest, cropland, or grassland categories. There is no corresponding area estimate for these wetlands in Canada.

In accordance with IPCC guidance (IPCC 2003), two types of managed wetlands are considered, where human intervention has directly altered the water table level and thereby the dynamics of GHG emissions/removals: peatlands drained for peat harvesting; and flooded land (namely, the creation of reservoirs). Owing to their differences in nature, GHG dynamics, and the general approaches to estimating emissions and removals, these two types of managed wetlands are considered separately.

### **7.6.1 Managed Peatlands**

#### *7.6.1.1 Source Category Description*

Of the estimated 123 Mha of peatlands in Canada<sup>63</sup>, approximately 19 kha are, or were at some point in the past, drained for peat extraction. Some 16 kha are currently being actively managed, the difference (3 kha) being peatlands that are no longer under production. In the Canadian context, generally only bog peatlands with a peat thickness of 2 m or greater and an area of 50 ha or greater are of commercial value for peat extraction (Keys 1992 in Cleary 2003). Peat production is concentrated in the provinces of New Brunswick, Quebec, and Alberta. Canada produces only horticultural peat.

Since the 1980s, virtually all peat extraction in Canada has relied on the vacuum harvest technology; approximately 100 t/ha (wet basis) of horticultural peat is extracted with this technology (Cleary 2003). A drawback of the technology, as opposed to the traditional cut-block method, is poor natural vegetation regrowth on the post-production phase. In the 1990s, peatland restoration activities took on greater significance.

Peat extraction activities expanded during the 1990–2006 period, with a near doubling of the land area under active peat extraction, from 10 kha in 1990 to 19.1 kha in 2006. Owing to this expansion and to the significant contribution of vegetation clearing and decay to the overall GHG

---

63. This area includes peatlands that would be classified as forest, cropland, and grassland in the IPCC land classification.

budget, emissions from managed peatlands show a significant increase over the assessment period (Figure 7-3).

Emissions from managed peatlands are reported under land converted to wetlands for the first 20 years after conversion and under wetlands remaining wetlands thereafter.

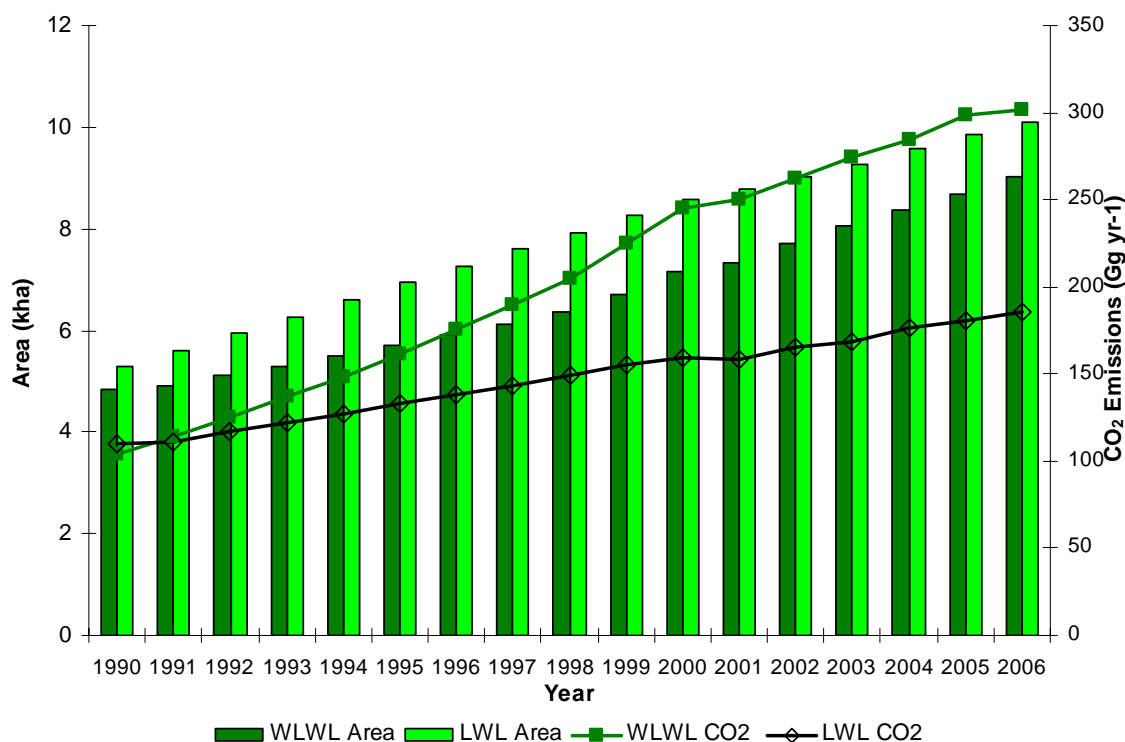


Figure 7-3: Areas of and CO<sub>2</sub> Emissions from Managed Peatlands, 1990–2006 (LWL: land converted to wetlands; WLWL: wetlands remaining wetlands)

#### 7.6.1.2 Methodological Issues

CO<sub>2</sub> is the dominant GHG emitted from commercial peatlands and the only gas reported under this category. The general phases of peat extraction are 1) drainage, 2) vegetation clearing, 3) extraction, 4) stockpiling, 5) abandonment, and 6) peatland restoration and natural revegetation. The main sources of emissions are vegetation clearing upon conversion, the continuing decay of dead organic matter, and the rapid oxidation of exposed peat, resulting in a threefold increase in CO<sub>2</sub> emission rates (Waddington and Warner 2001). Estimates were developed using a Tier 2 methodology, based on domestic emission factors. They include emissions and removals during all five phases. More information on estimation methodology can be found in Section A3.4.

Note that the methodology does not include carbon losses from the peat transported off-site; should these be included, total emissions from managed peatlands would significantly increase.



### 7.6.1.3 *Uncertainty and Time-Series Consistency*

There was no formal uncertainty assessment for carbon emissions and removals in managed peatlands. The most important sources of uncertainty are discussed below.

Emission factors were derived from flux measurements made mostly over abandoned peatlands, which introduces significant uncertainty when applied to actively managed peatlands, and peat stockpiles. All measurements were conducted in eastern Canada, adding uncertainties to estimates for western Canada. A single estimate of preconversion forest biomass carbon density (20 t C/ha) was assumed; based on the characteristics of forest stands converted to peatland, an average 63% of above-ground biomass was deemed harvested at clearing.

It is very difficult to obtain spatially referenced information on the areas of managed peatlands. The areas converted annually were modelled based on the total productive area in 2004 and expert knowledge of trends in domestic peat production since 1990 (G. Hood, personal communication to D. Blain, 2006). In addition, the fate of abandoned peatlands is not monitored in Canada; older peat fields could have been converted to other uses. Therefore, the area estimate of abandoned peatlands is probably conservative.

### 7.6.1.4 *QA/QC and Verification*

Annex 6 describes the general QA/QC procedures being implemented for Canada's GHG inventory; they apply to this category as well. Areas were derived in collaboration with the Canadian Sphagnum Peat Moss Association.

## 7.6.2 **Flooded Lands (Reservoirs)**

This category includes in theory all lands converted to flooded lands regardless of purpose. Owing to data limitations, this submission includes only large hydroelectric reservoirs created by land flooding. Existing water bodies dammed for water control or energy generation were not considered if flooding was minimal (e.g. Manitoba's Lake Winnipeg; the Great Lakes).

Since 1970, land conversion to flooded lands occurred in reporting zones 4, 5, 8, 10, and 14. The total land area flooded for 10 years or less declined from 829 kha in 1990 to 91.6 kha in 2006. In 2006, 59% of the 91.6 kha of reservoirs flooded for 10 years or less were previously forested (mostly unmanaged forests).

Total emissions from reservoirs declined from 4.1 Mt in 1990 to 1.6 Mt in 2006.

### 7.6.2.1 *Methodological Issues*

Two concurrent estimation methodologies were used to account for GHG fluxes from flooded lands—one for forest clearing and the other for flooding. When there was evidence of forest biomass clearing and removal prior to flooding, the corresponding carbon stock changes for all non-flooded carbon pools were estimated as in all forest conversion events, using the CBM-CFS3 (refer to Section 7.8 below and Section A3.4). Emissions from the burning and decay of all non-flooded dead organic matter are reported under Land Converted to Wetlands for the first 10 years post-clearing and in wetlands remaining wetlands beyond this period. The recent construction of new, large reservoirs in northern Quebec (Toulnustuc, Eastmain-1), whose impoundment was completed in 2006, resulted in this type of forest clearing prior to flooding. Note that emissions

from forest clearing in the general area surrounding future reservoirs (e.g. for infrastructure development) are reported under forest conversion to settlements.

The second methodology is applied to estimate CO<sub>2</sub> emissions from the surface of reservoirs whose flooding has been completed. The default approach to estimate emissions from flooding assumes that all forest biomass carbon is emitted immediately (IPCC 2003). In the Canadian context, this approach would overestimate emissions from reservoir creation, since the largest proportion of any submerged vegetation does not decay for an extended period. A domestic approach was developed and used to estimate emissions from reservoirs based on measured CO<sub>2</sub> fluxes above reservoir surfaces, consistent with the descriptions of IPCC Tier 2 methodology (IPCC 2003, 2006) and following the guidance in Appendix 3a.3 of IPCC (2003). Section A3.4 contains more detail on this estimation methodology. In keeping with good practice, only CO<sub>2</sub> emissions are included in the assessment. Emissions from the surface of flooded lands are reported for a period of 10 years after flooding, in an attempt to minimize the potential double-counting of dissolved organic carbon lost from managed lands in the watershed and subsequently emitted from reservoirs. Therefore, only CO<sub>2</sub> emissions are calculated for hydroelectric reservoirs where flooding had been completed some time between 1980 and 2006.

For each reservoir, the proportion of pre-flooding area that was forest is used to apportion the resulting emissions to the categories forest land converted to wetlands and other land converted to wetlands.

It is important to note that fluctuations in the area of lands converted to wetlands (reservoirs) reported in the CRF tables are not indicative of changes in current conversion rates, but reflect the difference between land areas recently flooded (less than 10 years before the inventory year) and older reservoirs (more than 10 years before the inventory year), whose areas are thus transferred out of the inventory. The reporting system does not encompass all the reservoir areas in Canada.

#### 7.6.2.2 *Uncertainties and Time-Series Consistency*

For Forest Land Converted to Wetlands, refer to the corresponding subheading in Section 7.8, Forest Conversion. Section A3.4 discusses the uncertainty associated with the Tier 2 estimation methodology.

Owing to current limitations in LULUCF estimation methodologies, it is not possible to fully monitor the fate of dissolved organic carbon and ensure that it is accounted for under the appropriate land category. The possibility of double-counting in the Wetlands category is, however, limited to watersheds containing managed lands, which would exclude several large reservoirs in reporting zones 4 and 5.

#### 7.6.2.3 *QA/QC and Verification*

Annex 6 describes the general QA/QC procedures being implemented for Canada's GHG inventory; they apply to this category as well.

For forest land converted to wetlands, also refer to the corresponding subheading in Section 7.8, Forest Conversion.

Canada's approach to estimating emissions from forest flooding is more realistic temporally than the default approach (IPCC 2003), which assumes that all biomass carbon on flooded forests is immediately emitted. Canada's method is more refined in that it distinguishes forest clearing and

flooding; emissions from the former are estimated as in all forest clearing associated with land-use change. Further, in Canada's approach, emissions from the surface of reservoirs are derived from measurements, rather than from an assumption (decay of submerged biomass) that clearly is not verified.

#### *7.6.2.4 Planned Improvements*

The monitoring of dissolved organic carbon as it travels through the landscape to the point of emission or long term storage is beyond current scientific capabilities, and will require long term investments in research. No improvements are planned in the near future, other than developing uncertainty estimates.

### **7.7 Settlements**

The Settlements category is very diverse, including all roads and transportation infrastructure; rights-of-way for power transmission and pipeline corridors; residential, recreational, commercial, and industrial lands in urban and rural settings; and land used for resource extraction other than forestry (oil and gas, mining).

In settlements remaining settlements, urban trees contribute very little to the national GHG budget. Preliminary estimates indicate modest removals of less than 0.2 Mt.

For the purpose of this inventory, two types of land conversion to settlement were estimated: forest land conversion to settlements, and non-forest land conversion to settlements in the Canadian north. In 2006, 435 kha of lands converted to settlements accounted for emissions of 8 Mt. Forest land conversion to settlements represents over 99% of these emissions. The conversion of cropland to settlements is known to occur in Canada; an estimation methodology is under development.

#### **7.7.1 Settlements Remaining Settlements**

This category includes estimates of carbon sequestration in urban trees. No modification has been made in activity data or methods since the last submission. This component, although approximate, makes a very minor contribution to the LULUCF Sector and represents a low priority for improvement.

#### **7.7.2 Land Converted to Settlements**

##### *7.7.2.1 Source Category Description*

This section covers non-forest land conversion to settlements in the Canadian north. Section 7.9, Forest Conversion, summarizes issues and emissions associated with the conversion of forest land to settlements.

In 2005, the conversion of non-forest land to settlements in the Canadian north accounted for emissions of 0.2 Mt.

##### *7.7.2.2 Methodological Issues*

Resource development in Canada's vast northern ecumene is the dominant driver of land-use change. An accurate estimation of this direct human impact in northern Canada requires that

activities be geographically located and the preconversion vegetation known—a significant challenge, considering that the area of interest extends over 557 Mha, intersecting with eight reporting zones (2, 3, 4, 8, 10, 13, 17, and 18). For all reporting zones except 4 and 8, various information sources and geographic data sets were used to identify areas of high land-use change potential and narrow down the geographical domain of interest. These areas were targeted for change detection analysis using 23 Worldwide Reference System Landsat frames from circa 1985, 1990, and 2000. The scenes cover more than 8.7 Mha, or 56% of the area with high potential for land-use change. Lack of available imagery prevented the implementation of the system beyond 2000.

For reporting zones 4 and 8, a change detection procedure was run on the entire area.

Emissions include only the carbon in preconversion above-ground biomass. In spite of the existing relevant literature, the estimation of actual or average biomass density over such a large area is challenging and remains fraught with uncertainty.

#### *7.7.2.3 Uncertainties and Time-Series Consistency*

For forest land converted to settlements, refer to the corresponding subheading in Section 7.8, Forest Conversion.

The uncertainty about the area of non-forest land converted to settlements in the Canadian north is estimated at 20%; the uncertainty about the preconversion standing biomass varies between 35% and 50%. Section A3.4 of Annex 3 provides more information.

#### *7.7.2.4 QA/QC and Verification*

Annex 6 describes the general QA/QC procedures being implemented for Canada's GHG inventory; they apply to this category as well.

For forest land converted to settlements, refer to the corresponding subheading in Section 7.8, Forest Conversion.

### **7.8 Forest Conversion**

Forest conversion is not a reporting category, since it overlaps with the subcategories of land converted to cropland, land converted to wetlands, and land converted to settlements; it is nevertheless reported as a memo item. This section will briefly discuss methodological issues specific to this type of land-use change and outline the general approach taken to estimate its extent, location, and impact. A consistent approach was applied for all types of forest conversion, minimizing omissions and overlaps, while maintaining spatial consistency as much as possible.

In 2006, forest conversion to cropland, wetlands, and settlements amounted to total emissions of about 16 Mt, down from 26 Mt in 1990. This decline includes a 6.6 Mt decrease over the period of immediate and residual emissions due to forest conversion to cropland; a 1.6 Mt decrease in emissions from the surface of reservoirs attributed to forest conversion, as several reservoirs had been flooded for over 10 years and were withdrawn from the accounting; and a reduction of 1.2 Mt in emissions from forest conversion to settlements.

Care should be taken to distinguish annual deforestation rates (73 kha in 1990 and 86 kha in 2006) from the total area of forest land converted to other uses as reported in the CRF tables for

each inventory year. The CRF figures encompass all forest land conversion for 20 years prior to the current inventory year (10 years for reservoirs) and hence are significantly higher than the annual deforestation rates.

It is also important to note that immediate emissions from forest conversion, which occur upon the conversion event, are only a fraction of the total emissions due to current and previous forest conversion activities reported in any inventory year. In 2006, immediate emissions from forest conversion (8.2 Mt) represent only 50% of the total reported emissions due to deforestation, the balance being accounted for by residual emissions due to prior deforestation events. Decay rates for dead organic matter are such that residual emissions continue beyond 20 years, after which they are reported in the carbon stock changes in cropland remaining cropland and wetlands remaining wetlands.

With 38 kha, forest conversion to wetlands accounts for the largest share of forest losses to other land categories in 2006. A large proportion of it (73%) is accounted for by the completion of the Eastmain-1 reservoir impoundment. Still in 2006, conversion to cropland (26 kha) is the second most important cause of deforestation, representing 30% of all forest area lost. Loss of forest land to settlement land (22 kha) follows closely making up the remainder.

Geographically, the highest rates of forest conversion occur in the Boreal Shield East and Boreal Plains (reporting zones 5 and 10), which respectively account for 41% and 26% of the total area deforested in 2006.

Forest conversion affects both managed and unmanaged forests. Losses of unmanaged forests occur mainly in reporting zone 4 (Taiga Shield East) and are caused mostly by reservoir impoundment, but they occur to a smaller extent in reporting zones 8 and 9.

### **7.8.1 Methodological Issues**

Forest conversion to other land categories is still a prevalent practice in Canada. This phenomenon is driven by a great variety of circumstances across the country, including policy and regulatory frameworks, market forces, and resource endowment. The economic activities causing forest losses are very diverse; they result in heterogeneous spatial and temporal patterns of forest conversion, which, until recently, were not systematically documented. The challenge has been to develop an approach that would integrate a large variety of information sources to capture the various forest conversion patterns across the Canadian landscape, while maintaining a consistent approach in order to minimize omissions and overlaps.

The approach adopted for estimating forest areas converted to other uses—or “deforested areas”—is based on three main information sources: systematic or representative sampling of remote sensing imagery, records, and expert judgement. The methodology is in its first phase of implementation and should be considered as a transition towards a refined and comprehensive system for monitoring forest conversion.

The core method involves mapping of deforestation on samples from remotely sensed Landsat images dated circa 1975, 1990, and 2000. For implementation purposes, all permanent forest removal wider than 20 m from tree base to tree base and at least 1 ha was considered forest conversion. This convention was adopted as a guide to consistently label linear patterns in the landscape. The other main information sources consist of databases or other documentation on forest roads, power lines, oil and gas infrastructure, and hydroelectric reservoirs. Expert opinion was called upon when records data were unavailable or of poor quality, or the remote sensing

sample was insufficient. Expert judgement was also used to resolve differences among records and remote sensing information and to resolve apparent discrepancies between the 1975–1990 and 1990–2000 area estimates. A more detailed description of the approach and data sources is provided in Section A3.4. Imagery post-2000 is being assembled for use to extend the time series.

All estimates of emissions due to forest conversion were generated using the CBM-CFS3, except when forests were flooded without prior clearing. Hence, methods are in general consistent with those used in the forest land remaining forest land category. Section A3.4 summarizes the estimation procedures.

### **7.8.2 Uncertainties and Time-Series Consistency**

Based on expert judgement, an overall uncertainty of  $\pm 38\%$  bounds the estimate of the total forest area converted annually in Canada (Leckie et al. 2006b), placing with 95% confidence the true value of this area for 2006 between 47 kha and 104 kha. Care should be taken not to apply the 38% range to the cumulative area of forest land converted to another category over the last 20 years (land areas reported in the CRF tables). Section A3.4 in Annex 3 describes the main sources of uncertainty about area estimates derived from remote sensing and records.

Work is ongoing to improve uncertainty quantification.

### **7.8.3 QA/QC and Verification**

Annex 6 describes the general QA/QC procedures being implemented for Canada's GHG inventory; they apply to this category as well. In addition, detailed Tier 2 QA/QC procedures were carried out during estimate development procedures, involving documented QC of imagery interpretation, field validation, cross-calculations, and detailed examination of results (Leckie et al. 2006a). The calculations, use of records data, and expert judgement are traceable through the compilation system and documented. More information is available in Section A3.4.

### **7.8.4 Recalculations**

Over the last two years, recalculations have occurred in this category as a result of additional deforestation sampling and improved mapping activity. This additional mapping activity is part of ongoing activity to improve national level estimates for forest land conversion. Some examples are improved delineation of actual deforestation events, improved scaling methods when converting sample estimates to regional estimates, and changes implemented as part of ongoing quality control procedures. In addition, changes were made to the flooding date for a major reservoir event. These recalculations had a moderate affect on overall estimates for both base year and subsequent year estimates. A more detailed discussion of these recalculations and their impact is provided in Chapter 9.

### **7.8.5 Planned Improvements**

Planned improvements emphasize QA/QC, increased mapping coverage in areas with high uncertainty, extension of the time period of mapping, field validation, use of additional records, and enhanced efficiency in the data compilation process.

## 8 Waste (CRF Sector 6)

### 8.1 Overview

This category includes emissions from the treatment and disposal of wastes. Sources include solid waste disposal on land (landfills), wastewater treatment, and waste incineration. The categories evaluated are CH<sub>4</sub> emissions from solid waste disposal on land, CH<sub>4</sub> and N<sub>2</sub>O emissions from wastewater treatment, and CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O emissions from waste incineration.

Much of the waste treated or disposed of is biomass or biomass based. CO<sub>2</sub> emissions attributable to such wastes are not included in inventory totals but are reported in the inventory as a memo item. CO<sub>2</sub> emissions of biogenic origin are not reported if they are reported elsewhere in the inventory or the corresponding CO<sub>2</sub> uptake is not reported in the inventory (e.g. annual crops). Therefore, in this circumstance, the emissions are not included in the inventory emission totals, since the absorption of CO<sub>2</sub> by the harvested vegetation is not estimated by the Agriculture Sector and, thus, the inclusion of these emissions in the Waste Sector would result in an imbalance. Also, CO<sub>2</sub> emissions from wood and wood products are not included, because these emissions are accounted for in the LULUCF Sector at the time of tree harvest. In contrast, CH<sub>4</sub> emissions from anaerobic decomposition of wastes are included in inventory totals as part of the Waste Sector.

If carbon is lost from forests at an unsustainable rate (i.e. faster than annual regrowth), the carbon budget for forest lands will be negative for net emissions.

In 2006, the GHG emissions from the Waste Sector contributed 21 Mt to the national inventory, compared with 18 Mt for 1990, an increase of 15%. In comparison, the national total emissions increased by 23% over the same time interval. The emissions from this sector represented 3.1% and 2.9% of the overall Canadian GHG emissions in 1990 and 2006, respectively.

Emissions from the Solid Waste Disposal on Land subsector, which consists of the combined emissions from municipal solid waste (MSW) landfills and wood waste landfills, accounted for 20 Mt or 94% of the emissions from this sector in 2006. The chief contributor to the Waste Sector emissions is the CH<sub>4</sub> released from MSW landfills, which amounted to 17 Mt (0.8 Mt CH<sub>4</sub>) in 2006. This net emission value is determined by subtracting the amount of CH<sub>4</sub> captured from the total estimated CH<sub>4</sub> generated within the landfill by the Scholl Canyon model, then adding the quantity of the captured CH<sub>4</sub> that was not combusted by the flaring operation, where applicable. Approximately 28% of the CH<sub>4</sub> generated in Canadian MSW landfills in 2006 was captured and combusted (either for energy recovery, or flared).

Overall, the increase in the CH<sub>4</sub> generation rate from MSW landfills is directly dependent upon the population growth and the waste generation rate and is mitigated by landfill gas capture programs, provincial/municipal waste diversion projects, and international exportation of MSW. It is expected that as larger and more “state of the art” landfills are constructed, where gas collection systems will be required, a greater portion of landfill gas will be captured in the future, resulting in a greater reduction of emissions from this sector. Nationally, in 2004, over 33 Mt of non-hazardous waste (residential, institutional, commercial, industrial, construction, and demolition) were generated. Waste diversion initiatives began in the early 1990s, and, based upon the national figures for 2004, approximately 24% of the waste generated is diverted from disposal (landfill or incineration) (Statistics Canada 2007a).

Table 8-1 summarizes the Waste Sector and subsector GHG contributions for 1990, 2005, and 2006 inventory years.

**Table 8-1: Waste Sector GHG Emission Summary, Selected Years**

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)		
	1990	2005	2006
Waste Sector TOTAL	18 000	21 000	21 000
a. Solid Waste Disposal on Land	17 000	19 000	20 000
b. Wastewater Handling	780	940	930
c. Waste Incineration	400	240	240

Note: Totals may not add up due to rounding.

## **8.2 Solid Waste Disposal on Land (CRF Category 6.A)**

### **8.2.1 Source Category Description**

Emissions are estimated from two types of landfills in Canada:

- MSW landfills; and
- wood waste landfills.

In Canada, most waste disposal on land occurs in managed municipal or privately owned landfills. Very few, if any, unmanaged waste disposal sites exist. Therefore, it has been assumed that all waste is disposed of in managed facilities. Residential, institutional, commercial, and industrial wastes are disposed of in MSW landfills. In the last 15 years, dedicated construction and demolition landfills were established. Typically, these landfills do not require CH<sub>4</sub> collection systems, as the CH<sub>4</sub> generation rate is very low due to the minimal organic content in the waste stream. Therefore, these landfills are currently excluded from the analysis.

Wood waste landfills are mostly privately owned and operated by forest industries, such as saw mills and pulp and paper mills. These industries use the landfills to dispose of surplus wood residue, such as sawdust, wood shavings, bark, and sludges. Some industries have shown increasing interest in waste-to-energy projects that produce steam and/or electricity by combusting these wastes. In recent years, residual wood previously regarded as a waste is now being processed as a value-added product—e.g. wood pellets for residential and commercial pellet stoves and furnaces, and hardboard, fibreboard, and particle board. Wood waste landfills have been identified as a source of CH<sub>4</sub> emissions; however, there is a great deal of uncertainty in the estimates. These landfills are a minor source of CH<sub>4</sub> emissions in comparison with MSW landfills.

The Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997) provide two methodologies for estimating emissions from landfills: a default method and a first-order kinetics method, also known as the Scholl Canyon model. The default method relates emissions to the quantity of waste landfilled in the previous year, whereas the Scholl Canyon model relates emissions to the cumulative biologically available waste that has been landfilled in previous years.

The composition and amount of waste landfilled in Canada have significantly changed over the past several decades, primarily as a result of waste diversion initiatives and population growth, respectively. For this reason, a static model such as the default method is not felt to be appropriate. Therefore, emissions from MSW landfills and wood waste landfills are estimated



using the Scholl Canyon model. The Scholl Canyon model, used for estimation of Canada's CH<sub>4</sub> emissions from landfills, has been validated independently through a study conducted by the University of Manitoba (Thompson et al. 2006).

Landfill gas, which is composed mainly of CH<sub>4</sub> and CO<sub>2</sub>, is produced by the anaerobic decomposition of organic wastes. The first phase of this process typically begins after waste has been in a landfill for 10–50 days. Although the majority of the CH<sub>4</sub> and CO<sub>2</sub> gases are generated within 20 years of landfilling, emissions can continue for 100 years or more (Levelton 1991).

A number of important site-specific factors contribute to the generation of gases within a landfill, including the following:

**Waste Composition:** Waste composition is probably the most important factor affecting landfill gas generation rates and quantities. The amount of landfill gas produced is dependent on the amount of organic matter landfilled. The rate at which gas is generated is dependent on the distribution and type of organic matter in the landfill.

**Moisture Content:** Water is required for anaerobic degradation of organic matter; therefore, moisture content within a landfill significantly affects gas generation rates.

**Temperature:** Anaerobic digestion is an exothermic process. The growth rates of bacteria tend to increase with temperature until an optimum is reached. Therefore, landfill temperatures may be higher than ambient air temperatures. The extent to which ambient air temperatures influence the temperature of the landfill and gas generation rates depends mainly on the depth of the landfill. Temperature variations can affect microbial activity, subsequently affecting their ability to decompose matter (Maurice and Lagerkvist 2003).

**pH and Buffer Capacity:** The generation of CH<sub>4</sub> in landfills is greatest when neutral pH conditions exist. The activity of methanogenic bacteria is inhibited in acidic environments.

**Availability of Nutrients:** Certain nutrients are required for anaerobic digestion. These include carbon, hydrogen, nitrogen, and phosphorus. In general, MSW contains the necessary nutrients to support the required bacterial populations.

**Waste Density and Particle Size:** The particle size and density of the waste also influence gas generation. Decreasing the particle size increases the surface area available for degradation and therefore increases the gas production rate. The waste density, which is largely controlled by compaction of the waste as it is placed in the landfill, affects the transport of moisture and nutrients through the landfill, which also affects the gas generation rate.

### **8.2.2 Methodological Issues**

CH<sub>4</sub> produced from the decomposition of waste in landfills is calculated using the Scholl Canyon model, which is a first-order decay model. This reflects the fact that waste degrades in landfills over many years. Data pertaining to landfill gas capture were obtained directly from the owners/operators of specific landfills with landfill gas collection systems.

CH<sub>4</sub> emissions are determined by calculating the amount of CH<sub>4</sub> generated from landfill waste decomposition through the Scholl Canyon model, subtracting the CH<sub>4</sub> captured through landfill gas recovery systems, then adding the quantity of uncombusted CH<sub>4</sub> emitted by the flares for those locations where a portion or all of the recovered landfill gas is burned without energy

recovery. The GHG emissions associated with the combustion of that portion of the landfill gas that is captured and utilized for energy generation purposes are accounted for in the Energy Sector. A more detailed discussion of the methodologies is presented in Annex 3.5.

### 8.2.2.1 *CH<sub>4</sub> Generation*

The Scholl Canyon model was used to estimate the quantity of CH<sub>4</sub> generated. The model is based upon the following first-order decay equation (IPCC/OECD/IEA 1997):

**Equation 8-1:**

$$Q_{T,x} = k M_x L_0 e^{-k(T-x)}$$

where:

$Q_{T,x}$	=	amount of CH <sub>4</sub> generated in the current year (T) by the waste $M_x$ , kt CH <sub>4</sub> /year
$x$	=	the year of waste input
$M_x$	=	the amount of waste disposed of in year $x$ , Mt
$k$	=	CH <sub>4</sub> generation rate constant, /year
$L_0$	=	CH <sub>4</sub> generation potential, kg CH <sub>4</sub> /t waste
$T$	=	current year

**Equation 8-2:**

$$Q_T = \sum Q_{T,x}$$

where:

$Q_T$	=	the amount of CH <sub>4</sub> generated in the current year (T), kt CH <sub>4</sub> /year
-------	---	---

In order to estimate CH<sub>4</sub> emissions from landfills, information on several of the factors described above is needed. To calculate the net emissions for each year, the sum of  $Q_{T,x}$  for every section of waste landfilled in past years was taken (Equation 8-2), and the captured gas was subtracted for each province. A computerized model has been developed to estimate aggregate emissions on a regional basis (by province and territory) in Canada. The national CH<sub>4</sub> emission value is the summation of emissions from all regions.

## **Waste Disposed of Each Year or the Mass of Refuse ( $M_x$ )**

### ***MSW Landfills***

Two primary sources were used in obtaining waste generation and landfill data for the GHG inventory. The amounts of MSW landfilled in the years 1941 through to 1990 were estimated by Levelton (1991). For the years 1998, 2000, 2002, and 2004, MSW disposal data were obtained from the Waste Management Industry Survey that is conducted by Statistics Canada on a biennial basis (Statistics Canada 2000, 2003, 2004, 2007a). For the intervening odd years (1999, 2001, and 2003), the MSW disposal values, including both landfilled and incinerated MSW, were obtained by taking an average of the corresponding even years. Incinerated waste quantities were subtracted from the Statistics Canada disposal values in order to obtain the amounts of MSW landfilled for 1998–2004. For the years 1991–1997, with the exception of Prince Edward Island, the Northwest Territories, Nunavut, and the Yukon, the quantities of waste disposed of were estimated from an interpolation using a multiple linear regression approach applied to the Levelton (1991) and Statistics Canada (2000, 2003, 2004, 2007a) MSW landfill values. MSW landfill values for Prince Edward Island and the Northwest Territories, Nunavut, and the Yukon

for the period 1991–2006 are obtained by trending historical landfill data with the provincial populations for 1971–2006 (Statistics Canada 2006a, 2007b).

### ***Wood Waste Landfills***

British Columbia, Quebec, Alberta, and Ontario together landfill 93% of the wood waste in Canada (NRCan 1997). The amount of wood waste landfilled in the years 1970 through to 1992 has been estimated at a national level based on the National Wood Residue Data Base (NRCan 1997). Data for the years 1998 and 2004 were provided by subsequent publications (NRCan 1999, 2005). A linear regression trend analysis was conducted to interpolate the amount of wood residue landfilled in the years 1991–1997 and 1999–2006.

### **CH<sub>4</sub> Generation Rate Constant (k)**

The CH<sub>4</sub> kinetic rate constant (k) represents the first-order rate at which CH<sub>4</sub> is generated after waste has been landfilled. The value of k is affected by four major factors: moisture content, temperature, availability of nutrients, and pH. It is assumed that in a typical MSW landfill, the nutrient and pH conditions are attained, therefore, these factors are not limiting. In many parts of Canada, subzero conditions exist for up to seven months of the year, with temperatures dropping below –30°C (Thompson et al. 2006); however, evidence suggests that ambient temperature does not affect landfill decay rates (Maurice and Lagerkvist 2003; Thompson and Tanapat 2005). In addition, seasonal temperature variations in the waste are minimal when compared with atmospheric temperature variations (Maurice C, Lagerkvist A. 2003). At depths exceeding 2 m, the landfill temperature is independent of the ambient temperature. It has been shown in Canadian field experiments that an insignificant amount of variation in landfill CH<sub>4</sub> production occurs between the winter and summer seasons (Bingemer and Crutzen 1987; Thompson and Tanapat 2005). Therefore, of all these factors, moisture content is the most influential parameter for Canadian landfills and is largely determined by the annual precipitation received at the landfills.

### ***MSW Landfills***

The k values used to estimate methane emissions originate from a study conducted by the University of Manitoba. This study employed the provincial precipitation data from 1971 to 2000 (Thompson et al. 2006) to obtain k values from a precipitation versus k value relationship developed by the U.S. EPA. The U.S. k values are related to precipitation, assuming that the moisture content of a landfill is a direct function of the annual precipitation. Based on both the U.S. k values and precipitation data and the average annual precipitation at Canadian landfills surveyed by Levelton (1991), k values were assigned to each of the provinces (Thompson et al. 2006).

The k values used to estimate emissions from MSW landfills have been chosen from the range of k value estimates for each province (Thompson et al. 2006). These values are provided in Table 8-2.

**Table 8-2: MSW Landfill k Value Estimates for Each Province/Territory**

Province/ Territories	NL	PE	NS	NB	QC	ON	MB	SK	AB	BC	NT	NU	YT
k Value Estimates	0.052	0.044	0.056	0.046	0.042	0.037	0.025	0.022	0.023	0.048	0.018	0.018	0.018

### ***Wood Waste Landfills***

Based upon the default value for estimating wood products industry landfill CH<sub>4</sub> emissions recommended by the National Council for Air and Stream Improvement, Inc., a k value of 0.03/year was assumed to represent the CH<sub>4</sub> generation rate constant k for all of the wood waste landfills in Canada (NCASI 2003).

### **CH<sub>4</sub> Generation Potential (L<sub>0</sub>)**

#### ***MSW Landfills***

The values of theoretical and measured L<sub>0</sub> range from 4.4 to 194 kg CH<sub>4</sub>/t of waste (Pelt et al. 1998). Over the time series used by the MSW portion of the emission estimation model, i.e., 1941 to 2006, three different L<sub>0</sub>'s were used to represent discrete time periods where studies showed significant changes in waste composition from one period to the next. L<sub>0</sub> is a function of degradable organic carbon (DOC), which is in turn determined from the composition of the waste, as described below.

The provincial and territorial DOCs were calculated from waste disposal composition values for three distinct time periods: 1941–1975, 1976–1989, and 1990–2006. Using waste composition data obtained from a Natural Resources Canada (NRCan) study, which was based on the 2002 data year (NRCan 2006), DOC values were derived and assumed to be constant over the period 1990–2004. Since the waste diversion programs were not significant prior to 1990, a second set of DOC's were developed to represent the waste composition at disposal from 1976 to 1989 by adding the NRCan landfill to the 2004 Statistics Canada recycled waste composition data (Environment Canada 2007). A third set of DOCs were developed from a 1967 national study to cover the period from 1941 to 1975 (CRC Press 1973). A summary of the L<sub>0</sub> values for the provinces and territories over the three time periods is given in Table 8-3. The percentages of organic waste diverted in 2002 for all Canadian provinces are also given, as a reference for that year. As waste disposal practices in Canada change and as new information is made available, the L<sub>0</sub> values will be adjusted accordingly.

L<sub>0</sub> was determined employing the methodology provided by the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997) (Equation 8-3) using the provincial waste composition data as input to the degradable organic carbon (DOC) calculation:

#### **Equation 8-3**

$$L_0 = MCF \times DOC \times DOC_F \times F \times 16/12 \times 1\,000 \text{ kg CH}_4/\text{t CH}_4$$

where:

L <sub>0</sub>	=	CH <sub>4</sub> generation potential (kg CH <sub>4</sub> /t waste)
MCF	=	CH <sub>4</sub> correction factor (fraction)
DOC	=	degradable organic carbon (t C/t waste)
DOC <sub>F</sub>	=	fraction DOC dissimilated
F	=	fraction of CH <sub>4</sub> in landfill gas
16/12	=	stoichiometric factor

According to the Revised 1996 IPCC Guidelines, the MCF for managed landfill sites has a value of 1.0 (IPCC/OECD/IEA 1997). The fraction of CH<sub>4</sub> emitted from a landfill (F) ranges from 0.4 to 0.6 and was assumed to be 0.5. From the IPCC Good Practice Guidance (2000), a DOC<sub>F</sub> value

of 0.6 was selected from a default range of 0.5 to 0.6. This  $\text{DOC}_F$  value best reflects the lower concentration of lignin in the MSW waste since the majority of wood wastes from pulp and paper industries and saw mills are disposed of in dedicated wood waste landfills.

The DOC calculation is derived from the biodegradable portion of the MSW (Equation 8-4):

**Equation 8-4:**

$$\text{DOC} = (0.4 \times A) + (0.17 \times B) + (0.15 \times C) + (0.3 \times D)$$

where:

- A = fraction of MSW that is paper and textiles
- B = fraction of MSW that is garden or park waste
- C = fraction of MSW that is food waste
- D = fraction of MSW that is wood or straw

**Table 8-3: CH<sub>4</sub> Generation Potential (L<sub>0</sub>) from 1941 to Present**

Province/Territory	2002 Organic Waste Diversion <sup>a</sup> (%)	1941 to 1975		1976 to 1989		1990 to Present	
		DOC	Lo (kg CH <sub>4</sub> /t waste)	DOC	Lo (kg CH <sub>4</sub> /t waste)	DOC	Lo (kg CH <sub>4</sub> /t waste)
<b>British Columbia</b>	23.3	0.28	111.86	0.17	69.89	0.16	63.71
<b>Alberta</b>	16.7	0.39	157.63	0.26	104.46	0.18	71.87
<b>Saskatchewan</b>	4.3	0.36	143.92	0.22	86.39	0.22	86.75
<b>Manitoba</b>	4.9	0.33	131.37	0.19	76.82	0.19	76.59
<b>Ontario</b>	16.4	0.36	143.74	0.21	82.75	0.21	83.00
<b>Quebec</b>	13.7	0.36	144.45	0.21	82.52	0.20	81.23
<b>New Brunswick</b>	19.8	0.23	93.91	0.16	65.91	0.16	63.22
<b>Nova Scotia</b>	29.7	0.25	100.89	0.16	62.35	0.16	64.10
<b>Prince Edward Island</b>	N/A	0.27	108.74	0.17	67.19	0.16	64.63
<b>Newfoundland</b>	N/A	0.28	112.62	0.18	73.28	0.18	73.35
<b>Territories (YT, NT and NU)</b>	N/A	0.22	87.59	0.15	58.54	0.16	65.13

Sources:

Note: Derived from data obtained from NRCAN (2006), Statistics Canada (2007a) and CRC (1973).

a. Thompson et al. (2006).

N/A = Unavailable categorical information.

### ***Wood Waste Landfills***

Equation 8-3 generated an L<sub>0</sub> value of 80 kg CH<sub>4</sub>/t of wood waste, which was used to estimate emissions from wood waste landfills by the Scholl Canyon model. IPCC defaults were used for MCF in unmanaged deep landfills (MCF = 1); the fraction of CH<sub>4</sub> in the landfill gas (F = 0.5); and the fraction DOC dissimilated ( $\text{DOC}_F$  = 0.5), where the lower end of the default range for wastes containing lignin was selected (IPCC/OECD/IEA 1997). One hundred percent wood or straw waste composition was assumed to calculate the fraction of DOC in Equation 8-4.

### 8.2.2.2 *Captured Landfill Gas*

Some of the CH<sub>4</sub> that is generated in MSW landfills is captured as landfill gas and combusted, either by flaring or burning the gas for energy recovery. Combustion of the landfill gas converts CH<sub>4</sub> to CO<sub>2</sub>, thus reducing the CH<sub>4</sub> emissions. To calculate the net CH<sub>4</sub> emissions from landfills, the amount of CH<sub>4</sub> captured, as provided by the landfill facilities, is subtracted from the quantity of CH<sub>4</sub> generated, as estimated by the Scholl Canyon model. Added to this value, to account for the combustion inefficiency of the flares, is the quantity of captured CH<sub>4</sub> that passes through the flare uncombusted. The captured gas is wholly or partially flared or combusted for electricity or heat generation. GHG emissions affiliated with the use of landfill gas for energy recovery are accounted for in the Energy Sector.

Flaring combustion efficiency for CH<sub>4</sub> in landfill gas of 99.7% was used to determine the quantity of CH<sub>4</sub> that circumvented the flare. This value was obtained from Table 2.4–3 of Chapter 2.4 of EPA AP 42 (EPA 1995). The quantities of landfill gas collected from 1983 to 1996 were obtained from a personal communication with M.E. Perkin of Environment Canada's National Office of Pollution Prevention in 1998. Then, for 1997–2003, data on the amount of landfill gas captured were collected directly from individual landfill operators biennially by Environment Canada's National Office of Pollution Prevention (Environment Canada 1997, 1999b, 2001, 2003a). As of 2006, beginning with the 2005 data year, this survey is now being conducted by Environment Canada's Greenhouse Gas Division (Environment Canada 2007). Landfill gas capture data are collected every odd year; therefore, for the purposes of the national GHG inventory, the landfill gas capture data for the subsequent even years are averaged from the odd years starting from 1997. In lieu of landfill gas capture data for 2006; for the purposes of 2008 NIR submission, it was assumed that the values held constant from 2005.

### 8.2.3 **Uncertainties and Time-Series Consistency**

The following discussion on uncertainty for the categories within this sector is based upon the results as reported in an uncertainty quantification study of the Canadian NIR (ICF Consulting 2004). This Tier 2 evaluation of uncertainty employed values from the 2001 inventory year (2003 submission). However, there have been modifications made to the methodology, emission factors, and sources of information as a consequence of the findings of this uncertainty study. Therefore, the results of this study may not be an accurate representation of the current uncertainty around the emissions from this subsector and the model inputs. However, in the absence of a follow-up Tier 2 study, it is expected that the improvements made would result in a reduction of the uncertainty for this subsector.

The CH<sub>4</sub> emissions from this key category include CH<sub>4</sub> emissions from MSW landfills and wood waste landfills. The level of uncertainty associated with the CH<sub>4</sub> emissions from the combined subsectors was estimated to be in the range of –35% to +40%, which closely resembles the uncertainty range of –40% to +35% estimated in this study for the CH<sub>4</sub> emissions from MSW landfills. The level uncertainty range provided by the ICF Consulting (2004) study is only slightly larger than the ± 30% span estimated with a 90% confidence level by a previous study, which used a Tier 1 approach based upon 1990 data (McCann 1994). However, it should be noted that the ICF Consulting (2004) study's uncertainty range is quoted for a 95% confidence interval, which would typically be larger than the range quoted for a 90% confidence interval.

The MSW landfills contributed to over 90% of the total CH<sub>4</sub> emissions from this key category in 2001 (Environment Canada 2003b). The uncertainty estimates for CH<sub>4</sub> emissions from MSW landfills seem to have been largely influenced by the uncertainty in the inventory values for L<sub>0</sub> for

1941–1989 and 1990–2001 and the CH<sub>4</sub> generation rate constant  $k$ , where the uncertainty for both  $k$  and  $L_0$  were based upon an estimate from one expert elicitation. A simplified model of the Scholl Canyon method was used for the Monte Carlo simulation, which may have had a bearing on relevancy of the uncertainty values. An error was introduced in the calculation of the MSW landfill CH<sub>4</sub> emission uncertainty by the use of the year 2000 value (instead of the 2001 value) for the total CH<sub>4</sub> captured in Canada, resulting in an uncertainty range of +20% to +24% for these activity data. The actual uncertainty for this activity data entry should have been  $\pm 2\%$ .

Although the uncertainty range estimated in this study for wood waste landfills was significantly higher (i.e. –60% to +190%) than that for MSW landfills, its contribution to the uncertainty in the key category was much lower, owing to its relatively low contribution of emissions (i.e. less than 10%) (Environment Canada 2003b). The uncertainty estimate for wood waste landfills seems to have been largely influenced by the CH<sub>4</sub> generation rate, carbon content of the waste landfilled, and the biodegradable fraction of the waste, where the uncertainties were assumed by ICF Consulting (2004) based upon the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997) and/or IPCC Good Practice Guidance (IPCC 2000), where available.

The estimates are calculated in a consistent manner over time.

#### **8.2.4 QA/QC and Verification**

A Tier 1 QC review was conducted for this key category. Some transcription errors were detected and corrected accordingly. No significant anomalies were identified.

#### **8.2.5 Recalculations**

Recalculations have occurred over the last two years for the MSW and wood waste landfill subsectors affecting CH<sub>4</sub> emissions. These were due to the introduction of new activity data and model parameters. A more detailed description of these modifications and their ramifications for the emission estimates is presented in Chapter 9.

#### **8.2.6 Planned Improvements**

Continuing our engagement to produce a biennial report on the status of landfill gas collection and utilization in Canada, the Greenhouse Gas Division will be conducting a survey during the summer of 2008 to compile activity data for the 2007 data year. The quantities of CH<sub>4</sub> gas captured, as obtained from the survey, will be used to update the 2009 NIR submission.

A study is being considered to review the quantity of wood waste being placed in Canadian wood and pulp and paper industry landfills and to verify the methodology, emission factors, and historical activity data currently employed.

### **8.3 Wastewater Handling (CRF Category 6.B)**

#### **8.3.1 Source Category Description**

Emissions from municipal and industrial wastewater treatment were estimated. Both municipal and industrial wastewater can be aerobically or anaerobically treated. When wastewater is treated anaerobically, CH<sub>4</sub> is produced; however, it is typical that systems with anaerobic digestion in Canada contain and combust the produced CH<sub>4</sub>. CH<sub>4</sub> emissions from aerobic systems are assumed to be negligible. Both types of treatment system generate N<sub>2</sub>O through the nitrification and denitrification of sewage nitrogen (IPCC/OECD/IEA 1997).

CO<sub>2</sub> is also a product of aerobic and anaerobic wastewater treatment. However, as detailed in Section 8.1, CO<sub>2</sub> emissions originating from the decomposition of organic matter are not included with the national total estimates, in accordance with the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997).

The emission estimation methodology for municipal wastewater handling is divided into two areas: CH<sub>4</sub> from anaerobic wastewater treatment and N<sub>2</sub>O from human sewage.

### 8.3.2 Methodological Issues

A more detailed discussion of the methodologies is presented in Annex 3.5.

#### 8.3.2.1 CH<sub>4</sub> Emissions

##### **Municipal Wastewater Treatment**

The IPCC default method was not used because the required data were not available. A method developed for Environment Canada (ORTECH Corporation 1994) was used to calculate an emission factor. Based on the amount of organic matter generated per person in Canada and the conversion of organic matter to CH<sub>4</sub>, it was estimated that 4.015 kg CH<sub>4</sub>/person per year could potentially be emitted from anaerobically treated wastewater.

CH<sub>4</sub> emissions were calculated by multiplying the emission factors by the population of the respective province (Statistics Canada 2006a, 2007b) and by the fraction of wastewater that is treated anaerobically.

##### **Industrial Wastewater Treatment**

Owing to a lack of activity data, the CH<sub>4</sub> emissions from this category have not been evaluated. Although aerobic treatment of industrial wastewater is typically the standard practice, it is known that a few anaerobic treatment units had commenced operations in 2006. The methodology that will be applied, once the activity data is obtained, is presented in Annex 3.5.

#### 8.3.2.2 N<sub>2</sub>O Emissions

##### **Municipal Wastewater Treatment**

The N<sub>2</sub>O emissions from municipal wastewater treatment facilities were calculated using the IPCC default method (IPCC/OECD/IEA 1997). This method estimates the N<sub>2</sub>O emission factor as the product of the annual per capita protein consumption, the assumed protein nitrogen content (16%), the quantity of N<sub>2</sub>O-N produced per unit of sewage nitrogen (0.01 kg N<sub>2</sub>O-N/kg sewage nitrogen), and the N<sub>2</sub>O/N<sub>2</sub>O-N conversion factor (1.57). Protein consumption estimates, in kg/person per year, were obtained from an annual food statistics report published by Statistics Canada (2007c). Data is provided for the years 1991, 1996, and 2001 to 2006. Protein consumption data for missing years is estimated by applying a multiple linear regression application to the Statistics Canada data. Emissions were calculated by multiplying the emission factor by the population of the respective provinces (Statistics Canada 2007b). A summary of the values for these two parameters over the time series is given in Table 8-4.



**Table 8-4: N<sub>2</sub>O Emission Factors**

<b>Year</b>	<b>Annual per Capita Protein Consumption (kg protein/person per year)</b>	<b>N<sub>2</sub>O Emission Factor (kg N<sub>2</sub>O/person per year)</b>
1990	25.74	0.065
1991 <sup>1</sup>	25.00	0.063
1992	26.01	0.065
1993	26.15	0.066
1994	26.29	0.066
1995	26.42	0.066
1996 <sup>1</sup>	26.00	0.065
1997	26.68	0.067
1998	26.79	0.067
1999	26.89	0.068
2000	26.98	0.068
2001 <sup>1</sup>	27.72	0.070
2002 <sup>1</sup>	27.54	0.069
2003 <sup>1</sup>	27.17	0.068
2004 <sup>1</sup>	27.41	0.069
2005 <sup>1</sup>	27.18	0.068
2006 <sup>2</sup>	26.40	0.066

Source:

1. Statistics Canada (2006b). The data have been adjusted for retail, household, cooking, and plate loss.
2. Statistics Canada (2007c). The data have been adjusted for retail, household, cooking, and plate loss.

## **Industrial Wastewater Treatment**

The revised 1996 IPCC guidelines (IPCC/OECD/IEA 1997) do not address the methodology for the estimation of N<sub>2</sub>O emissions from industrial wastewater treatment. Owing to a lack of activity data, the N<sub>2</sub>O emissions from this category have not been evaluated.

### **8.3.3 Uncertainties and Time-Series Consistency**

The following discussion on uncertainty for the categories within this sector is based upon the results as reported in an uncertainty quantification study of the Canadian NIR (ICF Consulting 2004). This Tier 2 evaluation of uncertainty employed values from the 2001 inventory year (2003 submission). However, there have been modifications made to the methodology, emission factors, and sources of information as a consequence of the findings of this uncertainty study. Therefore, the results of this study may not be an accurate representation of the current uncertainty around the emissions from this subsector and the model inputs. However, in the absence of a follow-up Tier 2 study, it is expected that the improvements made would result in a reduction of the uncertainty for this subsector.

The overall level uncertainty associated with the wastewater treatment subsector was estimated to be in the range of –40% to +55%. The level uncertainty range provided by the ICF Consulting (2004) study is less than the ±60% span estimated with a 90% confidence level by a previous study, which used a Tier 1 approach based on 1990 data (McCann 1994). This is an improvement to the uncertainty as assessed for this category, since the uncertainty range quoted by ICF Consulting (2004) for a 95% confidence interval should typically show a larger value than that

quoted for a 90% confidence interval. Based on 2001 data, the trend uncertainty associated with the total GHG emissions (comprising CH<sub>4</sub> and N<sub>2</sub>O) from the wastewater treatment systems was estimated to be in the range of about +12% to +13%. The extrapolation of trend uncertainty in 2001 to the 2006 inventory should be made with caution, as trend uncertainty is more sensitive than level uncertainty to the changes in the inventory estimate values for the more recent years.

Since the methods and data sources have remained unchanged over the time series, the estimates for this category are consistent over time.

### **8.3.4 QA/QC and Verification**

A Tier 1 QC review was conducted for this key category. No significant anomalies were identified.

### **8.3.5 Recalculations**

Recalculations have occurred over the last two years for the municipal wastewater subsector regarding CH<sub>4</sub> and N<sub>2</sub>O emissions. These were due to the introduction of new activity data and emission factors. A more detailed description of these modifications and their ramifications for the emission estimates is presented in Chapter 9.

### **8.3.6 Planned Improvements**

Canada is planning a study that would review the most recent data obtained from a biennial Environment Canada survey of water use and wastewater treatment in Canada. This study would verify the suitability of using these data within the present model and, through a gap analysis, provide recommendations for the organization conducting the survey to better suit the resulting data to the requirements of the NIR. Additionally, the study will complete a quality assurance review of the present model.

## **8.4 Waste Incineration (CRF Category 6.C)**

### **8.4.1 Source Category Description**

Emissions from both MSW and sewage sludge incineration are included in the inventory. Some municipalities in Canada utilize incinerators to reduce the quantity of MSW sent to landfills and to reduce the amount of sewage sludge requiring land application.

GHG emissions from incinerators vary, depending on factors such as the amount of waste incinerated, the composition of the waste, the carbon content of the non-biomass waste, and the facilities' operating conditions.

#### **8.4.1.1 MSW Incineration**

A combustion chamber of a typical mass-burn MSW incinerator is composed of a grate system on which waste is burned and is either water-walled (if the energy is recovered) or refractory-lined (if it is not). GHGs that are emitted from MSW incinerators include CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O.

As per the revised 1996 IPCC guidelines (IPCC/OECD/IEA 1997), CO<sub>2</sub> emissions from biomass waste combustion are not included in the inventory totals. The only CO<sub>2</sub> emissions detailed in this section are from fossil fuel-based carbon waste, such as plastics and rubber.

CH<sub>4</sub> emissions from MSW incineration are assumed to be negligible and are not calculated owing to a lack of underlying emission research.

#### 8.4.1.2 *Sewage Sludge Incineration*

Two different types of sewage sludge incinerators are used in Canada: multiple hearth and fluidized bed. In both types of incinerators, the sewage sludge is partially de-watered prior to incineration. The de-watering is typically done in a centrifuge or using a filter press. Currently, municipalities in Ontario and Quebec operate sewage sludge incinerators. GHGs emitted from the incineration of sewage sludge include CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O, as in the case of MSW incinerators; however, since the carbon present in the wastewater sewage sludge is of biological origin, the CO<sub>2</sub> emissions are not accounted for in the inventory totals from this source.

### 8.4.2 **Methodological Issues**

The emission estimation methodology depends on waste type and gas emitted. A more detailed discussion of the methodologies is presented in Annex 3.5.

#### 8.4.2.1 *CO<sub>2</sub> Emissions*

The revised 1996 IPCC guidelines (IPCC/OECD/IEA 1997) do not specify a method to calculate CO<sub>2</sub> emissions from the incineration of fossil fuel-based waste (such as plastics and rubber). Therefore, the following three-step method was developed for MSW incineration:

- *Calculating the Amount of Waste Incinerated:* The amount of waste incinerated each year was estimated based on a regression analysis using data from an Environment Canada (1996b) study, which contains detailed provincial incineration data for the year 1992, and from a study performed by A.J. Chandler & Associates Ltd. for Environment Canada, which provided incineration data for 1999, 2000, and 2001 (Environment Canada 2003c).
- *Developing Emission Factors:* Provincial CO<sub>2</sub> emission factors are founded on the assumption that carbon contained in waste undergoes complete oxidation to CO<sub>2</sub>. The amount of fossil fuel-based carbon available in the waste incinerated has been determined using typical percent weight carbon content values (Tchobanoglous et al. 1993). The amount of carbon per tonne of waste is estimated and converted to tonnes of CO<sub>2</sub> per tonne of waste by multiplying by the ratio of the molecular mass of CO<sub>2</sub> to that of carbon.
- *Calculating CO<sub>2</sub> Emissions:* Emissions were calculated on a provincial level by multiplying the amount of waste incinerated by the appropriate emission factor.

The CO<sub>2</sub> generated from the incineration of sewage sludge is not reported in the inventory emission totals, since the sludge consists solely of biogenic matter.

#### 8.4.2.2 *N<sub>2</sub>O and CH<sub>4</sub> Emissions*

### **MSW Incineration**

Emissions of N<sub>2</sub>O from MSW incineration were estimated using the IPCC default method (IPCC/OECD/IEA 1997). An average emission factor was calculated assuming that the IPCC five-stoker facility factors were most representative. To estimate emissions, the calculated emission factor was multiplied by the amount of waste incinerated by each province. CH<sub>4</sub> emissions from MSW incinerators are assumed to be negligible.

## Sewage Sludge Incineration

Emissions generated from the incineration of sewage sludge are dependent on the amount of dried solids incinerated. To calculate the CH<sub>4</sub> emissions, the amount of dried solids incinerated is multiplied by an appropriate emission factor. Estimates of the amount of dried solids in the sewage sludge incinerated in the years 1990–1992 are based on a study completed in 1994, as related in a personal communication with W. Fettes in February of 1994 from an interchange between Senes Consultants and Puitan Bennet. Data for the years 1993–1996 were acquired through telephone surveys of facilities that incinerate sewage sludge. Data for the years 1997 and 1998 were obtained from a Compass Environmental Inc. study prepared for Environment Canada (Environment Canada 1999a). Activity data for 1999, 2000, and 2001 were taken from a study conducted by A.J. Chandler and Associates Ltd. for Environment Canada (Environment Canada 2003c). To estimate the amount of sewage sludge incinerated in the years 2002–2006, a regression analysis was completed using the Chandler and Compass Environmental Inc. incineration values.

CH<sub>4</sub> emissions are estimated based on emission factors obtained from the U.S. EPA publication *Compilation of Air Pollutant Emission Factors* (EPA 1995). It is assumed that sewage sludge incineration is conducted with fluidized bed incinerators. Therefore, the emission factor is 1.6 t CH<sub>4</sub>/kt of total dried solids for fluidized bed sewage incinerators equipped with venture scrubbers. To estimate emissions, the emission factor was multiplied by the amount of waste incinerated by each province. The national emissions were then determined as the summation of these emissions for all provinces.

Emissions of N<sub>2</sub>O from sewage sludge incineration were estimated using the IPCC default emission factor for fluidized beds, 0.8 kg N<sub>2</sub>O/t of dried sewage sludge incinerated (IPCC 2000). To estimate emissions, the emission factor was multiplied by the amount of waste incinerated by each province. The national emissions were then determined as the summation of these emissions for all provinces.

### 8.4.3 Uncertainties and Time-Series Consistency

The following discussion on uncertainty for the categories within this sector is based upon the results as reported in an uncertainty quantification study of the Canadian NIR (ICF Consulting 2004). This Tier 2 evaluation of uncertainty employed values from the 2001 inventory year (2003 submission). However, there have been modifications made to the methodology, emission factors, and sources of information as a consequence of the findings of this uncertainty study. Therefore, the results of this study may not be an accurate representation of the current uncertainty around the emissions from this subsector and the model inputs. However, in the absence of a follow-up Tier 2 study, it is expected that the improvements made would result in a reduction of the uncertainty for this subsector.

The overall level uncertainty associated with the waste incineration source category was estimated to be in the range of –12% to +65%. For 2001 inventory estimates, the overall trend uncertainty associated with the total GHG emissions (comprising CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O) from incineration of wastes (comprising MSW and sewage sludge) was estimated to be in the range of about +10% to +11%. The inventory trend uncertainty was estimated at +10%. The extrapolation of trend uncertainty in 2001 to the 2006 inventory should be made with caution, as the trend uncertainty is more sensitive than level uncertainty to the changes in the inventory estimate values for the more recent years. CH<sub>4</sub> accounted for over 80% of the total GHG emissions from this source category.

#### **8.4.4 QA/QC and Verification**

A Tier 1 QC review was conducted for the key category: CO<sub>2</sub> emissions from MSW incineration. No significant anomalies were identified.

#### **8.4.5 Recalculations**

Recalculations have occurred over the last two years for the MSW and sewage sludge subsectors, affecting CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O emissions. These were due to the introduction of new activity data and emission factors. A more detailed description of these modifications and their ramifications for the emission estimates is presented in Chapter 9.

#### **8.4.6 Planned Improvements**

Activity data from 1990 to 2005 are presently being compiled through an internal study by the Division. This study includes an analysis of the municipal incineration activity data, development of a current inventory of all Canadian MSW incinerators, waste composition, annual throughputs for each unit, and estimated GHG emission factors.

## 9 Recalculations and Improvements

This chapter brings together all the recalculations implemented in Canada's national GHG inventory since its 2006 submission, to facilitate an integrated view of all changes. Two separate recalculation efforts took place: (1) recalculations in the 2006 submission, which led to its resubmission to the UNFCCC Secretariat in January 2008; and (2) recalculations implemented since the 2006 resubmission. The introductory section to this chapter provides details on the 2006 resubmission. Sections 9.1 to 9.7 describe the corrections and improvements that have occurred since. Section 9.8 provides information on improvements planned for Canada's national system. The NIR submitted in 2007 is no longer valid because the 2006 inventory was resubmitted: this report replaces the 2007 NIR and acts as both the 2007 resubmission as well as the 2008 submission.

From 5th to 10th November 2007, an expert review team (ERT) performed a thorough review of the 2006 submission of the Canadian GHG inventory. This review was part of the review of Canada's initial report, under the terms of the Kyoto Protocol, in order to establish Canada's assigned amount. In response to the ERT's recommendations, Canada provided a 2006 resubmission on 23 January 2008 with revised emission estimates for all years of the inventory time-series (1990–2004). Estimates were recalculated in the following categories: combustion of liquid fuels (CO<sub>2</sub>); combustion of solid fuels (coal-CO<sub>2</sub>); ammonia production (CO<sub>2</sub>); production of HCFC-22 (HFC-23); electrical equipment (SF<sub>6</sub>); other and undifferentiated (CO<sub>2</sub>); enteric fermentation (CH<sub>4</sub>) — live weights of non-dairy cattle; direct soil emissions (N<sub>2</sub>O) — country specific emission factor (EF); indirect emissions (N<sub>2</sub>O) — default EF; solid waste disposal on land (CH<sub>4</sub>); and wastewater handling (N<sub>2</sub>O).

Overall, the incorporation of the revised estimates in Canada's 2006 resubmission changed its 1990 baseline emissions from 599 Mt (submission 2006) to 594 Mt (resubmission 2006), a reduction of 5 Mt. These changes are also reflected in the time-series estimates reported in the 2008 submission, although additional changes may have been introduced in the 2008 submission, due to further refinements in the activity data and/or emission factors. Highlights of the changes and recalculations performed for the 2006 resubmission follow by IPCC sector:

### Energy

#### CO<sub>2</sub> — combustion of liquid fuels:

The estimates for combustion of liquid fuels, based on consistent data as referenced from McCann (2000), were revised for both carbon content and fuel densities. The impact of this, combined with a revision in the oxidation factor was to reduce the emission estimates from liquid fuels for the base year, from 195 Mt CO<sub>2</sub> to 191 Mt (a decrease of 2.0 percent or 3.9 Mt).

#### CO<sub>2</sub> — combustion of solid fuels:

The EFs for CO<sub>2</sub> for American bituminous coal in Nova Scotia was changed to 2 500 g/kg from 2 300 g/kg (as stated in the NIR), and for Canadian bituminous coal in New Brunswick was changed to 2 330g/kg from 2 230 g/kg. This changed the base year emissions from 91.82 Mt CO<sub>2</sub> to 91.87 Mt (increase of 0.04 percent or 40.9 kt).

## Industrial Processes

### CO<sub>2</sub> — ammonia production:

The method used to estimate CO<sub>2</sub> emissions from ammonia production was changed for the entire time series. CO<sub>2</sub> bound in exported urea was no longer subtracted from the CO<sub>2</sub> emissions of ammonia production. As a result, the base year estimate increased from 3.9 Mt CO<sub>2</sub> to 5.0 Mt CO<sub>2</sub>.

### HFC-23 from the production of HCFC-22:

The category of HFC-23 emissions from the production of HCFC-22 was added to the 2006 resubmission. As a result, HFC-23 emissions for the base year increased by 0.77 Mt CO<sub>2</sub> eq. It should also be noted that there were HFC-23 emissions (from this category) only for 1990–1992, because there have been no HCFC-22 production since 1993.

### SF<sub>6</sub> — electrical equipment:

The 1990–1995 estimates for SF<sub>6</sub> from electrical equipment were recalculated based on the assumption that there was no decline in SF<sub>6</sub> consumption between 1990 and 1995. In other words, the estimates for the base year and for the intervening years were set equal to the 1995 value. This caused the base year estimate of this category to decrease by 15.2% or 0.27 Mt CO<sub>2</sub> eq.

### CO<sub>2</sub> — Non-energy use of fuels:

To avoid double-counting, emission estimates for the Other and Undifferentiated category were recalculated by excluding CO<sub>2</sub> emissions from the use of carbon electrodes in steel production. Changes made to the 1990–2004 estimates varied from -32 kt CO<sub>2</sub> to -19 kt CO<sub>2</sub>. The base year estimate changed from 8.31 Mt CO<sub>2</sub> to 8.29 Mt CO<sub>2</sub>.

## Agriculture

### CH<sub>4</sub> — enteric fermentation - live weights of non-dairy cattle

Average live weights for relevant subcategories of non-dairy cattle (bulls, beef cows, beef heifers, heifers for slaughter and steers) were recalculated using data on the carcass weight as drivers, resulting in annual values of live weights and emission factors for enteric fermentation. The revision resulted in a 0.7 Mt CO<sub>2</sub> eq decrease of base year CH<sub>4</sub> emissions.

In addition to changes in CH<sub>4</sub> emissions from enteric fermentation, changes in live body weights affected — through the development of annual N excretion rates — N<sub>2</sub>O emissions from most categories. Base year N<sub>2</sub>O emissions from animal manure on pasture, range, and paddock decreased by 0.4 Mt CO<sub>2</sub>eq, and declined by 0.4 Mt CO<sub>2</sub> eq in manure management systems.

### N<sub>2</sub>O Direct Soil Emissions — country-specific EF

Canada uses a country-specific base emission factor, EF<sub>CT</sub>, which responds to variations in the climate and topography of ecodistricts. The EF<sub>CT</sub> values are estimated by regression analysis of measured data against actual precipitation/potential evapotranspiration, for different types of soils in various regions of Canada, and the resulting regression parameters are used for ecodistricts with no measurements. The regression was redone to include N<sub>2</sub>O emissions during Eastern

Canada's spring thaw in the growing season emissions. This change in deriving N<sub>2</sub>O emission factors at the ecodistrict level resulted in recalculations for the entire time series for a number of emission sources including synthetic nitrogen fertilizers, animal manure N applied to cropland as fertilizer, crop residue decomposition, summerfallow, and conservation tillage.

Revised 1990 estimates from the direct soil emissions are 12.5 Mt CO<sub>2</sub> eq, against the early estimate of 10.9 Mt CO<sub>2</sub> eq.

N<sub>2</sub>O Indirect Soil Emissions — default EF:

Canada has reverted to the default EF recommended in the revised 1996 IPCC guidelines (0.0225 kg N<sub>2</sub>O-N/kg N) and submitted revised estimates. When this modification is combined with the recalculated manure N excretion rates for some non-dairy cattle categories, the emission estimates from leaching and runoff of N are 7.0 Mt CO<sub>2</sub> eq for the 1990 value in contrast to the earlier estimate of 3.6 Mt CO<sub>2</sub> eq.

Waste

CH<sub>4</sub> — solid waste disposal on land:

The recalculated estimates for this category were based on the revised values for degradable organic carbon (DOC), and degradable organic carbon dissimilated (DOC<sub>F</sub>). The new DOC<sub>F</sub> value of 0.6 reflects the lower concentration of lignin in the MSW, as Canada estimates CH<sub>4</sub> emissions from the dedicated industrial wood waste landfills (pulp and paper and sawmills) separately from MSW sites. The revised emissions for solid waste disposal on land resulted in a decrease in base year CH<sub>4</sub> emissions from 0.99 Mt to 0.78 Mt CO<sub>2</sub> (a decrease of 26.8 % or 5.6 Mt CO<sub>2</sub> eq).

N<sub>2</sub>O — wastewater handling:

The N<sub>2</sub>O emission estimates are now based on annual protein consumption data from Statistics Canada, instead of a constant value that was used for the original 2006 submission, which resulted in an overestimation of the emissions. For the base year, the revised estimate for this category decreased from 2.8 kt N<sub>2</sub>O to 1.8 kt (a decrease of 36.1 % or 0.31 Mt CO<sub>2</sub> eq).

## ***9.1 Explanations and Justifications for Recalculations – 2008 Submission***

Each year, Environment Canada reviews and, if necessary, revises and recalculates the emission and removal estimates for all years in the inventory. This work is carried out as part of continuous improvement efforts to integrate refined data or methods, incorporate new information or additional sources and sinks, implement any new guidance, and correct errors and omissions.

As explained at the beginning of this chapter, this and the following sections describe corrections and improvements implemented in the inventory since the complete resubmission of the 1990–2004 inventory in January 2008. The resubmission, being the most recent submission prior to the current one, serves as the reference for recalculations of 1990–2004 estimates.

Table 9-1 provides a summary by sector, and for national GHG totals, of the quantitative effects of the recalculations for the 1990–2004 time series. More discussion of the impacts on levels and trends are presented in section 9.1.1 and 9.1.2.



Table 9-1: Summary of Recalculations

Sector	GHG Emissions per year																
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
<b>National Total<sup>1</sup></b>																	
2006 Resub. (Mt CO <sub>2</sub> eq)	594	587	605	606	627	644	662	675	682	694	721	714	721	750	753	NA	NA
Current (Mt CO <sub>2</sub> eq)	592	585	603	604	624	642	660	673	679	692	718	710	717	741	743	734	721
Change (%)	-0.3	-0.4	-0.3	-0.3	-0.4	-0.4	-0.3	-0.3	-0.4	-0.3	-0.5	-0.6	-0.6	-1.2	-1.4	–	–
<b>Energy</b>																	
2006 Resub. (Mt CO <sub>2</sub> eq)	472	464	481	481	498	513	528	541	551	565	591	586	593	618	615	NA	NA
Current (Mt CO <sub>2</sub> eq)	470	461	479	480	495	510	526	538	548	562	587	582	588	609	604	596	583
Change (%)	-0.4	-0.5	-0.4	-0.4	-0.6	-0.6	-0.4	-0.4	-0.6	-0.5	-0.7	-0.7	-0.7	-1.5	-1.7	–	–
<b>Industrial Processes</b>																	
2006 Resub. (Mt CO <sub>2</sub> eq)	55	56	54	53	56	57	58	58	54	51	51	50	50	51	56	NA	NA
Current (Mt CO <sub>2</sub> eq)	55	56	54	53	56	57	58	58	54	51	51	50	50	51	55	55	54
Change (%)	-0.1	0.0	-0.2	-0.2	-0.1	-0.1	-0.1	-0.6	-0.4	-0.1	-0.2	-0.1	-0.1	0.0	-0.6	–	–
<b>Solvent</b>																	
2006 Resub. (Mt CO <sub>2</sub> eq)	0.42	0.42	0.43	0.43	0.44	0.44	0.45	0.45	0.45	0.46	0.46	0.47	0.47	0.48	0.48	NA	NA
Current (Mt CO <sub>2</sub> eq)	0.17	0.17	0.14	0.16	0.17	0.21	0.21	0.23	0.21	0.22	0.24	0.21	0.17	0.22	0.21	0.18	0.32
Change (%)	-58	-61	-68	-64	-61	-53	-52	-50	-54	-53	-48	-55	-65	-54	-56	–	–
<b>Agriculture</b>																	
2006 Resub. (Mt CO <sub>2</sub> eq)	48	48	49	51	53	54	56	56	57	57	58	58	58	60	61	NA	NA
Current (Mt CO <sub>2</sub> eq)	49	49	51	52	54	56	58	58	58	59	60	59	58	61	63	63	62
Change (%)	3	3	2	3	3	3	3	3	3	3	2	2	1	2	2	–	–
<b>Waste</b>																	
2006 Resub. (Mt CO <sub>2</sub> eq)	19	19	20	20	20	20	20	20	20	20	20	20	21	21	21	NA	NA
Current (Mt CO <sub>2</sub> eq)	18	18	19	19	19	19	19	19	20	20	20	20	20	20	20	21	21
Change (%)	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-3	-3	-3	-3	–	–
<b>LULUCF</b>																	
2006 Resub. (Mt CO <sub>2</sub> eq)	-82	-97	-163	-75	15	194	-78	-125	89	-45	-131	-121	6	-11	81	NA	NA
Current (Mt CO <sub>2</sub> eq)	-106	-83	-131	-50	-65	164	-62	-105	110	-14	-98	-88	51	12	41	-8	31
Change (%)	30	-15	-19	-34	-537	-16	-20	-16	23	-68	-25	-27	728	-202	-49	–	–

Notes:

1. National totals exclude all gases from the LULUCF Sector.

NA = not applicable.

Emissions have been rounded from the estimated values. Percent differences were calculated based on the non-rounded estimated values.

### 9.1.1 Implications for Emission Levels

Total GHG emissions (excluding the LULUCF Sector) were overall revised downwards by less than 1%, except for 2003 and 2004, with downward revisions slightly above 1%. The 2004 inventory year saw the largest recalculations (-10 Mt, or -1.4% of national totals). Recalculations in the Energy Sector have the greatest impact on emission levels. Recalculations in the LULUCF sector were of the greatest magnitude, but as this sector is not included in Canada's total, these changes have no impact on overall emissions. Recalculations in the Energy Sector resulted in an overall decrease in reported emissions for the entire time series between 1990 and 2004. The revisions varied from about -2 Mt (-0.4%) in 1993 to about -10 Mt (-1.7%) in 2004.

For the Industrial Processes Sector, recalculations resulted in an emission decrease of about -0.06 Mt (-0.10%) for 1990. The revised emissions varied, for 1990–2004, by less than 1%. Recalculations impacted the 1997 estimates the most; the reported emissions decreased by -0.37 Mt (-0.64%).

The changes in the annual emissions in the Solvent and Other Product Use Sector have varied from -0.3 Mt (-68%) to -0.2 Mt (-48%).

In the Agriculture Sector, recalculations resulted in changes between +1 Mt (+2%, 1990) and +1.4 Mt (+3%, 1999) in reported emissions.

For the Waste Sector, recalculations resulted in a decrease in reported emissions by between -1.9 Mt (-7%, 1997) and -1.4 Mt (-5%, 2004).

The important recalculations in the LULUCF Sector do not affect national totals. Additional explanations are provided in Section 9.6 below.

### 9.1.2 Implications for Emission Trends

Overall, the recalculations of the total GHG estimates (excluding the LULUCF Sector) had a moderate effect on the long-term trend (1990–2004), now reported as a 25% increase instead of the previously reported 27% increase.

In the Energy Sector, the emission trend over 1990–2004 was changed from +30% to +29%.

The trend in the Industrial Processes Sector over 1990–2004 has slightly changed from 1.4% to 1.0%.

In the Solvent and Other Product Use Sector, recalculations have increased the emission trend over 1990–2004 from 15% (2006 resubmission) to 21% (this submission).

In the Agriculture Sector, the upward trend in GHG emissions over 1990–2004 was revised from 28% (previous submission) to 26%.

In the Waste Sector, the emission trend during 1990–2004 was recalculated to be 11%, compared with the 12% previously reported.

The net GHG balance in LULUCF displays an important annual variability due to the erratic occurrence of forest disturbances. Recalculations did not significantly alter this pattern.

## 9.2 Recalculations – Energy Sector

Overall, revised 2004 data, as published by Statistics Canada, have resulted in recalculations to the stationary combustion, transport, and fugitive emission estimates from petroleum refining. The revised data primarily affected the estimates for the Energy Industries, Transport, Manufacturing Industries and Construction, and Other sectors. Impacts were noticeable in the Public Electricity and Heat Production source category due to the changes in the types of coal consumed. The activity data recalculations mainly affected the Energy Industries, and the revisions to the liquid fuel emission factors had the greatest overall impact.

With the objective of improving the quality of the fugitive inventory, a complete time-series recalculation of fugitive emissions for the oil sands and upgrading industry was implemented to account for production and technology changes since the initial industry study in 1999. Improvements were based on results from a joint industry association and provincial and federal government study of the oil sands industry. In addition, revised coal activity data, and pipeline distribution length also resulted in recalculation of fugitive emissions. Specific discussions associated with improvements to the Energy Sector that resulted in emission recalculation or reporting reallocation are presented in the following sections.

### 9.2.1 Stationary Fossil Fuel Combustion

Stationary combustion estimates were revised because of the following factors:

*Model upgrades:* The stationary fuel combustion model was upgraded by conversion into a database software format, which resulted in a complete review of all aspects of the model, including methodology, activity data, and emission factors.

*Methodology updates:* The largest recalculation impact was the result of applying new methodologies and emission factors to fuels used in the bitumen upgrading and petroleum refining industries. New emission factors for petroleum coke and still gas (or self-generated gas, such as refinery fuel gas) resulted in a review of the methodology for estimating emissions in the two industries and in the common reporting format (CRF) categories. The methodology change reflects an improvement in previous assumptions, such that these two fuels can now also be attributed to bitumen upgrading (Manufacture of Solid Fuels and Other Energy Industries), whereas previously all emissions were allocated to the Petroleum Refining sector. These refinements had an impact of 1–2 Mt on total estimates and an even more significant impact at the subsector level.

*Statistics Canada fuel consumption data:* Historical activity data were obtained in an electronic format and at a higher degree of precision, which affected data primarily between 1990 and 1998. Also, QA/QC checks identified typographical errors in historic fuel consumption data. Revised data was obtained from Statistics Canada that primarily affected the 2004 data year and corrected a fuel consumption underestimate for the Energy Industries. The general impact on the previous estimates is in the range of +1 to +2 Mt.

*Typographic errors:* Minor typographic errors were identified in the transcription of emission factors from reference documents to the estimation model. The corrections impacted estimates from 1990 to 1998, and the impacts were minor.

*Fuel quantity recalculations:* In addition to the review of the stationary combustion methodology, emission estimates for still gas were recalculated for the entire time series based on reported

consumption in energy units, since the physical volumetric data are reported in liquid fuel oil equivalent, whereas revised emission factors are on a gaseous basis.

*Landfill gas usage:* Emissions associated with the combustion of landfill gas have been included in the inventory based on data provided by the Waste Sector. CH<sub>4</sub> and N<sub>2</sub>O emissions are included under Energy Industries, while CO<sub>2</sub> emissions are reported separately as a memo item under biomass fuels.

*Flaring emission allocation:* QC checks on CO<sub>2</sub> and CH<sub>4</sub> emissions from gaseous fuels under the Manufacture of Solid Fuels and Other Energy Industries category identified that the flaring emissions in the oil and gas sector had been double-counted (i.e. fugitive emissions were not subtracted from the gaseous total under their respective categories). This impact was observed throughout the time series.

### 9.2.2 Transport

Transportation estimates were revised because of the following factors:

*Statistics Canada fuel consumption data:* Two changes contributed to recalculations. An electronic data set for 1990–2003 was obtained, which provided data with more resolution than the paper copies historically used, and a revised data set for 2004 was received. Minor adjustments resulted for all years.

*Higher disaggregation of activity data within the MGEM model:* Vehicle populations in MGEM are now disaggregated by class and model year for all provinces and territories. Other data improvements in MGEM included refined technology penetration assumptions, Fuel Consumption Ratios (FCRs), and Vehicle Kilometres Travelled (VKTs). These changes have resulted in a reallocation of fuel and associated emissions between vehicle classes and technologies for all years.

*Accuracy and applicability of emission factors :* All transportation emission factors were investigated to evaluate their accuracy with respect to references and unit conversion methodology. A technical review of all on-road diesel and gasoline CH<sub>4</sub> and N<sub>2</sub>O emission factors was carried out to ensure that the most appropriate emission factors were being used. As part of the technical review, the applicability of separate N<sub>2</sub>O emission factors for new and aged (over 20 000 km) Tier 0 catalysts on vehicles was reviewed. It was concluded that age alone does not affect the N<sub>2</sub>O removal efficiency of Tier 0 catalysts. An average N<sub>2</sub>O emission factor based on aged Tier 0 vehicles is used for all Tier 0 vehicles in the 1990–2006 estimates. Minor adjustments resulted for all years.

*Modification of the on- and off-road fuel allocation methodology:* Owing to an improved understanding of the vehicle fleet, the fuel allocated by MGEM to road transportation has a higher certainty. The fuel normalization routine used by MGEM to ensure that all transportation fuels are accounted for has been modified to take into account the increased certainty in the on-road calculation (see Annex 2). The modification has reallocated fuel to off-road applications from on-road transportation for all years.

### 9.2.3 Fugitive Sources

Key improvements that resulted in a recalculation or a reallocation of the fugitive estimates were due to the following:

- revised estimates for the oil sands and heavy oil upgrading (OS/HOU) industry based on the CAPP (2006) study of the industry for 1990–2003;
- reporting reallocation of unintentional and intentional emissions for the oil and gas industry for 1990–2004;
- revised coal production data for 2002–2004;
- revised petroleum refining energy consumption data for 1991–1994 and from 2003 onwards; and
- revised pipeline and distribution length for 2002–2004.

Improvements and updates to the fugitive model for the oil and gas industry were based on CAPP's (2006) bitumen study (also referred to as *An Inventory of GHGs, CACs, and H<sub>2</sub>S Emissions by the Canadian Bitumen Industry: 1990–2003*). The reallocation of unintentional and intentional sources of emissions resulted in a complete time-series recalculation, whereas only certain years were affected by revised coal activity data (for 2002–2004). Also revised were refinery energy consumption data (1991–1994 and from 2003 onwards) and the pipeline distribution length (2002–2004).

Upstream oil and gas industry: A complete time-series recalculation of emissions associated with the bitumen and synthetic crude oil production industry was implemented for the Fugitive Oil and Gas subsector, based on results from the bitumen study (CAPP 2006) as prepared by David Picard of Clearstone Engineering Ltd. for CAPP. In general, an IPCC Tier 3 approach was applied by each operator to develop a bottom-up approach in estimating GHG emissions for their Oil Sands/Heavy Oil Upgrading (OS/HOU) operation. Wherever gaps existed, estimates were prepared by Clearstone Engineering Ltd. (CAPP 2006) and were provided to each operator for their review. QA/QC and an uncertainty analysis following the IPCC good practice guidance (IPCC 2000) was also included in the study. For 1990–2003, fugitive emissions from OS/HOU operations resulting from process venting (e.g. hydrogen production), flaring, venting (including mine surfaces and tailing pond surfaces), storage and handling losses, and equipment leaks were directly incorporated into the national inventory fugitive model.

An extrapolation model was developed based on results from the bitumen study (CAPP 2006) for use in estimating emissions from 2004 onwards, along with publicly available activity information from Statistics Canada, the National Energy Board and Energy Resources Conservation Board (previously known as the Alberta Energy and Utilities Board).

This has resulted in recalculations for 1990–2004 emission estimates of the OS/HOU industry in the following categories: 1.B.2.a.ii. Oil Production; 1.B.2.c.i. Venting—Oil; and 1.B.2.c.ii. Flaring—Oil. In addition, recalculation specifically for the year 2004 also includes 1) correction of provincial flaring activity data for the OS/HOU industry and 2) correction of cell referencing errors in for the crude oil production industry.

Fugitive emissions associated with intentional sources such as process emissions from hydrogen production in the oil and gas industry from 1990 to 2004 were reallocated from 1.B.2.a.iv. Oil Refining/Storage and from 1.B.2.b.ii. Natural Gas Production/Processing to 1.B.2.c.i. Venting Oil and to 1.B.2.c.ii. Venting Gas, respectively, and vice versa for unintentional venting. This reallocation of process vent emissions did not have an impact on the overall total for fugitive emissions from the oil and gas industry, since the methodology, activity data and/or emission factors were not revised; but to ensure consistent reporting, of intentional and unintentional fugitive emissions.

*Coal mining:* Coal mining emissions for 2002 to 2004 were recalculated with publicly available coal mining activity data from Statistics Canada. Prior to this, the 2001 mining activity data were used to estimate the GHG emissions for this industry.

*Petroleum refining:* Updates to the petroleum refining activity data, the natural gas transmission, and the distribution length have also resulted in year-specific recalculations. The annual activity data that the refinery model uses to interpolate fugitive emissions for 1991–1993 and to extrapolate from 2003 onwards are the fuel consumption data from the stationary combustion model for the Petroleum Refining category. Improvement to the stationary combustion methodology (as discussed in the Energy Industries section of Chapter 3 and in Annex 2 resulted in an update to the activity data. GHG emissions associated with venting, flaring, and oil refining were revised for 1991–1993 and for 2003 onwards.

*Transmission and distribution:* For natural gas transmission and distribution, fugitive emissions were recalculated for the years 2002–2004 based on new natural gas pipeline and distribution length as published by Statistics Canada (Statistics Canada Catalogue No. 57-205-XIB).

### **9.3 Recalculations – Industrial Processes Sector**

The changes in the emissions estimates found in the 2008 submission (as a result of the recalculations), and their impacts are summarized below. They were mainly driven by activity data updates and some methodological improvements.

CO<sub>2</sub> emissions from cement production were recalculated due to an update to the emission factor used. In the 2008 submission, an unrounded value of 0.5071 t CO<sub>2</sub>/t clinker (IPCC/OECD/IEA 1997) has been used, resulting in a minor increase of 0.02% in the 1990–2004 emission estimates. In physical units, the impact ranges from 0.88 to 1.4 kt CO<sub>2</sub> eq only.

Recalculation was done for the 2004 emission estimate of lime production due to updates of data on national lime production and national hydrated lime production obtained from the *Canadian Minerals Yearbook* (NRCan). The 2004 emission estimate decreased by 2.4% or 44 kt CO<sub>2</sub> eq.

For the category of limestone and dolomite use, there were revisions for the whole time series primarily because of the use of unrounded values from the sub-source “other chemical use.” Furthermore, since the values of the amount of stone used as flux in iron and steel furnace for 1998 and 1999 were considered anomalous, an average of the values of the other years (including that of 2006) was used to re-estimate CO<sub>2</sub> emissions of these two years. In addition, acquisition of updated 2004 data in the *Canadian Minerals Yearbook* led to further revision of the 2004 estimate. These changes impacted the 1990–2004 time series by -14.1% (-40 kt CO<sub>2</sub> eq) to +0.1% (+0.32 kt CO<sub>2</sub> eq).

CO<sub>2</sub> emissions from soda ash use for 2004 have been recalculated based on new soda ash import data. The update in activity data resulted in a minute emission decrease of less than 1% (0.014 kt CO<sub>2</sub> eq).

Acquisition of updated magnesite use data for 2004 caused a minor recalculation of the 2004 emission estimate. It decreased by 2.7% or 5.1 kt CO<sub>2</sub> eq.

For the category of ammonia production, the 1990–2004 emissions were re-estimated, as more accurate plant-specific data on ammonia production that did not involve the use of steam methane reforming (SMR) became available through a study (Cheminfo Services 2006). Specifically,

instead of assuming a constant value of 500 kt for the production not using SMR, plant-specific values were used to recalculate 1990–2004 emissions. The activity data update caused moderate changes of -2.5% (-177 kt CO<sub>2</sub> eq) to +3.3% (193 kt CO<sub>2</sub> eq) in the time series.

The 1990–2004 emission estimates for nitric acid production were revised upward due to acquisition of plant-specific data/information on production and emission abatement technologies during a study (Cheminfo Services 2006). In the past, to estimate emissions from nitric acid production, total national production values had been used and assumptions on the abatement technologies used by plants had been made. The impact of the activity data revisions on the 1990–2004 time series ranged from 25% (191 kt CO<sub>2</sub> eq) to 62% (489 kt CO<sub>2</sub> eq).

The 1990–2004 time series for iron and steel production was revised due to the change in the emission factor for steel production in EAFs from 4.58 kg CO<sub>2</sub>/t steel to 5 kg CO<sub>2</sub>/t steel. Additionally, slight revisions of the 1990–1998 metallurgical coke consumption data (i.e. data with higher resolution provided by Statistics Canada) contributed to the recalculations of the emission estimates of these years. Statistics Canada also provided a correction for the 2004 data on metallurgical coke use. Altogether and for the 1990–2004 time-series, these changes had an impact of -12% (-959 kt CO<sub>2</sub> eq) to +0.08% (+6 kt CO<sub>2</sub> eq). It should be noted that the correction made to the activity data was the main driver of the difference of 959 kt CO<sub>2</sub> eq for the 2004 estimate; the update in the EAF emission factor contributed very little to this effect.

There were minute revisions in the aluminium production 1990–2004 time series, ranging from -0.0005% (-0.041 kt CO<sub>2</sub> eq) to +0.08% (+7.3 kt CO<sub>2</sub> eq). The changes that contributed to the overall recalculations of the category were the revised 1990–2004 SF<sub>6</sub> estimates provided by a company. Another company also updated its 2004 CO<sub>2</sub> and PFC estimates (as updated coefficients became available).

For the category of magnesium production, updated 1999–2001 data (i.e. data with higher resolution) became available on the NPRI's website. Hence, revisions of -0.005% (-0.12 kt CO<sub>2</sub> eq) to 0.004% (0.07 kt CO<sub>2</sub> eq) were made to the 1999–2001 estimates of this category.

The 1991–2004 SF<sub>6</sub> emission estimates for magnesium casting were slightly revised to correct transcription errors and to include updated data provided by companies. The impact of the recalculations ranged from -2.0% (-5.0 kt CO<sub>2</sub> eq) to +7.8% (+35 kt CO<sub>2</sub> eq).

For the category of consumption of HFCs, 1996–2004 emissions were recalculated. Minor revisions were made in the calculation of HFCs contained in existing systems (including refrigeration, AC, and foam) for 1996–2004. In addition, data on HFC consumption for 2004 gathered by Environment Canada's Chemical Controls Division became available to the GHG Division. These data were used to revise the 2004 estimates, which had been developed in the previous inventory based on the assumption that the quantities of HFCs consumed in 2004 stayed at 2003 levels. These changes had an impact of -2.1% (-17 kt CO<sub>2</sub> eq) to +0.52% (+24 kt CO<sub>2</sub> eq) on the 1996–2004 HFC emission estimates.

As modifications were made to the activity data, the 2004 estimate for the category of SF<sub>6</sub> emissions from electrical equipment was revised. The impact was an emission increase of 3.8% (30 kt CO<sub>2</sub> eq).

The methodology used for estimating SF<sub>6</sub> emissions from semiconductor manufacturing has been switched from Tier 1 to Tier 2. Moreover, a correction was made to rectify a transcription error in the 2004 sales data. These improvements caused downward revisions in the 1990–2004 emission

estimates. The differences (as a result of the recalculations) ranged from -74% (-20 kt CO<sub>2</sub> eq) to -56% (-13 kt CO<sub>2</sub> eq).

Finally, there were recalculations of the time series of other and undifferentiated. These were due to updated activity data and updated and corrected emission factors for coals and petroleum coke. Improvements made to this category resulted in changes in the 1990–2004 emission estimates, ranging from -7.0% (-700 kt CO<sub>2</sub> eq) to +4.0% (+480 kt CO<sub>2</sub> eq).

#### **9.4 Recalculations – Solvent and Other Product Use Sector**

Emission estimates for 1990–2004 for this sector were recalculated because updated activity data (i.e. N<sub>2</sub>O sales data) were obtained during the Cheminfo study in 2006 (Cheminfo Services 2006). The activity data update had an impact of -68% (-300 kt CO<sub>2</sub> eq) to -48% (-220 kt CO<sub>2</sub> eq) on the 1990–2004 estimates.

#### **9.5 Recalculations – Agriculture Sector**

The recalculations implemented in the Agriculture Sector since the 2006 resubmission resulted in an overall upward change that varied from 0.8 Mt CO<sub>2</sub> eq (1%) up to 1.8 Mt CO<sub>2</sub> eq (3%) in the 1990–2006 inventory years.

##### **9.5.1 Cross-cutting Recalculations**

The recent release of the *2006 Census of Agriculture* provides 2006 population data for minor animal types such as horses, goats, buffaloes, and poultry; in previous submissions these data had been kept constant at the 2001 populations. The latter census also triggered revisions of all animal categories. These changes in animal populations resulted in recalculations of: CH<sub>4</sub> enteric fermentation, CH<sub>4</sub> and N<sub>2</sub>O manure management, as well as direct and indirect soil N<sub>2</sub>O emissions. The impact of the changes in animal populations on the emissions is very small (<0.1 Mt CO<sub>2</sub> eq).

Llamas is a required reporting animal category in the CRF Tables. Animal populations of llamas and alpacas are available in Canada and are included in the 2008 NIR. An enteric CH<sub>4</sub> emission factor of 8 kg CH<sub>4</sub>/year was used (IPCC 2006). The CH<sub>4</sub> emission factor from manure management and other parameters, such as N<sub>EX</sub> and animal waste management systems, are assumed to be the same as sheep until more suitable values are available. The inclusion of llamas and alpacas in the 2008 NIR affected most reporting source categories, but because of the small animal population in this category, its contribution to greenhouse gas emissions is minor.

In the 2007 submission, manure N excretion rates (N<sub>EX</sub>) were derived from ASAE (2003). There are small differences in N<sub>EX</sub> for various animal types between this publication and the most recent IPCC methodological report (Table 9-2). In the 2008 submission, it was decided that all N<sub>EX</sub> should be consistent with IPCC (2006).

**Table 9-2: Comparison of manure nitrogen excretion rates between ASAE (2003) and IPCC (2006)**

<b>Animal Category</b>	<b>N<sub>EX</sub> Used in 2007 NIR kg N/head/day</b>	<b>IPCC (2006) kg N/head/day</b>
Non-Dairy Cattle	0.34	0.31
Dairy Cattle	0.45	0.44
Swine	0.52	0.50
Poultry	1.02	0.83



The impact of the change in animal manure N excretion rates ( $N_{EX}$ ) resulted in recalculations for  $N_2O$  emissions from manure management systems (-0.2 ~ -0.3 Mt  $CO_2$  eq),  $N_2O$  emissions from animal manure on pasture, range, and paddock (-0.2 ~ -0.4 Mt  $CO_2$  eq),  $N_2O$  emissions from animal manure N applied to soils (-0.3 Mt  $CO_2$  eq), and other direct and indirect soil  $N_2O$  emissions (the magnitude of change in emissions were downward and moderate for all years).

In previous NIRs, climate data for calculating precipitation/potential evapotranspiration ratios (P/PE) were based on the 30-year long-term average from 1961 to 1990. More recent 30-year long-term climatic data from 1971 to 2000 are now available and were used in the 2008 submission. The update of long-term climatic data (P/PE) changed  $N_2O$   $EF_{BASE}$  and  $FRAC_{LEACH}$  at the ecodistrict level (see Section A3.3). Recalculated emissions were higher because of wetter than normal precipitation occurring in the late 1990s in most of the Canadian prairies. As a result, agricultural GHG emissions for the prairies provinces increased by approximately 10% annually.

The following section provides information on category-specific recalculations since the resubmission of the 2006 NIR, by agricultural source-gas categories.

### 9.5.2 Enteric Fermentation

Intercensal revisions and the addition of llamas and alpacas resulted in a small change of emissions ( $\pm 0.3$  Mt  $CO_2$  eq annually) for enteric fermentation, with no impact on the long-term trend.

### 9.5.3 Manure Management

Manure Management –  $CH_4$

Intercensal revisions and the addition of llamas and alpacas resulted in a change in  $CH_4$  emissions from 0.03 to 0.05 Mt  $CO_2$  eq annually and had no impact on the emission trend.

Manure Management –  $N_2O$

Changes in manure N excretion rates, updated animal populations for the intercensal period and inclusion of llamas and alpacas resulted in changes of from -0.2 to -0.4 Mt  $CO_2$  eq annually and had a small impact on the long-term trend.

### 9.5.4 Direct $N_2O$ Emissions from Agricultural Soils

Synthetic N Fertilizers

The use of synthetic nitrogen fertilizers for 2004 was updated with the most recent estimate. The emissions from this source were adjusted upward slightly because of a higher synthetic N consumption than the ones used in previous years. Recalculations have been carried out for the entire time series for this category. Overall, the combination of updated fertilizer consumption and revised  $N_2O$   $EF_{BASE}$  (see Section 9.5.1 above) increased the 1990 emissions by 0.4 Mt  $CO_2$  eq and the 2004 emissions by 0.8 Mt  $CO_2$  eq and have increased the 1990–2004 trend from +26% to +30%.

### Manure Applied as Fertilizer

Intercensal revisions of animal populations, manure N excretion rates, as well as updates of climate normals decreased N<sub>2</sub>O emissions by about 0.05 Mt CO<sub>2</sub> eq annually after 1990 and had a minimal impact on the long-term trend.

### Crop Residue Decomposition

Recalculations have been carried out because of revisions of crop yield data for some minor crop categories and changes in N<sub>2</sub>O EF<sub>BASE</sub> due to updates in climate data. Overall, these recalculations increased the 1990 emissions by 0.4 Mt CO<sub>2</sub> eq and the 2004 emissions by 0.6 Mt CO<sub>2</sub> eq, and the long-term trend in emissions has increased from 2% to 5%.

### Soil Texture

Soil texture plays a key role in controlling the release of N<sub>2</sub>O from denitrification and nitrification (Rochette et al. 2008) and thus soil texture is included as a factor for emission estimates from agricultural soils. EF<sub>BASE</sub> was modified by a soil texture ratio (RF<sub>TEXTURE</sub> - see Section A3.3), using available data at the ecodistrict level in the *Soil Landscapes of Canada*. The addition of this RF<sub>TEXTURE</sub> ratio factor changed the relative distribution of provincial agricultural GHG emissions depending on average soil texture for a province, but this would have very little impact on the total national agricultural GHG estimates. The inclusion of soil texture as a modifier of soil N<sub>2</sub>O emissions likely reduces the uncertainty of N<sub>2</sub>O estimates spatially.

### Adoption of No-Till and Reduced Tillage

The availability of tillage ratio factor (Rochette et al. 2008) for British Columbia and Eastern Canada allowed expanding geographically N<sub>2</sub>O estimates from direct soil sources. This expansion, combined to changes in manure N excretion rates, updated animal populations, N<sub>2</sub>O EF<sub>BASE</sub> resulted in slight changes in N<sub>2</sub>O removals due to conservation tillage, from 0.31 Mt CO<sub>2</sub> eq to 0.30 Mt CO<sub>2</sub> eq in 1990, and from 0.87 Mt CO<sub>2</sub> eq to 0.86 Mt CO<sub>2</sub> eq in 2004.

*Summerfallowing* — Because estimates of N<sub>2</sub>O emissions from summerfallow are derived from inputs of fertilizers, animal manure, and crop residue N, recalculations have been carried out due to changes in manure N excretion rates, animal populations, climate data, and N<sub>2</sub>O EF<sub>BASE</sub>. Overall, N<sub>2</sub>O emissions from summerfallow increased by approximately 0.3 Mt CO<sub>2</sub> eq for 1990 and 0.2 Mt CO<sub>2</sub> eq for 2004, and had little impact on the trend.

*Irrigation* — Because estimates of N<sub>2</sub>O emissions from irrigation are derived from inputs of fertilizers, animal manure, and crop residue N, recalculations have been carried out due to changes in manure N excretion rates and animal populations. Overall, these recalculations increased N<sub>2</sub>O emissions by about 0.3~0.4 Mt CO<sub>2</sub> eq annually and had no impact on the long-term trend.

### Manure on Pasture, Range, and Paddock

Percentages of manure nitrogen used on Pasture, Range, and Paddock as well as Solid Storage and Drylot for goats and horses were changed to be reported separately, rather than the average of both goats and horses, based on the original study of Marinier et al. (2004).

The combined changes in manure N excretion rates, updated animal populations, and inclusion of llamas and alpacas decreased N<sub>2</sub>O emissions by 0.2~0.4 Mt CO<sub>2</sub> eq annually and had little impact on the long-term trend.

### 9.5.5 Indirect Emissions of N<sub>2</sub>O from Soils

#### Volatilization and Redeposition of Nitrogen

The method for calculating N<sub>2</sub>O emissions from volatilization and re-deposition of nitrogen has been revised in the 2006 IPCC guidelines (IPCC 2006). In comparison with the early guidelines (IPCC 2000), the amount of volatilized NH<sub>3</sub>-N and NO<sub>x</sub>-N from animal manure applied as fertilizers to cropland has been added. The revised method was implemented to be consistent with the 2006 IPCC guidelines. N<sub>2</sub>O emissions from this additional volatilized nitrogen have been included; as a result, there is an upward adjustment of N<sub>2</sub>O emissions.

Recalculations have been carried out because of changes in manure N excretion rates, updated animal populations and updated equations for emission estimates (see Equation A3-27 in Section A3.3 ). Overall, these recalculations increased N<sub>2</sub>O emissions by 0.2~0.3 Mt CO<sub>2</sub> eq annually and had little impact on the long-term trend.

#### Leaching, Erosion, and Runoff

The amount of leached nitrogen subject to indirect N<sub>2</sub>O emissions was revised to account for corrections related to the change of perennial forage crops to annual crops in the previous year's submission. N<sub>2</sub>O emissions resulting from mineralization of organic matter due to conversion of perennial to annual crops were not included in 2007 and 2008 NIR, but the leached N included the contribution of mineralization of organic matter from conversion of perennial to annual crops in the 2007 NIR.

Recalculations have been carried out because of changes in animal populations, N<sub>ex</sub> and FRAC<sub>LEACH</sub> due to updates in long-term climate normals and correction of an error in the database. Overall, these recalculations resulted in small changes in N<sub>2</sub>O emissions of ±0.1 Mt CO<sub>2</sub> eq annually and had no impact on the long-term trend.

## 9.6 Recalculations – Land Use, Land-Use Change and Forestry Sector

Recalculations since the 2006 submission are important, and largely result from changes in activity data and estimation parameters, as opposed to method improvements. No new category is reported. Recalculations had the largest effects on inventory years 1994 (–80 Mt), 2002 (+45 Mt), 2004 (–40 Mt), 2000 (33 Mt), 2001 (+33 Mt), 1992 (+32 Mt), and 1995 (–31 Mt) – see Figure 9-1.

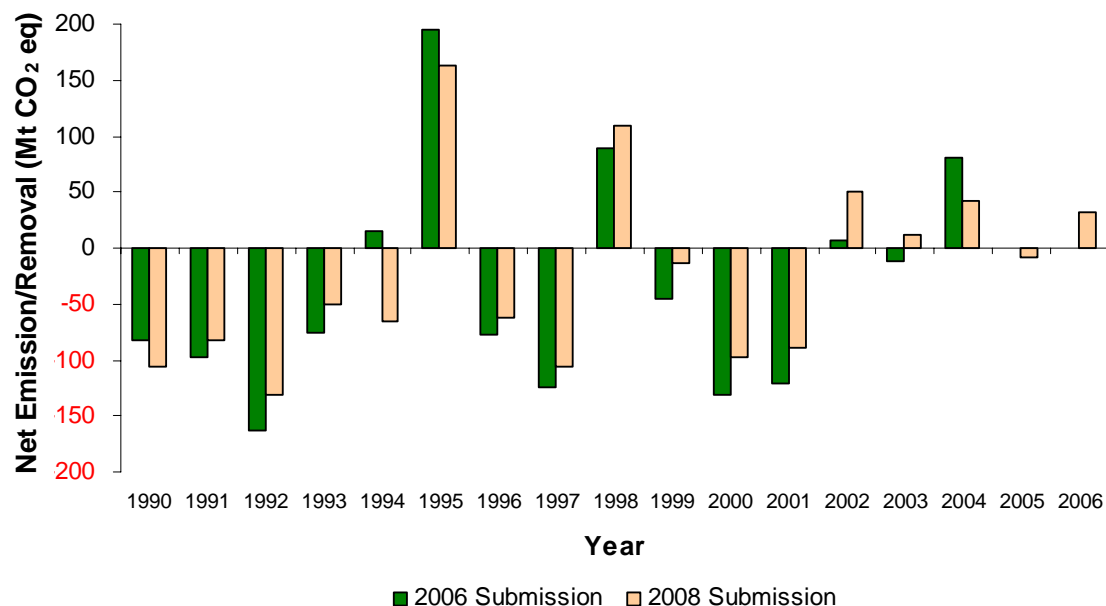


Figure 9-1: Emissions/removals in the 2006 and 2008 submissions, LULUCF Sector

Corrections and improvements in activity data consisted of revisions in the area of managed forests, expanded coverage of deforestation samples, and integration of expert knowledge of peatland management. QC activities and enhanced harmonization of multi-source data also led to corrections, notably in the area of flooded land.

The most important change to estimation parameters affected rates of decay of dead organic matter on forest land. Sections 9.6.1 to 9.6.4 provide details on the most important recalculations specific to each category.

### 9.6.1 Forest Land Remaining Forest Land

Recalculations in the LULUCF sector are largely driven by those in the Forest Land category. Large changes can be observed in inventory years 1994 (−80 Mt), 2002 (+43 Mt), 2004 (−42 Mt), 2000 (33 Mt), 1995 (−32 Mt), 2001 (+32 Mt), and 1992 (+31 Mt) (Figure 9-2). They largely derive from the correction of errors in the estimation of the area of managed forests in northern Canada (Stinson et al. 2006); recalibration of decay rates for selected DOM pools (Shaw et al. unpubl 2007; Smyth et al. 2007) and of fire disturbance matrices (De Groot et al. 2007); modification of the base carbon transfer rate between the above-ground and below-ground slow DOM pools (Shaw et al. unpubl. 2007); improved spatial attribution of fire events; and improvements in the parameters of stand volume to biomass equations. These changes, while explicitly documented in internal reports, cannot always be isolated and their individual effect tracked separately in the complex carbon modelling framework.

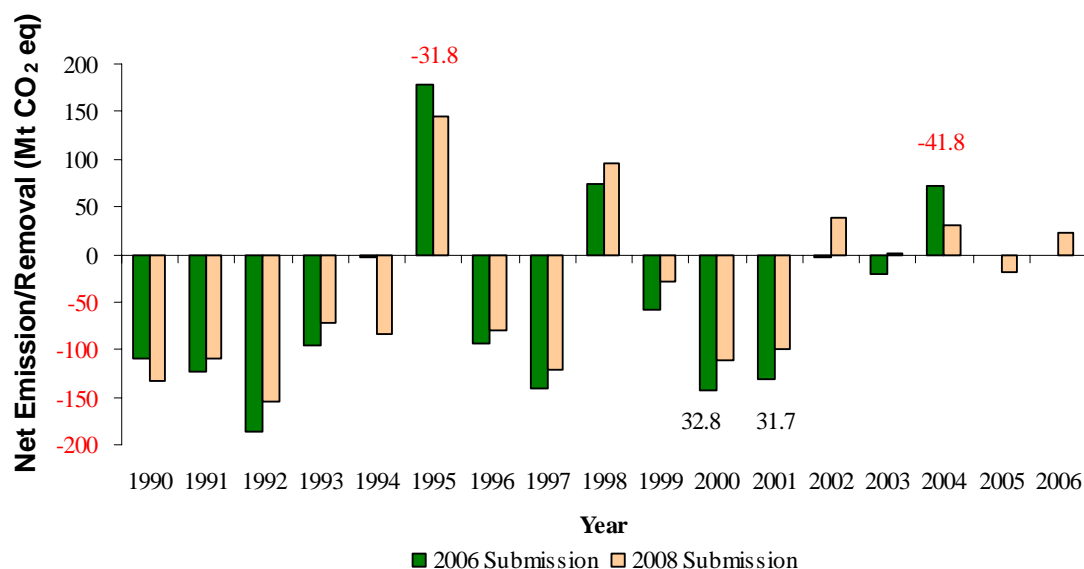


Figure 9-2: Trends in the Managed Forest Land Category, 2006 and 2008 submissions

The most obvious change is a downward correction of 25 Mha in the area of managed forests. In this submission, the area of managed forests in 1990 was 230 682 kha, compared with 255 477 kha in the 2006 submission (Table 9-3).

Table 9-3: Estimate of Managed Forest Area for inventory year 1990

Reporting Zone	2006 Submission (kha)	2008 Submission (kha)
4 - Taiga Shield East	4 741	1 103
5 - Boreal Shield East	56 474	55 692
6 - Atlantic Maritime	15 839	15 945
7 - Mixedwood Plains	2 677	2 742
8 - Hudson Plains		302
9 - Boreal Shield West	28 795	28 795
10 - Boreal Plains	36 595	36 531
11 - Subhumid prairies	1 890	1 890
12 - Semiarid Prairies		27
13 - Taiga Plain	29 062	20 051
14 - Montane Cordillera	37 930	35 500
15 - Pacific Maritime	14 914	13 240
16 - Boreal Cordillera	18 761	16 623
17 - Taiga Cordillera	904	412
18 - Taiga Shield West	6 897	1 830
Total	255 477	230 682

The most significant corrections to managed forest areas affect reporting zone (RZ)13 (Taiga Plain 9 Mha); RZ 18 (Taiga Shield West 5 Mha); RZ 4 (Taiga Shield East 3.6 Mha); RZ 14 (Montane Cordillera 2.4 Mha); RZ 16 (Boreal Cordillera 2.1Mha); RZ 15 (Pacific Maritime 1.7 Mha); and RZ 5 (Boreal Shield East 0.8 Mha).

The deletion of large forest tracts in some reporting zones affected the forests' average net primary productivity, notably in the Taiga Shield, East and West (Table 9-4).

**Table 9-4: Average Net Forest Primary Productivity in the 2006 and 2008 Submissions**

Reporting Zone	2006 Submission (tC/ha per year)	2008 Submission (tC/ha per year)
6 - Atlantic Maritime	3.44	3.35
16 - Boreal Cordillera	3.61	3.52
10 - Boreal Plains	3.77	3.57
5 - Boreal Shield East	3.08	3.19
9 - Boreal Shield West	2.20	2.40
8 - Hudson Plains	-	2.56
7 - Mixedwood Plains	3.90	4.06
14 - Montane Cordillera	4.37	4.18
15 - Pacific Maritime	6.98	6.89
11 - Subhumid Prairies	-	2.64
12 - Semiarid Prairies	3.13	3.38
17 - Taiga Cordillera	2.76	2.95
13 - Taiga Plains	2.37	2.57
4 - Taiga Shield East	2.04	2.48
18 - Taiga Shield West	1.27	1.91

A smaller area of managed forests resulted in reduced carbon removals throughout the period; more importantly, this led to considerable changes in the area of managed forests burned by wildfires in certain years, notably in 1994, 1995, 1998, and 2004 (Table 9-5). Consequently, immediate emissions from wildfires decreased substantially between the 2006 and 2008 submissions (Table 9-5), especially in inventory years 1994 (−100 Mt), 1995 (−51 Mt), and 2004 (−22 Mt).

Significantly smaller areas (by 145–855 kha) were also affected by insect epidemics, although the immediate impact is negligible. The recalibration of decay rates in fresh and humified litter to lower values and the reduced transfer rates of decayed carbon below-ground as dissolved carbon both contributed to greater accumulation of above-ground dead organic matter (DOM) fuel. This explains a 19% increase in average carbon emission rates during fires—partially offset in years when areas burned were revised downwards. Immediate emissions in CO<sub>2</sub> eq from wildfires have decreased by up to 53% (in 1994); in other years, these emissions have increased by up to 22% (in 2004).

Finally, a reduction in soil emissions accounts for lower residual emissions overall, although it is offset by smaller net removals in the biomass pool.

**Table 9-5: Areas of managed forest burned, with immediate emissions, 2006 and 2008 submissions**

Inventory Year	2006 Submission		2008 Submission	
	ha	Mt CO <sub>2</sub> eq	ha	Mt CO <sub>2</sub> eq
1990	350 880	46 802	268 155	40 821
1991	656 766	71 431	543 617	62 334
1992	123 004	14 455	94 623	14 188
1993	979 005	96 650	766 821	88 680
1994	1 808 272	182 875	514 820	85 700
1995	3 208 936	342 280	2 178 085	290 101
1996	698 715	64 301	530 842	58 426
1997	201 833	19 284	148 056	16 852
1998	1 920 782	224 423	1 501 440	225 667
1999	790 817	89 351	637 890	89 444
2000	192 980	18 163	92 280	11 001
2001	231 645	32 803	191 268	36 283
2002	1 183 211	140 341	1 173 604	167 170
2003	781 522	115 675	754 651	136 012
2004	1 216 888	195 015	748 325	152 666
2005			636 432	74 467
2006			647 500	105 205

### 9.6.2 Cropland

There were no changes in methodologies or factors associated with emission/removal estimates related to land management changes in cropland. However, the area of cropland subject to specific changes in management practices was affected, because the rules for allocating the afforested and deforested land were changed (see below). This change resulted in a reduction of sinks by 1.2 Mt in 1990 and by 0.8 Mt in 2005.

Afforestation activities were allocated to Soil Landscapes of Canada (SLC) polygons which showed a net decrease in agricultural land area between census periods. This differed from previous inventories in which afforestation was assumed to be associated with a decrease in land under annual crop production. This change reflected the limited knowledge of previous cropping activities (annual or perennial) on afforested land and built on the assumption that afforestation events at least partially account for net losses in agricultural land.

The changes to the integration of deforestation data only impacted the way deforested land was allocated in western Canada. In previous inventories all deforested land was initially allocated to annual crop production and then transferred to perennial crops. In this submission, the area of deforested land in western Canada was directly added to the area of perennial crops, where a net increase in perennial cropland area was observed between census periods. The impact of these changes resulted in a decreased source of residual emissions by approximately 0.7 Mt in 1990 and 0.8 Mt in 2005.

### 9.6.3 Wetlands

As a result of recalculations in this category the 1990–2004 downward emission trends was reduced from 79% (2006 submission) to 51% (2008 submission). This is largely due to

corrections in the reporting year of the impoundment of large reservoirs (see below). No changes were implemented to the approach or emission factors.

#### Peatlands

The recalculations of area cleared annually have been conducted based on expert input from the industry and updates in the deforested areas. The 2004 CO<sub>2</sub> emission estimates from all managed peatlands were revised upwards from 0.3 Mt to 0.5 Mt.

#### Flooded Land

Recalculations have occurred in this category as a result of methodological refinements, corrections to activity data, new events, and improved data reconciliation.

Emissions from the long-term decay of non-flooded DOM are now reported in the category land converted to wetlands for the first 10 years, and in the category wetlands remaining wetlands beyond this period.

- In the 2006 submission, the area of the Laforge 1 reservoir (flooding completed in 1995) was underestimated by 600 km<sup>2</sup>. This partially explains a large increase in the area of other land converted to wetlands/flooded land in 1995 and beyond (it did not affect the area of forest land converted to wetland, which was obtained from records). Flooding in La Forge 2 was mistakenly attributed to 1997 in the 2006 submission, whereas in reality the flooding was complete in 1985, although power generation began more than a decade later. This is reflected in a large decrease in the land area converted to flooded land and associated emissions in 1997 and subsequent years.
- New events include the flooding of the Toulmoustou and Eastmain-1 reservoirs (flooding was completed in 2006); these two reservoirs add an additional 61 000 ha to the total area of flooded land estimates.

Improved data integration allowed to eliminate double-counting.

These revisions combined resulted in a reduction of 1.5 Mt CO<sub>2</sub> in 1990 emissions, and increases of 0.7 Mt in 2004. The downward emission trend for flooded land was reduced from 85% (2006 submission) to 61% (2008 submission).

### 9.6.4 Forest Land Conversion

Several incremental enhancements, changes, and corrections were implemented for forest conversion that triggered recalculations of the entire time series (Table 9-6).



**Table 9-6: Emissions from Deforestation, 2006 and 2008 submissions**

Inventory Year	Deforestation Emissions (Mt CO <sub>2</sub> eq)	
	2006 Submission	2008 Submission
1990	27.3	25.7
1991	26.1	24.2
1992	24.1	22.8
1993	22.8	21.2
1994	20.9	19.3
1995	20.1	18.7
1996	19.8	18.1
1997	20.0	17.8
1998	19.5	17.8
1999	19.4	18.1
2000	18.6	17.0
2001	17.3	16.4
2002	17.1	16.7
2003	16.6	17.0
2004	16.4	17.0
2005	-	16.9
2006	-	16.3

Years with significant recalculations were 1997 (-2.2Mt), 1991 (-1.9Mt), 1998 and 1996 (-1.7 Mt), and 1994 (-1.6Mt). These changes are due to refinements in the estimation of forest land conversion to cropland, and changes in flooding dates for the large hydro reservoir La Forge 2. Revised estimates of conversion to cropland were a result of modifications in the deforestation strata to improve scaling up of samples within strata units. In addition, new sampling provided better estimates for reporting zones 6, 5, 9, 10, 11, and 12. In total, these changes reduced the estimate of conversion of forest land to cropland by approximately 3 kha annually over the entire 1990–2006 time series.

### **9.7 Recalculations – Waste Sector**

Updates to the provincial CH<sub>4</sub> generation rate constants, used in the Scholl Canyon model to estimate the CH<sub>4</sub> generation rate from municipal solid waste (MSW) landfills, resulted in an overall downward shift in emissions for this subsector across the time series, ranging from 4% to 6% compared with values in the 2006 resubmission. CH<sub>4</sub> density used for the conversion of captured MSW landfill gas volumes to mass units over the period 1990–1996 was corrected, resulting in a slight increase in the CH<sub>4</sub> emissions over those years. MSW landfilled waste quantities were updated from the most current issue of the biennial waste management report from Statistics Canada (2000, 2003, 2004, 2007a) resulting in a recalculation of CH<sub>4</sub> emissions for the years 2002, 2003, and 2004. A correction of the wood waste landfill emission model resulted in the appropriate distribution of CH<sub>4</sub> emissions from the provinces for the complete time series; however, this change did not require a recalculation of the national estimates.

A slight increase in N<sub>2</sub>O emissions from the municipal wastewater handling subsector, over the complete time series, had resulted from the use of 2006 protein consumption per capita data for

Canada, which included data revisions for earlier years (Statistics Canada 2007c). The percent difference in emissions varied from 0.02% to 0.95% for this category from 1990 to 2004.

MSW incineration saw slight increases in CO<sub>2</sub> and CH<sub>4</sub> emissions for 2003 and 2004 compared with the 2006 resubmission. This was due to updated population data used to extrapolate quantities of MSW incinerated for these two years.

Finally, minor recalculations of the CH<sub>4</sub> emissions from MSW landfills and municipal wastewater handling and N<sub>2</sub>O emissions from municipal wastewater handling were due to the updated population statistics generated by Statistics Canada (2006, 2007c).

### ***9.8 Planned Improvements***

The following is a discussion of planned improvement activities that are based on recommendations from both internal sources and external review processes such as the UNFCCC expert review teams' (ERT) annual reports, and collaboration with industry, other government departments, academia, and inventory sector experts. During the most recent in-country review, the ERT formulated a number of recommendations relating to the completeness and transparency of Canada's initial report and inventory submission. The key recommendations (reproduced below) are that Canada:

- (a) Expedite work on establishing a fully operational national registry in accordance with the requirements defined by decisions 13/CMP.1 and 5/CMP.1 and provide detailed information on the implementation of these activities in its next inventory submission under the Kyoto Protocol;
- (b) Allocate sufficient resources to its inventory preparation in order to maintain and improve the quality of its GHG inventory;
- (c) Improve the exchange of data between different governmental and nongovernmental institutions involved in the inventory preparation;
- (d) Further develop the mandatory facility reporting programme in order to improve and expand the use of emission data from the industry;
- (e) Develop a tier 2 key category analysis;
- (f) Update the uncertainty analyses more regularly and develop in-house expertise on uncertainty;
- (g) Include the LULUCF sector in its uncertainty analysis;
- (h) Further develop the improvement plan in order to better link QA/QC findings, uncertainty and key category analyses, and new scientific knowledge;
- (i) Finalize the implementation of Tier 2 category-specific and peer review procedures and consider conducting category-specific QA/QC activities more frequently than over a seven-year cycle;
- (j) Improve the description of methodologies in the NIR as far as possible;

- (k) Improve the consistency between the NIR and the CRF;
- (l) Improve the completeness of the inventory by including estimates in its next inventory submission for all identified categories for which emissions occur in the country.

As part of Canada's National System, improvement activities and work plans are developed on a continuous basis to further refine and increase the transparency, completeness, accuracy, consistency, and comparability of the Canadian GHG inventory. Improvement activities are developed by sector experts and prioritized by a Prioritization and Planning Committee (P&PC) using key category contributions, QA/QC activities, uncertainty assessments, resource availability and potential impacts as primary considerations. While Canada takes the ERT recommendations seriously, given time and resource constraints, the P&PC will prioritize and approve all proposed planned improvements achievable over the next few years. Specific planned improvements include the following:

### **9.8.1 National System**

Canada considers the GHG National Inventory Program a priority and the Department of the Environment is committed to ensuring adequate funding

### **9.8.2 National Registry**

Canada awarded Perrin Quarles Associates a contract to establish the national registry on 14 February 2008. Furthermore, VPN (virtual private network) connectivity testing was successfully completed on 23 January 2008; initialization with the International Transaction Log (ITL) is expected to be completed by the end of May 2008; and it is expected that the national registry will begin live operations with the ITL by mid July 2008. Additional information will be provided subsequent to this report when it becomes available.

### **9.8.3 Mandatory Facility Level Reporting**

As part of Canada's plan to regulate GHGs and air pollutants, additional work is now underway to develop an integrated data collection system for GHGs and air pollutants that should help to improve the usefulness of the mandatory facility level data in the National Inventory.

### **9.8.4 Quality Assurance/Quality Control**

Canada plans to continue its implementation of its QA/QC plan, described in Annex 6, with a focus on performing more comprehensive assessments using category-specific QC, QA and verification. Canada also aims to improve QA/QC processes as they relate to external partners (i.e., within the LULUCF sector and with Statistics Canada) and to encourage a greater depth of provincial collaboration through enhanced working relationships.

### **9.8.5 Uncertainties**

Planned improvements for uncertainty include the development of a program that will ensure Canada's ability to provide an uncertainty assessment on an annual basis. While the details of the program have not been finalized at the time of this publication, Canada will most likely build on previous methods and databases, including making use of the Monte Carlo simulation data and methods developed in 2004–05, i.e., those that are still relevant.

### 9.8.6 Key Categories

Improvement plans also include the development of an IPCC good practice guidance (IPCC 2000) Tier 2 key category analysis model based on uncertainty analysis results.

### 9.8.7 Energy Sector

#### 9.8.7.1 *Stationary Fossil Fuel Combustion*

The most significant planned improvement for the stationary fossil fuel combustion sector involves a detailed review of Canadian coal composition used in the electric power generation sector for the entire time series in order to increase the accuracy of coal emission factors. The use of waste fuels for energy production will also be studied. Technical improvements to the database model will also continue to increase the quality of the estimates and reduce potential errors in calculations and transcription. Increased communication and discussion with industry are planned to facilitate a cohesive approach to emission estimates to ensure accuracy, transparency, and consistency.

#### 9.8.7.2 *Transport*

The transportation model (MGEM) was upgraded between 2006 and 2008 and continuously evolves to take advantage of the power of the relational database to accommodate an increasing number of higher-resolution data sets being made available through partnerships and reporting.

Future improvements will concentrate on:

- developing a Tier 3a model to estimate aircraft emissions based on origin–destination data and aircraft-specific emission factors; the new aviation model will allow a more accurate disaggregation of emissions between civil aviation (domestic aviation) and aviation bunkers (international aviation);
- developing region- and time-specific fuel carbon characteristics; and
- acquiring historic biodiesel consumption data.

### 9.8.8 Industrial Processes Sector

Building upon improvements achieved in the methodology and the activity data, as reflected in the 2006 resubmission and the 2008 submission, future improvements planned for the Industrial Processes Sector include:

- updating of the uncertainty estimates for various categories (last uncertainty estimates for the sector were developed for the 2001 inventory);
- undertaking a study on potential CH<sub>4</sub> emissions from sources in the Industrial Processes Sector;
- separation of the emission estimates for petrochemical production from the category of Other and Undifferentiated Production;
- conducting a new survey to update activity data related to the consumption of PFCs;
- exploring the possibility of acquiring country-specific emission rates for the category of HFC consumption; and

- implementing a Tier 3 methodology for SF<sub>6</sub> emissions from electrical equipment and collection of SF<sub>6</sub> data directly from electric utilities.

For more detailed information on future improvements, please see Chapter 4.

### **9.8.9 Agriculture Sector**

In the current method for estimating CH<sub>4</sub> emissions, the digestible energy (DE) for beef and dairy cattle is assumed to be static over time, based on 2001 feed rations. Data on changes in feed ration digestibility over time are being investigated to assess the sensitivity of CH<sub>4</sub> emissions. In addition, work is being planned to potentially update CH<sub>4</sub>-producing potentials for various manure types.

For N<sub>2</sub>O soil emissions, the effects of soil texture and mineralization of soil organic matter influenced by management practices will be assessed. Supplementary efforts will be put into improving the transparency of documentation, including the publication of empirical data.

### **9.8.10 Land Use, Land-Use Change and Forestry Sector**

Canada has adopted an incremental approach to the implementation of its monitoring, accounting, and reporting system (MARS) for LULUCF, and each inventory submission incorporates improvements as they become available, rather than all at once. Work is continuing, through the MARS, to develop a land-use information system consistent with land reporting requirements described in the IPCC good practice guidance for LULUCF (IPCC 2003), and in particular through practical methods to translate land cover information into land use, permitting an increased use of remotely sensed data. Work is in progress to further improve data infrastructure. Targeted areas for improvements also include uncertainty analysis for the Forest Land category and other categories, additional documented QA/QC procedures, increased transparency, and the publication of peer-reviewed reports.

### **9.8.11 Waste Sector**

In addition to the production of the biennial report on the status of landfill gas collection and utilization in Canada, the Waste Sector is considering the following planned improvements:

- a review of the methodology and an update of the activity data for Canadian saw mill and pulp and paper industry wood waste landfills;
- a gap analysis of the most recent data obtained from a biennial Environment Canada survey of water use and wastewater treatment in Canada with the aim of better addressing inventory needs and compiling activity data from waste incinerators for the 1990 to 2005 time period.

## References

### Executive Summary

---

[IPCC] Intergovernmental Panel on Climate Change. 2000. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change, National Greenhouse Gas Inventories Programme. Available online at <http://www.ipcc-nggip.iges.or.jp/public/gp/english/>

[IPCC] Intergovernmental Panel on Climate Change. 2003. Good Practice Guidance for Land Use, Land-Use Change and Forestry. Intergovernmental Panel on Climate Change, National Greenhouse Gas Inventories Programme. Available online at <http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf.htm>

[IPCC/OECD/IEA]. Intergovernmental Panel on Climate Change / Organisation for Economic Co-operation and Development / International Energy Agency. 1997. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Available online at <http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm>.

McCann T.J. 1997. Fossil Fuel Energy Trade & Greenhouse Gas Emissions. Unpublished report prepared by T.J. McCann and Associates for Environment Canada, Ottawa.

Neitzert F, Olsen K, Collas P. 1999. Canada's Greenhouse Gas Inventory—1997 Emissions and Removals with Trends. Ottawa: Environment Canada.

[NRCan] Natural Resources Canada. 2005. Energy Efficiency Trends in Canada, 1990 to 2003. Ottawa: Office of Energy Efficiency, Natural Resources Canada. #M141-1/2003.

Nyboer J, Tu K. 2006. GHG Emission Trend Analysis in the Fossil Fuel Production Industries. Draft report. Burnaby (B.C.): Canadian Industrial Energy End-Use Data and Analysis Centre, Simon Fraser University.

Nyboer J, Tu K. 2008. GHG Emission Trend Analysis in the Fossil Fuel Production Industries: 2008 update. Burnaby (B.C.): Canadian Industrial Energy End-Use Data and Analysis Centre, Simon Fraser University.

Statistics Canada. Demographic Statistics, 1990–2008 (Annual). #91-213-XIB.

Statistics Canada. Report on Energy Supply–Demand in Canada (Annual). 1991–2008. #57-003-XIB.

[UNFCCC] United Nations Framework Convention on Climate Change. 2006. National Greenhouse Gas Inventory Data for the Period 1990–2004 and Status of Reporting. October. FCCC/SBI/2006/26. Available online at: <http://unfccc.int/resource/docs/2006/sbi/eng/26.pdf>

## Chapter 1, Introduction

---

- Canada. 1999. Canadian Environmental Protection Act (CEPA), 1999. Available online at [http://www.ec.gc.ca/CEPARRegistry/the\\_act/](http://www.ec.gc.ca/CEPARRegistry/the_act/).
- ICF Consulting. 2004. Quantitative Assessment of Uncertainty in Canada's National GHG Inventory Estimates for 2001. Unpublished report submitted to Environment Canada. Contract # K-2362-3-0060.
- ICF Consulting. 2005. Quantitative Assessment of Uncertainty in Canada's National GHG Inventory Estimates for 2001—Supplementary Analysis. Final Report. March.
- [IPCC] Intergovernmental Panel on Climate Change. 1995. The Science of Climate Change. Contribution of Working Group 1 to the Second Assessment of the Intergovernmental Panel on Climate Change. Cambridge, U.K.: Cambridge University Press.
- [IPCC] Intergovernmental Panel on Climate Change. 1996. Summary for Policy Makers—IPCC Working Group 1. Available online at <http://www.ipcc.ch/pdf/climate-changes-1995/spm-science-of-climate-changes.pdf>
- [IPCC] Intergovernmental Panel on Climate Change. 2000. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at <http://www.ipcc-nggip.iges.or.jp/public/gp/english/>
- [IPCC] Intergovernmental Panel on Climate Change. 2003. Good Practice Guidance for Land Use, Land-Use Change and Forestry. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at <http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf.htm>
- [IPCC] Intergovernmental Panel on Climate Change. 2007a. Climate Change 2007: The Physical Science Basis, Contribution of Working Group 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge (UK): Cambridge University Press. Available online at <http://www.ipcc.ch/ipccreports/ar4-wg1.htm>
- [IPCC] Intergovernmental Panel on Climate Change. 2007b. Climate Change 2007: Synthesis Report Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A.(eds.)]. Geneva, Switzerland. Available online at [http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4\\_syr.pdf](http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf)
- [IPCC/OECD/IEA] Intergovernmental Panel on Climate Change, Organisation for Economic Co-operation and Development / International Energy Agency. 1997. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Available online at <http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm>
- [UNFCCC] United Nations Framework Convention on Climate Change. 2007. National Greenhouse Gas Inventory Data for the Period 1990–2005. October. FCCC/SBI/2006/26. Available online at [http://unfccc.int/ghg\\_emissions\\_data/ghg\\_data\\_from\\_unfccc/time\\_series\\_annex\\_i/items/3841.php](http://unfccc.int/ghg_emissions_data/ghg_data_from_unfccc/time_series_annex_i/items/3841.php)

## REFERENCES

[WMO] World Meteorological Organization. 2007. Greenhouse Gas Bulletin: The State of Greenhouse Gases in the Atmosphere Using Global Observations through 2005. November. No. 2:1.

### **Chapter 2, Greenhouse Gas Emission Trends, 1990–2006**

---

Cheminfo Services. 2006. Improvements and Updates to Certain Industrial Process and Solvent Use-Related Sections in Canada's Greenhouse Gas Inventory. Final Report. Cheminfo Services, Markham, Ontario, Canada. September.

Environment Canada. 2007. An Inventory of Landfill Gas Recovery and Utilization in Canada 2005. Unpublished report prepared by the Greenhouse Gas Division of Environment Canada with the support of the University of Manitoba.

IPCC [Intergovernmental Panel on Climate Change]. 2003. Good Practice Guidance for Land Use, Land-Use Change and Forestry. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at <http://www.ipcc-nggip.iges.or.jp/public/gpoglulucf/gpoglulucf.htm>

[NRCAN] Natural Resources Canada. 2005. Energy Efficiency Trends in Canada, 1990 to 2003. Office of Energy Efficiency, Natural Resources Canada. Ottawa, Ontario, Canada. #M141-1/2003.

[NRCAN] Natural Resources Canada. 2005. Canadian Minerals Yearbook (section on Magnesium Production), 1990–2005 (Annual). Minerals and Metals Sector, Natural Resources Canada. Available online at [http://www.nrcan.gc.ca/mms/cmy/pref\\_e.htm](http://www.nrcan.gc.ca/mms/cmy/pref_e.htm)

[NRCAN] Natural Resources Canada. 2006. Canadian Minerals Yearbook (section on Cement Production), 1990–2006 (Annual). Minerals and Metals Sector, Natural Resources Canada. Available online at [http://www.nrcan.gc.ca/mms/cmy/pref\\_e.htm](http://www.nrcan.gc.ca/mms/cmy/pref_e.htm)

Ontario Ministry of the Environment. 2006. Background: The Ontario/Michigan Waste Issue. Available online at <http://www.ene.gov.on.ca/envision/news/2006/083101mb.pdf>

Statistics Canada. 2000, 2003, 2004, 2007. Waste Management Industry Survey: Business and Government Sectors. System of National Accounts, Statistics Canada. #16F0023XIE. Available online at <http://www.statcan.ca/bsolc/english/bsolc?catno=16F0023X&CHROPG=1>

Statistics Canada. 2005. Report on Energy Supply–Demand in Canada (Annual). #57-003-XIB

Statistics Canada. 2007. 2006 Census, Release no. 3, September 12, 2007 – Housing and shelter costs (including dwelling characteristics). Available online at [http://www12.statcan.ca/english/census06/release/release\\_housingshelter.cfm](http://www12.statcan.ca/english/census06/release/release_housingshelter.cfm)

Statistics Canada. Energy Statistics Handbook, #57-601-X.

Statistics Canada. Report on Energy Supply-Demand in Canada, #57-003



### Chapter 3, Energy

---

Alberta Energy and Utilities Board. ST-43: Mineable Alberta Oil Sands Annual Statistics. Available online at [http://www.ercb.ca/portal/server.pt/gateway/PTARGS\\_0\\_0\\_308\\_0\\_0\\_43/http%3B/ercbContent/publishedcontent/publish/ercb\\_home/publications\\_catalogue/publications\\_available/serial\\_publications/st43.aspx](http://www.ercb.ca/portal/server.pt/gateway/PTARGS_0_0_308_0_0_43/http%3B/ercbContent/publishedcontent/publish/ercb_home/publications_catalogue/publications_available/serial_publications/st43.aspx)

Canadian Facts. 1997. Residential Fuelwood Combustion in Canada. Canadian Facts. Prepared for the National Emission Inventory and Project Task Group. Toronto (ON): CF Group Inc. April.

Canadian Gas Association. 1997. 1995 Air Inventory of the Canadian Natural Gas Industry. Calgary (AB): Radian International LLC.

[CAPP] Canadian Association of Petroleum Producers. 1999. CH<sub>4</sub> and VOC Emissions from the Canadian Upstream Oil and Gas Industry, Vols. 1 and 2. Prepared for the Canadian Association of Petroleum Producers. Calgary (AB): Clearstone Engineering Ltd. Canada. Publication No. 1999-0010.

[CAPP] Canadian Association of Petroleum Producers. 2005a. A National Inventory of Greenhouse Gas (GHG), Criteria Air Contaminant (CAC) and Hydrogen Sulphide (H<sub>2</sub>S) Emissions by the Upstream Oil and Gas Industry, Vols. 1–5. Calgary (AB): Clearstone Engineering Ltd. January.

[CAPP] Canadian Association of Petroleum Producers. 2005b. Extrapolation of the 2000 UOG Emission Inventory to 2001, 2002 and 2003. Prepared for the Canadian Association of Petroleum Producers. Calgary (AB): Clearstone Engineering Ltd.

[CAPP] Canadian Association of Petroleum Producers. 2006. An Inventory of GHGs, CACs, and H<sub>2</sub>S Emissions by the Canadian Bitumen Industry: 1990 to 2003. Prepared for the Canadian Association of Petroleum Producers. Calgary (AB): Clearstone Engineering Ltd.

[CPPI] Canadian Petroleum Products Institute. 2004. Economic and Environmental Impacts of Removing Sulphur from Canadian Gasoline and Distillate Production. Prepared for the Canadian Petroleum Products Institute. Calgary (AB): Levelton Consultants Ltd. in association with Purvin & Gertz Inc. August.

Environment Canada. 1999. CAC Division 1995 Criteria Contaminants Emissions Inventory Guidebook, Version 1, Section 2.4. Ottawa (ON): National Emissions Inventory and Projections Task Group, Environment Canada. March.

Environment Canada. 2007. Bitumen-Oil Sands Extrapolation Model – Rev 3. Calgary (AB): Clearstone Engineering Ltd.

[EPA]. U.S. Environmental Protection Agency. 1995a. Compilation of Air Pollutant Emission Factors. Vol. I: Stationary Point and Area Sources, AP 42. 5th Edition. Available through National Technical Information Services, Springfield, Virginia, U.S.A. Publication No. PB95-196028.

## REFERENCES

- [EPA] U.S. Environmental Protection Agency. 1995b. Protocol for Equipment Leak Emission Estimates, Emission Standards Division. Washington (DC): U.S. Environmental Protection Agency. Report No. EPA-453-R-95-017.
- [EPA] U.S. Environmental Protection Agency. 1996. Compilation of Air Pollutant Emission Factors—Vol. I: Stationary Point and Area Sources, AP 42. 5th Edition, Supplement B. Washington (DC): U.S. Environmental Protection Agency. January.
- ICF Consulting. 2004. Quantitative Assessment of Uncertainty in Canada's National GHG Inventory Estimates for 2001. Final report submitted to the Greenhouse Gas Division, Environment Canada by ICF Consulting. September.
- [IPCC] Intergovernmental Panel on Climate Change. 2000. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at <http://www.ipcc-nggip.iges.or.jp/public/gp/english/>.
- [IPCC/OECD/IEA] Intergovernmental Panel on Climate Change / Organisation for Economic Co-operation and Development / International Energy Agency. 1997. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Available online at <http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm>.
- Jaques AP. 1992. Canada's Greenhouse Gas Emissions: Estimates for 1990. Environmental Protection, Conservation and Protection, Environment Canada. Report No. EPS 5/AP/4.
- King B. 1994. Management of Methane Emissions from Coal Mines: Environmental, Engineering, Economic and Institutional Implications of Options. Report prepared for Environment Canada by Neill and Gunter Ltd.
- McCann TJ. 1997. Fossil Fuel Energy Trade & Greenhouse Gas Emissions. Unpublished report. Prepared by T.J. McCann and Associates for Environment Canada.
- McCann TJ. 2000. 1998 Fossil Fuel and Derivative Factors. Report prepared by T.J. McCann and Associates for Environment Canada.
- National Energy Board. Estimated Production of Canadian Crude Oil and Equivalent. 1998–2008. Available online at <http://www.neb.gc.ca/clf-nsi/rnrgynfmetn/sttstc/crdlndptlmpdct/stmtdprdctn-eng.html>
- ORTECH Corporation. 1994. Inventory Methods Manual for Estimating Canadian Emissions of Greenhouse Gases. Unpublished report prepared for the Regulatory Affairs and Program Integration Branch, Conservation and Protection, Environment Canada. Report No. 93-T61-P7013-FG.
- Radke LF, Hegg DA, Hobbs PV, Nance JD, Lyons JH, Laursen KK, Weiss RE, Riggan PJ, Ward DE. 1991. Particulate and trace gas emissions from large biomass fires in North America. In: J.S. Levine (Ed.) *Global Biomass Burning: Atmospheric Climatic and Biospheric Implications*. Cambridge (MA): Massachusetts Institute of Technology.
- Rosland A, Steen M. 1990. Klimgass-Regnshap for Norge, Statens Forurensningstilsyn. Oslo, Norway.

SGA Energy Ltd. 2000. Emission Factors and Uncertainties for CH<sub>4</sub> & N<sub>2</sub>O from Fuel Combustion. Unpublished report prepared for the Greenhouse Gas Division, Environment Canada by SGA Energy Ltd.

Statistics Canada. Natural Gas Transportation and Distribution (Annual). #57-205-XIB.

Statistics Canada. Report on Energy Supply–Demand in Canada (Annual). #57-003-XIB.

Statistics Canada. 1995. Household Facilities and Equipment, Household Surveys Division. Statistics Canada. #64-202 (discontinued).

#### **Chapter 4, Industrial Processes**

---

[AAC] Aluminum Association of Canada. 2002a. Framework Agreement on Voluntary Greenhouse Gas Reductions in Québec entered into between the Government of Québec and the Aluminium Association of Canada. Montréal (QC) :Government of Québec and AAC. January.

[AAC] Aluminum Association of Canada. 2002b. Calculating Direct GHG Emissions from Primary Aluminium Metal Production. Prepared by Alcan, obtained from Aluminum Association of Canada (AAC), Montréal (QC).

[AIA] Association de l'Industrie d'Aluminium du Québec. 1993. The Aluminium Industry Today for the Needs of Tomorrow. Québec, Montréal (QC).

AMEC. 2006. Identifying and Updating Industrial Process Activity Data in the Minerals Sector for the Canadian Greenhouse Gas Inventory. AMEC Earth & Environmental, a division of AMEC Americas Ltd. March.

Cheminfo Services. 2002. Review of Canadian SF<sub>6</sub> Emissions Inventory. Markham (ON): Cheminfo Services Inc. September.

Cheminfo Services. 2005a. Improving and Updating Industrial Process-Related Activity Data and Methodologies in Canada's Greenhouse Gas Inventory, Sulphur Hexafluoride (SF<sub>6</sub>) from Electrical Equipment. Final Report. Markham (ON): Cheminfo Services Inc. March.

Cheminfo Services. 2005b. Improving and Updating Industrial Process-Related Activity Data and Methodologies Used in Canada's Greenhouse Gas Inventory, Sulphur Hexafluoride Emissions from the Magnesium Casting Sector. Final Report. Markham (ON): Cheminfo Services Inc. March.

Cheminfo Services. 2005c. Improving and Updating Industrial Process-Related Activity Data and Methodologies Used in Canada's Greenhouse Gas Inventory, Hydrofluorocarbons (HFCs). Final Report. Markham (ON): Cheminfo Services Inc. March.

Cheminfo Services. 2006. Improvements and Updates to Certain Industrial Process and Solvent Use-Related Sections in Canada's Greenhouse Gas Inventory. Final Report. Markham (ON): Cheminfo Services Inc. September.

[CIEEDAC] Canadian Industrial Energy End-Use Data and Analysis Centre. 2006. A Review of Energy Consumption in Canadian Oil Refineries 1990, 1994 to 2004. Burnaby (BC): Simon Fraser University. March.

## REFERENCES

- [CIEEDAC] Canadian Industrial Energy End-Use Data Analysis Centre. 2007. A Review of Energy Consumption and Related Data: Canadian Cement Manufacturing Industry, 1990 to 2004. Burnaby (BC): Simon Fraser University. January. Available online at <http://www.cieedac.sfu.ca>.
- [GTIS] Global Trade Information Services. 1995–2006. Trade data retrieved October 1, 2007, from the GTIS World Trade Atlas. Global Trade Information Services, Inc. Available online at <http://www.gtis.com>
- [HRAI] Heating, Refrigeration and Air Conditioning Institute of Canada. 2008. HCFC Phase-Out Awareness. Available online at <http://www.hrai.ca/hcfcphaseout/index.html>.
- [IAI] International Aluminium Institute. 2006. The Aluminium Sector Greenhouse Gas Protocol (Addendum to the WRI/WBCSD Greenhouse Gas Protocol), October. Available online at <http://www.world-aluminium.org/?pg=/Downloads/Publications/Full%20Publication&path=344>
- ICF Consulting. 2004. Quantitative Assessment of Uncertainty in Canada's National GHG Inventory Estimates for 2001. Final report. Submitted to the Greenhouse Gas Division, Environment Canada, by ICF Consulting. September.
- [IPCC] Intergovernmental Panel on Climate Change. 2000. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at <http://www.ipcc-nggip.iges.or.jp/public/gp/english/>
- [IPCC] Intergovernmental Panel on Climate Change. 2002. Background Papers – IPCC Expert Meetings on Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (section on HFC-23 Emissions from HCFC-22 Production). Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at <http://www.ipcc-nggip.iges.or.jp/public/gp/gpg-bgp.htm>
- [IPCC] Intergovernmental Panel on Climate Change. 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol. 3, Industrial Processes and Product Use. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at <http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol3.htm>
- [IPCC/OECD/IEA] Intergovernmental Panel on Climate Change / Organisation for Economic Co-operation and Development / International Energy Agency. 1997. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Available online at <http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm>
- Jaques AP. 1992. Canada's Greenhouse Gas Emissions: Estimates for 1990. Environmental Protection, Conservation and Protection, Environment Canada. Report EPS 5/AP/4.
- Laval University. 1994. Polyfluorocarbons and the Environment (Their Effect on Atmospheric Equilibrium). Study prepared by the Analytical Chemistry Group for Environment Canada. Québec (QC): Laval University. March.
- McCann TJ. 2000. 1998 Fossil Fuel and Derivative Factors. Prepared by TJ McCann and Associates for Environment Canada. March.

- Ministry of Energy, Mines and Petroleum Resources. 2006. MINFILE Mineral Inventory. Government of British Columbia. Available online at <http://www.em.gov.bc.ca/Mining/Geolsurv/Minfile>
- Ministry of Northern Development and Mines (1989), Limestone Industries and Resources of Central and Southwestern Ontario – Vol. III, a report prepared for the Aggregate Resources Section, Land Management Branch, Ontario Ministry of Natural Resources.
- [NRCan] Natural Resources Canada. Canadian Minerals Yearbook. 1990–2006 (Annual). Minerals and Metals Sector, Natural Resources Canada. Available online at [http://www.nrcan.gc.ca/mms/cmy/pref\\_e.htm](http://www.nrcan.gc.ca/mms/cmy/pref_e.htm).
- ORTECH Corporation. 1994. Inventory Methods Manual for Estimating Canadian Emissions of Greenhouse Gases. Unpublished report prepared for the Regulatory Affairs and Program Integration Branch, Conservation and Protection, Environment Canada. Report No. 93-T61-P7013-FG.
- Øye HP, Huglen R. 1990. Managing aluminium reduction technology—Extracting the most from Hall-Héroult, *Journal of the Minerals, Metals & Materials Society (JOM)*. 42(11): 23–28.
- SIDEX. 2004. 5th Strategic Diversification Newsletter: Exploration Outlook in Québec for a Neglected Commodity, *Société d'investissement dans la diversification de l'exploration*. March. Available online at <http://www.sidex.ca/Vpub/magnesite/Magnesite-presentation.pdf>.
- Statistics Canada. Canadian International Merchandise Trade Database. Available online at: [www.statcan.ca/trade/scripts/trade\\_search.cgi](http://www.statcan.ca/trade/scripts/trade_search.cgi)
- Statistics Canada. Cement, 1990–2004 (Monthly), #44-001-XIB.
- Statistics Canada. Industrial Chemicals and Synthetic Resins, 1990–2005 (Monthly). #46-002-XIE.
- Statistics Canada. Non-Metallic Mineral Products Industries (Annual). #44-250-XIE (discontinued).
- Statistics Canada. Primary Iron and Steel, 1990–2003 (Monthly). #41-001-XIB.
- Statistics Canada. Report on Energy Supply–Demand in Canada, 1990–2006 (Annual). #57-003-XIB.
- Statistics Canada. Steel, Tubular Products and Steel Wire, 2004–2006 (Monthly). #41-019-XIE.
- Statistics Canada. 2007. CANSIM Database Table 303-0060: Production, Shipments and Stocks of Cement, Monthly (Metric Tonnes) 2005. Available online at <http://cansim2.statcan.ca>.

## **Chapter 5, Solvent and Other Product Use**

---

Cheminfo Services. 2006. Improvements and Updates to Certain Industrial Process and Solvent Use-Related Sections in Canada's Greenhouse Gas Inventory. Final Report. Markham (ON): Cheminfo Services Inc. September.

## REFERENCES

[IPCC] Intergovernmental Panel on Climate Change. 2000. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at <http://www.ipcc-nggip.iges.or.jp/public/gp/english/>

[IPCC/OECD/IEA] Intergovernmental Panel on Climate Change / Organisation for Economic Co-operation and Development / International Energy Agency. 1997. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Available online at <http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm>

Statistics Canada. Canadian International Merchandise Trade Database. Available online at [www.statcan.ca/trade/scripts/trade\\_search.cgi](http://www.statcan.ca/trade/scripts/trade_search.cgi)

Statistics Canada. Demographic Statistics. 1990–2003 (Annual). #91-213-XIB.

Statistics Canada. Demographic Statistics. 2004–2006 (Annual). #91-215-X.

## Chapter 6, Agriculture

---

Beauchemin KA, McGinn SM. 2005. Methane emissions from feedlot cattle fed barley or corn diets. *Journal of Animal Science*. 83(3): 653–661.

Boadi DA, Wittenberg KM. 2002. Methane production from dairy and beef heifers fed forages differing in nutrient density using the sulphur hexafluoride (SF<sub>6</sub>) tracer gas technique. *Canadian Journal of Animal Science*. 82: 201–206.

Boadi DA, Wittenberg KM, Kennedy AD. 2002a. Variation of the sulphur hexafluoride (SF<sub>6</sub>) tracer gas technique for measurement of methane and carbon dioxide production by cattle. *Canadian Journal of Animal Science*. 82: 125–131.

Boadi DA, Wittenberg KM, McCaughey WP. 2002b. Effects of grain supplementation on methane production of grazing steers using the sulphur (SF<sub>6</sub>) tracer gas technique. *Canadian Journal of Animal Science*. 82: 151–157.

Boadi DA, Ominski KH, Fulawka DL, Wittenberg KM. 2004. Improving Estimates of Methane Emissions Associated with Enteric Fermentation of Cattle in Canada by Adopting an IPCC (Intergovernmental Panel on Climate Change) Tier-2 Methodology, Final report submitted to the Greenhouse Gas Division, Environment Canada. Winnipeg (MB): Department of Animal Science, University of Manitoba.

Campbell, CA, Zentner RP, Janzen HH, Bowren KE. 1990. Crop Rotation Studies on the Canadian Prairie. Ottawa (ON): Canadian Government Publishing Centre.

[CANSIM] Canadian Socio-Economic Information Management System [database on the Internet]. Statistics Canada. [updated daily]. Available online at <http://cansim2.statcan.ca/>

Gregorich EG, Rochette P, VandenBygaart AJ, Angers DA. 2005. Greenhouse gas contributions of agricultural soils and potential mitigation practices in eastern Canada, *Soil & Tillage Research*. 83: 53–72.

- Hutchinson JJ, Rochette P, Vergé X, Worth D, Desjardins R. 2007. Uncertainties in Methane and Nitrous Oxide Emissions Estimates from Canadian Agroecosystems Using Crystal Ball. Preliminary report submitted to the Greenhouse Gas Division, Environment Canada, by the Research Branch, Agriculture and Agri-Food Canada.
- ICF Consulting. 2004. Quantitative Assessment of Uncertainty in Canada's National GHG Inventory Estimates for 2001. Final report submitted to the Greenhouse Gas Division, Environment Canada by ICF Consulting. September.
- [IPCC] Intergovernmental Program on Climate Change. 2000. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at <http://www.ipcc-nggip.iges.or.jp/public/gp/english/>
- [IPCC] Intergovernmental Panel on Climate Change. 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol. 4: Agriculture, Forestry and Other Land Use. Intergovernmental Panel on Climate Change. Available online at <http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.htm>
- [IPCC/OECD/IEA] Intergovernmental Panel on Climate Change / Organisation for Economic Co-operation and Development / International Energy Agency. 1997. Revised 1996 IPCC Guidelines for Greenhouse Gas Inventories. Available online at <http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm>
- Jambert C, Delmas R, Serça D, Thouron L, Labroue L, Delprat L. 1997. N<sub>2</sub>O and CH<sub>4</sub> emissions from fertilized agricultural soils in southwest France. *Nutrient Cycling in Agroecosystems*. 48: 105–114.
- Janzen HH, Beauchemin KA, Bruinsma Y, Campbell CA, Desjardins RL, Ellert BH, Smith EG. 2003. The fate of nitrogen in agroecosystems: an illustration using Canadian estimates. *Nutrient Cycling in Agroecosystems*. 67: 85–102.
- Korol M. 2003. Canadian Fertilizer Consumption, Shipments and Trade, 2002/2003. Farm Input Markets Unit, Farm Income and Adaptation Policy Directorate, Agriculture and Agri-Food Canada.
- Liang BC, McConkey BG, Campbell CA, Curtin D, Lafond GP, Brandt SA, Lafond AP. 2004. Total and labile soil organic nitrogen as influenced by crop rotations and tillage in Canadian prairie soils. *Biology and Fertility of Soils*. 39: 249–257.
- Marinier M, Clark K, Wagner-Riddle C. 2004. Improving Estimates of Methane Emissions Associated with Animal Waste Management Systems in Canada by Adopting an IPCC Tier 2 Methodology. Final report submitted to the Greenhouse Gas Division, Environment Canada, by the Department of Land Resource Science. Guelph (ON): University of Guelph
- McCaughy WP, Wittenberg K, Corrigan D. 1997. Methane production by steers on pasture. *Canadian Journal of Animal Science*. 77: 519–524.
- McCaughy WP, Wittenberg K, Corrigan D. 1999. Impact of pasture type on methane production by lactating beef cows. *Canadian Journal of Animal Science*. 79: 221–226.

## REFERENCES

- McConkey BG, Campbell CA, Zentner RP, Dyck FB, Selles F. 1996. Long-term tillage effects on spring wheat production on three soil textures in the Brown soil zone. *Canadian Journal of Plant Science*. 76: 747–756.
- McGinn SM, Beauchemin KA, Coates T, Colombatto D. 2004. Methane emissions from beef cattle: Effects of monensin, sunflower oil, enzymes, yeast, and fumaric acid. *Journal of Animal Science*. 82(11): 3346–3356.
- McGinn SM, Flesch TK, Harper LA, Beauchemin KA. 2006. An approach for measuring methane emissions from whole farms. *Journal of Environmental Quality*. 35(1): 14–20.
- Rochette P, Janzen HH. 2005. Towards a revised coefficient for estimating N<sub>2</sub>O emissions from legumes. *Nutrient Cycling in Agroecosystems*. 73: 171–179.
- Rochette P, Worth DE, Lemke RL, McConkey BG, Pennock DJ, Wagner-Riddle C, Desjardins RL. 2008. An IPCC Tier II methodology for estimating N<sub>2</sub>O emissions from agricultural soils in Canada. *Canadian Journal of Soil Science* (In press)
- Statistics Canada. Farm Environmental Management Survey. Available online at <http://www.statcan.ca/cgi-bin/imdb/p2SV.pl?Function=getSurvey&SDDS=5044&lang=en&db=IMDB&dbf=f&adm=8&dis=2>
- Statistics Canada 2006. 2006 Census of Agriculture [Statistics Canada database]. Available online at: <http://www.statcan.ca/english/agcensus2006/index.htm>
- Statistics Canada 2007a. Agricultural perspectives from seven censuses, Canada and provinces: census years 1976 to 2006. Available online at <http://www.statcan.ca/english/freepub/95-632-XIE/2007000/tables/table2.16-en.htm>
- Statistics Canada. 2007b. Farm Data and Farm Operator Data Tables. #95-629. Available online at <http://www.statcan.ca/english/freepub/95-629-XIE/2007000/livestock.htm#poulinv>
- Statistics Canada. 2008. Alternative Livestock on Canadian Farms, Census years 1981, 1986, 1991, 1996, 2001 and 2006, #23-502-X.

## **Chapter 7, Land Use, Land-Use Change and Forestry**

---

- Bruce JP, Frome M, Haites E, Janzen H, Lal R, Paustian K. 1999. Carbon sequestration in soils. *Journal of Soil Water Conservation*. 54: 382–389.
- Campbell CA, McConkey BG, Zentner RP, Selles F, Curtin D. 1996. Long-term effects of tillage and crop rotations on soil organic C and total N in a clay soil in southwestern Saskatchewan. *Canadian Journal of Soil Science*. 76: 395–401.
- Cleary J. 2003. Greenhouse Gas Emissions from Peat Extraction in Canada: A Life Cycle Perspective. Montréal (QC): M.Sc. Thesis, McGill University. C2GCR Report No. 2003-1.
- Coleman HW, Steele JWG. 1999. Experimentation and Uncertainty Analysis for Engineers. New York (NY): John Wiley and Sons.



- Environment Canada. 2003. Wetlands in Canada. Available online at [http://www.ec.gc.ca/water/en/nature/wetlan/e\\_canada.htm](http://www.ec.gc.ca/water/en/nature/wetlan/e_canada.htm)
- Hélie R, Milton GR, Kazmerik B, Crevier Y, Grenier M, Dixon, Tedford R B, Smith K, Hurley J. 2003. Building Towards A National Wetland Inventory (Phase 1). 25th Canadian Remote Sensing Symposium & 11th Congress of the Association québécoise de télédétection. Montréal (QC): Université de Montréal.
- Hutchinson JJ, Rochette P, Verge X, Desjardins R, Worth D. 2007. Uncertainties in Methane and Nitrous Oxide Emissions Estimates from Canadian Agroecosystems Using Crystal Ball. Preliminary report submitted to the Greenhouse Gas Division, Environment Canada, by the Research Branch, Agriculture and Agri-Food Canada.
- [IPCC] Intergovernmental Panel on Climate Change. 2000. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at <http://www.ipcc-nggip.iges.or.jp/public/gp/english/>
- [IPCC] Intergovernmental Panel on Climate Change. 2003. Good Practice Guidance for Land Use, Land-Use Change and Forestry. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at <http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf.htm>
- [IPCC] Intergovernmental Panel on Climate Change. 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol. 4: Agriculture, Forestry and Other Land Use. Intergovernmental Panel on Climate Change. Available online at <http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.htm>
- Janzen HH, Campbell CA, Gregorich EG, Ellert BH. 1997. Soil carbon dynamics in Canadian agroecosystems, in: Lal R, Kimble JM, Follett RF, Stewart BA (Eds.) *Soil Processes and Carbon Cycles*. Boca Raton, Florida (US): CRC Press, pp. 57–80.
- Janzen HH, Campbell CA, Izaurrealde RC, Ellert BH, Juma N, McGill WB, Zentner RP. 1998. Management effects on soil C storage on the Canadian prairies. *Soil & Tillage Research*. 47: 181–195.
- Leckie D, Paradine D, Burt W, Hardman D, Eichel F, Tinis S, Tammadge D. 2006a. NIR 2007 Deforestation Area Estimation: Methods Summary, Digital Remote Sensing, Deforestation Monitoring Group. Victoria (BC): Canadian Forest Service, Natural Resources Canada.
- Leckie D, Paradine D, Hardman D, Tinis S. 2006b. NIR 2006 Deforestation Area Estimation: Methods Summary. Internal report. Victoria (BC): Canadian Forest Service, Natural Resources Canada. April. 13 p.
- Marshall IB, Shut P. 1999. A National Ecological Framework for Canada, Ecosystems Science Directorate, Environment Canada, and Research Branch, Agriculture and Agri-Food Canada. Available online at <http://sis.agr.gc.ca/cansis/nsdb/ecostrat/intro.html#ecological%20framework>
- McConkey B, Liang BC, Campbell CA, Curtin D, Moulin A, Brandt SA, Lafond GP. 2003. Crop rotation and tillage impact on carbon sequestration in Canadian prairie soils. *Soil & Tillage Research*. 74: 81–90.

## REFERENCES

- McConkey BG, VandenBygaart AJ, Hutchinson J, Huffman T, Martin T. 2007. Uncertainty Analysis for Carbon Change—Cropland Remaining Cropland. Report submitted to Environment Canada by the Research Branch. Agriculture and Agri-Food Canada.
- National Wetlands Working Group. 1997. The Canadian Wetland Classification System. 2nd Edition. Warner BG, Rubec CDA. (Eds.). Waterloo (ON): Wetlands Research Centre, University of Waterloo. Available online at <http://www.portofentry.com/Wetlands.pdf>
- [NRCan] Natural Resources Canada. 2001. Canada's National Forest Inventory. Natural Resources Canada. Available online at [http://nfi.cfs.nrcan.gc.ca/canfi/data/area-large\\_e.html](http://nfi.cfs.nrcan.gc.ca/canfi/data/area-large_e.html)
- [NRCan] Natural Resources Canada. 2005a. Feasibility Assessment of Afforestation for Carbon Sequestration (FAACS) Initiative: Afforestation Policy Analysis. Canadian Forest Service. Available online at <http://cfs.nrcan.gc.ca/subsite/afforestation/feasibilityafforestation>
- [NRCan] Natural Resources Canada. 2005b. Forest 2020 Plantation Demonstration Assessment (PDA): Afforestation Policy Analysis. Canadian Forest Service. Available online at <http://cfs.nrcan.gc.ca/subsite/afforestation/forest2020pda>
- VandenBygaart AJ, Gregorich EG, Angers DA. 2003. Influence of agricultural management on soil organic carbon: A compendium and assessment of Canadian studies. *Canadian Journal of Soil Science*. 83: 363–380.
- VandenBygaart AJ, McConkey BG, Angers DA, Smith W, De Gooijer H, Bentham M, Martin T. 2007. Soil carbon change factors for the Canadian agriculture national greenhouse gas inventory. *Canadian Journal of Soil Science* (under review).
- Waddington JM, Warner KD. 2001. Restoring the carbon sink function of cut-over peatlands. *Écoscience*. 8(3): 359–368.
- White T, Dymond C. 2008. NIR 2007 QAQC report. Internal report. Ottawa(ON): Environment Canada..
- White T, Dymond C. 2008. Summary of methodological changes to LULUCF reporting in the 2008 National Inventory Report 2008. Internal report. Victoria (BC): Canadian Forest Service – Natural Resources Canada.
- White T, Luckai N, Larocque GR, Kurz WA, Smyth C. 2008. A practical Approach for Assessing the Sensitivity of the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3). *Ecological Modelling* (in press).
- White T, Kurz WA. 2005. Afforestation on private land in Canada from 1990 to 2002 estimated from historical records. *The Forestry Chronicle*. 81(4): 491–497.

---

## Chapter 8, Waste

- Bingemer HG, Crutzen PJ. 1987. The production of methane from solid wastes. *Journal of Geophysical Research*. 92: 2181–2187.

- CRC Press. 1973. National Waste Composition (1967). Table 1.1-9: Summary of International Refuse Composition, of the Handbook of Environmental Control. Volume II: Solid Waste. CRC Press. 1973.
- Environment Canada. 1996a. Perspectives on Solid Waste Management in Canada, An Assessment of the Physical Economic and Energy Dimensions of Solid Waste Management in Canada. Vol. I. Prepared by Resource Integration Systems for Environment Canada. March.
- Environment Canada. 1997, 1999b, 2001, 2003a. Inventory of Landfill Gas Recovery and Utilization in Canada. National Office of Pollution Prevention.
- Environment Canada. 1999a. Municipal Solid Waste Incineration in Canada: An Update on Operations 1997–1998. Prepared by Compass Environmental Inc for Environment Canada and Federal Panel on Energy Research Development.
- Environment Canada. 2003b. Canada's Greenhouse Gas Inventory, 1990–2001. Greenhouse Gas Division.
- Environment Canada. 2003c. Municipal Solid Waste Incineration in Canada: An Update on Operations 1999–2001. Prepared by A.J. Chandler & Associates in conjunction with Compass Environmental Inc for Environment Canada.
- Environment Canada. 2007. An Inventory of Landfill Gas Recovery and Utilization in Canada 2005. Unpublished report prepared by the Greenhouse Gas Division of Environment Canada with the support of the University of Manitoba.
- [EPA] U.S. Environmental Protection Agency. 1995. Compilation of Air Pollutant Emission Factors. Vol. I. Stationary Point and Area Sources. Chapter 2: Solid Waste Disposal. 5th Edition. Available online at <http://www.epa.gov/ttn/chief/ap42/ch02>
- ICF Consulting. 2004. Quantitative Assessment of Uncertainty in Canada's National GHG Inventory Estimates for 2001. Final report submitted to the Greenhouse Gas Division. Environment Canada, by ICF Consulting. September.
- [IPCC] Intergovernmental Panel on Climate Change. 2000. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at <http://www.ipcc-nggip.iges.or.jp/public/gp/english/>
- [IPCC/OECD/IEA] Intergovernmental Panel on Climate Change / Organisation for Economic Co-operation and Development / International Energy Agency. 1997. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Available online at <http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm>
- Levelton BH. 1991. Inventory of Methane Emissions from Landfills in Canada. Unpublished report prepared for Environment Canada by Levelton & Associates.
- Maurice C, Lagerkvist A. 2003. LFG emission measurements in cold climatic conditions: season variations and methane emissions mitigation. Cold Regions Science and Technology. 36: 37–46.

## REFERENCES

- McCann TJ. 1994. Uncertainties in Canada's 1990 Greenhouse Gas Emission Estimates: A Quantitative Assessment. Prepared by T.J. McCann and Associates for Environment Canada. March.
- [NCASI] National Council for Air and Stream Improvement. 2003. Calculation Tools for Estimating Greenhouse Gas Emissions from Wood Products Manufacturing Facilities. Report prepared by National Council for Air and Stream Improvement, Inc.
- [NRCan] Natural Resources Canada. 1997. National Wood Residue Data Base. Natural Resources Canada. (Printouts from J. Roberts).
- [NRCan] Natural Resources Canada. 1999. Canada's Wood Residues: A Profile of Current Surplus and Regional Concentrations. Prepared for National Climate Change Process Forest Sector Table by the Industry. Economics and Programs Branch, Canadian Forest Service. Natural Resources Canada. March.
- [NRCan] Natural Resources Canada. 2005. Estimated Production, Consumption and Surplus Mill Wood Residues in Canada—2004. Report prepared for Natural Resources Canada by the Forest Products Association of Canada.
- [NRCan] Natural Resources Canada. 2006. An Analysis of Resource Recovery Opportunities in Canada and the Projection of Greenhouse Gas Emission Implications. Natural Resources Canada. March.
- ORTECH Corporation. 1994. Inventory Methods Manual for Estimating Canadian Emissions of Greenhouse Gases. Unpublished report prepared for the Regulatory Affairs and Program Integration Branch. Conservation and Protection. Environment Canada. Report No. 93-T61-P7013-FG.
- Pelt R, Bass RL, Heaton RE, White C, Blackard A, Burklin C, Reisdorph A. 1998. User's Manual Landfill Gas Emissions Model. Version 2.0. Report prepared for the Control Technology Centre. Office of Research and Development. U.S. Environmental Protection Agency. Radian International and the Eastern Research Group.
- Statistics Canada. 2000, 2003, 2004, 2007a. Waste Management Industry Survey: Business and Government Sectors. System of National Accounts. Statistics Canada. #16F0023XIE.
- Statistics Canada. 2006a. Demographic Statistics (Annual). #91-213-XIB.
- Statistics Canada. 2006b. Food Statistics – 2005. #21-020-XIE. December.
- Statistics Canada. 2007b. Annual Demographic Estimates: Canada, Provinces and Territories. Demography Division. Statistics Canada. 2007 – Revised. December 2007. #91-215-X
- Statistics Canada. 2007c. Food Statistics – 2006. #21-020-XIE. May.
- Tchobanoglous GH, Theisen, Vigil S. 1993. Integrated Solid Waste Management. New York (NY): McGraw Hill, Engineering Principles and Management Issues.
- Thompson S, Tanapat S. 2005. Waste management options for greenhouse gas reduction. *Journal of Environmental Informatics*. 6(1): 16–24.

Thompson S, Sawyer J, Bonam RK, Smith S. 2006. Recommendations for Improving the Canadian Methane Generation Model for Landfills. Winnipeg (MB): Natural Resources Institute. University of Manitoba.

## **Chapter 9, Recalculations and Improvements**

---

[ASAE] American Society of Agricultural Engineers. 2003. Manure Production and Characteristics in ASAE Standards 2003. St. Joseph (MI): The Society for Engineering in Agricultural, Food, and Biological Systems, 2950 Niles Road, 49085-9659. Pp. 683–685.

[CAPP] Canadian Association of Petroleum Producers. 2006. An Inventory of GHGs, CACs, and H<sub>2</sub>S Emissions by the Canadian Bitumen Industry: 1990 to 2003. Prepared for the Canadian Association of Petroleum Producers. Calgary (AB): Clearstone Engineering Ltd.

Cheminfo Services. 2006. Improvements and Updates to Certain Industrial Process and Solvent Use-Related Sections in Canada's Greenhouse Gas Inventory. Final report. Markham, Ontario, Canada: Cheminfo Services, Inc. September.

De Groot W, Landry R, Kurz W, Anderson KR, Englefield P, Fraser RH, Hall RJ, Raymond D, Decker V, Lynham TJ, Banfield E, Pritchard J. 2007. Estimating direct carbon emissions from Canadian wildland fires. *International Journal of Wildland Fire*. 16(5): 593–606.

[IPCC] Intergovernmental Panel on Climate Change. 2000. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at <http://www.ipcc-nggip.iges.or.jp/public/gp/english/>

[IPCC] Intergovernmental Panel on Climate Change. 2003. Good Practice Guidance for Land Use, Land-Use Change and Forestry. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at <http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf.htm>

[IPCC] Intergovernmental Panel on Climate Change. 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4: Agriculture, Forestry and Other Land Use. Intergovernmental Panel on Climate Change. Programme. Available online at <http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html>

[IPCC/OECD/IEA] Intergovernmental Panel on Climate Change / Organisation for Economic Co-operation and Development / International Energy Agency. 1997. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Available online at <http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm>.

Marinier M, Clark K, Wagner-Riddle C. 2004. Improving Estimates of Methane Emissions Associated with Animal Waste Management Systems in Canada by Adopting an IPCC Tier-2 Methodology. Final report submitted to the Greenhouse Gas Division, Environment Canada. Guelph (ON): Department of Land Resource Science. University of Guelph.

McCann TJ. 2000. 1998 Fossil Fuel and Derivative Factors. Report prepared by T.J. McCann and Associates Ltd for Environment Canada.

## REFERENCES

- [NRCan] Natural Resources Canada. Canadian Minerals Yearbook, 1990–2006 (Annual). Minerals and Metals Sector, Natural Resources Canada. Available online at [http://www.nrcan.gc.ca/mms/cmy/pref\\_e.htm](http://www.nrcan.gc.ca/mms/cmy/pref_e.htm)
- Rochette P, Worth DE, Lemke RL, McConkey BG, Pennock DJ, Wagner-Riddle C, Desjardins RL. 2008. An IPCC Tier II methodology for estimating N<sub>2</sub>O emissions from agricultural soils in Canada. Canadian Journal of Soil Science (In press)
- Shaw C, Banfield E, Simpson B, Smyth C, Trofymow T. 2006. Dead Organic Matter (DOM) Parameters for NIR 2007. Internal report. Ottawa(ON): Environment Canada.
- [SLC] Soil Landscapes of Canada. 2007. Agriculture and Agrifood Canada. Available online at <http://sis2.agr.gc.ca/cansis/>
- Smyth CE, Trofymow JA, Kurz WA. 2007. CIDET Working Group (unpub). Decreasing Uncertainty in CBM-CFS3 Estimates of Forest Soil C Sources and Sinks through Use of Long-Term Data from the Canadian Intersite Decomposition Experiment. Submitted as a BC-X report.
- Statistics Canada. Natural Gas Transportation and Distribution (Annual). #57-205-XIB.
- Statistics Canada. 2000, 2003, 2004, 2007a. Waste Management Industry Survey: Business and Government Sectors. System of National Accounts. Statistics Canada. #16F0023XIE.
- Statistics Canada. 2006. Demographic Statistics (Annual). #91-213-XIB.
- Statistics Canada. 2007b. Annual Demographic Estimates: Canada, Provinces and Territories. Demography Division. Statistics Canada. 2007 – Revised. December 2007. #91-215-X
- Statistics Canada. 2007c. Food Statistics – 2006. #21-020-XIE. May.
- Stinson G, White T, Kurz WA, Dymond C. 2006. Delineating Canada's Managed Forest for NIR 2007. Internal report. Ottawa(ON): Environment Canada.

## Annex 1 Key Categories

### ***A1.1 Key Categories—Methodology***

Both the IPCC Good Practice Guidance (IPCC 2000) and the IPCC Good Practice Guidance for LULUCF (IPCC 2003) recommend as good practice the identification of key categories of emissions and removals. The intent is to help inventory agencies prioritize their efforts to improve overall estimates. A key category is defined as “one that is prioritized within the national inventory system because its estimate has a significant influence on a country’s total inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both” (IPCC 2000).

This annex describes the key category analysis conducted for Canada’s inventory, according to IPCC approaches.

Good practice first requires that inventories be disaggregated into categories from which key sources and sinks may be identified. Source and sink categories are defined according to the following guidelines:

- IPCC categories should be used with emissions expressed in CO<sub>2</sub> equivalent units according to standard global warming potentials (GWPs).
- A category should be identified for *each* gas emitted or removed, since the methods, emission factors, and related uncertainties differ for each gas.
- Categories that use the same emission factors based on common assumptions should be aggregated before analysis.

Using the IPCC Tier 1 method, key categories are first identified by quantitative methods using a predetermined cumulative emission threshold. Second, Tier 1 key categories are determined by qualitative approaches. A more comprehensive Tier 2 approach is recommended if uncertainty estimates are available. In this approach, the results of the Tier 1 method are multiplied by the relative uncertainty of the source and sink category. Since current uncertainty estimates are not available for all sectors, a Tier 1 approach has been used for this analysis.

The quantitative approach identifies key categories from two perspectives: their contribution to the overall emissions, and to the emission trend. The level assessment analyzes the emission contribution that each category makes to the national total (with and without LULUCF). The trend assessment uses each category’s relative contribution to the overall emissions, but assigns greater weights to the categories whose relative trend departs from the overall one (with and without LULUCF); in this assessment, trends are calculated as the absolute changes between the base and most recent inventory years. The percent contributions to both levels and trends in emissions are calculated and sorted from greatest to least. A cumulative total is calculated for both approaches. A cumulative contribution threshold of 95% for both level and trend assessments is a reasonable approximation of 90% uncertainty for the Tier 1 method of determining key categories (IPCC 2000). This threshold has therefore been used in this analysis to define an upper boundary for key category identification. Hence, when source and/or sink contributions are sorted in decreasing order of importance, those largest ones that together contribute to 95% of the cumulative total are considered quantitatively to be key.

Level contribution of each source is calculated according to Equation A1-1, which follows IPCC (2000), whereas Equation A1-2 is used to calculate the level contribution from both sources and sinks following IPCC (2003):

**Equation A1-1 for source category level assessment:**

$$L_{x,t} = E_{x,t}/E_t$$

where:

$L_{x,t}$	=	the level assessment for source x in year t.
$E_{x,t}$	=	the emission estimate (CO <sub>2</sub> eq) of source category x in year t.
$E_t$	=	the total inventory estimate (CO <sub>2</sub> eq) in year t.

**Equation A1-2 for source/sink category level assessment:**

$$L_{x,t}^* = E_{x,t}^*/E_t^*$$

where:

$L_{x,t}^*$	=	the level assessment for source or sink x in year t. The asterisk (*) indicates that contributions from all categories (including LULUCF) are entered as absolute values (i.e. negative values are always recorded as the equivalent positive values).
$E_{x,t}^*$	=	$ E_{x,t} $ , the absolute value of the emission or removal estimate (CO <sub>2</sub> eq) of source or sink category x in year t.
$E_t^*$	=	$\sum_x  E_{x,t} $ , the sum of the absolute values of all emissions and removals (CO <sub>2</sub> eq) from all source or sink categories x in year t, kt CO <sub>2</sub> eq.

Trend contribution of each source is calculated according to Equation A1-3, which follows IPCC (2000), whereas Equation A1- 4 is used to calculate the trend contribution from both sources and sinks following IPCC (2003):

**Equation A1-3 for source category trend assessment:**

$$T_{x,t} = L_{x,t} \left| \left\{ [(E_{x,t} - E_{x,0})/E_{x,t}] - [(E_t - E_0)/E_t] \right\} \right|$$

where:

$T_{x,t}$	=	the contribution of the source category trend to the overall inventory trend (i.e. the trend assessment). The trend assessment is always recorded as an absolute value.
$L_{x,t}$	=	the level assessment for source x in year t (derived in Equation A1- 1).
$E_{x,t}$ and $E_{x,0}$	=	the emission estimates (CO <sub>2</sub> eq) of source category x in years t and 0, respectively.
$E_t$ and $E_0$	=	the total inventory estimates (CO <sub>2</sub> eq) in years t and 0, respectively.



**Equation A1- 4 for source and sink category trend assessment:**

$$T_{x,t} = E_{x,t}^* / E_t^* \left| \left\{ [(E_{x,t} - E_{x,0}) / E_{x,t}] - [(E_t - E_0) / E_t] \right\} \right|$$

where:

$T_{x,t}$	=	the contribution of the source or sink category trend to the overall inventory trend (i.e. the trend assessment). The trend assessment is always recorded as an absolute value.
$E_{x,t}^*$	=	$ E_{x,t} $ , the absolute value of the emission or removal estimate (CO <sub>2</sub> eq) of source or sink category x in year t.
$E_t^*$	=	$\sum_x  E_{x,t} $ , the sum of the absolute values of the emission and removal estimates (CO <sub>2</sub> eq) in year t.
$E_{x,t}$ and $E_{x,0}$	=	the emission estimates (CO <sub>2</sub> eq) of source or sink category x in years t and 0, respectively.
$E_t$ and $E_0$	=	$\sum_x E_{x,t}$ and $\sum_x E_{x,0}$ , the sum of all emissions and removals from source and sink categories x (CO <sub>2</sub> eq) in years t and 0, respectively. $E_t$ differs from $E_t^*$ in Equation A1-2 in that the removals are not entered as absolute values.

The qualitative approach enhances the foregoing quantitative analysis by considering more subjective criteria to determine if a category should be listed as key. Additional categories identified as key are added to the primary list. The IPCC Good Practice Guidance (IPCC 2000) and the IPCC Good Practice Guidance for LULUCF (IPCC 2003) identify several general criteria for qualitative analysis:

- *Mitigation techniques and technologies*: Identify those sources where emissions are being reduced significantly through the use of mitigation techniques or technologies.
- *High expected emission growth*: Identify sources with significant growth forecast.
- *High uncertainty*: Identify the most uncertain sources as key to help improve the accuracy of the inventory.
- *Unexpectedly low or high emissions*: Identify calculation errors and discrepancies by doing order-of-magnitude checks.
- *LULUCF*: If subcategories display large CO<sub>2</sub> fluxes that tend to cancel each other, or if deforestation or any other subcategory is larger than the smallest key category level, then these are identified as key sources.

This analysis uses several sources of information to support the qualitative assessment, notably the emission forecasts by NRCan (1999, 2006), some announcements by the Government of Canada (2006, 2007), and the quantitative uncertainty analysis (ICF Consulting 2004).

The overall purpose of identifying key categories is the institution of best practices in GHG inventory development. The appropriate aggregation of categories is crucial to reflect not only actual sources and sinks but also identical estimation procedures. Thus, while the UNFCCC common reporting format (CRF) categories provide a basis for identifying sources and sinks, some aggregation of these sources and sinks can occur when using the same emission factors based on common estimation assumptions. In this analysis, major categories such as Fuel Combustion, Fugitive Emissions, Industrial Processes, Agriculture, and Waste are in keeping with the CRF. Within these major categories, the aggregation of subcategories occurs when estimates are made based on common assumptions about emission factors and on common activity data. For example, within the Fuel Combustion category, emissions from Residential, Commercial, and Agriculture subsectors are combined.

### A1.1.1 Summary Assessment

Key categories were assessed for the 2006 inventory year using all criteria (level, trend, and qualitative) and for the base year on the level criterion only.

There were 37 level key categories in 1990, while in 2006 there were 45 with all combined criteria. In general, all the categories that were key in 1990 remained so in 2006, although the criteria may have changed. Results are shown in Table A1-1.

**Table A1-1: Key Category Analysis Summary, 2006 Inventory**

Source Table	IPCC Categories	Direct Greenhouse Gas	Key Category (2006/1990)	Criteria (2006/1990)
1-A-1-a	Fuel Combustion - Public Electricity and Heat Production	CO <sub>2</sub>	Yes / Yes	L,T,Q / L
1-A-1-a	Fuel Combustion - Public Electricity and Heat Production	CH <sub>4</sub>	No / No	
1-A-1-a	Fuel Combustion - Public Electricity and Heat Production	N <sub>2</sub> O	No / No	
1-A-1-b	Fuel Combustion - Petroleum Refining	CO <sub>2</sub>	No / No	
1-A-1-b	Fuel Combustion - Petroleum Refining	N <sub>2</sub> O	Yes / Yes	L,T,Q / L
1-A-1-c	Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries	CO <sub>2</sub>	Yes / Yes	L,T,Q / L
1-A-1-c	Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries	CH <sub>4</sub>	No / No	
1-A-1-c	Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries	N <sub>2</sub> O	No / No	
1-A-2	Fuel Combustion - Manufacturing Industries and Construction	CO <sub>2</sub>	Yes / Yes	L,T / L
1-A-2	Fuel Combustion - Manufacturing Industries and Construction	CH <sub>4</sub>	No / No	
1-A-2	Fuel Combustion - Manufacturing Industries and Construction	N <sub>2</sub> O	No / No	
1-A-3-a	Fuel Combustion - Civil Aviation (Domestic Aviation)	CO <sub>2</sub>	Yes / Yes	L,T,Q / L
1-A-3-a	Fuel Combustion - Civil Aviation (Domestic Aviation)	CH <sub>4</sub>	Yes / No	Q
1-A-3-a	Fuel Combustion - Civil Aviation (Domestic Aviation)	N <sub>2</sub> O	Yes / No	Q
1-A-3-b	Fuel Combustion - Road Transportation	CO <sub>2</sub>	Yes / Yes	L,T,Q / L
1-A-3-b	Fuel Combustion - Road Transportation	CH <sub>4</sub>	Yes / No	Q
1-A-3-b	Fuel Combustion - Road Transportation	N <sub>2</sub> O	Yes / Yes	T,Q / L
1-A-3-c	Fuel Combustion - Railways	CO <sub>2</sub>	Yes / Yes	L,T / L
1-A-3-c	Fuel Combustion - Railways	CH <sub>4</sub>	No / No	
1-A-3-c	Fuel Combustion - Railways	N <sub>2</sub> O	Yes / No	Q
1-A-3-d	Fuel Combustion - Navigation (Domestic Marine)	CO <sub>2</sub>	Yes / Yes	L,T,Q / L
1-A-3-d	Fuel Combustion - Navigation (Domestic Marine)	CH <sub>4</sub>	Yes / No	Q
1-A-3-d	Fuel Combustion - Navigation (Domestic Marine)	N <sub>2</sub> O	Yes / No	Q
1-A-3-e	Fuel Combustion - Other Transport (Off-Road)	CO <sub>2</sub>	Yes / Yes	L,T,Q / L
1-A-3-e	Fuel Combustion - Other Transport (Off-Road)	CH <sub>4</sub>	Yes / No	Q
1-A-3-e	Fuel Combustion - Other Transport (Off-Road)	N <sub>2</sub> O	Yes / No	Q
1-A-3-e	Fuel Combustion - Pipeline Transport	CO <sub>2</sub>	Yes / Yes	L,T / L
1-A-3-e	Fuel Combustion - Pipeline Transport	CH <sub>4</sub>	No / No	
1-A-3-e	Fuel Combustion - Pipeline Transport	N <sub>2</sub> O	No / No	
1-A-4	Fuel Combustion - Other Sectors	CO <sub>2</sub>	Yes / Yes	L,T / L
1-A-4	Fuel Combustion - Other Sectors	CH <sub>4</sub>	Yes / No	T
1-A-4	Fuel Combustion - Other Sectors	N <sub>2</sub> O	No / No	
1-B-1-a	Fugitive Emissions - Coal Mining	CH <sub>4</sub>	Yes / No	T
1-B-2-a	Fugitive Emissions - Oil	CO <sub>2</sub>	No / No	
1-B-2-a	Fugitive Emissions - Oil	CH <sub>4</sub>	Yes / Yes	L / L
1-B-2-a	Fugitive Emissions - Oil	N <sub>2</sub> O	No / No	
1-B-2-b	Fugitive Emissions - Natural Gas	CO <sub>2</sub>	No / No	
1-B-2-b	Fugitive Emissions - Natural Gas	CH <sub>4</sub>	Yes / Yes	L,T / L

Source Table	IPCC Categories	Direct Greenhouse Gas	Key Category (2006/1990)	Criteria (2006/1990)
1-B-2-c-1-1	Fugitive Emissions - Oil and Natural Gas - Venting - Oil	CO <sub>2</sub>	Yes Yes	L,T / L
1-B-2-c-1-1	Fugitive Emissions - Oil and Natural Gas - Venting - Oil	CH <sub>4</sub>	Yes / Yes	L,T / L
1-B-2-c-1-1	Fugitive Emissions - Oil and Natural Gas - Venting - Oil	N <sub>2</sub> O	No / No	
1-B-2-c-1-2	Fugitive Emissions - Oil and Natural Gas - Venting - Natural Gas	CO <sub>2</sub>	Yes / Yes	L,T / L
1-B-2-c-1-2	Fugitive Emissions - Oil and Natural Gas - Venting - Natural Gas	CH <sub>4</sub>	Yes / Yes	L,T / L
1-B-2-c-1-3	Fugitive Emissions - Oil and Natural Gas - Venting - Combined	CO <sub>2</sub>	No / No	
1-B-2-c-1-3	Fugitive Emissions - Oil and Natural Gas - Venting - Combined	CH <sub>4</sub>	No / No	
1-B-2-c-2-1	Fugitive Emissions - Oil and Natural Gas - Flaring - Oil	CO <sub>2</sub>	Yes / Yes	L / L
1-B-2-c-2-1	Fugitive Emissions - Oil and Natural Gas - Flaring - Oil	CH <sub>4</sub>	No / No	
1-B-2-c-2-1	Fugitive Emissions - Oil and Natural Gas - Flaring - Oil	N <sub>2</sub> O	No / No	
1-B-2-c-2-2	Fugitive Emissions - Oil and Natural Gas - Flaring - Natural Gas	CO <sub>2</sub>	No / No	
1-B-2-c-2-2	Fugitive Emissions - Oil and Natural Gas - Flaring - Natural Gas	CH <sub>4</sub>	No / No	
1-B-2-c-2-3	Fugitive Emissions - Oil and Natural Gas - Flaring - Combined	CO <sub>2</sub>	Yes / No	T
1-B-2-c-2-3	Fugitive Emissions - Oil and Natural Gas - Flaring - Combined	CH <sub>4</sub>	No / No	
2-A-1	Industrial Processes - Cement Production	CO <sub>2</sub>	Yes / Yes	L,T / L
2-A-2	Industrial Processes - Lime Production	CO <sub>2</sub>	No / No	
2-A-3	Industrial Processes - Limestone and Dolomite Use	CO <sub>2</sub>	Yes / No	T
2-A-4	Industrial Processes - Soda Ash Production and Use	CO <sub>2</sub>	No / No	
2-A-7-2	Industrial Processes - Magnesite Use	CO <sub>2</sub>	No / No	
2-B-1	Industrial Processes - Ammonia Production	CO <sub>2</sub>	Yes / Yes	L / L
2-B-2	Industrial Processes - Nitric Acid Production	N <sub>2</sub> O	No / No	
2-B-3	Industrial Processes - Adipic Acid Production	N <sub>2</sub> O	Yes / Yes	T / L
2-C-1	Industrial Processes - Iron and Steel Production	CO <sub>2</sub>	Yes / Yes	L,T / L
2-C-3	Industrial Processes - Aluminium Production	CO <sub>2</sub>	Yes / Yes	L,T / L
2-C-3	Industrial Processes - Aluminium Production	PFCs	Yes / Yes	T / L
2-C-4-1	Industrial Processes - Aluminium Production	SF <sub>6</sub>	No / No	
2-C-4-2	Industrial Processes - Magnesium Production	SF <sub>6</sub>	Yes / Yes	T,Q / L
2-C-5	Industrial Processes - Magnesium Casting	SF <sub>6</sub>	No / No	
2-F	Industrial Processes - Consumption of Halocarbons	HFCs	Yes / No	L,T
2-F	Industrial Processes - Consumption of Halocarbons	PFCs	No / No	
2-F-8	Industrial Processes - Consumption of SF <sub>6</sub> for Electrical Equipment	SF <sub>6</sub>	Yes / /No	T,Q
2-F-7	Industrial Processes - Consumption of SF <sub>6</sub> for Semi-Conductor	SF <sub>6</sub>	Yes / No	Q
2-G	Industrial Processes - Other (Undifferentiated Processes)	CO <sub>2</sub>	Yes / Yes	L,T,Q / L
3-D	Solvent and Other Product Use	N <sub>2</sub> O	No / No	
4-A	Agriculture - Enteric Fermentation	CH <sub>4</sub>	Yes / Yes	L,T / L
4-B	Agriculture - Manure Management	CH <sub>4</sub>	No / No	
4-B	Agriculture - Manure Management	N <sub>2</sub> O	Yes / Yes	
4-D-1	Agriculture - Direct Agricultural Soils	N <sub>2</sub> O	Yes / Yes	L,T,Q / L
4-D-2	Agriculture - Animal Manure on Pasture, Range and Paddock	N <sub>2</sub> O	Yes / No	L,T
4-D-3	Agriculture - Indirect Agricultural Soils	N <sub>2</sub> O	Yes / Yes	L,T,Q / L
5-A.1	LULUCF - Forest Land remaining Forest Land	CO <sub>2</sub>	Yes / Yes	L,T / L
5-A.1	LULUCF - Forest Land remaining Forest Land	CH <sub>4</sub>	Yes / Yes	L,T / L
5-A.1	LULUCF - Forest Land remaining Forest Land	N <sub>2</sub> O	Yes / No	L,T
5-A.2	LULUCF - Land converted to Forest Land	CO <sub>2</sub>	No / No	
5-B.1	LULUCF - Cropland remaining Cropland	CO <sub>2</sub>	Yes / No	L,T,Q
5-B.2	LULUCF - Land converted to Cropland	CO <sub>2</sub>	Yes / Yes	L,T / L
5-B.2	LULUCF - Land converted to Cropland	CH <sub>4</sub>	No / No	
5-B.2	LULUCF - Land converted to Cropland	N <sub>2</sub> O	No / No	
5-D.1	LULUCF - Wetlands remaining Wetlands	CO <sub>2</sub>	No / No	
5-D.2	LULUCF - Land converted to Wetlands	CO <sub>2</sub>	Yes / Yes	T / L

Source Table	IPCC Categories	Direct Greenhouse Gas	Key Category (2006/1990)	Criteria (2006/1990)
5-D.2	LULUCF - Land converted to Wetlands	CH <sub>4</sub>	No / No	
5-D.2	LULUCF - Land converted to Wetlands	N <sub>2</sub> O	No / No	
5-E.2	LULUCF - Settlements remaining Settlements	CO <sub>2</sub>	No / No	
5-E.2	LULUCF - Land converted to Settlements	CO <sub>2</sub>	Yes / Yes	L,T / L
5-E.2	LULUCF - Land converted to Settlements	CH <sub>4</sub>	No / No	
5-E.2	LULUCF - Land converted to Settlements	N <sub>2</sub> O	No / No	
6-A	Waste - Solid Waste Disposal on Land	CH <sub>4</sub>	Yes / Yes	L,T,Q / L
6-B	Waste - Wastewater Handling	CH <sub>4</sub>	No / No	
6-B	Waste - Wastewater Handling	N <sub>2</sub> O	Yes / No	Q
6-C	Waste - Waste Incineration	CO <sub>2</sub>	Yes / No	Q
6-C	Waste - Waste Incineration	CH <sub>4</sub>	No / No	
6-C	Waste - Waste Incineration	N <sub>2</sub> O	No / No	

## ***A1.2 Key Category Tables***

### **A1.2.1 Level Assessment With and Without LULUCF**

Table A1-2 shows key categories generated from level assessment with and without LULUCF, and Figure A1-1 shows the contribution of each category to the level assessment.

**Table A1-2: 2006 Key Categories by Level Assessment With and Without LULUCF**

Source Table	IPCC Source Categories	Direct	1990	2006	Level Assessment		Cumulative Total	
		GHG	kt CO <sub>2</sub> eq		without LULUCF	with LULUCF	without LULUCF	with LULUCF
1-A-3-b	Fuel Combustion - Road Transportation	CO <sub>2</sub>	94 923	129 687	0.178	0.166	0.178	0.166
1-A-1-a	Fuel Combustion - Public Electricity and Heat Production	CO <sub>2</sub>	94 824	116 254	0.160	0.149	0.338	0.315
1-A-4	Fuel Combustion - Other Sectors	CO <sub>2</sub>	68 795	72 383	0.100	0.093	0.438	0.408
1-A-2	Fuel Combustion - Manufacturing Industries and Construction	CO <sub>2</sub>	62 340	69 516	0.096	0.089	0.534	0.497
1-A-1-c	Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries	CO <sub>2</sub>	34 089	49 080	0.068	0.063	0.601	0.560
1-A-3-e	Fuel Combustion - Other Transport (Off-Road)	CO <sub>2</sub>	19 768	25 926	0.036	0.033	0.637	0.594
4-A	Agriculture - Enteric Fermentation	CH <sub>4</sub>	17 984	24 163	0.033	0.031	0.670	0.625
1-B-2-b	Fugitive Emissions - Natural Gas	CH <sub>4</sub>	12 876	21 284	0.029	0.027	0.699	0.652
6-A	Waste - Solid Waste Disposal on Land	CH <sub>4</sub>	16 983	19 756	0.027	0.025	0.727	0.677
1-B-2-c-1-1	Fugitive Emissions - Oil and Natural Gas - Venting - Oil	CH <sub>4</sub>	9 937	16 954	0.023	0.022	0.750	0.699
1-A-1-b	Fuel Combustion - Petroleum Refining	CO <sub>2</sub>	15 621	16 112	0.022	0.021	0.772	0.720
4-D-1	Agriculture - Direct Agricultural Soils	N <sub>2</sub> O	13 856	15 040	0.021	0.019	0.793	0.739
2-G	Industrial Processes - Other (Undifferentiated Processes)	CO <sub>2</sub>	8 030	12 454	0.017	0.016	0.810	0.755
5-A.1	LULUCF - Forest Land remaining Forest Land	CO <sub>2</sub>	-136 941	12 102		0.016		0.770
4-D-3	Agriculture - Indirect Agricultural Soils	N <sub>2</sub> O	9 024	10 766	0.015	0.014	0.820	0.784
5-B.1	LULUCF - Cropland remaining Cropland	CO <sub>2</sub>	-1 421	-9 564		0.012		0.797
1-A-3-e	Fuel Combustion - Pipeline Transport	CO <sub>2</sub>	6 703	9 386	0.013	0.012	0.838	0.809
1-A-3-a	Fuel Combustion - Civil Aviation (Domestic Aviation)	CO <sub>2</sub>	6 182	8 194	0.011	0.011	0.849	0.819
5-E.2	LULUCF - Land converted to Settlements	CO <sub>2</sub>	9 141	7 905		0.010		0.829
5-B.2	LULUCF - Land converted to Cropland	CO <sub>2</sub>	14 570	7 874		0.010		0.839
2-C-1	Industrial Processes - Iron and Steel Production	CO <sub>2</sub>	7 060	7 757	0.011	0.010	0.860	0.849
1-B-2-c-1-2	Fugitive Emissions - Oil and Natural Gas - Venting - Natural Gas	CO <sub>2</sub>	4 173	7 517	0.010	0.010	0.870	0.859
2-A-1	Industrial Processes - Cement Production	CO <sub>2</sub>	5 436	7 319	0.010	0.009	0.880	0.868

Source Table	IPCC Source Categories	Direct GHG	1990 kt CO <sub>2</sub> eq	2006 kt CO <sub>2</sub> eq	Level Assessment without LULUCF      with LULUCF		Cumulative Total without LULUCF      with LULUCF	
5-A.1	LULUCF - Forest Land remaining Forest Land	CH <sub>4</sub>	2 799	7 213		0.009		0.878
2-B-1	Industrial Processes - Ammonia Production	CO <sub>2</sub>	4 994	6 575	0.009	0.008	0.889	0.886
1-A-3-c	Fuel Combustion - Railways	CO <sub>2</sub>	6 159	5 656	0.008	0.007	0.897	0.893
1-B-2-a	Fugitive Emissions - Oil	CH <sub>4</sub>	4 055	5 495	0.008	0.007	0.904	0.900
1-A-3-d	Fuel Combustion - Navigation (Domestic Marine)	CO <sub>2</sub>	4 693	5 376	0.007	0.007	0.912	0.907
2-F	Industrial Processes - Consumption of Halocarbons	HFCs	767	5 274	0.007	0.007	0.919	0.914
2-C-3	Industrial Processes - Aluminium Production	CO <sub>2</sub>	2 715	5 004	0.007	0.006	0.926	0.920
1-B-2-c-1-2	Fugitive Emissions - Oil and Natural Gas - Venting - Natural Gas	CH <sub>4</sub>	3 198	4 800	0.007	0.006	0.933	0.926
4-B	Agriculture - Manure Management	N <sub>2</sub> O	3 450	4 778	0.007	0.006	0.939	0.933
5-A.1	LULUCF - Forest Land remaining Forest Land	N <sub>2</sub> O	1 738	4 480		0.006		0.938
1-B-2-c-2-1	Fugitive Emissions - Oil and Natural Gas - Flaring - Oil	CO <sub>2</sub>	3 311	4 090	0.005	0.005	0.945	0.944
4-D-2	Agriculture - Animal Manure on Pasture, Range and Paddock	N <sub>2</sub> O	2 557	3 838	0.005	0.005	0.950	0.949
1.B.2.c.1.2	Fugitive Emissions - Oil and Natural Gas - Venting - Natural Gas	CH <sub>4</sub>	1 917	3 715	0.005	0.005		0.953

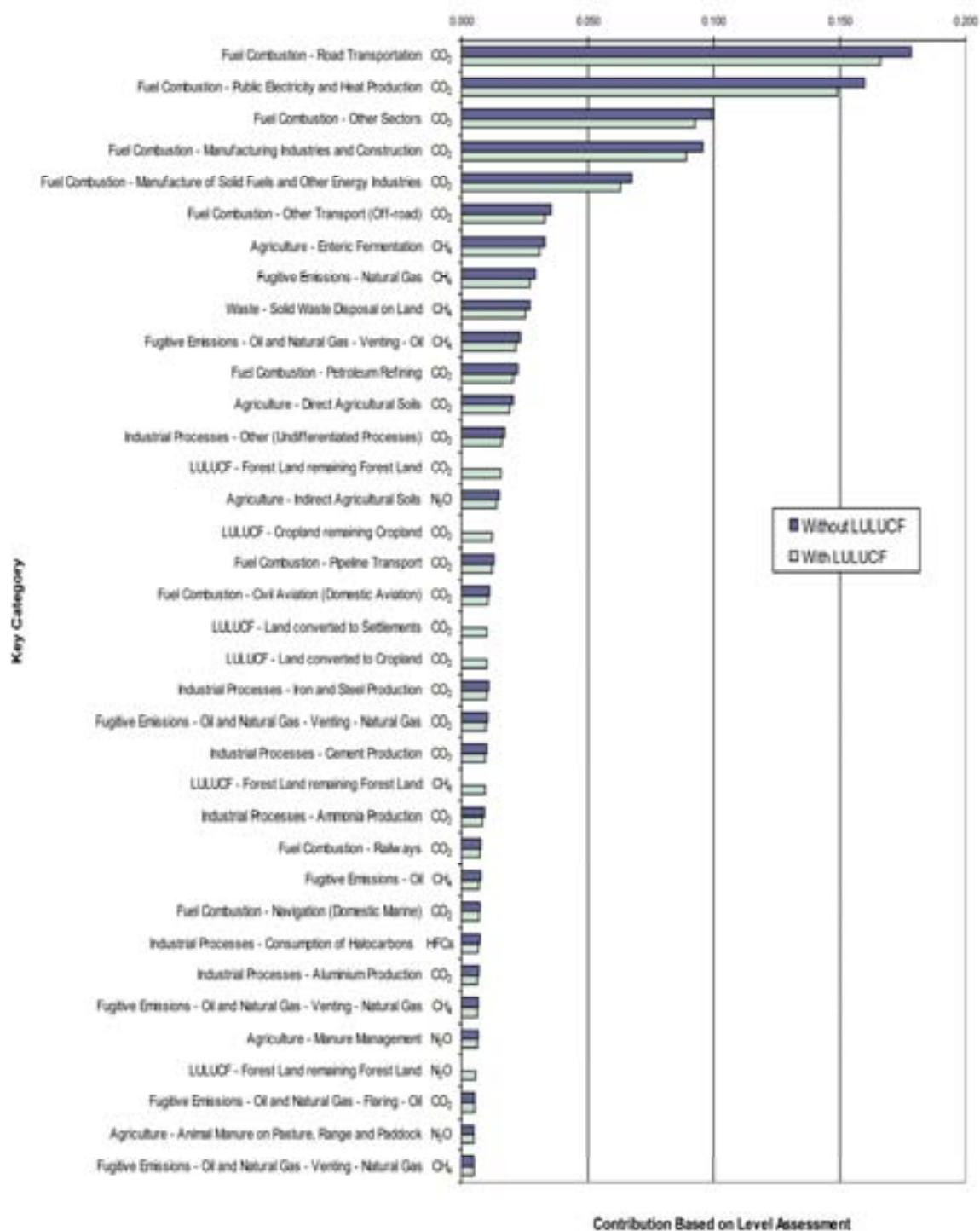


Figure A1-1: Contributions of Key Categories to Level Assessment With and Without LULUCF

### **A1.2.2 Trend Assessment With and Without LULUCF**

Table A1-3 shows key categories indicated from trend assessment with and without LULUCF, and Figure A1-2 shows the contribution of key categories to the trend assessment.

The integration of the LULUCF sector into the level assessment introduces additional key categories without much alteration of the relative categories' contributions. On the contrary, the integration of LULUCF to the trend assessment considerably alters the overall trend in emissions, which causes a rearrangement in the ranking of key categories. A single LULUCF category, Forest Land remaining Forest Land, contributes to almost 50% to the overall trend. The trend assessment without LULUCF identifies 33 key categories, while the same analysis with LULUCF results in fewer categories, even though 7 new key categories are identified in the LULUCF sector. The final list includes all the categories identified as key in either one of the analyses.



**Table A1-3: 2006 Key Categories by Trend Assessment<sup>1</sup> With and Without LULUCF**

Source Table	IPCC Source Categories	Direct GHG	1990 kt CO <sub>2</sub> eq	2006 kt CO <sub>2</sub> eq	Trend Assessment without LULUCF	Trend Assessment with LULUCF	Contribution to Trend without LULUCF	Contribution to Trend with LULUCF	Cumulative Total without LULUCF	Cumulative Total with LULUCF
5-A.1	LULUCF - Forest Land remaining Forest Land	CO <sub>2</sub>	-13 6941	12 102	NA	0.186	NA	0.467	NA	0.467
1-A-4	Fuel Combustion - Other Sectors	CO <sub>2</sub>	68 795	72 383	0.017	0.029	0.133	0.072	0.133	0.539
1-A-1-a	Fuel Combustion - Public Electricity and Heat Production	CO <sub>2</sub>	94 824	116 254	0.012	0.026	0.090	0.066	0.223	0.605
1-A-2	Fuel Combustion - Manufacturing Industries and Construction	CO <sub>2</sub>	62 340	69 516	0.010	0.023	0.078	0.057	0.302	0.662
1-A-3-b	Fuel Combustion - Road Transportation	CO <sub>2</sub>	94 923	129 687	0.010	0.015	0.076	0.038	0.377	0.700
2-B-3	Industrial Processes - Adipic Acid Production	N <sub>2</sub> O	10 718	1 209	0.010	0.013	0.075	0.032	0.452	0.732
5-B.2	LULUCF - Land converted to Cropland	CO <sub>2</sub>	14 570	7 874	0.009	0.012	0.073	0.031	0.525	0.763
1-A-1-b	Fuel Combustion - Petroleum Refining	CO <sub>2</sub>	15 621	16 112	0.005	0.007	0.043	0.017	0.568	0.780
2-C-3	Industrial Processes - Aluminium Production	PFCs	6 539	2610	0.005	0.006	0.041	0.016	0.609	0.796
5-B.1	LULUCF - Cropland remaining Cropland	CO <sub>2</sub>	-1 421	-9 564	0.005	0.006	0.040	0.015	0.649	0.811
6-A	Waste - Solid Waste Disposal on Land	CH <sub>4</sub>	16 983	19 756	0.005	0.006	0.039	0.014	0.688	0.825
4-D-1	Agriculture - Direct Agricultural Soils	N <sub>2</sub> O	13 856	15 040	NA	0.005	NA	0.014	NA	0.838
5-E.2	LULUCF - Land converted to Settlements	CO <sub>2</sub>	9 141	7 905	0.003	0.005	0.025	0.013	0.713	0.852
1-A-3-e	Fuel Combustion - Other Transport (Off-Road)	CO <sub>2</sub>	19 768	25 926	0.003	0.004	0.021	0.010	0.734	0.862
5-D.2	LULUCF - Land converted to Wetlands	CO <sub>2</sub>	3 648	851	0.003	0.004	0.021	0.010	0.755	0.872
1-A-1-c	Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries	CO <sub>2</sub>	34 089	49 080	0.002	0.003	0.019	0.009	0.774	0.880
2-F	Industrial Processes - Consumption of Halocarbons	HFCs	767	5 274	0.002	0.003	0.018	0.008	0.792	0.889
1-A-3-c	Fuel Combustion - Railways	CO <sub>2</sub>	6 159	5 656	0.002	0.003	0.017	0.008	0.809	0.897
4-A	Agriculture - Enteric Fermentation	CH <sub>4</sub>	17 984	24 163	0.001	0.003	0.006	0.008	0.815	0.905
4-D-3	Agriculture - Indirect Agricultural Soils	N <sub>2</sub> O	9 024	10 766	0.002	0.003	0.015	0.007	0.831	0.912
2-C-4-2	Industrial Processes - Magnesium Production	SF <sub>6</sub>	2 870	1 205	NA	0.003	NA	0.007	NA	0.919
2-C-1	Industrial Processes - Iron and Steel Production	CO <sub>2</sub>	7 060	7 757	NA	0.003	NA	0.007	NA	0.925
5-A.1	LULUCF - Forest Land remaining Forest Land	CH <sub>4</sub>	2 799	7 213	0.002	0.002	0.014	0.006	0.845	0.931

Source Table	IPCC Source Categories	Direct GHG	1990 kt CO <sub>2</sub> eq	2006	Trend Assessment without LULUCF	Trend Assessment with LULUCF	Contribution to Trend without LULUCF	Contribution to Trend with LULUCF	Cumulative Total without LULUCF	Cumulative Total with LULUCF
1-B-1-a	Fugitive Emissions - Coal Mining	CH <sub>4</sub>	1 914	640	NA	0.002	NA	0.005	NA	0.936
1-A-3-d	Fuel Combustion - Navigation (Domestic Marine)	CO <sub>2</sub>	4 693	5 376	0.001	0.002	0.009	0.004	0.854	0.940
5-A.1	LULUCF - Forest Land remaining Forest Land	N <sub>2</sub> O	1 738	4 480	0.002	0.001	0.012	0.004	0.866	0.944
1-A-3-b	Fuel Combustion - Road Transportation	N <sub>2</sub> O	3 202	3 350	0.002	0.001	0.012	0.003	0.878	0.947
1-A-3-a	Fuel Combustion - Civil Aviation (Domestic Aviation)	CO <sub>2</sub>	6 182	8 194	0.002	0.001	0.012	0.003	0.890	0.950
1-B-2-b	Fugitive Emissions - Natural Gas	CH <sub>4</sub>	12 876	21 284	0.006	NA	0.050	NA	0.521	NA
1-B-2-c-1-1	Fugitive Emissions - Oil and Natural Gas - Venting - Oil CH <sub>4</sub>	CH <sub>4</sub>	9 937	16 954	0.005	NA	0.044	NA	0.614	NA
2-G	Industrial Processes - Other (Undifferentiated Processes)	CO <sub>2</sub>	8 030	12 454	0.003	NA	0.024	NA	0.706	NA
1-B-2-c-1-2	Fugitive Emissions - Oil and Natural Gas - Venting - Natural Gas CO <sub>2</sub>	CO <sub>2</sub>	4 173	7 517	0.003	NA	0.022	NA	0.728	NA
2-C-3	Industrial Processes - Aluminium Production	CO <sub>2</sub>	2 715	5 004	0.006	NA	0.050	NA	0.571	NA
1-B-2-c-1-1	Fugitive Emissions - Oil and Natural Gas - Venting - Oil CO <sub>2</sub>	CO <sub>2</sub>	1 917	3 715	0.002	NA	0.012	NA	0.862	NA
1-A-3-e	Fuel Combustion - Pipeline Transport	CO <sub>2</sub>	6 703	9 386	0.001	NA	0.011	NA	0.873	NA
1-B-2-c-2-3	Fugitive Emissions - Oil and Natural Gas - Flaring - Combined	CO <sub>2</sub>	275	1 301	0.001	NA	0.009	NA	0.892	NA
1-B-2-c-1-2	Fugitive Emissions - Oil and Natural Gas - Venting - Natural Gas CH <sub>4</sub>	CH <sub>4</sub>	3 198	4 800	0.001	NA	0.008	NA	0.908	NA
4-D-2	Agriculture - Animal Manure on Pasture, Range and Paddock	N <sub>2</sub> O	2 557	3 838	0.001	NA	0.006	NA	0.914	NA
2-A-3	Industrial Processes - Limestone and Dolomite Use	CO <sub>2</sub>	734	250	0.001	NA	0.006	NA	0.920	NA
2-A-1	Industrial Processes - Cement Production	CO <sub>2</sub>	5 436	7 319	0.001	NA	0.006	NA	0.926	NA
2-F-8	Industrial Processes - Consumption of SF <sub>6</sub> for Electrical Equipment	SF <sub>6</sub>	1 524	1 317	0.001	NA	0.005	NA	0.947	NA
4-B	Agriculture - Manure Management	N <sub>2</sub> O	3 450	4 778	0.001	NA	0.005	NA	0.952	NA

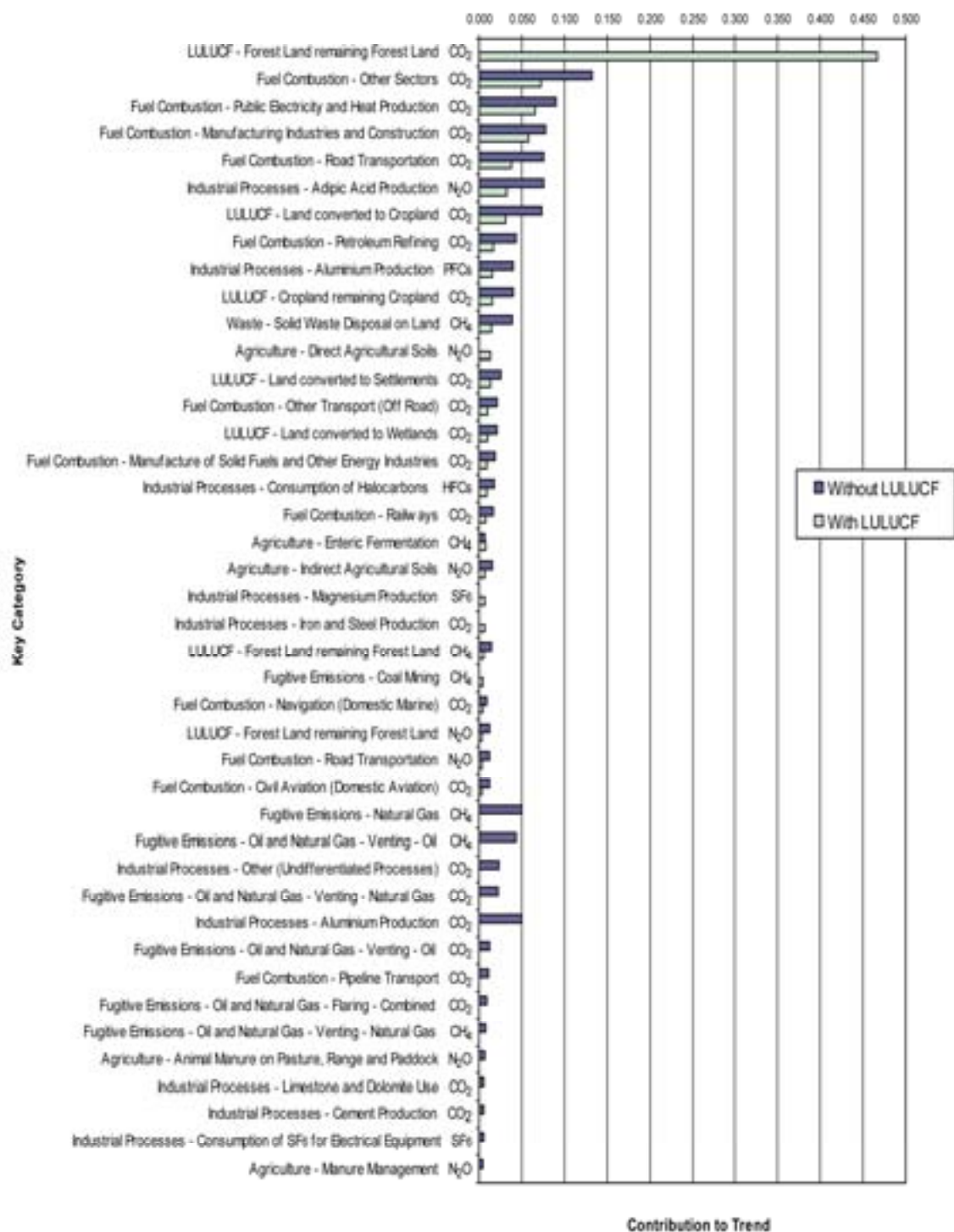


Figure A1-2: Contributions of Key Categories to Trend Assessment With and Without LULUCF

### A1.2.3 Qualitative Assessment

#### A1.2.3.1 *Mitigation Techniques and Technologies*

Mitigation techniques are important for good practice, in particular if they are inclined to produce departures from the norm under which activity data and emission factors are estimated. Table A1-4 shows key categories identified as a result of having significant mitigation techniques and technologies introduced that have had (since 1990), or will have, an impact on emission estimates.

**Table A1-4: Key Categories by Significant Mitigation Techniques and Technologies**

Key Category	GHG	Reference(s)	Comments
Fuel Combustion - Road Transportation	CO <sub>2</sub>	Government of Canada (2006)	Increased biofuel use
Fuel Combustion - Road Transportation	N <sub>2</sub> O	Government of Canada (2006)	Memorandum of Understanding between Government of Canada and Canadian Automakers
Fuel Combustion - Public Electricity and Heat Production	CO <sub>2</sub>	Government of Canada, ecoEnergy Initiatives (2007), NRCan (2006, 2007)	Utility deregulation continues to open markets and reduces barriers to interprovincial trade. Increased cogeneration to reduce fuel costs in the industrial sector in response to oil prices. Provincial programs to replace aging fossil fuel generating stations with nuclear, hydro, and other renewable sources. Significant interest in large new hydro projects in Manitoba, Ontario, Quebec, and Newfoundland and Labrador. Interest and investment in carbon capture and storage. Government programs and incentives to increase efficiency and reduce demand.
Waste - Solid Waste Disposal on Land	CH <sub>4</sub>	Environment Canada (1999, 2007)	Capture of CH <sub>4</sub> emitted landfills combustion or power generation: Policy measure.
Industrial Processes - Magnesium Production	SF <sub>6</sub>	Personal communication with J. Laperrière (2004)	Gradual replacement of SF <sub>6</sub> in magnesium casting and smelting by alternative cover gases: Voluntary measure
Cropland Remaining Cropland	CO <sub>2</sub>	See Chapter 7	Voluntary adoption of no till and reduced summerfallow by farmers does increase soil carbon stocks

#### A1.2.3.2 *High Emission Growth*

Table A1-5 shows key categories identified as a result of having emission and/or activity growth forecasts of over 20% between 1997 and 2020. Designation as key anticipates significant changes in the sector and indicates a need to establish sound estimating practices.

**Table A1-5: Key Categories Identified from Anticipated High Emission Growth**

Key Source	GHG	Reference	Comments
Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries	CO <sub>2</sub>	NRCan (1999)	Increased heavy oil production
Fuel Combustion - Petroleum Refining	CO <sub>2</sub>	NRCan (1999) NCCS (2000)	Increased heavy oil use
Fuel Combustion - Petroleum Refining	CO <sub>2</sub>	CPPI (2004)	Growth in emissions as a result of desulphurization initiatives for liquid fuels (for gasoline, diesel, and furnace oil)
Fuel Combustion - Road Transportation	CO <sub>2</sub>	NRCan (2006)	Growth in road transport
Fuel Combustion - Road Transportation	N <sub>2</sub> O	NRCan (2006)	Growth in road transport
Fuel Combustion - Road Transportation	CH <sub>4</sub>	NRCan (2006)	Growth in road transport
Fuel Combustion - Civil Aviation	CO <sub>2</sub>	NRCan (2006)	Growth in air travel
Fuel Combustion - Civil Aviation	N <sub>2</sub> O	NRCan (2006)	Growth in air travel
Fuel Combustion - Civil Aviation	CH <sub>4</sub>	NRCan (2006)	Growth in air travel
Fuel Combustion - Aviation Bunkers	CO <sub>2</sub>	NRCan (2006)	Growth in air travel
Fuel Combustion - Aviation Bunkers	N <sub>2</sub> O	NRCan (2006)	Growth in air travel
Fuel Combustion - Aviation Bunkers	CH <sub>4</sub>	NRCan (2006)	Growth in air travel
Fuel Combustion - Navigation (Marine)	CO <sub>2</sub>	NRCan (2006)	Growth in Navigation
Fuel Combustion - Navigation (Marine)	N <sub>2</sub> O	NRCan (2006)	Growth in Navigation
Fuel Combustion - Navigation (Marine)	CH <sub>4</sub>	NRCan (2006)	Growth in Navigation
Fuel Combustion - Marine Bunkers	CO <sub>2</sub>	NRCan (2006)	Growth in Navigation
Fuel Combustion - Marine Bunkers	N <sub>2</sub> O	NRCan (2006)	Growth in Navigation
Fuel Combustion - Marine Bunkers	CH <sub>4</sub>	NRCan (2006)	Growth in Navigation
Fuel Combustion - Other Transportation (Off-road)	CO <sub>2</sub>	NRCan (2006)	Growth in off-road use, especially fossil fuel mining
Consumption of HFCs and SF <sub>6</sub>	HFCs	HRAI (2008)	Increase due to replacement of CFCs

### *A1.2.3.3 High Uncertainty*

Although many updates have been made to the uncertainty source category since the initial studies of uncertainty associated with 2001 inventory estimates (ICF Consulting 2004, 2005), these studies still provide the majority of information on uncertainty levels. In these studies, uncertainties are reported following the UNFCCC CRF categories. Table A1-6 presents key categories identified as having a relatively high composite uncertainty, meaning both activity and emission factor uncertainties (refer to estimates in the tables of Annex 7 and, where relevant, updates in chapters 3–8).

**Table A1-6: Key Categories with a High Composite Uncertainty**

Key Category	GHG	Reference
Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries	CO <sub>2</sub>	ICF (2004)
Fuel Combustion - Petroleum Refining	CO <sub>2</sub>	ICF (2004)
Waste - Solid Waste Disposal on Land	CH <sub>4</sub>	ICF (2004)
Waste - Waste Incineration	CO <sub>2</sub>	ICF (2004)
Agriculture - Direct Agricultural Soils	N <sub>2</sub> O	ICF (2004)
Agriculture - Indirect Agricultural Soils	N <sub>2</sub> O	ICF (2004)
Waste - Wastewater Handling	N <sub>2</sub> O	ICF (2004)
Fuel Combustion - Other Transportation (Off-Road Diesel)	N <sub>2</sub> O	ICF (2004)
Fuel Combustion - Railways	N <sub>2</sub> O	ICF (2004)
Fuel Combustion - Road Transportation	CO <sub>2</sub>	ICF (2004)
Fuel Combustion - Road Transportation (Off-Road Diesel)	CO <sub>2</sub>	ICF (2004)
Fuel Combustion - Other Transportation (Off-Road Gasoline)	CO <sub>2</sub>	ICF (2004)
Fuel Combustion - Navigation (Marine)	N <sub>2</sub> O	ICF (2004)
Fuel Combustion - Civil Aviation	N <sub>2</sub> O	ICF (2004)
Fuel Combustion - Other Transportation (Off-Road Gasoline)	CH <sub>4</sub>	ICF (2004)
Industrial Processes - Other and Undifferentiated Production	CO <sub>2</sub>	ICF (2004)

#### *A1.2.3.4 Other Key Categories—Land Use, Land-Use Change and Forestry*

Following Good Practice Guidance for LULUCF (IPCC 2003), the qualitative assessment can also identify categories as key on the basis of other criteria. In the quantitative analysis, deforestation is divided into different land-use change categories—namely, Forest Land Converted to Cropland, Forest Land Converted to Wetlands, and Forest Land Converted to Settlements. Deforestation is identified as a key category in the national inventory because it is larger than the smallest key category identified in the quantitative analysis.

### **References**

- [CPPI] Canadian Petroleum Products Institute. 2004. Economic and Environmental Impacts of Removing Sulphur from Canadian Gasoline and Distillate Production. Prepared by Levelton Consultants Ltd. in association with Purvin & Gertz Inc. Calgary, Alberta, Canada. August.
- Environment Canada. 1999. Identification of Potential Landfill Sites for Additional Gas Recovery and Utilization in Canada. Prepared for Environment Canada by Conestoga-Rovers & Associates and the Delphi Group. July.
- Environment Canada. 2007. A Primer for Trading Greenhouse Gas Reductions from Landfills. Available online at: <http://www.ec.gc.ca/wmd-dgd/default.asp?lang=En&n=E67C32AF-1>
- Government of Canada. 2006. Canada's New Government Takes New Step to Protect the Environment with Biofuels. Available online at: [http://www.agr.gc.ca/cb/index\\_e.php?s1=n&s2=2006&page=n61220](http://www.agr.gc.ca/cb/index_e.php?s1=n&s2=2006&page=n61220)
- Government of Canada. 2007. ecoEnergy Initiatives. Available online at: <http://www.ecoaction.gc.ca/ecoenergy-ecoenergie/index-eng.cfm>.

[HRAI] Heating, Refrigeration and Air Conditioning Institute. 2008. HCFC Phase-Out Awareness. Mississauga, Ontario, Canada: Heating, Refrigeration and Air Conditioning Institute of Canada. Available online at: <http://www.hrai.ca/hcfcphaseout/phaseoutschedule.html>

ICF Consulting. 2004. Quantitative Assessment of Uncertainty in Canada's National GHG Inventory Estimates for 2001. Final report submitted to the Greenhouse Gas Division, Environment Canada, by ICF Consulting, September 2004.

ICF Consulting. 2005. Quantitative Assessment of Uncertainty in Canada's National GHG Inventory Estimates for 2001: Supplementary Analysis. Final report submitted to the Greenhouse Gas Division, Environment Canada, by ICF Consulting, March 2005.

[IPCC] Intergovernmental Panel on Climate Change. 2000. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at: <http://www.ipcc-nggip.iges.or.jp/public/gp/english/>

[IPCC] Intergovernmental Panel on Climate Change. 2003. Good Practice Guidance for Land Use, Land-Use Change and Forestry, Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at: <http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf.htm>

[NCCS] National Climate Change Secretariat. 2000. Canada's First National Climate Change Business Plan, Canada's National Climate Change Process. National Climate Change Secretariat.

[NRCan] Natural Resources Canada. 1999. Canada's Emissions Outlook: An Update. Report prepared for the Analysis and Modelling Group, National Climate Change Process, Natural Resources Canada. Available online at: <http://nrcan.gc.ca/es/ceo/update.htm>

[NRCan] Natural Resources Canada. 2006. Canada's Energy Outlook: The Reference Case 2006. Analysis and Modelling Group, Natural Resources Canada. Available online at: <http://www.nrcan.gc.ca/com/resoress/publications/peo/peo-eng.php>

[NRCan] Natural Resources Canada. 2007. Canadian CO<sub>2</sub> Capture & Storage Technology Network, Natural Resources Canada. Available online at: <http://www.co2network.gc.ca>

## Annex 2 Methodology and Data for Estimating Emissions from Fossil Fuel Combustion

The following presents an overview of the methodology, activity data, and emission factors used to estimate CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O emissions from fuel combustion sources for the Energy Sector. Additional methodological details and refinements to the general approach are presented in Section A2.4.1 for stationary sources and Section A2.4.2 for transport sources.

### A2.1 Methodology

In general, a top-down method following the Tier 3 and Tier 2 sectoral approach from the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997) is used to estimate GHG emissions from fuel combustion based on available quantity of fuel consumed at the source category level and country-specific emission factors. As illustrated by Equation A2-1, for each source category, the quantity of fuel at the national and/or provincial level of detail is multiplied by a specific emission factor. Further refinements and deviations from the general approach to estimating combustion emissions are discussed in the stationary combustion and transport sections of this annex (sections A2.4.1 and A2.4.2, respectively). The purpose of these refinements is to increase the accuracy and allocation of emissions associated with each source category when additional details or parameters are available; specific methodological issues are presented in the Energy section (Chapter 3) of this report.

**Equation A2-1 general fuel combustion equation:**

$$E_{Category,G} = FC_{F,R} \times EF_{G,F,R,T}$$

where:

- $E_{Category,G}$  = GHG emissions by source category and by gas.
- $FC_{F,R}$  = Quantity of fuel consumed (in physical units, such as kg, L, or m<sup>3</sup>) by type of fuel (i.e. natural gas, sub-bituminous coal, kerosene, etc.) and by region.
- $EF_{G,F,R,T}$  = Country-specific emission factor (in physical units) by GHG, by fuel type, by region for each coal type, and by technology (for non-CO<sub>2</sub> factors).

Relational databases are primarily used by the stationary and transport models to process the activity data and the emission factors at the national and/or provincial level of detail to estimate GHG emissions (Figure A2-1). The national energy balance is prepared by Statistics Canada. The fuel consumption and disposition data as reported by the producing and consuming sectors to Statistics Canada are in physical units rather than energy units. These data are considered more accurate, and country-specific emission factors were developed based on physical units so as to minimize the number of additional conversion factors and thus limit the uncertainty associated with the estimate. To further reduce the uncertainty of these estimates, when higher resolution emission factors at the regional level are available, then regional information is applied rather than national values (e.g. coal emission factors to account for the variation in the carbon content of coal over various regions and over time). Combustion technology differences are addressed by non-CO<sub>2</sub> emission factors.



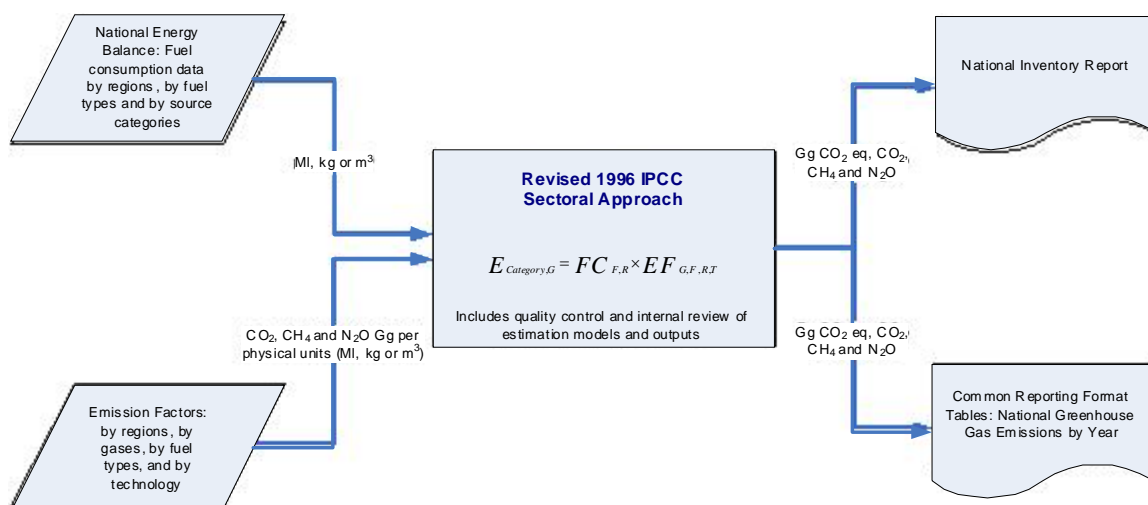


Figure A2-1: GHG Estimation Process Flow

## A2.2 Activity Data from Statistics Canada

The principal source of fossil fuel and energy data used to estimate combustion emissions is the annual Report on Energy Supply-Demand in Canada (RES-D, Statistics Canada #57-003). The RES-D uses a top-down approach to estimate the supply of and demand for energy in Canada. The production of fuels in Canada is balanced with the use of fuels in broad categories such as import/export, producer consumption, industry, and residential. Industrial energy-use data are divided into broad sectors based on the Standard Industrial Classification (SIC).

While the RES-D also provides fuel-use estimates at a provincial level, in general, the accuracy of these data is not as high as that of the national data. Statistics Canada generally collects the fuel data for the RES-D by surveying the suppliers of energy, provincial energy ministries, and some users of energy. The accuracy of the sectoral end-use data is less than that of the total energy supply data. As a result, the total emission estimates for Canada are known with more certainty than the emissions from specific categories. Since 1995, Statistics Canada has been collecting energy-use statistics from end users through the Annual Industrial Consumption of Energy Survey (ICE). This bottom-up approach to estimating fuel use by industry (as opposed to the top-down approach used in the RES-D) may provide more accurate information at the sectoral level for future inventories. Refer to Annex 4 for additional discussion on the development of the RES-D and the Industrial Consumption of Energy Survey data set, including a discussion on Statistics Canada's QA/QC activities.

As mentioned, the combustion model applies the quantity of fossil fuel consumed in physical units rather than in energy units, since this is how the information is reported to Statistics Canada by the reporting facilities following the *Statistics Act*. The quantities of fossil fuel consumed are also available in gross calorific units; however this is assumed to be less accurate, since an overall energy conversion factor was applied by Statistics Canada to the quantity of fuel consumed. The

accuracy of the estimates will decrease if emission estimates are based on energy units, as an overall energy conversion factor for different fuels over all source categories and regions is applied. The exception to this approach involves the quantity of still gas reported in the RESD. The physical units are back calculated from the reported energy values because of the different energy conversion factors used by Statistics Canada for still gas consumed by refineries or by upgrading facilities and volumetric quantities (liquid versus gaseous).

Additional activity data sources used by the combustion and transport models, such as landfill gas quantities and vehicle fleet information are included in the specific methodological discussions (sections A2.4.1 and A2.4.2).

### **A2.3 Fuel Combustion Emission Factors**

A description of emission factors employed in estimating the emissions for the current fossil fuel combustion models can be found in Annex 12. In general:

*Natural Gas Fuels:* The emission factors vary by fuel type and/or combustion technology.

*Refined Petroleum Products (RPP) Fuels:* The emission factors vary by fuel type and/or combustion technology.

*Coal Fuels:* The emission factors for CO<sub>2</sub> vary with the properties of the coal. Therefore, emission factors are assigned for different provinces based upon the origins of the coal used. The emission factors for CH<sub>4</sub> and N<sub>2</sub>O vary with the combustion technology.

#### **A2.3.1 CO<sub>2</sub> Emission Factors**

CO<sub>2</sub> emissions from fuel combustion activities depend upon the amount of fuel consumed, the carbon content of the fuel, and the fraction of the fuel oxidized (Jaques 1992). The basis of the CO<sub>2</sub> emission factor derivations has been discussed in previous publications (e.g. Jaques 1992). The factors have been obtained and developed from a number of studies conducted by Environment Canada, the U.S. EPA, and other domestic and international organizations. The methods used to derive the factors are based on the carbon contents of the fuels and the typical fraction of carbon oxidized. Both the hydrocarbons and particulate formed during combustion are accounted for to some extent, but emissions of CO are included in the estimates of CO<sub>2</sub> emissions. It is assumed that CO in the atmosphere undergoes complete oxidation to CO<sub>2</sub> shortly after combustion (within 5 to 20 weeks of its release).

The emission factors used in Canada's GHG inventory are based upon the physical quantity of fuel combusted, rather than on the energy content of the fuel. Emission factors based on the physical quantity of fuel combusted provide a more accurate estimate of emissions, since the number of conversions required to derive the estimates is minimized and since quantity of fuel consumed is reported in physical units to Canada's statistical agency (i.e. Statistics Canada). These Canadian-specific emission factors differ from those of the IPCC in that they relate emissions to the quantity of fuel consumed and not to the energy content of the fuel. The emission factors employed to estimate emissions are subdivided by the type of fuel used and, in the case of N<sub>2</sub>O and CH<sub>4</sub> emissions, the combustion technology employed.

### **A2.3.2 Non-CO<sub>2</sub> Emission Factors**

Emission factors for all non-CO<sub>2</sub> GHGs from combustion activities vary to a lesser or greater degree with:

- fuel type;
- technology;
- operating conditions; and
- maintenance and vintage of technology.

During combustion of carbon-based fuels, a small portion of the fuel remains unoxidized as CH<sub>4</sub>. Additional research is necessary to better establish CH<sub>4</sub> emission factors for many combustion processes. Overall factors are developed for sectors based on typical technology splits and available emission factors for the sector. In several sectors, CH<sub>4</sub> emission factors are not known.

During combustion, some of the nitrogen in the fuel and air is converted to N<sub>2</sub>O. The production of N<sub>2</sub>O is dependent upon the combustion temperature and the control technology employed. Additional research is necessary to better establish N<sub>2</sub>O emission factors for many combustion processes. Overall factors are developed for sectors based on typical technologies and available emission factors for the sector. In several sectors, N<sub>2</sub>O emission factors are not known. Non-CO<sub>2</sub> emission factors in this inventory are listed in Annex 12.

### **A2.3.3 Biomass**

For UNFCCC reporting, CO<sub>2</sub> emissions from biomass fuels (including landfill gas) are not to be included in the Energy Sector total. CO<sub>2</sub> emissions from biomass fuel combustion are accounted for in the LULUCF Sector as a loss of biomass (forest) stocks. CO<sub>2</sub> from biomass combustion for energy purposes is reported as a memo item for information only. CH<sub>4</sub> and N<sub>2</sub>O emissions from biomass fuel combustion are reported in the Energy Sector in the appropriate subsectors and included in inventory totals.

## ***A2.4 Methodology for Stationary Combustion and Transport***

### **A2.4.1 Stationary Combustion**

The methodology used to estimate GHG emissions from stationary fuel combustion are consistent with the IPCC Tier 2 sectoral approach along with country-specific emission factors as outlined in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997). The methodology and emissions of SF<sub>6</sub> from the transmission of electricity generation (CRF Category 1.A.1.a) are included in the Industrial Processes Sector.

The emissions are calculated based on nationally reported activity data, except when emission factors are available at the provincial/territorial level. In these instances, the provincial/territorial emissions are aggregated to a national total.

Table A2-1 presents a breakdown by source category of the application of activity data and emission factors. Discussions on assumptions of the estimation methodology for the following subsectors are also provided:

- Public Electricity and Heat Production;
- Fossil Fuel Industries;
- Manufacturing Industries and Construction;
- Other Sectors; and
- Pipelines.

Details on specific source categories are included in the notes section of Table A2-1. The complexity of the stationary combustion model lies in the allocation and distribution of the data presented in the RESD in order to comply with the UNFCCC CRF framework. Emission estimates are calculated based on Equation A2-1 exclusively and are consistent with the IPCC Tier 2 approach.

Table A2-1 presents the methodology and emission factors according to the fuel types presented in Table A2-2. Fossil fuels have been grouped based on their physical state at the point of consumption in terms of solid, liquid, and gaseous fuel, with the exception of biomass. For example, NGLs such as propane, ethane, and butane are classified as gaseous fuels, whereas petroleum coke is included under solid fuels.

**Table A2-1: Estimation Methodology for GHG Emissions from Stationary Combustion**

Source Category <sup>1</sup>	Fuels List	Activity Data Source <sup>2</sup>	Notes
1.A.1.a.i Electricity Generation - Utilities	Solid Fuels Coke Petroleum coke – Refineries & Others Coal: Canadian bituminous, sub-bituminous, lignite, anthracite, foreign bituminous	Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table F – Coal Details  Line 10 – Transformed to Other fuels: Electricity – by utilities	Canada total for CO <sub>2</sub> is the sum of all provinces' /territories' emissions due to regional emission factors being used EXCEPT for petroleum coke emissions, which are based on the national total reported in the RESD.  Canada totals for CH <sub>4</sub> and N <sub>2</sub> O are based on the national total reported in the RESD.
	Liquid Fuels Kerosene and stove oil, light fuel oil, heavy fuel oil, motor gasoline, diesel fuel oil, aviation gasoline, aviation turbo fuel	Table D – Refined Petroleum Products  Line 10 – Transformed to Other fuels: Electricity – by utilities	Canada totals for CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O are based the national total reported in the RESD.
	Gaseous Fuels Natural gas, coke oven gas Still gas – Refineries & Others Propane, butane, ethane	Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table 17 – Details of Natural Gas Liquids  Line 10 – Transformed to Other fuels: Electricity – by utilities	Canada totals for CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O are based the national total reported in the RESD.
	Biomass (NA)		
1.A.1.a.ii Electricity Generation - Industry	Solid Fuels Coke Petroleum coke – Refineries & Others Coal: Canadian bituminous, Sub-bituminous, lignite, anthracite, foreign bituminous	Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table F – Coal Details  Line 11 – Transformed to Other fuels: Electricity – by industry	Canada total for CO <sub>2</sub> is the sum of all provinces' /territories' emissions due to regional emission factors being used EXCEPT for petroleum coke emissions, which are based on the national total reported in the RESD.  Canada totals for CH <sub>4</sub> and N <sub>2</sub> O are based on the national total reported in the RESD.

Source Category <sup>1</sup>	Fuels List	Activity Data Source <sup>2</sup>	Notes
	Liquid Fuels Kerosene and stove oil, light fuel oil, heavy fuel oil, motor gasoline, diesel fuel oil, aviation gasoline, aviation turbo fuel	Table D - Refined Petroleum Products  Line 11 – Transformed to Other fuels: Electricity – by industry	Canada totals for CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O are based the national total reported in the RESD.
	Gaseous Fuels Natural gas, coke oven gas Still gas – Refineries & Others Propane, Butane, Ethane	Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table 17 – Details of Natural Gas Liquids  Line 11 – Transformed to Other fuels: Electricity – by industry	Canada totals for CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O are based the national total reported in the RESD.
	Biomass (NA)		
1.A.1.a.iii Heat & Steam Generation	Solid Fuels Coke Petroleum coke – Refineries & Others Coal: Canadian bituminous, sub-bituminous, lignite, anthracite, foreign bituminous	Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table F – Coal Details  Line 14 – Transformed to Other fuels: Steam generation	Canada total for CO <sub>2</sub> is the sum of all provinces'/territories' emissions due to regional emission factors being used. Canada total for CH <sub>4</sub> and N <sub>2</sub> O are based on the national total reported in the RESD.
	Liquid Fuels Kerosene and stove oil, light fuel oil, heavy fuel oil	Table D - Refined Petroleum Products  Line 14 – Transformed to Other fuels: Steam generation	Canada totals for CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O are based the national total reported in the RESD. Motor gasoline, diesel fuel oil, aviation gasoline, aviation turbo fuel not included in this subsector because there is no data reported in the table.
	Gaseous Fuels Natural gas, coke oven gas Still gas – Refineries & Others	Table B – Primary and Secondary Energy Table D – Refined Petroleum Products  Line 14 – Transformed to Other fuels: Steam generation	Canada totals for CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O are based the national total reported in the RESD.
	Biomass Landfill gas	Landfill gas utilization provided by Waste sector.	Canada totals for CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O are based the national total provided by the Waste sector. CO <sub>2</sub> emissions are not included in national totals but reported as a memo item.

Source Category <sup>1</sup>	Fuels List	Activity Data Source <sup>2</sup>	Notes
1.A.1.b. Petroleum Refining (Upstream & Downstream Oil and Gas Industries)	Solid Fuels Coke Petroleum coke – Refineries & Others Coal: Canadian bituminous, sub-bituminous, lignite, anthracite, foreign bituminous	Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table F – Coal Details  Line 25 – Petroleum refining  Table 21 – Estimated Additions to Still Gas, Diesel, Petroleum Coke and Crude Oil	Canada total for CO <sub>2</sub> is the sum of all provinces'/territories' emissions due to regional emission factors being used EXCEPT for petroleum coke emissions, which are based on the national total MINUS that used by crude bitumen upgraders reported in the RESD.  Canada total for CH <sub>4</sub> and N <sub>2</sub> O are based on the national total reported in the RESD.
	Liquid Fuels Kerosene & stove oil, light fuel oil, heavy fuel oil Motor gasoline, diesel fuel oil, aviation gasoline, aviation turbo fuel	Table D - Refined Petroleum Products  Line 25 – Petroleum refining  Oil flaring data from Fugitive Emissions model	Canada totals for CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O are based on the national total reported in the RESD MINUS emission related to flaring. The activity data reported in the RESD includes the amount fuel used to flare. CO <sub>2</sub> and CH <sub>4</sub> emissions from flaring activity is considered a fugitive source following the IPCC Guidelines, therefore the fugitive emission and fuel value is subtracted from the estimated emissions and the RESD value.  Due to a lack of resolution with the activity data (that is, the amount flared by refineries versus upgraders), negative values can occur when fugitives are subtracted (i.e., CH <sub>4</sub> emissions). Any residual fugitives are applied in the Manufacture of Solid Fuel and Other Energy Industries category.

Source Category <sup>1</sup>	Fuels List	Activity Data Source <sup>2</sup>	Notes
	Gaseous Fuels Natural gas, coke oven gas Still gas – Refineries & Others Propane, Butane, Ethane	Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table 17 – Details of Natural Gas Liquids  Line 25 – Petroleum refining  Table 21 – Estimated Additions to Still Gas, Diesel, Petroleum Coke and Crude Oil	Canada totals for CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O are based the national total reported in the RESD.
	Biomass (NA)		
1.A.1.c. Manufacture of Solid Fuels and Other Energy Industries	Solid Fuels Coke Petroleum coke – Upgraders Coal: Canadian bituminous, sub-bituminous, lignite, anthracite, foreign bituminous	Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table F – Coal Details  Line 16 – Producer consumed  Table 21 – Estimated Additions to Still Gas, Diesel, Petroleum Coke and Crude Oil	Canada total for CO <sub>2</sub> is the sum of all provinces'/territories' emission due to regional emission factors being used EXCEPT for petroleum coke – emissions, which are based on the national total USED BY upgraders reported in the RESD.  Canada totals for CH <sub>4</sub> and N <sub>2</sub> O are based on the national total reported in the RESD.
	Liquid Fuels (IE)	IE	Liquid fuels included in inventory elsewhere (1.A.1.b).
	Gaseous Fuels Natural gas, coke oven gas Still gas – upgraders Propane, Butane, Ethane	Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table 17 – Details of Natural Gas Liquids  Line 16 – Producer consumed  Table 21 – Estimated Additions to Still Gas, Diesel, Petroleum Coke and Crude Oil  Natural gas & other gas flaring data from Fugitive emissions model	The activity data for natural gas reported in the RESD includes the amount flared. Flared and vented emissions is considered a fugitive source, therefore both the fugitive emission and quantity of fuel associated with flaring and venting are subtracted from the estimated emissions and RESD value to avoid double counting, respectively. Any residual fugitive emissions from the petroleum refining subsector are applied to ensure no double counting.
	Biomass (NA)		



Source Category <sup>1</sup>	Fuels List	Activity Data Source <sup>2</sup>	Notes
1.A.2.a. Iron & Steel	Solid Fuels Coke Petroleum coke – Refineries & Others Coal: Canadian bituminous, sub-bituminous, lignite, anthracite, foreign bituminous	Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table F – Coal Details  Line 22 – Iron and steel	Canada total for CO <sub>2</sub> is the sum of all provinces'/territories' emissions due to regional emission factors being used EXCEPT for petroleum coke emissions, which are based on the national total reported in the RESD.  Canada totals for CH <sub>4</sub> and N <sub>2</sub> O are based on the national total reported in the RESD. CO <sub>2</sub> emissions from coke are not included here, but are included in Industrial Processes. However, CH <sub>4</sub> and N <sub>2</sub> O emissions are counted here. The CO <sub>2</sub> is considered part of the process (i.e. acts as a catalyst), while the CH <sub>4</sub> and N <sub>2</sub> O are byproducts of combustion.
	Liquid Fuels Kerosene and stove oil, light fuel oil, heavy fuel oil	Table D - Refined Petroleum Products  Line 22 – Iron and steel	Canada totals for CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O are based the national total reported in the RESD.  CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O associated with Transport fuels (i.e., gasoline and diesel) are included in the Transport subsector.
	Gaseous Fuels Natural gas, coke oven gas Still gas – Refineries & Others Propane, Butane, Ethane	Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table 17 – Details of Natural Gas Liquids  Line 22 – Iron and steel	Canada totals for CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O are based the national total reported in the RESD.
	Biomass (NA)		

Source Category <sup>1</sup>	Fuels List	Activity Data Source <sup>2</sup>	Notes
1.A.2.b. Non-Ferrous Metals	Solid Fuels Coke Petroleum coke – Refineries & Others Coal: Canadian bituminous, sub-bituminous, lignite, anthracite, foreign bituminous	Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table F – Coal Details  Line 23 – Smelting and refining, non-ferrous	Canada total for CO <sub>2</sub> is the sum of all provinces'/territories' emissions due to regional emission factors being used EXCEPT for petroleum coke emissions, which are based on the national total reported in the RESD. Canada total for CH <sub>4</sub> and N <sub>2</sub> O are based on the national total reported in the RESD.
	Liquid Fuels Kerosene and stove oil, light fuel oil, heavy fuel oil	Table D - Refined Petroleum Products  Line 23 – Smelting and refining, non-ferrous	Canada totals for CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O are based the national total reported in the RESD.  CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O associated with Transport fuels (i.e., gasoline and diesel) are included in the Transport subsector.
	Gaseous Fuels Natural gas, coke oven gas Still gas – Refineries & Others Propane, Butane, Ethane	Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table 17 – Details of Natural Gas Liquids  Line 23 – Smelting and refining, non-ferrous	Canada totals for CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O are based the national total reported in the RESD.
	Biomass (NA)		
1.A.2.c. Chemicals	Solid Fuels Coke Petroleum coke – Refineries & Others Coal: Canadian bituminous, sub-bituminous, lignite, anthracite, foreign bituminous	Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table F – Coal Details  Line 26 - Chemicals	Canada total for CO <sub>2</sub> is the sum of all provinces'/territories' emissions due to regional emission factors being used EXCEPT for petroleum coke emissions, which are based on the national total reported in the RESD.  Canada totals for CH <sub>4</sub> and N <sub>2</sub> O are based on the national total reported in the RESD.

Source Category <sup>1</sup>	Fuels List	Activity Data Source <sup>2</sup>	Notes
	Liquid Fuels Kerosene and stove oil, light fuel oil, heavy fuel oil	Table D - Refined Petroleum Products  Line 26 – Chemicals	Canada totals for CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O are based the national total reported in the RESD.  CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O associated with Transport fuels (i.e., gasoline and diesel) are included in the Transport subsector.
	Gaseous Fuels Natural gas, coke oven gas Still gas – Refineries & Others Propane, Butane, Ethane	Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table 17 – Details of Natural Gas Liquids  Line 26 - Chemicals	Canada totals for CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O are based the national total reported in the RESD.
	Biomass (NA)		
1.A.2.d. Pulp, Paper & Print	Solid Fuels Coke Petroleum coke – Refineries & Others Coal: Canadian bituminous, sub-bituminous, lignite, anthracite, foreign bituminous	Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table F – Coal Details  Line 21 – Pulp and paper	Canada total for CO <sub>2</sub> is the sum of all provinces'/territories' emission due to regional emission factors being used EXCEPT for petroleum coke emissions, which are based on the national total reported in the RESD.  Canada total for CH <sub>4</sub> and N <sub>2</sub> O are based on the national total reported in the RESD.
	Liquid Fuels Kerosene & stove oil, light fuel oil, heavy fuel oil	Table D - Refined Petroleum Products  Line 21 – Pulp and paper	Canada totals for CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O are based the national total reported in the RESD.  CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O associated with Transport fuels (i.e., gasoline and diesel) are included in the Transport subsector.
	Gaseous Fuels Natural gas, coke oven gas Still gas – Refineries & Others Propane, Butane, Ethane	Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table 17 – Details of Natural Gas Liquids  Line 21 – Pulp and paper	Canada totals for CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O are based the national total reported in the RESD.

Source Category <sup>1</sup>	Fuels List	Activity Data Source <sup>2</sup>	Notes
	Biomass Spent pulping liquor, solid wood waste	Table 20 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption	Total biomass is the amount of Solid Wood Waste and Spent Pulping Liquors combusted. Canada totals for CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O are based the national total reported in the RESD. Biomass CO <sub>2</sub> emissions are not included in the national totals although CH <sub>4</sub> and N <sub>2</sub> O emissions are.
1.A.2.e. Food Processing, Beverages and Tobacco	Solid Fuels	IE	Emissions for this subsector are included 1.A.2.f.iv. Other Manufacturing.
	Liquid Fuels	IE	Emissions for this subsector are included 1.A.2.f.iv. Other Manufacturing.
	Gaseous Fuels	IE	Emissions for this subsector are included 1.A.2.f.iv. Other Manufacturing.
	Biomass	IE	Emissions for this subsector are included 1.A.2.f.iv. Other Manufacturing.
1.A.2.f.i. Cement	Solid Fuels Coke Petroleum coke – Refineries & Others Coal: Canadian bituminous, sub- bituminous, lignite, anthracite, foreign bituminous	Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table F – Coal Details  Line 24 – Cement	Canada total for CO <sub>2</sub> is the sum of all provinces'/territories' emission due to regional emission factors being used EXCEPT for petroleum coke emissions, which are based on the national total reported in the RESD.  Canada totals for CH <sub>4</sub> and N <sub>2</sub> O are based on the national total reported in the RESD.
	Liquid Fuels Kerosene and stove oil, light fuel oil, heavy fuel oil	Table D - Refined Petroleum Products  Line 24 – Cement	Canada totals for CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O are based the national total reported in the RESD.  CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O associated with Transport fuels (i.e., gasoline and diesel) are included in the Transport subsector.

Source Category <sup>1</sup>	Fuels List	Activity Data Source <sup>2</sup>	Notes
	Gaseous Fuels Natural gas, coke oven gas Still gas – Refineries & Others Propane, Butane, Ethane	Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table 17 – Details of Natural Gas Liquids  Line 24 – Cement	Canada totals for CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O are based the national total reported in the RESD.
	Biomass (NA)		
1.A.2.f.ii. Mining	Solid Fuels Coke Petroleum coke – Refineries & Others Coal: Canadian bituminous, sub-bituminous, lignite, anthracite, foreign bituminous	Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table F – Coal Details  Line 20 – Total mining & oil & gas extraction	Canada total for CO <sub>2</sub> is the sum of all provinces'/territories' emission due to regional emission factors being used EXCEPT for petroleum coke emissions, which are based on the national total reported in the RESD. Mining according to the RESD includes fuel consumed for mining and extraction of oil and gas.  Canada total for CH <sub>4</sub> and N <sub>2</sub> O are based on the national total reported in the RESD.
	Liquid Fuels Kerosene and stove oil, light fuel oil, heavy fuel oil	Table D - Refined Petroleum Products  Line 20 – Total mining & oil & gas extraction	Canada totals for CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O are based the national total reported in the RESD.  CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O associated with Transport fuels (i.e., gasoline and diesel) are included in the Transport subsector.
	Gaseous Fuels Natural gas, coke oven gas Still gas – Refineries & Others Propane, Butane, Ethane	Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table 17 – Details of Natural Gas Liquids  Line 20 – Total mining & oil & gas extraction	Canada totals for CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O are based the national total reported in the RESD.
	Biomass (NA)		

Source Category <sup>1</sup>	Fuels List	Activity Data Source <sup>2</sup>	Notes
1.A.2.f.iii. Construction	Solid Fuels Coke Petroleum coke – Refineries & Others Coal: Canadian bituminous, sub-bituminous, lignite, anthracite, foreign bituminous	Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table F – Coal Details  Line 30 - Construction	Canada total for CO <sub>2</sub> is the sum of all provinces'/territories' emission due to regional emission factors being used EXCEPT for petroleum coke emissions, which are based on the national total reported in the RESD.  Canada total for CH <sub>4</sub> and N <sub>2</sub> O are based on the national total reported in the RESD.
	Liquid Fuels Kerosene and stove oil, light fuel oil, heavy fuel oil	Table D - Refined Petroleum Products  Line 30 – Construction	Canada totals for CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O are based the national total reported in the RESD. CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O associated with Transport fuels (i.e., gasoline and diesel) are included in the Transport subsector.
	Gaseous Fuels Natural gas, coke oven gas Still gas – Refineries & Others Propane, Butane, Ethane	Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table 17 – Details of Natural Gas Liquids  Line 30 – Construction	Canada totals for CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O are based the national total reported in the RESD.
	Biomass (NA)		
1.A.2.f.iv. Other Manufacturing	Solid Fuels Coke Petroleum coke – Refineries & Others Coal: Canadian bituminous, sub-bituminous, lignite, anthracite, foreign bituminous	Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table F – Coal Details  Line 27 – Other manufacturing	A weighted emission factor is calculated for all three GHGs based on fuel consumption and applied on an annual basis.
	Liquid Fuels Kerosene and stove oil, light fuel oil, heavy fuel oil	Table D - Refined Petroleum Products  Line 27 – Other manufacturing	A weighted emission factor is calculated for all three GHGs based on fuel consumption and applied on an annual basis.  CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O associated with Transport fuels (i.e., gasoline and diesel) are included in the Transport subsector.

Source Category <sup>1</sup>	Fuels List	Activity Data Source <sup>2</sup>	Notes
	Gaseous Fuels Natural gas, coke oven gas Still gas – Refineries & Others Propane, Butane, Ethane	Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table 17 – Details of Natural Gas Liquids  Line 27 – Other manufacturing	A weighted emission factor is calculated for all three GHGs based on fuel consumption and applied on an annual basis.  A weighted emission factor is calculated for all three GHGs and applied on an annual basis.
	Biomass (NA)		
1.A.3.e. Pipelines (Transport)	Solid Fuels Coke Petroleum coke – Refineries & Others Coal: Canadian bituminous, sub-bituminous, lignite, anthracite, foreign bituminous	Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table F – Coal Details  Line 39 - Pipelines	Canada total for CO <sub>2</sub> is the sum of all provinces'/territories' emissions due to regional emission factors being used. Canada totals for CH <sub>4</sub> and N <sub>2</sub> O are based on the national total reported in the RESD.
	Liquid Fuels Kerosene and stove oil, light fuel oil, heavy fuel oil Motor gasoline, diesel fuel oil, aviation gasoline, aviation turbo fuel	Table D - Refined Petroleum Products  Line 39 – Pipelines	Canada totals for CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O are based the national total reported in the RESD.
	Gaseous Fuels Natural gas, coke oven gas Still gas – Refineries & Others Propane, butane, ethane	Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table 17 – Details of Natural Gas Liquids  Line 39 – Pipelines	Canada totals for CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O are based the national total reported in the RESD.
	Biomass (NA)		
1.A.4.a.i. Commercial and Other Institutional	Solid Fuels Coke Petroleum coke – Refineries & Others Coal: Canadian bituminous, sub-bituminous, lignite, anthracite, foreign bituminous	Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table F – Coal Details  Line 46 – Commercial and institutional	Canada total for CO <sub>2</sub> is the sum of all provinces'/territories' emissions due to regional emission factors being used. Canada totals for CH <sub>4</sub> and N <sub>2</sub> O are based on the national total reported in the RESD.

Source Category <sup>1</sup>	Fuels List	Activity Data Source <sup>2</sup>	Notes
	Liquid Fuels Kerosene and stove oil, light fuel oil, heavy fuel oil	Table D - Refined Petroleum Products  Line 46 – Commercial and institutional	Canada totals for CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O are based the national total reported in the RESD.  CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O associated with Transport fuels (i.e., gasoline and diesel) are included in the Transport subsector.
	Gaseous Fuels Natural gas, coke oven gas Still gas – Refineries & Others Propane, Butane, Ethane	Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table 17 – Details of Natural Gas Liquids  Line 46 – Commercial and institutional	Canada totals for CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O are based the national total reported in the RESD.
	Biomass (NA)		
1.A.4.a.ii. Public Administration	Solid Fuels Coke Petroleum coke – Refineries & Others Coal: Canadian bituminous, sub-bituminous, lignite, anthracite, foreign bituminous	Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table F – Coal Details  Line 45 – Public administration	Canada total for CO <sub>2</sub> is the sum of all provinces'/territories' emissions due to regional emission factors being used. Canada totals for CH <sub>4</sub> and N <sub>2</sub> O are based on the national total reported in the RESD.
	Liquid Fuels Kerosene and stove oil, light fuel oil, heavy fuel oil	Table D - Refined Petroleum Products  Line 45 – Public administration	Canada totals for CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O are based the national total reported in the RESD.  CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O associated with Transport fuels (i.e., gasoline and diesel) are included in the Transport subsector.
	Gaseous Fuels Natural gas, coke oven gas Still gas – Refineries & Others Propane, butane, ethane	Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table 17 – Details of Natural Gas Liquids  Line 45 – Public administration	Canada totals for CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O are based the national total reported in the RESD.
	Biomass (NA)		



Source Category <sup>1</sup>	Fuels List	Activity Data Source <sup>2</sup>	Notes
1.A.4.b. Residential	Solid Fuels Coke Petroleum coke – Refineries & Others Coal: Canadian bituminous, sub-bituminous, lignite, anthracite, foreign bituminous	Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table F – Coal Details  Line 44 - Residential	Canada total for CO <sub>2</sub> is the sum of all provinces'/territories' emission due to regional emission factors being used. Canada totals for CH <sub>4</sub> and N <sub>2</sub> O are based on the national total reported in the RESD.
	Liquid Fuels Kerosene and stove oil, light fuel oil, heavy fuel oil	Table D - Refined Petroleum Products  Line 44 – Residential	Canada totals for CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O are based the national total reported in the RESD.
	Gaseous Fuels Natural gas, coke oven gas Still gas – Refineries & Others Propane, butane, ethane	Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table 17 – Details of Natural Gas Liquids  Line 44 – Residential	Canada totals for CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O are based the national total reported in the RESD.
	Biomass Residential firewood	Firewood consumption estimated by Residential Fuelwood model.	Total biomass is the amount of Residential fuelwood combusted and is based on Environment Canada's survey data. CO <sub>2</sub> emissions are not included in the national totals but CH <sub>4</sub> and N <sub>2</sub> O emissions are.
1.A.4.c.i. Forestry	Solid Fuels Coke Petroleum coke – Refineries & Others Coal: Canadian bituminous, sub-bituminous, lignite, anthracite, foreign bituminous	Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table F – Coal Details  Line 29 – Forestry	Canada total for CO <sub>2</sub> is the sum of each provinces/territories emission due to regional emission factors being used. Canada total for CH <sub>4</sub> and N <sub>2</sub> O are based on the national total reported in the RESD.
	Liquid Fuels Kerosene and stove oil, light fuel oil, heavy fuel oil	Table D – Refined Petroleum Products  Line 29 – Forestry	Canada totals for CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O are based the national total reported in the RESD.  CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O associated with Transport fuels (i.e., gasoline and diesel) are included in the Transport subsector.

Source Category <sup>1</sup>	Fuels List	Activity Data Source <sup>2</sup>	Notes
	Gaseous Fuels Natural gas, coke oven gas Still gas – Refineries & Others Propane, butane, ethane	Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table 17 – Details of Natural Gas Liquids  Line 29 – Forestry	Canada totals for CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O are based the national total reported in the RESD.
	Biomass (NA)		
1.A.4.c.ii. Agriculture	Solid Fuels Coke Petroleum coke – Refineries & Others Coal: Canadian bituminous, sub-bituminous, lignite, anthracite, foreign bituminous	Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table F – Coal Details  Line 43 – Agriculture	Canada total for CO <sub>2</sub> is the sum of all provinces'/territories' emission due to regional emission factors being used. Canada totals for CH <sub>4</sub> and N <sub>2</sub> O are based on the national total reported in the RESD.
	Liquid Fuels Kerosene and stove oil, light fuel oil, heavy fuel oil	Table D - Refined Petroleum Products  Line 43 – Agriculture	Canada totals for CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O are based the national total reported in the RESD.  CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O associated with Transport fuels (i.e., gasoline and diesel) are included in the Transport subsector.
	Gaseous Fuels Natural gas, coke oven gas Still gas – Refineries & Others Propane, butane, ethane	Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table 17 – Details of Natural Gas Liquids  Line 43 – Agriculture	Canada totals for CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O are based the national total reported in the RESD.
	Biomass (NA)		
1.A.5. Other Information (not included elsewhere)	Included elsewhere (IE)	IE	Emissions for this subsector are included 1.A.2.f.iv. Other Manufacturing.

## Notes:

1. CRF categories listed are the lowest-level subsectors for which emissions are estimated.
2. Activity data refers to the specific location of the data in the RESD (Statistics Canada #57-003).
3. NA = not applicable
4. IE = Included elsewhere

**Table A2-2: General Fuel Type Categories for Stationary Combustion Methodology**

<b>Fuel Types</b>	<b>Fuels</b>
Liquid Fuels	Motor gasoline Kerosene and stove oil Diesel fuel oil Light fuel oil Heavy fuel oil Aviation gasoline Aviation turbo fuel
Solid Fuels	Coke (coal) Canadian bituminous Sub-bituminous (foreign & domestic) Lignite Anthracite Foreign bituminous Petroleum coke—Refineries & Others Petroleum coke—Upgraders
Gaseous Fuels	Natural gas Coke oven gas Propane Butane Ethane Still gas—Refineries & Others Still gas—Upgraders
Biomass	Solid wood waste Spent pulping liquor Residential firewood Landfill gas

Activity data sources are presented in Table A2-3 for reference in the stationary combustion model methodology. The data are made available to Environment Canada in electronic format and may differ slightly when compared with Statistics Canada's rounded, published values.

**Table A2-3: Activity Data Model References**

<b>Title</b>
<p>Statistics Canada—Manufacturing, Construction and Energy Division; <i>Report on Energy Supply—Demand in Canada</i> (RES-D), #57-003-XPB.</p> <p>Table B—Primary and Secondary Energy</p> <p>Table D—Refined Petroleum Products</p> <p>Table E—Non-Energy Refined Petroleum Products</p> <p>Table F—Coal Details</p> <p>Table 17—Details of Natural Gas Liquids</p> <p>Table 20—Solid Wood Waste and Spent Pulping Liquor</p> <p>Table 21—Estimated Additions to Still Gas, Diesel, Petroleum Coke and Crude Oil</p> <p>Fugitive Emissions Model—Based on: King, B. (1994), <i>Management of Methane Emissions from Coal Mines: Environmental, Engineering, Economic and Institutional Implications of Options</i>, Report prepared for Environment Canada by Neill and Gunter Ltd.</p> <p>Residential Fuelwood Consumption—Based on: Environment Canada (1999), <i>1995 Criteria Contaminants Emissions Inventory Guidebook</i>, Version 1, Section 2.4, National Emissions Inventory and Projections Task Group, Criteria Air Contaminants Division, Environment Canada, March.</p> <p>Landfill Gas Utilization – See Annex 3 Additional Methodologies.</p>

#### *A2.4.1.1 Public Electricity and Heat Production (CRF Category 1.A.1.a)*

The Public Electricity and Heat Production sector include the subsectors 1.A.1.a.i Electricity Generation, 1.A.1.a.ii Combined Heat and Power Generation, and 1.A.1.a.iii Heat Plants. This sector should include all emissions from main activity producers (previously known as public utilities) of electricity generation, combined heat and power generation, and heat plants. However, the data resolution that is currently available in the RESD does not distinguish between electricity and heat generated by industry for its own use and the amount that is supplied to the public. Currently, emissions associated with the combustion of landfill gas are included under 1.A.1.a.iii Heat Plants.

CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O emissions are estimated by applying Equation A2-1 to activity data and emission factors for specific fuels on a national basis. Coal emission factors for these sectors have been developed on a regional basis. As previously discussed, nationally reported activity data are of a higher quality than provincial/territorial data. In order to obtain higher accuracy in GHG emissions, regional emission factors are applied to provincial/territorial data in this circumstance. For the remaining fuels, the emission factors are applied to the nationally reported data.

#### *A2.4.1.2 Fossil Fuel Industries (CRF Categories 1.A.1.b & 1.a.1.c)*

The Fossil Fuel Industries include 1.A.1.b Petroleum Refining and 1.a.1.c Manufacture of Solid Fuels and Other Energy Industries. The emission total for the Fossil Fuel Industries has a higher level of accuracy owing to the resolution of the activity data. To meet the reporting requirements of the CRF category, assumptions were applied to reallocate some of the activity data for the industry as a whole into two separate categories. These categories include combustion emissions that support the production and processing of 1) crude oil and 2) gaseous and solid fuels. The methodology for estimating emissions from these sectors involves applying Equation A2-1 on a national basis and subtracting emissions associated with flaring from the total GHG emissions for each category. The fuel-use data reported in the RESD include volumes of flared fuels; however, flaring emissions are calculated and reported separately in the fugitive category. The fuel use, energy content, and emission data associated with flaring are subtracted to avoid double counting.

To determine the activity data associated with the Petroleum Refining sector, some data reported in the RESD must be reallocated. All RPPs that are reported as producer consumed are allocated to the Petroleum Refining sector based on the assumption that they are consumed by the producers. Calculating the emissions associated with the fuels listed below involves summing the activity data reported under petroleum refining and producer consumed and applying Equation A2-1:

- petroleum coke;
- still gas;
- kerosene;
- light fuel oil;
- heavy fuel oil;
- propane;
- butane; and
- ethane.

To estimate emissions for the Petroleum Refining sector for the transportation fuels listed below, the activity data reported under producer consumed are used in Equation A2-1 and the emissions are included under Petroleum Refining. Emissions associated with these fuels are not included in the Manufacture of Solid Fuels and Other Energy Industries sector:

- gasoline;
- diesel fuel oil;
- aviation gasoline; and
- aviation turbo fuel.

The IPCC default emission factors for N<sub>2</sub>O are used to estimate emissions for petroleum coke and motor gasoline and are based on the calorific value of the fuel. The GCV for petroleum coke is reported in the RESD and can change annually. As such, the emission factor for petroleum coke for both oil sands/crude bitumen production and refineries changes on an annual basis. The conversion between GCV and net calorific value (NCV) is based on data reported to and published by the Canadian Industrial Energy End-use Data Analysis Centre (CIEEDAC).

To calculate GHG emissions from the Manufacture of Solid Fuels and Other Energy Industries sector, activity data for the following fuels reported as producer consumed in the RESD are used in Equation A2-1:

- natural gas; and
- coal.

The following fuels are reported as producer-consumed in the oil sands/crude bitumen production industry in the RESD. These amounts are subtracted from the Petroleum Refining sector and included in the Manufacture of Solid Fuels and Other Energy Industries sector. Consumption of both fuels is reported in a separate table in the RESD and allocated to upgrading facilities:

- petroleum coke; and
- still gas.

As previously mentioned in Section A.2.4.1.1, coal emissions are estimated at a provincial/territorial level and aggregated to a national level. To avoid double counting, the emissions associated with natural gas flaring are subtracted from the total for this sector.

#### *A2.4.1.3 Manufacturing Industries and Construction (CRF Category 1.A.2)*

The Manufacturing Industries and Construction sector includes a number of subsectors and industries. Activity data in the RESD are reported for the main economic and fuel-consuming industrial categories. Future improvement to the RESD will allow for further disaggregation of these industrial categories to be consistent with the NAICS.

Emissions are calculated for the following categories:

- Mining;
- Iron and Steel;
- Non-Ferrous Metals;

- Chemicals;
- Pulp, Paper, and Print;
- Cement;
- Construction; and
- Other Manufacturing (includes Food Processing, Beverages, and Tobacco).

GHG emissions associated with the Manufacturing Industries and Construction sector are calculated by applying Equation A2-1 to activity data reported in the RESD and emission factors for specific fuels on a national basis. Coal emissions are handled as described in Section A.2.4.1.1. Emissions resulting from fuels used as feedstocks are reported under the Industrial Processes Sector, whereas emissions generated from the use of transportation fuels (e.g. diesel and gasoline) are reported under the Transport sector.

CO<sub>2</sub> emissions associated with the use of metallurgical coke in the iron and steel industry for the reduction of iron ore in blast furnaces have been allocated to the Industrial Processes Sector. CH<sub>4</sub> and N<sub>2</sub>O emissions, however, are included, as they are by-products of the combustion process.

CO<sub>2</sub> emissions associated with biomass combustion in the Pulp, Paper, and Print sector are not included in the national totals; however, CH<sub>4</sub> and N<sub>2</sub>O emissions are included in the totals. Industrial consumption of biomass and spent pulping liquors is reported in the RESD. It is assumed that solid wood waste is reported on a wet weight basis and that the average moisture content is 50%.

#### *A2.4.1.4 Other Sectors (CRF Category 1.A.4)*

The Other Sectors subsector consists of three categories: Commercial/Institutional, Residential, and Agriculture/Forestry/Fisheries. GHG emissions associated with the Other Sectors subsector are calculated by applying Equation A2-1 to activity data reported in the RESD and emission factors for specific fuels on a national basis.

CO<sub>2</sub> emissions associated with biomass combustion in the Residential category are not included in the national total; however, CH<sub>4</sub> and N<sub>2</sub>O emissions are included. Further detail on estimating CO<sub>2</sub> emissions from biomass is presented in the Residential Firewood section (Section 3.4.2.1) of Chapter 3.

The Agriculture/Forestry/Fisheries category (CRF Category 1.A.4.c) includes emissions from stationary fuel combustion only from the agricultural and forestry industries. Emissions are from on-site machinery operation and from space heating and are estimated based on fuel use data for agriculture and forestry as reported in the RESD. Fishery emissions are reported under either the Transportation or Other Manufacturing (i.e. food processing) category. Mobile emissions associated with this category are not disaggregated and are included as off-road or marine emissions reported under Transport.

#### **A2.4.2 Transport (CRF Category 1.A.3)**

GHG emissions from the Transport subsector are divided into five categories:

- Civil Aviation (Domestic Aviation);
- Road Transportation;

- Railways;
- Navigation (Domestic Marine); and
- Other Transportation (Off-Road and Pipelines).

Emission estimates are developed at the provincial/territorial level and aggregated to the national level.

Fuel combustion emissions associated with the Transport sector are calculated using various adaptations of Equation A2-1.

CO<sub>2</sub> emissions are predominantly dependent on the type and characteristics of fuel being combusted, whereas N<sub>2</sub>O and CH<sub>4</sub> emissions are dependent on both the fuel combusted and emission control technologies present. Annex 12 provides a complete listing of transportation-related emission factors and their specific references.

Owing to the complexity of the Transport sector, Canada's Mobile Greenhouse Gas Emission Model (MGEM) is used to calculate the emissions from aviation, road transportation, railways, navigation, and off-road. The combustion emissions associated with pipeline transport are estimated separately.

#### *A2.4.2.1 Road Transportation (CRF Category 1.A.3.b)*

The methodology used to estimate Road Transportation GHG emissions follows a detailed IPCC Tier 3 approach.

### **Step 1: Activity Data—Vehicle Populations, Technology Penetration, Catalyst Survival Rate, Fuel Consumption Ratios, and Vehicle Kilometres Travelled**

#### ***Vehicle Populations***

Vehicles are separated into different classes depending on their fuel type, body configuration (car versus truck), and gross vehicle weight rating (GVWR). GVWR is the maximum allowable weight of a fully loaded road vehicle, including the weight of the vehicle, fuel, passengers, cargo, and other miscellaneous items, including optional accessories.

Two distinct data sets are used to develop a complete vehicle population profile. Light-duty vehicle and truck populations for 1990–2002 were obtained from the Canadian Vehicles in Operation Census, which is maintained by DesRosiers Automotive Consultants Inc. Light-duty vehicle and truck populations for 2003–2006 were estimated based on observed trends. Heavy-duty vehicle populations were obtained from R.L. Polk & Co. for 1994–2002. Heavy-duty vehicle populations for 1990–1993 and 2003–2006 were estimated based on historical populating trends. Light-duty vehicles (cars) and light-duty trucks (pickups, minivans, SUVs, etc.) are those with a GVWR less than or equal to 3900 kg, whereas heavy-duty classes have a GVWR above 3900 kg.

Motorcycle populations for 1990–2006 were obtained from the Motorcycle & Moped Industry Council (MMIC 2003).

#### ***Technology Penetration***

To account for the effects that emission control technologies have on emissions of CH<sub>4</sub> and N<sub>2</sub>O, estimates of the number of vehicles on the road equipped with catalytic converters and other

control technologies were developed. Figure A2-2 illustrates the varying penetration percentages of evolving technologies into the new LDGVs and LDGTs in successive model years. Technology penetration for HDGVs, HDDVs, light-duty diesel vehicles (LDDVs), light-duty diesel trucks (LDDTs), and motorcycles (MCs) are detailed in Table A2-4 (EPA 2007).

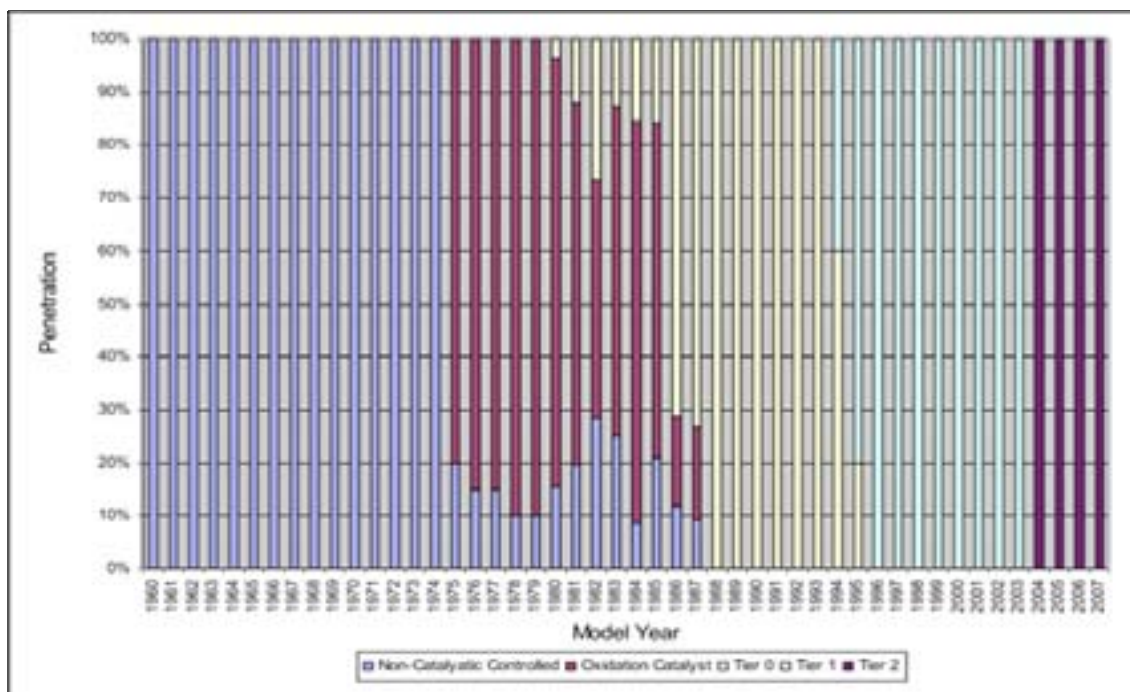


Figure A2-2: Technology Penetration for Light-Duty Gasoline Vehicles and Trucks

Table A2-4: Technology Penetration for HDGVs, HDDVs, LDDVs, LDDTs, and MCs

Control Technology	Model years
<b>Heavy-Duty Gasoline Vehicles (HDGVs)</b>	
Uncontrolled	1960–1984
Non-Catalytic Controlled	1985–1995
Three-Way Catalyst	1996–2007
<b>Heavy-Duty Diesel Vehicles (HDDVs)</b>	
Uncontrolled	1960–1982
Moderate Controls	1983–1995
Advanced Controls	1996–2007
<b>Light-Duty Diesel Vehicles &amp; Trucks (LDDVs &amp; LDDTs)</b>	
Uncontrolled	1960–1982
Moderate Controls	1983–1995
Advanced Controls	1996–2003
Tier 2	2004–2007
<b>Motorcycles (MCs)</b>	
Uncontrolled	1960–1995
Non-Catalytic Controlled	1996–2007



### ***Catalyst Survival Rate***

With use, catalytic converters deteriorate, affecting tailpipe emission rates. Based on information from industry experts, a technology-specific deterioration rate is applied to LDGVs and LDGTs with catalytic controlled technologies. To model the deterioration effect, the vehicles with deteriorated catalysts are assigned to the Non-Catalytic Controlled technology. For provinces with inspection and maintenance (I/M) programs (Ontario and British Columbia), the catalyst survival rate is not applied to Tier 0, Tier 1, or Tier 2 technologies, as these emission control technologies are inspected and replaced or repaired as necessary.

### ***Fuel Consumption Ratios***

Average provincial fuel consumption ratios (FCRs) by vehicle class and model year (based on provincial vehicle sales) are available for LDGVs and LDGTs (NRCan 2006). FCRs for LDDVs and LDDTs (NRCan 2006) and HDGVs (IPCC/OECD/IEA 1997) are based on a vehicle class and model year average. HDDV and motorcycle FCRs are based on a yearly fleet average (NRCan 2006).

Laboratory FCRs are determined by standardized vehicle emission tests. However, research has shown that real-world fuel consumption is consistently higher than laboratory-generated data. Based on studies performed in the United States, on-road vehicle fuel consumption figures in MGEM have been adjusted to 25% above the laboratory FCR ratings (Maples 1993).

### ***Vehicle Kilometres Travelled***

Vehicle kilometres travelled (VKTs), a measure of the annual kilometres travelled. For light-duty cars and trucks, VKTs are estimated based on a report examining the difference in odometer readings taken from these vehicles in successive I/M tests in Ontario (Stewart Brown Associates 2004). Since VKTs by vehicle class and vehicle age are not available for the other provinces and territories, the Ontario VKT data are applied to all provinces and territories in Canada.

## **Step 2: On-Road Fuel Calculation**

On-road gasoline and diesel consumption is estimated using Equation A2-2:

**Equation A2-2:**

$$\text{Fuel Consumption} = \text{Population} \times \text{VKT} \times \text{FCR}$$

For the most part, these parameters are different for each province, vehicle class, model year, and inventory year. On-road vehicles are grouped into seven major vehicle classes, identical to those used by the U.S. EPA in its MOBILE Emissions Factor Model. The EPA designations are

- LDGVs;
- LDGTs;
- HDGVs;
- MCs;
- LDDVs;
- LDDTs; and
- HDDVs.

It is assumed that all natural gas and propane fuel is consumed by light-duty vehicles. No breakdown by vehicle classification is utilized for natural gas and propane vehicles.

### **Step 3: Normalization**

In an effort to improve the allocation of diesel and gasoline between on- and off-road applications, a balancing algorithm has been incorporated into MGEM. This algorithm attempts to reconcile the fuel reportedly consumed by fuel surveys and the fuel consumption calculated by MGEM.

#### ***Gasoline***

The first on-road gasoline estimate is calculated in step 2 and represents a “bottom-up” estimate based upon vehicle population, FCRs, and VKTs.

The second estimate is based on the “top-down” gross and taxed gasoline sales reported by Statistics Canada (CANSIM Table 405-0002). This survey polls individual provinces for their retail and non-retail fuel sales. The value reported as “gross gasoline sales” (taxed plus non-taxed) is adjusted to equal the total gasoline available for transport as reported in the RESD (Statistics Canada #57-003). That same adjustment is then applied to the taxed gasoline sales and becomes the second or “top-down” on-road gasoline estimate.

At a provincial level, the top-down and bottom-up gasoline consumption estimates differ slightly; however, on a national level, there is a high degree of correlation between the two estimates. If the bottom-up estimate is larger than the top-down one, the adjusted taxed sales are taken as the final on-road gasoline estimate. If the top-down estimate exceeds the bottom-up estimate, the average of the two estimates is taken as the final on-road gasoline estimate.

#### ***Diesel Oil***

The first on-road diesel estimate is calculated in step 2 (bottom-up).

The second estimate (top-down) is based on taxed diesel sales reported by Statistics Canada (CANSIM Table 405-0002).

At a provincial level, the two estimates of on-road diesel consumption differ slightly; however, on a national level, there is a high degree of correlation between the two estimates. If the first on-road diesel estimate is larger than the second estimate, the taxed sales are taken as the final on-road diesel estimate. If the second estimate is larger than the first estimate, the average of the two estimates is taken as the final on-road diesel estimate.

### **Step 4: On-Road Emission Calculation**

Emission estimates are based on fuel type, the total fuel consumed, and the appropriate emission factor.

Emissions are calculated using Equation A2-1.

#### **A2.4.2.2      *Off-Road (CRF Category I.A.3.e)***

The methodology used to estimate GHG emissions from off-road transportation follows a simple IPCC Tier 1 approach.

## Step 1: Off-Road Fuel Calculation

Off-road fuel is calculated using Equation A2-3:

### Equation A2-3:

$$\text{Off-Road Fuel Consumption} = \text{Fuel Available for Transportation} - \text{On-Road Fuel Consumption}$$

## Step 2: Off-Road Emission Calculation

Emission estimates are based on fuel type, the total fuel consumed, and an emission factor.

Emissions are calculated using Equation A2-1.

### A2.4.2.3 *Civil Aviation (Domestic Aviation) (CRF Category 1.A.3.a)*

The methodology used to estimate GHG emissions from civil aviation follows a modified IPCC Tier 1 approach.

This subsector includes all emissions from domestic air transport (commercial, private, military, agricultural, etc.). Although the IPCC Guidelines call for military air transportation emissions to be reported elsewhere, they have been included here owing to security restrictions on military aviation data. Excluded are emissions from fuel used at airports for ground transport (reported under Other Transportation—Off-Road) and fuel used in stationary combustion applications at airports. Emissions from international flights are designated as “bunker” emissions and are not included in national totals but are estimated and reported separately under international bunkers.

Emission estimates are calculated based upon the quantities of aircraft fuels apparently consumed (IPCC/OECD/IEA 1997) and fuel-specific emission factors. Aircraft fuel consumption (Aviation Turbo and Aviation Gasoline) is reported in the RESD (Statistics Canada #57-003) for Canadian airlines, foreign airlines, public administration, and commercial/institutional.

A method has been developed to attribute fuel sold to Canadian airlines that is consumed during international flights. The method incorporates the use of tonne-kilometre activity data reported by Canadian airlines for both domestic and international flights and regionally allocates the fuel sold using activity data representing passenger traffic. Data representing both passenger traffic (Statistics Canada #51-005 and #51-203—Air Carrier Traffic at Canadian Airports) and freight activity, which includes the weight of passengers (Statistics Canada #51-206—Canadian Civil Aviation), are publicly available and illustrate the separation between domestic and international activity. The aviation model has been calibrated to align with more complex flight path models (SAGE—United States and AERO2K—United Kingdom).

Emissions resulting from fuel sold to Canadian carriers and consumed during international flights along with fuel sold to foreign carriers are reported separately under international bunkers.

### A2.4.2.4 *Navigation (Domestic Marine) (CRF Category 1.A.3.d)*

The emission calculation methodology is considered to be a modified IPCC Tier 1 method. Domestic marine fuel consumption reported in the RESD (Statistics Canada #57-003) is multiplied by fuel-specific emission factors (see Annex 12). Emissions resulting from fuel sold to foreign marine vessels are assumed to be used only for international travel and are reported separately under international bunkers.

Some Canadian vessels are engaged in international marine travel. Comprehensive data that would allow an accurate disaggregation of domestic and international shipping activities by Canadian vessels are currently unavailable.

#### *A2.4.2.5 Railways (CRF Category 1.A.3.c)*

The methodology is considered to be a modified IPCC Tier 1 method. Railway fuel consumption reported in the RESD (Statistics Canada #57-003) is multiplied by fuel-specific emission factors (see Annex 12).

In Canada, locomotives are powered primarily by diesel fuel. Emissions associated with steam trains are assumed to be negligible, whereas electrically driven locomotives are accounted for under electricity production.

#### *A2.4.2.6 Biomass (CRF Category 1.A.3.e)*

The methodology used to estimate emissions from biomass fuels (currently limited to ethanol) used in the Transport sector follows the same approach as for gasoline on-road transportation (detailed IPCC Tier 3 method) and off-road transportation (IPCC Tier 1 method).

In lieu of reviewed CH<sub>4</sub> and N<sub>2</sub>O emission factors for biofuels, the gasoline and diesel emission factors from the equivalent emission technology classes are applied. CO<sub>2</sub> emission factors are developed according to the chemical properties of the fuel.

#### *A2.4.2.7 Pipelines (CRF Category 1.A.3.e)*

Pipelines represent fossil fuel combustion engines used to power motive compressors to transport oil and natural gas products. The fuel used is primarily natural gas, but some refined petroleum such as diesel fuel is also used. Oil pipelines tend to use electric motors to operate pumping equipment.

Combustion-related GHG emissions associated with this equipment are calculated by applying Equation A2-1 to activity data and emission factors for specific fuels on a national basis.

### **References**

DesRosiers. Canadian Vehicles in Operation Census (CVIOC). Annual reports prepared by DesRosiers Automotive Consultants.

Environment Canada. 1999. 1995 Criteria Contaminants Emissions Inventory Guidebook, Version 1, Section 2.4, National Emissions Inventory and Projections Task Group, Criteria Air Contaminants Division, Environment Canada.

[EPA] United States Environmental Protection Agency. 2007. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2005. Washington (DC): Environmental Protection Agency, U.S.A., Report EPA 430-R-07-002.

[IPCC/OECD/IEA] Intergovernmental Panel on Climate Change, Organisation for Economic Co-operation and Development, and International Energy Agency. 1997. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Available online at: <http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm>

Jaques AP. 1992. Canada's Greenhouse Gas Emissions: Estimates for 1990. Environmental Protection, Conservation and Protection, Environment Canada. Report No. EPS 5/AP/4.

King B. 1994. Management of Methane Emissions from Coal Mines: Environmental, Engineering, Economic and Institutional Implications of Options. Report prepared by Neill and Gunter for Environment Canada.

Maples JD. 1993. The Light-Duty Vehicle MPG Gap: Its Size Today and Potential Impacts in the Future. Knoxville (TN): University of Tennessee, Transportation Centre U.S.A.

[MMIC] Motorcycle and Moped Industry Council. 2003. Motorcycle and All—Terrain Vehicle Annual Industry Statistics Report.

[NRCan] Natural Resources Canada. 2006. Transportation End-Use Model (FCR Calculations), Natural Resources Canada.

Polk RL. Vehicles in Operation (VIO) Database. compiled by R.L. Polk and Co., Southfield, Michigan, USA.

Statistics Canada. Air Carrier Traffic at Canadian Airports. Catalogue No. 51-005 (discontinued).

Statistics Canada. Air Carrier Traffic at Canadian Airports. Catalogue No. 51-203-XIE. Available online at:  
<http://dsp-psd.pwgsc.gc.ca/Collection-R/Statcan/51-203-XIB/51-203-XIB-e.html>

Statistics Canada. Canadian Civil Aviation. Catalogue No. 51-206-XIB.

Statistics Canada. CANSIM Database Table 405-0002: Road Motor Vehicles, Fuel Sales, Annual (Litres). Available online at: <http://cansim2.statcan.ca>

Statistics Canada. Report on Energy Supply–Demand in Canada (Annual). Catalogue No. 57-003-XIB.

Stewart Brown Associates. 2004. Vehicle Fleet Profiles for Ontario and British Columbia; Annual Kilometer Accumulation Rates; Vehicle–Kilometers Traveled; and I/M Program Effectiveness.

## Annex 3 Additional Methodologies

### ***A3.1 Methodology for Fugitive Emissions from Fossil Fuel Production, Processing, Transmission, and Distribution***

A detailed methodology of the Fugitive Emissions sector is covered in this annex. This discussion relates to solid fuel production and the oil and gas industry.

A primary source of fugitive emissions, Canada's large oil and gas industry consists of a mix of production types, from natural gas production and processing, to light, medium and heavy crude oil production, and the oil sands mining, extraction and synthetic oil production. Refer to Chapter 3 of this report for a detailed description of sources of fugitive emissions.

All GHG emissions from stationary combustion and transportation are reported under the Energy Industries (Section 3.2.1) and transportation (Section 3.2.3) sections of Chapter 3, and their respective methodologies can be found in Annex 2 (sections A2.4.1 and A2.4.2).

#### **A3.1.1 Solid Fuels**

##### ***A3.1.1.1 Coal—Production***

Fugitive emission estimates are based on the study *Management of Methane Emissions from Coal Mines: Environmental, Engineering, Economic and Institutional Implications of Options*, prepared by B. King in 1994 for Neill and Gunter Ltd. In the study, emission factors were calculated for all types of coal and coal mines. There are two types of coal mine in Canada: underground mines and surface mines. The method used by King (1994) to estimate emission rates from coal was based on a modified procedure from the Coal Industry Advisory Board. It consists of a hybrid of IPCC Tier 3- and Tier 2-type methodologies, depending on the availability of mine-specific data. Underground mining activity emissions and surface mining activity emissions are separated, and both include post-mining activity emissions. The methodologies used to estimate the emissions from both types are explained below. For further details, please consult the King (1994) study.

#### **Underground Mines**

King (1994) estimated emissions for underground mines on a mine-specific basis by summing emissions from the ventilation system, degasification systems, and post-mining activities. Emissions from the mine shaft ventilation system were estimated (if measured data were not available) using Equation A3-1:

##### **Equation A3-1:**

$$Y = 4.1 + (0.023 \times X)$$

where:

- Y = emissions of CH<sub>4</sub> per tonne of coal mined, m<sup>3</sup> CH<sub>4</sub>/t coal
- X = depth of mine, m

Emissions from post-mining activities were estimated by assuming that 60% of the remaining coal CH<sub>4</sub> (after removal from the mine) is emitted to the atmosphere before combustion. If the gas content of the mined coal was not known, then it was assumed that the CH<sub>4</sub> content was 1.5 m<sup>3</sup>/t (the global average for coals). Emissions from post-mining activities are included in the coal production emission factors.

## Surface Mines

For surface mines, it was assumed that the average CH<sub>4</sub> content of surface-mined bituminous or sub-bituminous coals was 0.4 m<sup>3</sup>/t (based on U.S. measured data). Of this, it was assumed that 60% is released to the atmosphere before combustion (King 1994). For lignite, gas content values determined previously for Canada were used (Hollingshead 1990).

A significant source of emissions from surface mines is the surrounding unmined strata. An attempt was made to account for this by applying a high-wall adjustment to account for the out-gassing of the surrounding unmined strata to a depth of 50 m below the mining surface. It was estimated that base emission factors for surface mining should be increased by 50% (King 1994) to account for this. The emission factors shown in Table A3-1 have been adjusted accordingly.

The emission factors for CH<sub>4</sub> from coal mining determined in the King (1994) study are used to estimate the CH<sub>4</sub> fugitive emissions from coal mines in Canada. The emission factors vary for each region and the type of mine, above or below ground.

To obtain the emissions from coal mining, Equation A3-2 is used:

### Equation A3-2:

$$\text{Emissions}_{i,j} = \text{EF}_{i,j} \times \text{Amount of Coal}_i \text{ Mined in Province}_j$$

where:

Emissions <sub>i,j</sub>	= CH <sub>4</sub> emissions from the mining of coal <sub>i</sub> in province <sub>j</sub> , t
EF <sub>i,j</sub>	= the emission factor from the King (1994) study for coal <sub>i</sub> in province <sub>j</sub>
Amount of Coal <sub>i</sub> Mined in Province <sub>j</sub>	= the gross mine output production data for coal <sub>i</sub> in province <sub>j</sub> , t CH <sub>4</sub> per kt coal

The emissions are calculated for each province and then summed to determine the emission estimate for Canada.

### A3.1.1.2 Activity Data

The activity data required are the gross mine output data for each type of coal mined in each province from Statistics Canada's *Coal and Coke Statistics publication* (#45-002, Table 2). However, the Coal and Coke Statistics publication was cancelled in 2002 by Statistics Canada and this information is now provided directly to Environment Canada through a memorandum of understanding. A consistent data set was used to estimate emissions from 1990 to 2001 and from 2004 to 2006. For 2002–2003, an interpolation model was developed to estimate provincial emissions based on publicly available national quantity of coal produced by mines (regions) and by coal types.

### A3.1.1.3 Emission Factors

The specific emission factors by mine and coal type that were determined in the King (1994) study are listed in Table A3-1.

**Table A3-1: Fugitive Emission Factors for Coal Mining**

Area	Coal Type	Mine Type	Emission Factor t CH <sub>4</sub> /kt coal mined
Nova Scotia	Bituminous	Surface	0.13
Nova Scotia	Bituminous	Underground	13.79
New Brunswick	Bituminous	Surface	0.13
Saskatchewan	Lignite	Surface	0.06
Alberta	Bituminous	Surface	0.45
Alberta	Bituminous	Underground	1.76
Alberta	Sub-bituminous	Surface	0.19
British Columbia	Bituminous	Surface	0.58
British Columbia	Bituminous	Underground	4.1

Source: King (1994).

### A3.1.2 Oil and Natural Gas

#### A3.1.2.1 Upstream Oil and Natural Gas Production

The fugitive emissions from the upstream oil and gas (UOG) industry are based on the study *A National Inventory of Greenhouse Gas (GHG), Criteria Air Contaminant (CAC) and Hydrogen Sulphide (H<sub>2</sub>S) Emissions by the Upstream Oil and Gas Industry* (CAPP 2005a), as prepared for the Canadian Association of Petroleum Producers (CAPP) by Clearstone Engineering. A Tier 3 analysis was performed to estimate all GHG emissions from the UOG sector for the year 2000, with the exclusion of mined bitumen/oil sands extraction and upgrading. The emissions were then backcast to the years 1990 through to 1999 to develop emission estimates for the sector. The UOG fugitive emissions for 1990–2000 were taken directly from the UOG study (CAPP 2005a).

UOG fugitive emissions for 2001 and onwards were taken directly from the UOG extrapolation model (CAPP 2005b). The extrapolation of UOG emissions was also prepared for CAPP by Clearstone Engineering (CAPP 2005b) and is based on information from CAPP's previous UOG study (CAPP 2005a). The extrapolation model is divided into the same sectors and sources as the 1990–2000 UOG inventory.

Table A3-2 lists the sectors and sources that were estimated in the UOG study (CAPP 2005a) and the allocation of these emissions according to the CRF category.

The methodology, emission factors, and activity data used to estimate the 1990 to 1999 and 2001 to 2006 emissions were developed by Clearstone Engineering Ltd. and are presented in the following subsections. For further details, please consult the UOG study (CAPP 2005a) and the UOG extrapolation model (CAPP 2005b).



**Table A3-2: Allocation of UOG Inventory Emissions to CRF Fugitive Categories**

Sector	Source	CRF Fugitive Category
Accidents and Equipment Failures	Surface Casing Vent Flow/Gas Migration	2.B.iii Natural Gas—Other Leakage at Industrial Plants and Power Stations
Accidents and Equipment Failures	Spills/Pipeline Ruptures	2.B.iii Natural Gas—Other Leakage at Industrial Plants and Power Stations
Conventional Oil Production	Glycol Dehydrator Off-Gas	2.C.i Venting—Oil
Conventional Oil Production	Flaring	2.C.i Flaring—Oil
Conventional Oil Production	Fugitive Equipment Leaks	2.A.ii Oil—Production
Conventional Oil Production	Loading/Unloading	2.A.ii Oil—Production
Conventional Oil Production	Reported Venting	2.C.i Venting—Oil
Conventional Oil Production	Storage Losses	2.A.ii Oil—Production
Conventional Oil Production	Unreported Venting	2.C.i Venting—Oil
Oil and Gas Well Drilling	Reported Venting	2.C.ii Venting—Combined
Natural Gas Production	Glycol Dehydrator Off-Gas	2.C.ii Venting—Natural Gas
Natural Gas Production	Flaring	2.C.ii Flaring—Natural Gas
Natural Gas Production	Fugitive Equipment Leaks	2.B.i Natural Gas—Production/Processing
Natural Gas Production	Reported Venting	2.C.ii Venting—Natural Gas
Natural Gas Production	Storage Losses	2.B.i Natural Gas—Production/Processing
Natural Gas Production	Unreported Venting	2.C.ii Venting—Natural Gas
Natural Gas Processing	Glycol Dehydrator Off-Gas	2.C.ii Venting—Natural Gas
Natural Gas Processing	Flaring	2.C.ii Flaring—Natural Gas
Natural Gas Processing	Fugitive Equipment Leaks	2.B.i Natural Gas—Production/Processing
Natural Gas Processing	Loading/Unloading	2.B.i Natural Gas—Production/Processing
Natural Gas Processing	Formation CO <sub>2</sub>	2.C.ii Venting—Natural Gas
Natural Gas Processing	Storage Losses	2.B.i Natural Gas—Production/Processing
Natural Gas Processing	Unreported Venting	2.C.ii Venting—Natural Gas
Heavy Oil/Cold Bitumen Production	Glycol Dehydrator Off-Gas	2.C.i Venting—Oil
Heavy Oil/Cold Bitumen Production	Flaring	2.C.i Flaring—Oil
Heavy Oil/Cold Bitumen Production	Fugitive Equipment Leaks	2.A.ii Oil—Production
Heavy Oil/Cold Bitumen Production	Loading/Unloading	2.A.ii Oil—Production
Heavy Oil/Cold Bitumen Production	Reported Venting	2.C.i Venting—Oil
Heavy Oil/Cold Bitumen Production	Storage Losses	2.A.ii Oil—Production
Heavy Oil/Cold Bitumen Production	Unreported Venting	2.C.i Venting—Oil
Thermal Operations	Flaring	2.C.i Flaring—Oil
Thermal Operations	Fugitive Equipment Leaks	2.A.ii Oil—Production
Thermal Operations	Loading/Unloading	2.A.ii Oil—Production
Thermal Operations	Reported Venting	2.C.i Venting—Oil
Thermal Operations	Storage Losses	2.A.ii Oil—Production
Thermal Operations	Unreported Venting	2.C.i Venting—Oil
Liquid Product Transportation	Flaring	2.C.i Flaring—Oil
Liquid Product Transportation	Fugitive Equipment Leaks	2.A.iii Oil—Transport
Liquid Product Transportation	Storage Losses	2.A.iii Oil—Transport
Liquid Product Transportation	Reported Venting	2.C.i Venting—Oil
Well Testing	Flaring	2.C.iii Flaring—Combined
Well Testing	Reported Venting	2.C.iii Venting—Combined

### Methodology for the 2000 Estimates

The 2000 UOG emissions were developed using a bottom-up approach, beginning with individual facilities and their equipment. To fulfil this, the study drew on official data from the producing provinces, supplemented by survey information on 1500 facilities provided by oil and gas producers. The following fugitive emissions sources were estimated:

- flaring;
- formation CO<sub>2</sub> releases;

- venting; and
- fugitive and other unintentional releases (equipment leaks, storage and handling losses, and accidental releases).

The resulting emissions were then aggregated to determine overall emissions by facility type, activity type, and geographic area. The basic methods used to estimate GHG emissions are the following:

- emission monitoring results;
- emission source simulation results;
- emission factors; and
- destruction and removal efficiencies.

The following data were collected from the facilities and used to develop the 2000 inventory:

- measured volumes of natural gas taken from the process;
- vented and flared waste gas volumes;
- fuel purchases (propane, diesel fuel, etc.);
- fuel analyses;
- emission monitoring results;
- process operating conditions that may be used to infer the work being done by combustion devices (gas compositions, temperatures, pressures and flows, etc.); and
- spill and inspection reports.

Other required data included the following:

- types of processes being used;
- equipment inventories;
- emission source control features;
- sulphur content of the fuels consumed and waste gas flared; and
- composition of the inlet and outlet streams.

The data were compiled and used to estimate the 2000 UOG fugitive emissions. Refer to the UOG study (CAPP 2005a) for further details.

### **Methodology for the 1990–1999 estimates**

The emissions for 1990–1999 were backcast for the UOG industry at a provincial level based on the 2000 UOG data (CAPP 2005a) and annual production data, with the exception of Nova Scotia. Nova Scotia switched production in 2000 from an oil-only production industry (from 1992 to 1999) to a gas-only production from 2000 onwards. Nova Scotia's fugitive emissions were extrapolated based on CAPP's 1995 UOG study data.

Refer to the UOG study (CAPP 2005a) for further details.

## Methodology for the 2001–2006 estimates

The 2001–2006 emissions were estimated by extrapolating the 2000 UOG emission data using activity data for each emission source in each subsector. There are 11 activity parameters for each province/territory and year that were used to pro-rate the 2000 estimates from the UOG study for the years 2001–2006:

- gas production;
- conventional oil (CO);
- heavy oil (HO);
- crude bitumen (CB);
- fuel gas;
- flared gas;
- wells drilled;
- spills;
- total wells;
- CO + HO + CB; and
- HO + CB.

Equation A3-3 was used for pro-rating:

### Equation A3-3:

$$ER_{i,j}^k = ER_{i,j}^{2000} \times \left( \frac{AF_j^k}{AF_j^{2000}} \right)$$

where:

- |                   |   |  |
|-------------------|---|--|
| $ER_{i,j}^k$      | = | emission rate of compound i, source j, and year k, t/year          |
| $ER_{i,j}^{2000}$ | = | base year (2000) emission rate for compound i and source j, t/year |
| $AF_j^k$          | = | activity factor for source j and year k                            |
| $AF_j^{2000}$     | = | base year activity factor for source j                             |

The activity data listed in Table A3-3 are used to calculate the 11 activity parameters given above, which are used in the extrapolation of the emissions for 2001–2006. These data are input into the model, and the output is the UOG fugitive emission estimates for the specified year.

**Table A3-3: Required Activity Data and Their Source**

<b>Publisher</b>	<b>Publication</b>	<b>Activity Data</b>
Statistics Canada	Table 131-0001 Supply and disposition of natural gas, monthly	Gross new production Less field flared and waste Field disposition and usage Gathering system disposal and use Plant uses
	Table 126-0001 Supply and disposition of crude oil and equivalent	Heavy crude oil Light and medium crude oil Synthetic crude oil Crude bitumen
Saskatchewan Industry and Resources	Monthly Production and Disposition of Crude Oil at the Producer Level; Table 2-1-9 Mineral Statistics Yearbook, Miscellaneous Report	Light and medium crude oil production Heavy crude oil production
	2006-2007 Annual Report; Table 5-2-4 Mineral Statistics Yearbook	Total capable wells (Saskatchewan)
Canadian Association of Petroleum Producers (CAPP)	Industry Facts and Information by Region and Province ( <a href="http://www.capp.ca/default.asp?V_DOC_ID=6">http://www.capp.ca/default.asp?V_DOC_ID=6</a> )	Total wells drilled (including dry and service)
Alberta Energy and Utilities Board (AEUB)	AEUB ST-99 Provincial Surveillance and Compliance Summary	Sum of blowouts (drilling, servicing & other), kicks and pipeline ruptures
	AERCB ST-59 Alberta Drilling Activity Monthly Statistics	December capable oil and gas wells (Alberta)
British Columbia Ministry of Energy and Mines	Drilling, Production and Distribution Statistics 1990-2006 (calendar years)	Sum of producing oil wells and producing gas wells (British Columbia)
Manitoba Science, Technology, Energy and Mines	Manitoba Petroleum Statistics	Wells capable of producing (December) (Manitoba)
Canada—Newfoundland Offshore Petroleum Board	Development Wells – Hibernia	Sum of all oil producers and gas injectors
	Development Wells – Terra Nova	Sum of all oil producers and gas injectors
	Development Wells – White Rose	Sum of all oil producers and gas injectors

Table A3-4 contains a list of the activity factors used to pro-rate the emissions and the dependent source category.

**Table A3-4: Activity Data Used to Pro-rate Emission Sectors and Sources**

<b>Emission Sector Category</b>	<b>Emission Source Category</b>	<b>Activity Factors</b>
Accidents/Equipment Failures	Spills, Ruptures, Blowouts	Total mass of spills, ruptures and blowouts
Accidents/Equipment Failures	Surface Casing Vent Flows,	Total number of capable wells
Accidents/Equipment Failures	Gas Migration	Total number of capable wells
Light/Medium Oil Production	Flaring	Flared gas volume
Light/Medium Oil Production	Fugitive Equipment Leaks	Light/medium oil production
Light/Medium Oil Production	Glycol Dehydrator Off-Gas	Light/medium oil production
Light/Medium Oil Production	Loading/Unloading Losses	Light/medium oil production
Light/Medium Oil Production	Reported Venting	Light/medium oil production
Light/Medium Oil Production	Storage Losses	Light/medium oil production
Light/Medium Oil Production	Unreported Venting	Light/medium oil production
Well Drilling	Venting	Wells drilled
Gas Production	Flaring	Flared gas volume
Gas Production	Fugitive Equipment Leaks	Raw gas production
Gas Production	Glycol Dehydrator Off-Gas	Raw gas production
Gas Production	Loading/Unloading Losses	Raw gas production
Gas Production	Reported Venting	Raw gas production
Gas Production	Storage Losses	Raw gas production
Gas Production	Unreported Venting	Raw gas production
Gas Processing	Flaring	Flared gas volume
Gas Processing	Fugitive Equipment Leaks	Raw gas production
Gas Processing	Glycol Dehydrator Off-Gas	Raw gas production
Gas Processing	Loading/Unloading Losses	Raw gas production
Gas Processing	Formation CO <sub>2</sub>	Raw gas production
Gas Processing	Reported Venting	Raw gas production
Gas Processing	Storage Losses	Raw gas production
Gas Processing	Unreported Venting	Raw gas production
Heavy Oil Cold Production	Flaring	Flared gas volume
Heavy Oil Cold Production	Fugitive Equipment Leaks	Heavy oil production
Heavy Oil Cold Production	Glycol Dehydrator Off-Gas	Heavy oil production
Heavy Oil Cold Production	Loading/Unloading Losses	Heavy oil production
Heavy Oil Cold Production	Reported Venting	Heavy oil production
Heavy Oil Cold Production	Storage Losses	Heavy oil production
Heavy Oil Cold Production	Unreported Venting	Heavy oil production
Well Service	Venting	Wells drilled
Well Service	Flaring	Wells drilled
Heavy Oil/Bitumen Thermal Production	Flaring	Flared gas volume
Heavy Oil/Bitumen Thermal Production	Fugitive Equipment Leaks	Heavy oil and crude bitumen production
Heavy Oil/Bitumen Thermal Production	Loading/Unloading Losses	Heavy oil and crude bitumen production
Heavy Oil/Bitumen Thermal Production	Reported Venting	Heavy oil and crude bitumen production
Heavy Oil/Bitumen Thermal Production	Storage Losses	Heavy oil and crude bitumen production
Heavy Oil/Bitumen Thermal Production	Unreported Venting	Heavy oil and crude bitumen production
Product Transportation	Flaring	Fuel gas volume
Product Transportation	Fugitive Equipment Leaks	Light/medium oil, heavy oil, and crude bitumen production
Product Transportation	Venting	Light/medium oil, heavy oil, and crude bitumen production
Product Transportation	Storage Losses	Light/medium oil, heavy oil, and crude bitumen production
Well Testing	Flaring	Wells drilled
Well Testing	Venting	Wells drilled

Source: Extrapolation of the 2000 UOG Emission Inventory to 2001, 2002 and 2003. CAPP (2005b).

### A3.1.2.2 Natural Gas Transmission

#### Methodology

Virtually all of the natural gas produced in Canada is transported from the processing plants to the gate of the local distribution systems by high-pressure pipelines. The gas transmission system emission sources are from the transportation system from the processing plant to the distribution system gate. The majority of emissions are from equipment leaks and process vents.

Fugitive emissions for natural gas transmission are based on two documents. The first is the *CH<sub>4</sub> and VOC Emissions from the Canadian Upstream Oil and Gas Industry*, prepared by Clearstone Engineering for CAPP in July 1999. The second source is ancillary tables provided by Brian Ross (Clearstone Engineering) that cover the CO<sub>2</sub> emissions. There are no N<sub>2</sub>O fugitive emissions from natural gas transmission. The CO<sub>2</sub> and CH<sub>4</sub> emissions for 1990–1996 are taken directly from the two sources. The CO<sub>2</sub> and CH<sub>4</sub> emissions for 1997 to the present are estimated using specific provincial emission factors.

Equation A3-4 is used to estimate the emissions:

#### Equation A3-4:

$$\text{Emissions (kt)} = \text{Pipeline Length (km)} \times \text{Emission Factor (leakage rate, kt/km)}$$

The emissions are calculated per province, as the provinces have unique emission factors, and then summed to get the total CO<sub>2</sub> and CH<sub>4</sub> emissions for Canada. Newfoundland and Labrador, Prince Edward Island, the Yukon, the Northwest Territories, and Nunavut do not have natural gas transmission pipelines.

#### Emission Factors

Provincial emission factors from 1997 onward (Table A3-5) were developed based on the 1996 emissions and length of pipeline from the *CH<sub>4</sub> and VOC Emissions from the Canadian Upstream Oil and Gas Industry* study as prepared by Clearstone Engineering Ltd. for CAPP (CAPP 1999). In 1998 and 1999, there were no fugitive emissions in Nova Scotia or New Brunswick, since natural gas pipelines were not installed in these provinces at the time.

**Table A3-5: Natural Gas Transmission Emission Factors for 1997–2006**

Province	Emission Factors (kt/km)	
	CO <sub>2</sub>	CH <sub>4</sub>
Nova Scotia	$2.40 \times 10^{-5}$	0.0032
New Brunswick	$2.40 \times 10^{-5}$	0.0032
Quebec	$7.20 \times 10^{-5}$	0.0096
Ontario	$1.60 \times 10^{-5}$	0.0022
Manitoba	$2.90 \times 10^{-5}$	0.0039
Saskatchewan	$1.50 \times 10^{-5}$	0.0021
Alberta	$2.80 \times 10^{-5}$	0.0038
British Columbia	$2.90 \times 10^{-5}$	0.0039

## Activity Data

The activity data used to estimate the fugitive emissions for 1998–2005 are the length of the natural gas pipeline used for natural gas transmission. These data are published annually by Statistics Canada in Catalogue #57-205, *Natural Gas Transportation and Distribution*, and the data are found in Table 5, Natural Gas Pipeline Distance, by Province, as of December 31, under Transmission—Transport.

### A3.1.2.3 *Petroleum Refining*

The refinery model is based on the study *Economic and Environmental Impacts of Removing Sulphur from Canadian Gasoline and Distillate Production* (CPPI 2004), prepared for the Canadian Petroleum Products Institute (CPPI), Natural Resources Canada (NRCan), Environment Canada, and Industry Canada in 2004 by Levelton Consultants Ltd. The study surveyed the refinery industry and used these data, along with data collected by CIEEDAC, to develop GHG emission estimates for 1990 and 1994–2002.

There are three sections in the refinery methodology: fugitive, flare, and process venting.

## Methodology

### *Fugitive Emissions*

The fugitive emissions for 1991–1993 and for 2003 onwards are generated using Equation A3-5:

#### Equation A3-5:

$$\text{Fugitive GHG Emissions (t)} = \text{Emission Factor (t/GJ)} \times \text{Refinery Annual Energy Consumption (GJ)}$$

The refinery annual energy consumption (GJ) is the sum of the energy of all fuels consumed by refineries in the RESD (Statistics Canada #57-003), including fuels listed under producer consumption. The energy consumption is the same as that in the stationary combustion model for 1.A.1.b Petroleum Refining.

Two emission factors, one for CO<sub>2</sub> emissions and the other for CH<sub>4</sub> emissions, were developed and used in the refinery study (CPPI 2004). These emission factors are used to estimate the fugitive emissions for the years not included in the study: 1991–1993 and 2003 to present.

The emission factors are:

Annex 1	CO <sub>2</sub> : 2.78 t CO <sub>2</sub> /GJ
Annex 2	CH <sub>4</sub> : 11.89 t CH <sub>4</sub> /GJ

The refinery study (CPPI 2004) has listed fugitive N<sub>2</sub>O emissions for 1990 and 1994–2002 as a constant 0.1 kt N<sub>2</sub>O/year; however, there were not enough data to develop an emission factor for them. The N<sub>2</sub>O emissions were kept constant at 0.1 kt N<sub>2</sub>O/year for the years 1991–1993 and 2003 to present.

### *Process Emissions (Venting)*

Process emissions are mainly associated with the venting of CO<sub>2</sub> from the production of hydrogen using natural gas. The process emissions for the years 1991–1993 and 2003 to present were estimated based on an average emission factor and energy consumption data.

### ***Flaring Emissions***

Flaring emissions have been determined separately for CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O in the refinery study (CPPI 2004). As the study did not generate any factors to use in estimating emissions from 2003 onward, an average emission factor was developed based on results from the refinery study. Flaring emissions for the years 1991–1993 and 2003 to present were estimated based on an average emission factor and energy consumption data.

### **Activity Data**

The activity data required to estimate the fugitive emissions from refineries are listed by publisher:

Statistics Canada

Report on Energy Supply–Demand in Canada (RESO), Statistics Canada #57-003

- Refinery and producer consumption (by refineries) annual energy consumption

Canadian Petroleum Producers Institute (CPPI)

Economic and Environmental Impacts of Removing Sulphur from Canadian Gasoline and Distillate Production by Levelton Consultants Ltd. (CPPI 2004)

- Fugitive Emissions

Table 3-2 CPPI Regional GHG Inventory—Detailed (kilotonnes)

- Process Emissions

Table 3-2 CPPI Regional GHG Inventory—Detailed (kilotonnes)

- Flaring Emissions

Appendix E— Flare Gas

#### ***A3.1.2.4 Natural Gas Distribution***

### **Methodology**

The fugitive emissions from natural gas distribution are based on the Canadian Gas Association (CGA) report, *1995 Air Inventory of the Canadian Natural Gas Industry* (CGA 1997). The emissions are estimated using activity data from Statistics Canada and the leakage rate from the CGA report. This is the case for all years from 1990 to 2005. There are only fugitive CH<sub>4</sub> emissions from the distribution of natural gas. The relationship between the data and emission factors is as follows:

#### **Equation A3-6:**

$$\text{Emissions}_x \text{ (kt)} = \text{Length of Pipeline (km)} \times \text{Emission Factor}_x \text{ (leakage rate, kt/km)}$$

The fugitive emissions for natural gas distribution are estimated for each province and then summed to get the overall emissions for Canada. For the years 1990–2005, there were no natural gas distribution pipelines in the following provinces and territories: Newfoundland and Labrador, Prince Edward Island, Nova Scotia, New Brunswick, Nunavut, the Yukon, and the Northwest Territories.



## Emission Factors

The leakage rates are from the CGA report *1995 Air Emissions Inventory of the Canadian Natural Gas Industry* (CGA 1997). These leakage rates are listed in Table A3-6.

**Table A3-6: CH<sub>4</sub> Emission Factors for Fugitive Natural Gas Distribution Emissions**

Years	Leakage rate (kt/km)
1990–1992	0.0008
1993–2005	0.0007

## Activity Data

The activity data required is the length of natural gas pipeline per province. The data is published annually in *Natural Gas Transportation and Distribution* (Statistics Canada #57-205) and are located in Table 5, Natural Gas Pipeline Distance, by Province, under Distribution–Distribution.

### A3.1.2.5 Oil Sands and Heavy Oil Upgrading Industry

The oil sands and heavy oil upgrading (OS/HOU) industry produces synthetic crude oil and other products from bitumen. Bitumen is a naturally occurring viscous mixture consisting of hydrocarbons heavier than pentane and other contaminants (e.g. sulphur compounds), which, in its natural state, will not flow under reservoir conditions or on the surface. Bitumen occupies the lower end of the range of heavy crude oils and is sometimes referred to as ultra-heavy crude oil. “Oil sands” is a term applied by the Government of Alberta to a particular geographical area of the province of Alberta that contain concentrations of bituminous sands as well as deposits of other heavy crude oil. Bituminous sands are an unconsolidated mixture of sand, clay, water, and bitumen.

In this area, bitumen is extracted from open-pit mined oil sands or from in situ bitumen operations using thermal extraction techniques. The emissions from the secondary and thermal extraction are included in the UOG study (CAPP 2005a). Emissions included in the report *An Inventory of GHGs, CACs, and H<sub>2</sub>S Emissions by the Canadian Bitumen Industry: 1990 to 2003* (CAPP 2006), prepared by Clearstone Engineering Ltd. for CAPP, are from the mining, processing, and upgrading of bitumen and heavy oil.

The bitumen report (CAPP 2006) is the basis for the 1990–2003 fugitive emissions from oil sands mining and upgrading activities.

From 2004 onwards, the emissions are estimated using an extrapolation model created by Clearstone Engineering Ltd. for Environment Canada’s Bitumen-Oilsands Extrapolation Model – Rev 3 in 2007. This model uses results from the bitumen report (CAPP 2006) as its basis, along with annual production data as reported by the AEUB and the NEB. The methodology, model, and data used are briefly discussed below. For more details, please refer to the bitumen report (CAPP 2006).

The major emission sources in the OS/HOU industry are the following:

- Annex 3      process emissions from the steam reforming of natural gas to produce hydrogen for upgraders;
- Annex 4      CH<sub>4</sub> present in the oil sands deposits that is released during mining, mine dewatering, and ore handling activities;

Annex 5	volatilization of hydrocarbons from the exposed oil sands and during transport and handling of the oil sands;
Annex 6	biogenic gas formation (primarily CH <sub>4</sub> ) in some tailings ponds;
Annex 7	volatilization and decomposition of residual bitumen and diluent, which carry through to the tailings ponds;
Annex 8	fugitive equipment leaks, venting, flaring, and storage losses at ore preparation, extraction, and upgrader plants and their associated utility and cogeneration plants;
Annex 9	spills and accidental releases; and
Annex 10	secondary sources, such as sewage treatment facilities, landfills, onsite construction and fabrication activities, motor vehicle fleets, corporate aircraft, and boats and dredges used on the tailings ponds.

These emissions have been grouped in the source categories and process areas listed in Table A3-7.

**Table A3-7: Emission Source Categories and Process Areas in the Bitumen Report (CAPP 2006)**

Source Category	Process Area
Flaring	All
Fugitives	American Petroleum Institute (API) Separator Equipment Leaks Exposed Oil Sands Ponds Other Storage Tanks
Process Venting	FGD Formation CO <sub>2</sub> from Acid Gas Hydrogen Plant Non-Combustion Point Sources

### Bitumen Report: 1990–2003 Emission Estimates

The bitumen report (CAPP 2006) is a compilation of the individual Tier 3 inventories of the facilities involved in the OS/HOU industry: Syncrude Canada Ltd. (Mildred Lake mining, extraction, and upgrading facility and Aurora North mining and extraction facility); Suncor Energy (mining, extraction, and upgrading facility); Husky Energy (Lloydminster upgrader); Consumers' Co-operative Refineries Limited (Regina upgrader); Albion Sands Energy (Muskeg River mining and extraction facility); and Shell Canada Limited (Fort Saskatchewan upgrader). The facility boundaries were determined to ensure that all target emissions, including those from cogeneration facilities, were included.

Where available, the bitumen report (CAPP 2006) used the emissions from the individual facility reports. These emissions were verified against inventories and data reported to Alberta Environment. When this was not possible, emissions were estimated based on available activity data and emission factor data. There were two methods for estimating emissions. The first method is the emission factor method, which used specific activity data and standard emission factors. If there were no activity data available, the emission factor ratio technique was applied. Refer directly to the bitumen report (CAPP 2006) for specific methodological discussions.

Activity data sources used to estimate emissions using activity data and emission factor data were the following:

- operators;
- energy statistics published by the Alberta Energy and Utility Board (AEUB);
- source emission monitoring results reported to Alberta Environment;
- data from company submissions to the Voluntary Challenge Registry;
- Environment Canada's National Pollutions Release Inventory (NPRI);
- environmental impact assessment files as part of recent energy development applications in the OS/HOU industry; and
- open literature.

Consult the bitumen report (CAPP 2006) for more details.

### **Extrapolation Model: 2004 to Present Emission Estimates**

The extrapolation model estimates GHG emissions from thermal heavy oil production and oil sands mining, extraction, and upgrading in Canada. The model was developed based on the results from the bitumen report (CAPP 2006) along with publicly available activity data and company-specific emission data to extrapolate emissions for the years 2004 to the present. It provides the same level of disaggregation of the emissions by source category as is reported in the base inventories. In 2006, emissions from the new Petro-Canada UTS Fort Hills oil sands operations were estimated based on emission factors derived from Albion's Muskeg River operations. Refer directly to the report on the extrapolation model (Environment Canada 2007) for specific methodological discussions.

#### ***Extrapolation Methodology***

The extrapolation model provides emission estimates for the OS/HOU industry for the years 2004 to the present by applying facility-specific emission factors and pro-rating factors derived from the facility base inventories (1990–2003) to appropriate publicly available activity data for the specific year. It uses Equation A3-7 to extrapolate the emissions:

#### **Equation A3-7:**

$$ER_i = EF_i \times (A_1 + A_2)$$

where:

$ER_i$	=	emissions of substance i, t/year
$EF_i$	=	emission factor for substance i
$A_1, A_2$	=	activity values applicable to the emission factor

#### ***Emission Factors***

For the OS/HOU sector in Alberta and Saskatchewan, source-specific factors were developed for each facility by correlating the most recent 3 or 4 years of emission data for the facility, from the

bitumen report (CAPP 2006), with available site-specific production accounting data. These emission factors can be found in the extrapolation model (Environment Canada 2007)

### **Activity Data**

There are two activity data sources used to extrapolate emissions. The source for Alberta facilities is the AEUB's ST-43: *Mineable Alberta Oil Sands Annual Statistics*, which is published annually. The source for Saskatchewan is the amount of heavy oil production in Saskatchewan as reported by the National Energy Board (NEB), as listed in the tables under Estimated Production of Canadian Crude Oil and Equivalent (NEB). The required data are listed in Table A3-8.

**Table A3-8: Activity Data Required for the Extrapolation Model**

<b>Required data from the AEUB ST-43 Report for Alberta emission estimates</b>		
<b>Operator</b>	<b>Site</b>	<b>Required Parameters</b>
Albian Sands	Muskeg River	Bitumen Production Oil Sands Mined
Petro-Canada UTS	Fort Hills	Bitumen Production Oil Sands Mined
Shell	Scotford Upgrader	Process Gas Flared/Wasted Synthetic Crude Production
Suncor	Tar Island	Diluent Naphtha Flared/Wasted Diluent Naphtha Further Processed Diluent Naphtha Production Sulphur Flared/Wasted Synthetic Crude Fuel/Used Synthetic Crude Production
Syncrude	Mildred Lake	Oil Sands Mined
		Bitumen Production
		Intermediate Hydrocarbon Production
		Oil Sands Mined
		Synthetic Crude Fuel/Used
	Aurora	Synthetic Crude Production
		Bitumen Production
		Oil Sands Mined
		Synthetic Crude Fuel/Used
<b>Required data from the NEB for Saskatchewan emission estimates</b>		
<b>Crude Type</b>	<b>Crude Subcategory</b>	<b>Province</b>
Heavy Crude	SK CONV	Saskatchewan

### **A3.2 Methodology for Industrial Processes**

The Industrial Processes Sector covers GHG emissions arising from non-energy-related industrial activities. The processes included in this sector are mineral production and use, chemical production, metal production, consumption of halocarbons and SF<sub>6</sub>, and other and undifferentiated production. Each of these can be further divided into various categories, such as CO<sub>2</sub> emissions from iron and steel production and SF<sub>6</sub> emissions from magnesium casting, as discussed in Chapter 4. The purpose of this section of Annex 3 is to describe in detail the

methodologies (i.e. specific equations, activity data, and emission factors) that are used to derive the estimates for the following categories of the Industrial Processes Sector:

- CO<sub>2</sub> from other and undifferentiated production; and
- CO<sub>2</sub> from ammonia production.

### **A3.2.1 CO<sub>2</sub> Emissions from Other and Undifferentiated Production**

#### *A3.2.1.1 Methodology*

CO<sub>2</sub> emissions from non-energy use of hydrocarbons are reported under the category of Other and Undifferentiated Production. These emissions primarily relate to the petrochemical production activities, although non-energy use of fuels in the mining and other chemical sectors (such as production of carbon black), form smaller parts. The fossil fuels can be grouped into three types: gaseous, solid, and liquid. Estimations of emissions coming from each type of fuel are discussed separately in the following subsections.

#### **Gaseous Fuels**

The only gaseous fuel considered in this category is natural gas used for non-energy purposes. Although it can be used in methanol and thermal carbon black production, a big portion of it actually goes to SMR for producing the hydrogen needed in ammonia plants. To estimate CO<sub>2</sub> emissions, non-energy use of natural gas in each province/territory is multiplied by an emission factor of 1522 g CO<sub>2</sub> emitted/m<sup>3</sup> (Cheminfo Services 2005). Summing all the provincial/territorial emissions together gives the national estimate. At the national level, the CO<sub>2</sub> emissions from non-energy use of natural gas are adjusted for the CO<sub>2</sub> emissions associated with ammonia production. More specifically, CO<sub>2</sub> from ammonia production, at the national level, is subtracted from total CO<sub>2</sub> from non-energy use of natural gas to avoid double counting. It should also be noted that emissions arising from the non-energy use of natural gas to produce hydrogen in the oil refining and bitumen industries are allocated to the Energy Sector of the inventory.

#### **Solid Fuels**

Emissions from the following non-energy uses of solid fuels are included in Other and Undifferentiated Production:

- Canadian bituminous coal;
- sub-bituminous coal;
- foreign bituminous coal;
- lignite;
- anthracite; and
- metallurgical coke.

To determine, by province, the CO<sub>2</sub> emissions coming from these solid fuels, fuel-, province-, and year-specific emission factors (Jaques 1992; McCann 2000), shown in Table A12-5 of Annex 12, are applied to the consumption quantities reported as non-energy use. The national emission estimate for non-energy use of solid fuels is the total of all provincial/territorial emissions.

The emission factors used for estimating releases of CO<sub>2</sub> from non-energy use of coal and coal products are the same as those for combustion; it is assumed that 99% of the carbon in these products will eventually be oxidized and emitted as CO<sub>2</sub>.

## Liquid Fuels

In addition to the emissions coming from gaseous and solid fuels mentioned above, CO<sub>2</sub> emissions from the non-energy use of liquid fuels such as petroleum coke, primary NGLs, oil refinery petrochemical feedstocks, and lubricants, are also included in the category of Other and Undifferentiated Production.

To estimate these emissions at provincial/territorial levels, the non-energy use quantity of petroleum coke and NGLs is multiplied by the corresponding emission factor, as shown in Table A12-3 of Annex 12 for petroleum coke, and in Table A3-9 for other liquid fuels. The summation of the provincial/territorial estimates gives the national emission estimate.

It should also be noted that owing to the way in which energy statistics are currently collected in Canada, other non-energy uses of liquid fuels (e.g. heavy fuel oil) have been reported under energy use. Hence the latter emissions are included in the Energy Sector.

In the case of non-energy use of NGLs, factors that account for the potential emissions that occur when all the carbon is oxidized are provided in the McCann (2000) study. The *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997) show a default value for the fraction of carbon that can be stored in products that are manufactured using propane, butane, or ethane as feedstock. The McCann (2000) potential emission factors are multiplied by the IPCC default fraction of carbon stored of 0.8 to give the non-energy-use emission factors of the three NGLs as shown in Table A3-9.

**Table A3-9: CO<sub>2</sub> Emission Factors for Natural Gas Liquids**

	Fraction of Carbon Stored in Products	Emission Factors (g CO <sub>2</sub> /L)	Sources
Propane	0.8	303	IPCC/OECD/IEA (1997); McCann (2000)
Butane	0.8	349	IPCC/OECD/IEA (1997); McCann (2000)
Ethane	0.8	197	IPCC/OECD/IEA (1997); McCann (2000)

The non-energy use of petroleum products coming out of the oil refineries, i.e., petrochemical feedstocks, naphthas, lubricants, greases, and other petroleum products also results in CO<sub>2</sub> emissions that are accounted for in the category of Other and Undifferentiated Production. These non-energy products can be employed in producer consumption, mining, manufacturing, forestry, construction, transportation, agriculture, public administration, and commercial and institutional sectors. Their carbon factors (mass of carbon emitted per volume of product used) come from Jaques (1992). These factors are then multiplied by the molecular weight ratio between CO<sub>2</sub> and carbon, 44/12, and by (1 - fraction of carbon stored) to give the CO<sub>2</sub> emission factors used to estimate emissions. As in the case of NGLs, the default values of fraction of carbon stored are found in the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC/OECD/IEA 1997). Derivations of the non-energy-use emission factors are shown in Table A3-10. To estimate emissions at national and provincial/territorial levels, the volume of non-energy product used is multiplied by its corresponding emission factor.

**Table A3-10: CO<sub>2</sub> Emission Factors for Non-Energy Petroleum Products**

Non-Energy Products	Carbon Factor (g C/L)	Molecular Weight Ratio between CO <sub>2</sub> and Carbon	Fraction of Carbon Stored (IPCC Default)	Resulting CO <sub>2</sub> Emission Factor (g CO <sub>2</sub> /L)
	A	B	C	D = A × B × (1 – C)
Petrochemical Feedstocks	680	44/12	0.8	500
Naphthas	680	44/12	0.75	625
Lubricating Oils and Greases	770	44/12	0.5	1410
Petroleum Used for Other Products	790	44/12	0.5	1450

The “gross” emission total for the subsector of Other and Undifferentiated Production is the sum of emission estimates for non-energy use of gaseous, liquid, and solid fuels. To calculate the “net” emission totals (i.e. the reported emission estimates) at national and provincial levels, all emissions accounted for in other categories are subtracted from the gross emission totals. For instance, CO<sub>2</sub> emissions from aluminium production, ammonia production, and consumption of EAF electrodes are reported in other subsectors; hence, they are subtracted from the gross emission totals of Other and Undifferentiated Production to avoid double counting. However, it should be noted that, at a provincial level, CO<sub>2</sub> emissions from ammonia production are included in the Other and Undifferentiated Production emission estimates.

#### A3.2.1.2 Data Sources

The RESD (Statistics Canada #57-003) is the activity data source for the Other and Undifferentiated Production category. This report presents data by fuel type and area of application (i.e. energy-use versus non-energy-use applications).

### A3.2.2 CO<sub>2</sub> Emissions from Ammonia Production

#### A3.2.2.1 Methodology

To estimate emissions from ammonia production, an emission factor of 1.56 t CO<sub>2</sub>/t NH<sub>3</sub> produced was used. The emission factor was developed, in *Canada’s Greenhouse Gas Emissions: Estimates for 1990* (Jaques 1992), based on the natural gas requirement for producing 1 t of liquefied ammonia. Information on the feedstock requirement for the SMR process was originally obtained from *Industrial Chemicals* (Lowenheim and Moran 1980). Table A3-11 details the derivation of the ammonia production-based emission factor (1.56 t CO<sub>2</sub>/t NH<sub>3</sub>).

**Table A3-11: Derivation of Ammonia Production–Based Emission Factor**

Natural Gas Component	No. of Carbons	Potential CO <sub>2</sub> Emissions per Mole of Component (g/mol)	Natural Gas Composition (% by volume)	Volume of Each Component in 812 m <sup>3</sup> of Natural Gas (m <sup>3</sup> )	No. of Moles of Each Component in 812 m <sup>3</sup> of Natural Gas (mol)	CO <sub>2</sub> Emissions from Each Component (t)
	C	D = C × 44 g CO <sub>2</sub> /mol	E	F = E × A	G = F / B	H = G × D / 1 000 000
Methane (CH <sub>4</sub> )	1	44	92	747	31 554	1.39
Ethane (C <sub>2</sub> H <sub>6</sub> )	2	88	3.6	29	1 235	0.11
Propane (C <sub>3</sub> H <sub>8</sub> )	3	132	1.0	8	343	0.05
Butane (C <sub>4</sub> H <sub>10</sub> )	4	176	0.3	2	103	0.02
Nitrogen	0	0	3.1	25	1 063	0.00
<b>Resulting Emission Factor (t CO<sub>2</sub>/t NH<sub>3</sub>)</b>						<b>1.56</b>

Notes:

Basis of derivation: 1 t NH<sub>3</sub>Volume of natural gas required to make 1 t NH<sub>3</sub>: 812 m<sup>3</sup> (A)Molar volume of natural gas at 15°C: 0.02365 m<sup>3</sup>/mol (B)

Since the hydrogen needed for the Haber-Bosch process can be acquired from processes other than steam methane reforming (SMR), not all ammonia production involves emissions of CO<sub>2</sub>. Therefore, it is necessary to multiply only the net CO<sub>2</sub>-related ammonia production by the emission factor. Data on CO<sub>2</sub>-related production used in the calculation can be either directly collected from ammonia plants or estimated nationally.

Not all of the ammonia manufacturing plants provided their 1990–2006 operational data. In order to estimate the unreported part of the CO<sub>2</sub>-emitting ammonia production, the amount of ammonia produced using by-product hydrogen and that using hydrogen from SMR, as reported by plants, are subtracted from the national total ammonia production found in Industrial Chemicals and Synthetic Resins (Statistics Canada #46-002). The total unreported production is then multiplied by the capacity share of each of the non-reporting plants to give the estimated unreported production by plant. (It should be noted here that plants using by-product hydrogen had all reported their productions and emissions; hence, the unreported part of emissions related to the CO<sub>2</sub>-emitting ammonia plants only.) Multiplying both reported and unreported CO<sub>2</sub>-related ammonia production by the emission factor of 1.56 t CO<sub>2</sub>/t NH<sub>3</sub> gives the total amount of CO<sub>2</sub> generated. To estimate by province the amount of CO<sub>2</sub> generated from the SMR process, the plant-specific estimated production and reported production are aggregated by province based on location. Once the provincial total production is calculated, it is then multiplied by the output-based emission factor. However, for inventory purposes, the provincial CO<sub>2</sub> generation estimates for ammonia production are included in the category of Other and Undifferentiated Production.

It should be noted that the quantity of natural gas used to produce hydrogen that feeds the ammonia production process was also recorded by Statistics Canada with all other non-energy uses of natural gas. Therefore, to avoid double counting at the national level, the CO<sub>2</sub> emissions from ammonia production were subtracted from the total non-energy fossil fuel use CO<sub>2</sub> emissions.

The estimation technique (emissions = production of ammonia × emission factor) described in this section is one of the default methods suggested in the *Revised 1996 IPCC Guidelines for*



*National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997). However, it should be noted that the emission factor of 1.56 t CO<sub>2</sub>/t NH<sub>3</sub> produced is a national average value. Methodological issues for calculating CO<sub>2</sub> emissions from ammonia production are not addressed specifically in the *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000).

#### A3.2.2.2 Data Sources

Ammonia production data are collected from facilities, whenever possible. Production data for 1990–2004 were collected through or estimated in the 2006 Cheminfo study (Cheminfo Services 2006). For 2005–2006, data are reported by companies to the Greenhouse Gas Division on a voluntary basis. *Industrial Chemicals and Synthetic Resins* (Statistics Canada #46-002) provides data on national total ammonia production.

### A3.3 Methodology for the Agriculture Sector

This section of Annex 3 describes the estimation methodologies, specific equations, activity data, emission factors and parameters that are used to derive the GHG estimates for the agriculture sector, namely:

- CH<sub>4</sub> emissions from enteric fermentation;
- CH<sub>4</sub> and N<sub>2</sub>O emissions from manure management;
- N<sub>2</sub>O emissions from agricultural soils (direct emissions, indirect emissions, and animal manure emissions on pasture, range, and paddock).

Animal population data which are common to agricultural sources are presented first with sources of data in A3.3.1 and cattle population is then characterized in A3.3.2. The methodologies for agricultural GHG estimates are described in sections A3.3.3 to A3.3.6. Note that agricultural soils also emit and sequester CO<sub>2</sub>, but these sources/sinks are reported by the LULUCF Sector (see section A3.4).

#### A3.3.1 Animal Population Data Sources

Annual livestock and poultry population data at a provincial level were used to develop emission estimates. Livestock and poultry populations for each animal category/subcategory, and by province, were obtained from Statistics Canada (Table A3-12). CANSIM (undated) is Statistics Canada's on-line database that stores the most up-to-date statistics available in Canada. Livestock and poultry population data are expressed on an annual basis, although the data are derived from the Census of Agriculture, which is conducted every 5 years, combined with semi-annual or quarterly surveys for important animal categories.

To annualize the animal population of cattle, sheep, lamb and swine that are reported in both the Census of Agriculture and in surveys, the survey data is averaged by taking the simple mean. The populations of horses, goats, buffalo, llamas and alpacas, and poultry are estimated every 5 years by the Census of Agriculture exclusively. These populations are annualized by linear interpolation in order to avoid large annual changes. In addition, buffalo population were not collected in 1986, thus buffalo population was set constant for 1990 at the 1991 level.

**Table A3-12: Data Sources for Animal Populations**

Category	Sources/Notes
<b>Cattle</b>	Data downloaded from CANSIM in January 2008
<b>Sheep and Lambs</b>	Data downloaded from CANSIM in January 2008
<b>Swine</b>	Data downloaded from CANSIM in January 2008
<b>Poultry</b>	Selected Historical Data from the Census of Agriculture, Section 2 – Agricultural perspectives from seven censuses, Canada and provinces: census years 1976 to 2006, Table 2.16 (Statistics Canada 2007, catalogue number 95-632): <a href="http://www.statcan.ca/english/freepub/95-632-XIE/2007000/tables/table2.16-en.htm">http://www.statcan.ca/english/freepub/95-632-XIE/2007000/tables/table2.16-en.htm</a> Farm data and farm operator data tables: <a href="http://www.statcan.ca/english/freepub/95-629-XIE/2007000/livestock.htm">http://www.statcan.ca/english/freepub/95-629-XIE/2007000/livestock.htm</a> Focus on selected commodities, Canada and provinces: census years 1970 to 2006, Table 4.4: ( <a href="http://www.statcan.ca/english/freepub/95-632-XIE/2007000/tables/table4.4-en.htm">http://www.statcan.ca/english/freepub/95-632-XIE/2007000/tables/table4.4-en.htm</a> )
<b>Goats, Horses, Llamas &amp; Alpacas and Buffaloes</b>	Statistics Canada (2008), <i>Alternative Livestock on Canadian Farms: Census Years 1981, 1986, 1991, 1996, 2001 and 2006</i> (Statistics Canada #23-502-X)

### A3.3.2 Cattle Characterization

For beef and dairy cattle, the IPCC Tier 2 approach (IPCC 2000) was adopted to estimate CH<sub>4</sub> emission factors from enteric fermentation and manure management. To achieve this, the 2001 cattle population was characterized by animal type, physiological status, age, sex, weight, rate of weight gain, level of activity, and production environment.

When available, data from surveys of production and management practices published in scientific journals were utilized to describe the production environment and associated performance of classes of animals. Because the information was not available for all classes of cattle, a survey of dairy and beef production practices was conducted and administered to regional and provincial beef and dairy cattle specialists across the country. Additional information was obtained from research scientists at universities and federal research institutions, as well as from provincial/national associations and provincial/regional performance recording organizations (Boadi et al. 2004).

The feeding practices for beef and dairy cattle are detailed in this section.

#### A3.3.2.1 Dairy Cattle

##### Production and Performance

Production practices vary across the country because of differences in land values, climate, forage availability and market access. The predominant practices for each province are reflected by province-specific parameters inputted into the IPCC Tier 2 equations.

Table A3-13 provides a summary of the production performance of Canadian dairy cattle.

**Table A3-13: Characteristics of Dairy Production in 2001 in Canada**

Animal Category/Parameters	Production Characteristics <sup>1</sup>	Data Sources <sup>2</sup>
Dairy Cows		
Average weight, kg	634 (51)	Okine and Mathison (1991); Kononoff et al. (2000); Petit et al (2001)
Mature weight, kg	646 (55)	
Conception rate, %	59.2 (7.3)	
Calves		
Birth weight, kg	41 (3.3)	Western Canadian Dairy Herd Improvement Services (2002)
Average weight, kg	186 (18.5)	
Mature weight, kg	330.5 (37.6)	
Daily weight gain, kg/day	0.7 (0.3)	
Calf crop <sup>3</sup> , %	93 (6)	
Replacement heifers		
Average weight, kg	461.6 (24.7)	Western Canadian Dairy Herd Improvement Services (2002)
Beginning weight (1 year), kg	327.8 (31.0)	
Mature weight at calving, kg	602.1 (45.9)	
Mature weight, kg	646.1 (54.9)	
Daily weight gain, kg/day	0.77 (0.14)	
Replacement rate, %	32.3 (3.2)	

Notes:

1. The numbers in parentheses are the standard deviation.
2. Values with no reference were obtained from expert consultations (see Boadi et al. 2004).
3. "Calf crop" is the percentage of the overwintering cows that produced a live calf.

Data from Holstein Ontario does not indicate an increase in live weight of dairy cows over the 1990–2006 time period. As a result, dairy cows and dairy heifer's live weight are set constant to the 2001 weight, estimated in Boadi et al. (2004).

### ***Milk Yield and Fat Data***

The emission factor derived for dairy cows reflects the increase in milk productivity over time (Table A3-14). Average milk production for each province from 1995 to 2006 was drawn from the annual publication of *Dairy Animal Improvement Statistics* (Agriculture and Agri-Food Canada, 2005b) and from *Statistics of the Canadian Dairy Industry* (Agriculture and Agri-Food Canada 2005a) and was used to calculate net energy for lactation ( $NE_{lactation}$  or  $NE_l$ ).

The provincial annual average milk production per day was calculated by dividing the provincial average production by the number of milking days per year. Note that for the years 1990 to 1994 inclusively, only the national milk yield data were published and provincial production estimates were derived by dividing the national average production by the number of milking days per year of a given province. As there is no milk productivity data for Newfoundland, it was assumed to be the same as Nova Scotia's. Milk fat data were also obtained from Agriculture and Agri-Food Canada yearly publications named in previous paragraph.

**Table A3-14: Average Milk Production from 1990 to 2006 and Number of Milking Days at a Provincial Level**

Year	Average Milk Production (kg/cow per day) <sup>1</sup>									
	NF	PE	NS	NB	QC	ON	MB	SK	AB	BC
1990	24.2	25.0	24.7	24.5	24.5	24.5	25.3	25.4	25.1	24.6
1991	24.6	25.3	25.1	24.9	24.8	24.8	25.7	25.8	25.5	25.0
1992	25.5	26.3	26.0	25.8	25.7	25.7	26.6	26.7	26.4	25.9
1993	26.1	26.9	26.6	26.5	26.4	26.4	27.3	27.4	27.1	26.5
1994	26.5	27.3	27.0	26.8	26.7	26.7	27.7	27.8	27.5	26.9
1995	26.4	27.2	26.9	26.7	26.2	27.0	28.2	28.5	30.1	30.0
1996	26.6	27.4	27.2	27.0	26.8	27.7	28.7	29.2	30.6	30.3
1997	27.0	27.8	27.5	27.4	27.2	27.9	29.0	29.7	30.9	29.9
1998	27.4	28.3	28.0	27.8	28.2	28.7	29.3	30.6	31.5	30.7
1999	28.4	29.2	28.9	28.7	29.2	29.3	30.1	31.1	32.1	31.5
2000	30.0	29.9	30.6	29.9	30.0	29.7	31.2	31.9	32.8	32.4
2001	30.3	30.3	30.9	30.9	30.5	29.6	32.3	32.8	33.5	32.8
2002	30.3	31.1	30.9	31.2	31.1	30.9	31.8	33.8	34.4	33.9
2003	30.6	31.3	31.2	30.9	31.0	30.8	32.1	34.0	34.7	34.3
2004	30.5	30.9	31.1	30.7	30.9	30.5	32.3	34.0	34.2	34.3
2005	30.5	31.3	31.1	30.6	30.6	30.6	31.5	34.0	33.7	34.0
2006	30.4	31.8	31.0	30.5	30.9	31.0	31.0	33.8	33.8	33.6
Milk days per year <sup>2</sup>	306	297	300	302	303	303	293	292	295	301

Notes:

1. Data source: Agriculture and Agri-Food Canada (2006).

2. Data source: Boadi et al. (2004).

***Duration of Time in a Production Environment***

It was assumed that animals that were dry during the summer months were on pasture; animals that were dry during the remainder of the year were in confinement. Further, replacement heifers were assumed to calve at 24 months, although they may have been more than 24 months of age at calving in some circumstances.

***Percentage of Cows Pregnant***

An estimate of the percentage of cows pregnant in the herd at any given time was calculated according to J.C. Plaizier (University of Manitoba, personal communication, unreferenced) using the following formula:

$$\text{Percentage of cows pregnant} = (\text{gestation length/calving interval} \times 100) - \text{percentage of cows culled due to reproductive failure}$$

***Ration Digestible Energy***

Digestible Energy (DE) values determined by Christensen et al. (1977) for forages grown on the prairies were used to estimate DE for Alberta, Saskatchewan, and Manitoba. U.S. National Research Council values (NRC 2001) were used to estimate DE for British Columbia and the eastern provinces. Total mixed rations for cattle were assumed to be mainly forage and grain due to limited information regarding other feed ingredients. It was also assumed that lactating cows on pasture were supplemented with grain; therefore, DE values were assumed to be similar to those of rations fed in confinement.

A3.3.2.2 *Non-Dairy Cattle***Production Practices and Performance**

Production practices vary across the country. The study conducted by Boadi et al. (2004) characterized the predominant practices, in 2001, for each province according to animal type, physiological status, age, gender, rate of weight gain, level of activity and production environment. The values, presented in Table A3-15 represent an average for all provinces.

**Table A3-15: Characteristics of Beef Production in Canada in 2001**

<b>Animal Category/Parameters</b>	<b>Production Characteristics<sup>1</sup></b>	<b>Data Sources<sup>2</sup></b>
<b>Beef Cows</b>		
Average weight, kg	603 (36)	Kopp et al. (2004)
Mature weight, kg	619 (52)	AAFRD (2001)
Milk, kg/day	7.3 (1.2)	Kopp et al. (2004)
Milk fat, %	3.6 (0.6)	Kopp et al. (2004)
Conception rate, %	93.7 (1.3)	Manitoba Agriculture and Food (2000); AAFRD (2001)
<b>Replacement Heifers</b>		
Average weight, kg	478 (34)	
Mature weight, kg	620 (51)	
Daily weight gain, kg/day	0.64 (0.14)	
Replacement rate, %	14.4 (3.1)	Manitoba Agriculture and Food (2000)
<b>Bulls</b>		
Yearling weight, kg	541 (18)	
Average weight, kg	940 (98)	
Mature weight, kg	951 (112)	
Daily weight gain, kg/day	1.0 (0.17)	
<b>Calves (including Dairy Calves)</b>		
Birth weight, kg	40 (3)	AAFRD (2001)
Wean weight, kg	258.4 (19.1)	Small and McCaughey (1999)
Age at weaning, days	215 (15)	
<b>Daily weight gain, kg/day</b>		
- Replacement heifers	0.67 (0.13)	Kopp et al. (2004)
- Backgrounder	0.98 (0.17)	
- Finisher	1.37 (0.12)	
Calf crop, %	95 (2.3)	
<b>Heifer and Steer Stockers</b>		
Average weight, kg	411 (47)	Kopp et al. (2004)
Mature weight, kg	620 (51)	
Daily weight gain, kg/day	0.98 (0.16)	
Proportion to feedlot, %	65 (30)	
<b>Feedlot Animals</b>		
Average weight, kg		
- Direct finish	540 (25)	
- Background finish	562 (64)	
Mature weight, kg	630 (46)	
Finish weight, kg	609 (28)	
Daily weight gain, kg/day	1.37 (0.12)	

Notes:

1. The numbers in parentheses are the standard deviation.

2. Values with no reference were obtained from expert consultations (Boadi et al. 2004).

Carcass weight data is collected by the Canadian Beef Grading Agency (CBGA) and published by Agriculture and Agri-Food Canada (AAFC 1990 to 2006). The data, presented in Figure A3-1, shows a clear increase in carcass weight from 1990 to 2006 of beef cows, heifers for slaughter, steers and bulls.

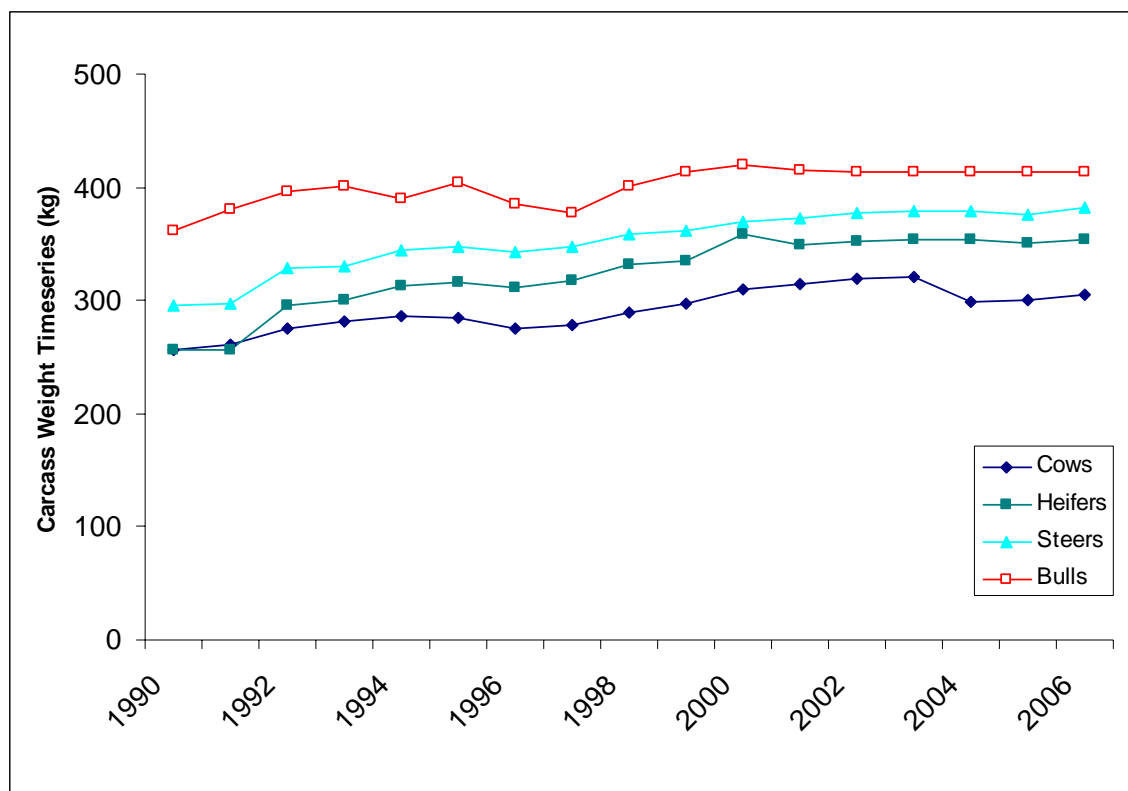


Figure A3-1: Non-dairy cattle carcass weight, based on data collected by CBGA and published by AAFC.

As a result, trends in carcass weights are used as an indicator of live weights using the 2001 benchmark live weights determined by Boadi et al. (2004) as per Table A3-16. Beginning in 2003, the Canadian meat cattle industry was affected by bovine spongiform encephalopathy (BSE) disease, which shut down beef exports to the United States. As a consequence, the entire production system was affected: older beef cattle remained in Canada, increasing the cattle population; older cattle were fed a lower quality ration which affected their average weight and presumably, the associated emission factors. Because there is no reliable documentation on changes in production practices, and since the situation is considered transient, bull's average live weights were maintained at their 2002 value for the duration of the crisis.

**Table A3-16: Carcass weights used as an indicator of live body weight change over time for some of non-dairy cattle**

<b>Cattle Subcategory</b>	<b>Trend in live weight applied</b>
Beef cows	Trends in beef cow carcass weight used as an indicator of live weight from 1990 to 2006
Heifers for slaughter	Trends in heifer carcass weight used as an indicator of live weight from 1990 to 2006
Beef heifers	Trends in beef cow carcass weight used as an indicator of live weight from 1990 to 2006
Steers	Trends in steer carcass weight used as an indicator of live weight from 1990 to 2006
Bulls	Trends in bull carcass weight used as an indicator of live weight from 1990 to 2002; 2003 to 2006 live weight are set constant to the 2002 live weight
Calves	No change
Dairy heifers <sup>a</sup>	No change

Note:

a. As dairy cows' live weight did not increase over time, it was assumed that dairy heifers did not increase either.

### **Duration of Time in a Production Environment**

Replacement heifers over 15 months of age are assumed to be bred or pregnant. All replacement stock (breeding bulls, young and replacement heifers over 12 months of age) is assumed to enter the breeding herd (breeding bulls, mature and beef cows) at 24 months of age.

### **Ration Digestible Energy**

Forage DE values determined by Christensen et al. (1977) for forages utilized on the prairies were used to estimate DE for Saskatchewan and Manitoba. Values from AAFRD and University of Alberta (2003) were used for Alberta, whereas NRC (2001) values were used to estimate DE of rations for British Columbia and the eastern provinces.

Calves were assumed to have a non-functional rumen or to consume very small amounts of dry feed from birth until 2–3 months of age. Therefore, enteric CH<sub>4</sub> emissions in these first few months are assumed to be zero.

### **A3.3.3 CH<sub>4</sub> Emissions from Enteric Fermentation**

The release of CH<sub>4</sub> from enteric fermentation from various categories of livestock in Canada is calculated using Equation A3-8. CH<sub>4</sub> emissions from enteric fermentation for cattle are estimated using the country specific emission factors (Table A3-17). For the other animal categories, the IPCC Tier 1 methodology and default emission factors are applied (see Annex 12).

**Equation A3-8:**

$$CH_{4EF} = \sum_T (N_T \times EF_{(EF)T})$$

where:

- $CH_{4EF}$  =  $CH_4$  emissions from enteric fermentation for all animal categories  
 $N_T$  = animal population for the Tth animal category or subcategory in each province  
 $EF_{(EF)T}$  = emission factor for the Tth animal category or subcategory (Table A3-17 for cattle; for other animal categories, see Annex 12).

### A3.3.3.1 Enteric $CH_4$ Emission Factors for Cattle

Provincial emission factors were derived using IPCC Tier 2 equations for different categories of cattle (dairy cows, dairy heifers, beef cows, beef heifers, bulls, calves, heifer replacement, heifers >1 year, and steers >1 year) based on stages of production. For example, dairy cattle emissions were estimated for two production categories: dry cows and lactating cows. The duration time an animal spends in a production category can be variable; a weighted average emission factor was calculated. Criteria used in the weighting included duration of time spent in the production category and relative percentage of the population in each stage of production. Provincial emission factors were then weighted on the basis of provincial animal population with respect to the national population in order to calculate a national emission factor for each category, for the entire time series (Table A3-17).

**Table A3-17:  $CH_4$  Emission Factors for Enteric Fermentation for Cattle from 1990 to 2006**

Year	EF <sub>(EF)T</sub> - kg $CH_4$ /head/year							
	Dairy Cows <sup>1</sup>	Dairy Heifers	Bulls	Beef Cows	Beef Heifers	Heifers for Slaughter	Steers	Calves
1990	116.0	73	85.5	78.2	71.8	58.9	54.6	48.6
1991	117.7	73	88.2	78.9	72.4	59.0	54.8	48.5
1992	120.3	73	90.3	81.2	73.4	61.7	57.0	48.4
1993	122.3	73	91.0	82.2	73.8	62.4	56.6	48.4
1994	123.0	73	89.5	83.1	74.4	63.2	57.7	48.5
1995	123.8	73	91.6	82.7	74.2	63.4	57.4	48.5
1996	125.6	73	89.0	81.2	73.2	63.4	57.6	48.4
1997	126.1	73	87.9	81.6	74.0	64.1	58.3	48.4
1998	128.0	73	91.2	83.3	75.0	65.4	59.4	48.5
1999	130.1	73	93.0	84.4	75.8	66.2	60.0	48.4
2000	132.1	73	93.8	86.4	76.9	67.6	60.6	48.5
2001	132.9	73	93.1	86.9	77.4	67.1	60.6	48.5
2002	135.2	73	93.1	87.5	78.0	67.3	60.8	48.5
2003	135.3	73	93.0	87.7	77.9	66.9	60.5	48.4
2004	134.8	73	92.9	84.2	75.2	66.8	60.1	48.4
2005	134.8	73	92.9	84.3	75.0	66.7	59.8	48.3
2006	135.2	73	92.9	84.8	75.3	67.0	60.4	48.3

Note:

1. Dairy cow emission factors are derived from Boadi et al. (2004) for enteric fermentation.

### A3.3.3.2 Enteric $CH_4$ Emission Factors for Non- cattle

For non-cattle animal categories, the IPCC Tier 1 emission factors are applied (see Annex 12).



### A3.3.4 CH<sub>4</sub> Emissions from Manure Management

The IPCC Tier 2 methodology is used to estimate CH<sub>4</sub> emission factors from manure management systems (IPCC 2000). Equation A3-9 is used to calculate CH<sub>4</sub> emissions from manure management for various categories of livestock in Canada. Sources of animal population data are the same as those used in the enteric fermentation estimations and are listed in Table A3-12.

#### Equation A3-9:

$$CH_{4MM} = \sum_T (N_T \times EF_{(MM)T})$$

where:

- CH<sub>4MM</sub> = emissions for all animal categories
- N<sub>T</sub> = animal population for the Tth animal category or subcategory in each province
- EF<sub>(MM)T</sub> = emission factor for the Tth animal category or subcategory (Table A3-23 and A3-13)

To develop country-specific CH<sub>4</sub> emission factors from manure management, country-specific inputs taking into account livestock diet, type and distribution of manure storage and climate were needed. The following equation represents an IPCC Tier 2 estimate of CH<sub>4</sub> emission factors from manure management systems:

#### Equation A3-10:

$$EF_{(MM)T} = VS_T \times 365 \text{ days/year} \times B_{0T} \times 0.67 \text{ kg/m}^3 \times \sum_{ij} (MCF_{ij} \times MST_{ij})$$

where:

- EF<sub>(MM)T</sub> = annual emission factor for defined animal population T, kg/head-year
- VS<sub>T</sub> = daily volatile solids excreted for an animal within the defined population T, kg/day
- B<sub>0T</sub> = maximum CH<sub>4</sub> producing potential for manure produced by an animal within defined population T, m<sup>3</sup>/kg VS
- MCF<sub>ij</sub> = CH<sub>4</sub> conversion factor for each manure management system i in climate region j
- MST<sub>ij</sub> = system distribution factor, defined as the fraction of animal category T's manure that is handled using manure system i in climate region j (IPCC 2000, Equation 4.17, p. 4.34)

The following sections outline the input values for Equation A3-3: VS, GE, DE and ASH.

#### A3.3.4.1 Volatile Solids

Volatile solids (VS) are the organic fraction of total solids within the manure. VS can be measured from manure samples; alternatively, VS can be estimated using the IPCC methodology based on dietary intake (DE), gross energy (GE) and manure ash content, as per Equation A3-11 (IPCC 2006). As for GE, as shown in Equation A3-12, it depends on many factors, including live body weight, lactation stage and time of year.

Note that for cattle subcategories, GE was estimated during the IPCC Tier 2 process of CH<sub>4</sub> emissions from cattle enteric fermentation. Therefore, VS was derived in the same manner: provincial VS for different categories of cattle based on stages of production from 1990 to 2006.

The following sections examine the data sources for estimating VS for major animal categories.

**Equation A3-11:**

$$VS = GE \times \left(1 \text{ kg} - \frac{dm}{18.45 \text{ MJ}}\right) \times \left(1 - \frac{DE}{100}\right) \times \left(1 - \frac{ASH}{100}\right)$$

where:

VS	=	volatile solids excretion, kg/head per day
GE	=	gross energy, MJ/day
DE	=	digestible energy of the ration, %
ASH	=	ash content of the manure, %

**Equation A3-12:**

$$GE = \left[ \frac{(NE_m + NE_a + NE_l + NE_p)}{(NE_m/DE)} \right] + \left[ \frac{NE_g}{(NE_g/DE)} \right] \left/ \left[ \frac{DE}{100} \right] \right.$$

where:

GE	=	gross energy, MJ/day
NE <sub>m</sub>	=	net energy required for maintenance, MJ/day
NE <sub>a</sub>	=	net energy required for activity, MJ/day
NE <sub>l</sub>	=	net energy required for lactation, MJ/day
NE <sub>p</sub>	=	net energy required for pregnancy, MJ/day
NE <sub>m</sub> /DE	=	ratio of net energy available in a diet for maintenance to digestible energy
NE <sub>g</sub>	=	net energy required for growth, MJ/day
NE <sub>g</sub> /DE	=	ratio of net energy available in a diet for growth to digestible energy
DE	=	digestible energy of the ration, %

### Digestible Energy (DE) and Dry Matter Intake (DMI)

DE for both dairy and non dairy cattle is detailed in sections A3.3.2.1 and A3.3.2.2 respectively.

Broad regional differences in ration composition were identified for sheep, horses and swine. Regional differences were not considered for goats or poultry, since such data were not available.

Generally, rations for grazing livestock consist of grains and roughage. Diet digestibility will vary, with grains having a higher digestibility than roughages. The distribution of grain-based and roughage-based diets was estimated for sheep and horses in each province. Knowing the approximate DE for grains and roughages for each animal type and the distribution of grain and roughage usage by province, a weighted estimate of DE was obtained (Table A3-18). It should be noted that this method does not account for additives that may increase or decrease digestibility. Ranges for DMI for non-cattle were determined through consultation with experts and published values (Table A3-19).

**Table A3-18: Approximate Digestible Energy (DE) for Selected Livestock and Data Sources**

Animal Category	DE (%)	Data Sources <sup>1</sup>
Goat	65	W. Whitmore, Manitoba Agriculture and Food
Laying Hen	80	S. Leeson, University of Guelph; D. Korver, University of Alberta
Chicken	80	S. Leeson, University of Guelph; D. Korver, University of Alberta
Turkey	78	S. Leeson, University of Guelph
Swine	87	C.F. deLange, University of Guelph
<b>Feeding on Grain Diet</b>		
Sheep	74	Weston (2002)
Horse	70	L. Warren, Colorado State University
<b>Feeding on Roughage Diet</b>		
Sheep	65	W. Whitmore, Manitoba Agriculture and Food
Horse	60	L. Warren, Colorado State University

Note:

1. Data sources: Expert consultations (Marinier et al. 2004).

**Table A3-19: Dry Matter Intake for Selected Livestock**

Animal Category	DMI (kg/head per day)	Data Sources
<b>Sheep and Lamb</b>		
Ewes	1.2–2.8	NRC (1985)
Rams	2.1–3.0	Personal communication with W. Whitmore, Manitoba Agriculture and Food
Replacement Lambs	1.2–1.5	NRC (1985)
Market Lambs	1.3–1.6	NRC (1985)
<b>Horses</b>		
Mature Idle Horses	7.4–11	NRC (1989); personal communication with L. Warren, Colorado State University
Mature Working Horses	7.4–13.7	NRC (1989); L. Warren, Colorado State University
Weanlings	3.6–6.3	NRC (1989)
<b>Swine</b>		
Starters (5–20 kg)	0.55–0.72	C. Wagner-Riddle, University of Guelph
Growers (20–60 kg)	1.4–2.1	J. Patience, Prairie Swine Centre
Finishers (60–110 kg)	2.1–3.3 <sup>1</sup>	M. Nyachoti, University of Manitoba; C. Pomar, Agriculture and Agri-Food Canada
Sows	2.28	C. Wagner-Riddle, University of Guelph
Boars	2.0–2.5	Personal communication with M. Nyachoti, University of Manitoba; NRC (1998)
<b>Goats</b>		
Does	1.2–2.8	NRC (1981)
Bucks	1.4–2.3	CRAAQ (1999)
Kids	1.4	CRAAQ (1999)
<b>Poultry</b>		
Laying Hens	0.072–0.11	Personal communication with S. Leeson, University of Guelph; personal communication with D. Korver, University of Alberta
Broilers	0.085–0.088	S. Leeson, University of Guelph; D. Korver, University of Alberta
Turkeys	0.023–0.53	Hybrid Turkeys (2001)

Note:

1. Calculated as 3.5% of body weight.

### Manure Ash Content (ASH)

The ash content in the manure represents the inorganic portion of the manure. Table A3-20 contains the recommended values obtained and their sources.

**Table A3-20: Manure Ash Content for Selected Livestock and Data Sources**

Animal Category	ASH (%)	Data Sources
Cattle	8	IPCC (2000)
Sheep	8	IPCC (2000)
Goat	8	IPCC (2000)
Horse	4	IPCC (2000)
Laying Hen	10	Marinier et al. (2004)
Chicken	7	Marinier et al. (2004)
Turkey	5	Marinier et al. (2004)
Swine	5	Marinier et al. (2004)

### Uncertainty assessment - Volatile Solid (VS) Calculation and Error Assessment

Values for DMI, DE and ASH were used to calculate VS for non-cattle livestock categories by province. A Monte Carlo simulation was performed using Crystal Ball® (Decisioneering 2000), whereby a probability distribution was assigned to each of the inputs of DMI, DE and ASH. Equation A3-11 was calculated 10 000 times using inputs within the assigned distributions to arrive at the mean VS and 95% confidence interval (Table A3-21).

**Table A3-21: Mean Volatile Solids and associated 95% confidence interval, expressed as a percentage of the mean for non-cattle category per province**

	Mean VS <sup>1</sup> (kg/head per day)									
	BC	AB	SK	MB	ON	QC	NB	NS	PE	NL
<b>Sheep</b>										
Ewes	0.6 (42)	0.62 (42)	0.6 (42)	0.62 (42)	0.6 (41)	0.6 (41)	0.6 (42)	0.6 (42)	0.6 (42)	0.6 (41)
Rams	0.8 (20)	0.8 (20)	0.8 (20)	0.8 (20)	0.8 (20)	0.8 (20)	0.8 (20)	0.8 (20)	0.8 (20)	0.8 (20)
Breeding Lambs	0.4 (20)	0.4 (20)	0.4 (20)	0.4 (19)	0.4 (19)	0.4 (20)	0.4 (19)	0.4 (19)	0.4 (19)	0.4 (19)
Market Lambs	0.5 (13)	0.5 (13)	0.4 (15)	0.5 (13)	0.5 (13)	0.4 (15)	0.5 (13)	0.4 (14)	0.5 (13)	0.5 (13)
<b>Horses</b>										
Mature Horses	3.2 (15)	3.2 (15)	3.3 (16)	3.2 (15)	3.2 (15)	3.1 (16)	3.2 (15)	3.2 (15)	3.2 (16)	3.2 (15)
<b>Swine</b>										
Starters (5–20 kg)	0.08 (80)	0.08 (80)	0.08 (80)	0.08 (100)	0.08 (80)	0.08 (80)	0.08 (80)	0.08 (80)	0.08 (80)	0.08 (80)
Growers (20–60 kg)	0.23 (35)	0.23 (35)	0.23 (35)	0.20 (40)	0.22 (36)	0.22 (36)	0.23 (35)	0.23 (35)	0.23 (35)	0.23 (35)
Finishers (60–110 kg)	0.36 (33)	0.36 (33)	0.36 (33)	0.31 (39)	0.34 (35)	0.34 (35)	0.36 (33)	0.36 (33)	0.36 (33)	0.36 (33)
Sows	0.28 (53)	0.28 (53)	0.28 (53)	0.28 (57)	0.28 (56)	0.28 (56)	0.28 (53)	0.28 (53)	0.28 (53)	0.28 (53)
Boars	0.29 (27)	0.29 (27)	0.29 (27)	0.25 (32)	0.28 (29)	0.28 (29)	0.29 (27)	0.29 (27)	0.29 (27)	0.29 (27)
<b>Goats</b>										
All Goats	0.64 (41)	0.64 (41)	0.64 (41)	0.64 (41)	0.64 (41)	0.64 (41)	0.64 (41)	0.64 (41)	0.64 (41)	0.64 (41)
<b>Poultry</b>										
Laying Hens	0.02 (26)	0.02 (26)	0.02 (26)	0.02 (26)	0.02 (26)	0.02 (26)	0.02 (26)	0.02 (26)	0.02 (26)	0.02 (26)
Chickens	0.02 (16)	0.02 (16)	0.02 (16)	0.02 (16)	0.02 (16)	0.02 (16)	0.02 (16)	0.02 (16)	0.02 (16)	0.02 (16)
Turkeys	0.06 (28)	0.06 (28)	0.06 (28)	0.06 (28)	0.06 (28)	0.06 (28)	0.06 (28)	0.06 (28)	0.06 (28)	0.06 (28)

Note:

1. Numbers in parentheses are a 95% confidence interval expressed as a percentage of the mean.

**A3.3.4.2 Maximum CH<sub>4</sub> Producing Potential (B<sub>0</sub>)**

B<sub>0</sub> is defined as the maximum volume of CH<sub>4</sub> that can be produced from 1 kg of VS loaded into a manure management system and is expressed in m<sup>3</sup>/kg VS loaded. Because it is a measure of the maximum CH<sub>4</sub> production, B<sub>0</sub> is not affected by the temperature at which manure is digested (Hashimoto et al. 1981). Factors that affect B<sub>0</sub> include diet, age of manure, amount of foreign material and species. B<sub>0</sub> was determined from several studies examining anaerobic digestion (Hashimoto et al. 1981; Safely et al. 1992). Swine manure has the highest CH<sub>4</sub> producing potential, followed by poultry, beef cattle, and dairy cattle. Very little research has been done to determine the B<sub>0</sub> for horses, and no research could be found on sheep or goat manure. Because of a lack of available data in Canada, the IPCC default B<sub>0</sub> values were used (see Annex 12). For buffalos, non-dairy cattle values are used.

#### A3.3.4.3 *Methane Conversion Factor (MCF)*

MCF is the proportion of  $B_0$  that is realized and is affected by the storage system (for cattle and swine) and climate region. The IPCC default values were used (see Annex 12). For buffalos, non-dairy cattle values are used.

#### A3.3.4.4 *Manure System Distribution Factor (MS)*

MS is the proportional distribution of AWMS of a livestock category within a given area. There is no scientific literature published on the distribution of manure management systems in Canada. While every provincial department of agriculture has information about manure management practices, no consistent and systematic information could be found on the distribution of these practices among provinces.

A survey of expert opinion was conducted in 2003–2004 as part of the Tier 2 study by Marinier et al. (2004); results are shown in Table A3-22. Values for beef, dairy, swine and poultry were calculated using a weighted average based on population. For horses, sheep & lamb, and goats, these values were a simple average of survey responses. No specific data were available for covered lagoons and biodigesters, they are assumed to be part of Other systems.

**Table A3-22: Percentage of Manure Handled by Animal Waste Management Systems (AWMS) (Marinier et al. 2004)**

Animal Category	Liquid Systems ( $N_L$ )	Solid Storage and Drylot ( $N_{SSD}$ )	Pasture, Range and Paddock ( $N_{PRP}$ )	Other Systems ( $N_O$ )
Non-Dairy Cattle	1	47	48	4
Dairy Cattle	42	40	18	0
Poultry	10	88	2	0
Sheep & Lamb	0	38	62	0
Llamas and Alpacas <sup>1</sup>	0	38	62	0
Swine	96	3	0	1
Goat	0	40	60	0
Horse	0	43	57	0
Buffalo <sup>2</sup>	0	43	57	0

Notes:

1. Assuming manure N handled by AWMS the same for llamas and alpacas are same as sheep and lambs.
2. Assuming manure N handled by AWMS the same for buffalo as for horses.

#### A3.3.4.5 *Cattle Manure Management CH<sub>4</sub> Emission Factors*

Cattle emission factors used for CH<sub>4</sub> manure management category are listed Table A3-23. The emission factors are derived from Marinier et al. (2004), but include modifications that increased consistency with the enteric fermentation model and incorporated the latest scientific information available from the *IPCC 2006 Guidelines for National Greenhouse Gas Inventories*. As a result, an emission factor time series was derived for cattle to reflect i) the increase in milk productivity of dairy cows ii) the increase in liveweight of non-dairy cattle as explained in Section A3.3.2.2.

**Table A3-23: CH<sub>4</sub> Emission Factors for Manure Management for Dairy and Non-Dairy Cattle from 1990 to 2006**

Year	EF <sub>(MM)T</sub> - kg CH <sub>4</sub> /head/year							
	Dairy Cows	Dairy Heifers	Bulls	Beef Cows	Beef Heifers	Heifers for Slaughter	Steers	Calves
1990	25.7	15.4	3.3	3.0	2.6	1.8	1.7	2.1
1991	25.9	15.4	3.4	3.1	2.6	1.8	1.7	2.1
1992	26.5	15.4	3.5	3.1	2.6	1.9	1.8	2.1
1993	26.9	15.4	3.5	3.3	2.6	2.0	1.7	2.1
1994	27.1	15.4	3.5	3.2	2.6	2.0	1.8	2.1
1995	27.3	15.4	3.6	3.2	2.6	2.0	1.8	2.1
1996	27.4	15.4	3.4	3.1	2.6	2.0	1.8	2.1
1997	27.6	15.4	3.4	3.2	2.6	2.0	1.8	2.1
1998	27.9	15.4	3.5	3.2	2.7	2.1	1.9	2.1
1999	28.2	15.4	3.6	3.3	2.7	2.1	1.9	2.1
2000	29.0	15.4	3.6	3.3	2.7	2.1	1.9	2.1
2001	29.3	15.4	3.6	3.4	2.8	2.1	1.9	2.1
2002	29.6	15.4	3.6	3.4	2.8	2.1	1.9	2.1
2003	29.7	15.4	3.6	3.4	2.8	2.1	1.9	2.1
2004	29.6	15.4	3.6	3.2	2.7	2.1	1.9	2.1
2005	29.7	15.4	3.6	3.3	2.7	2.1	1.9	2.1
2006	29.6	15.4	3.6	3.3	2.7	2.1	1.9	2.1

#### A3.3.4.6 Non-Cattle Manure Management CH<sub>4</sub> Emission Factors

Manure management emission factors for non-cattle categories, presented in Table A3-24, are derived from Marinier et al. (2004) with modifications following the guidance provided by IPCC (2000).

**Table A3-24: CH<sub>4</sub> Emission Factors for Manure Management for Non-Cattle**

Non-Cattle Animal Categories	Manure Management Emission Factors
	EF <sub>(MM)</sub> (kg CH <sub>4</sub> /head-year)
<b>Pigs</b>	
Boars	6.4
Sows	6.3
Pigs <20 kg	1.8
Pigs 20–60 kg	5.1
Pigs >60 kg	7.9
<b>Other Livestock</b>	
Sheep	0.3
Lambs	0.2
Goats	0.3
Horses	2.3
Buffalo	2.0
<b>Poultry</b>	
Chickens	0.03
Hens	0.03
Turkeys	0.08

### A3.3.5 N<sub>2</sub>O Emissions from Manure Management

The IPCC Tier 1 methodology is used to estimate N<sub>2</sub>O emissions from AWMS using Equation A3-13. Three factors are required to estimate N<sub>2</sub>O emissions from manure management: 1) N excretion rates for various animal types and categories 2) types of AWMS 3) emission factors associated with each manure management system.

Table A3-22 summarizes the distribution of manure management systems, by animal category, in Canada. Emissions of N<sub>2</sub>O from manure on pasture, range and paddock systems are not included under manure management, as they are reported under the category agricultural soils, Section A3.3.6.2. Animal population data were detailed in Section A3.3.1.

#### Equation A3-13:

$$N_2O_{AWMS} = \sum_{AWMS, T} (N_T \times N_{AWMS} \times N_{EX, T} \times EF_{AWMS}) \times \frac{44}{28}$$

where:

$N_2O_{AWMS}$	=	N <sub>2</sub> O emissions for all AWMS, excluding manure N on pasture, range, and paddock
$N_T$	=	population for the Tth animal category or subcategory ( <i>see section A3.3.1</i> )
$N_{AWMS}$	=	percentage of N produced by each AWMS ( <i>see Table A3-22</i> )
$N_{EX, T}$	=	N excretion rate for the Tth animal category or subcategory ( <i>see Table A3-25 for non cattle and Table A3-26 for cattle</i> )
$EF_{AWMS}$	=	N <sub>2</sub> O emission factors from manure management for each specific AWMS ( <i>see Annex 12</i> )
44/28	=	molecular weight ratio of N <sub>2</sub> O to N <sub>2</sub>

#### A3.3.5.1 Nitrogen Excretion Rates for Various Domestic Animals

Annual N produced from manure excreted is estimated by multiplying the N excretion rate of a given animal category by its average body weight. As specific Canadian average manure, N excretion rates are not available, the default values from the *IPCC 2006 Guidelines for National Greenhouse Gas Inventories* were used for non-cattle categories as well as average body weight (Table A3-25), except for the Buffalo category, which is assumed to have the same average body weight as Steer. For cattle populations annual live weights (*see Section A3.3.2*) were multiplied to the IPCC default N excretion rate to result in a time series of manure N excretion rates (Table A3-26).



**Table A3-25: Manure N excretion rates for non-cattle**

Animal Categories	N Excretion Rate <sup>1</sup> (kg N-1000 kg <sup>-1</sup> -day <sup>-1</sup> )	Average Body Weight <sup>1</sup> (kg)	Annual Manure N (kg N – head <sup>-1</sup> – year <sup>-1</sup> )
Swine	0.50	61	11.1
Sheep	0.42	27	4.1
Lambs	0.42	27	4.1
Goats	0.45	64	10.5
Horses	0.30	450	49.3
Llamas and Alpacas	0.42	112	17.2
Buffalo	0.32	468 <sup>2</sup>	54.7
Hens	0.83	1.8	0.5
Broilers	1.1	0.9	0.4
Turkeys	0.74	6.8	1.8

Notes

1. Data source: IPCC (2006).

2. For Buffalo, average live weight was assumed to be the same as Steers.

**Table A3-26: Manure N excretion rates time series for cattle (kg N/head/year)<sup>1</sup>**

	Dairy Cows	Beef Cows	Bulls	Heifers	Steers	Calves
1990	105.9	57.2	69.1	43.0	50.6	32.0
1991	105.9	58.2	72.7	43.3	50.9	31.9
1992	105.9	61.5	75.8	45.8	56.4	31.9
1993	105.9	62.8	76.8	46.2	56.5	31.9
1994	105.9	64.0	74.6	47.3	59.1	31.9
1995	105.9	63.6	77.4	47.3	59.5	31.9
1996	105.9	61.6	73.6	46.4	58.8	31.9
1997	105.9	62.2	72.1	47.1	59.4	31.9
1998	105.9	64.6	76.6	48.7	61.6	31.9
1999	105.9	66.3	79.0	49.6	62.2	31.9
2000	105.8	69.3	80.2	51.9	63.6	31.9
2001	105.9	70.4	79.2	51.7	64.1	31.9
2002	105.8	71.3	79.1	52.1	64.8	31.9
2003	106.0	71.6	79.3	52.1	65.0	31.9
2004	105.9	66.7	79.3	50.9	64.6	31.8
2005	105.9	67.1	79.2	50.9	64.2	31.8
2006	105.9	67.9	79.3	51.4	65.3	31.9

Note:

1. N excretion rate for dairy cattle is 0.44 kg N-1000 kg<sup>-1</sup>-day<sup>-1</sup> (IPCC 2006 Table 10.10); N excretion rate for other cattle is 0.31 kg N-1000 kg<sup>-1</sup>-day<sup>-1</sup> (IPCC 2006 Table 10.10); Data source: IPCC (2006), Volume 4, Agriculture, Forestry and Other Land Uses, Table 11.1.

### A3.3.5.2 Emission Factors Associated with AWMS

The type of AWMS has a significant impact on N<sub>2</sub>O emissions. Less aerated systems such as liquid systems generate little N<sub>2</sub>O, whereas drylots or manure on pasture and paddock produce more. However, there is little scientific information in Canada specifying amounts of N<sub>2</sub>O emissions associated with manure management systems. Therefore, IPCC default emission factors, as listed in Annex 12, were used to estimate emissions.

### A3.3.6 N<sub>2</sub>O Emissions from Agricultural Soils

Emissions of N<sub>2</sub>O from agricultural soils consist of direct and indirect emissions as well as emissions from animal manure on pasture, range and paddock. The emissions of N<sub>2</sub>O that result from anthropogenic N inputs occur through direct (directly from the soils to which the N is added) and indirect pathways: i) through volatilization of synthetic fertilizer and manure N as NH<sub>3</sub> and NO<sub>x</sub> and subsequent deposition ii) through leaching and runoff of N.

#### A3.3.6.1 *Direct N<sub>2</sub>O Emissions from Soils*

Direct sources include synthetic fertilizers, animal manure applied as fertilizer, crop residue decomposition, modification of tillage practices, summerfallow, irrigation and cultivation of histosols. The methodologies for estimating emissions of N<sub>2</sub>O for most of the direct emission sources from agricultural soils are country-specific and IPCC Tier 2 approaches.

It is known that moisture regimes and landscape impact on N<sub>2</sub>O emissions (Rochette et al. 2008). Consequently, data on long-term climate normals and topographic characteristics are used to develop a base N<sub>2</sub>O emission factor (EF<sub>BASE</sub>).

#### **Base N<sub>2</sub>O Emission Factor (EF<sub>BASE</sub>)**

The influence of local climatic conditions was assessed by the determination of regional EF<sub>BASE</sub>. These factors were estimated using the same approach as for the determination of the IPCC Tier 1 emission factor by Bouwman (1996), i.e. EF<sub>BASE</sub> = slope of the “N<sub>2</sub>O emissions versus N fertilizer rate” relationship. EF<sub>BASE</sub> was estimated for the three regions where field N<sub>2</sub>O measurements are available: Quebec–Ontario; Brown and Dark Brown soil zones; and Grey and Black soil zones. The “EF<sub>BASE</sub> versus fertilizer N” relationship determined for the Quebec–Ontario region has a similar slope (0.012 kg N<sub>2</sub>O-N/kg N, excluding emissions during winter and spring thaw) (Gregorich et al. 2005) and fit ( $r^2 = 0.43$ ) as the IPCC Tier 1 default emission factor derived by Bouwman (1996) using global data. In the Prairie region, low and variable N<sub>2</sub>O emissions were measured across the range of N fertilizer rates (Brown-Dark Brown soils = 0.0016 kg N<sub>2</sub>O-N/kg N; Grey and Black soils = 0.008 kg N<sub>2</sub>O-N/kg N). These observations suggest that soil N<sub>2</sub>O production in the Prairie region is not limited by mineral N availability but rather by the low denitrification activity under well-aerated dry soil conditions.

N<sub>2</sub>O is mostly produced during denitrification and, as a result, is greatly influenced by the soil oxygen status. Accordingly in moisture-limited conditions, N<sub>2</sub>O emission factors have been shown to increase with increasing rainfall (Dobbie et al. 1999), and climate-variable emission factors have been used in estimating soil N<sub>2</sub>O inventory (Flynn et al. 2005). A similar approach is proposed in this methodology by estimating emission factors at the ecodistrict level as a function of the ratio of the long-term normals (AAFC-archived database; S. Gameda, personal communication, unreferenced) of precipitation over potential evapotranspiration (P/PE) from May to October (Rochette et al. 2008). Despite the uncertainty in the determination of emission factors in the Prairie region, this approach is deemed a valid option to account for the influence of moisture limitations on N<sub>2</sub>O emissions in that region. To account for the topographical effect, an EF<sub>BASE</sub> was estimated at a P/PE = 1 (0.017 kg N<sub>2</sub>O-N/kg N) for the lower sections of the landscapes. The fraction of the landscape to which this condition was applied differs among landscape types.

Landscape segmentation data were incorporated into the calculation of the national N<sub>2</sub>O emission estimates, based upon the observations that N<sub>2</sub>O emissions are greater in lower sections of the

landscape where intermittently saturated soil conditions are favourable to denitrification (Corre et al. 1996, 1999; Pennock and Corre 2001; Izaurre et al. 2004). The fraction of the landscape occupied by such lower sections, or F<sub>TOPO</sub>, was applied to concave portions of the landscape (i.e. lower and depressional landscape positions) where soils are likely to be saturated for significant periods of time on a regular basis and soils are imperfectly and poorly drained with mottles<sup>64</sup> within 50 cm of the land surface. MacMillan and Pettapiece (2000) used digital elevation models to characterize the areal extent of upper, mid, lower, and depressional portions of the landscape and their associated characteristics (slope and length). Their results were used to determine proportions of landforms in the Soil Landscapes of Canada (SLC), which was the basis for determining the proportion of the landscape to apply F<sub>TOPO</sub> for deriving N<sub>2</sub>O emission estimates (Rochette et al. 2008).

To derive EF<sub>BASE</sub> for an ecodistrict, the following equation was used:

**Equation A3-14:**

$$EF_{BASE} = EF_{CT, P/PE=1} \times F_{TOPO} + EF_{CT} \times (1 - F_{TOPO})$$

where:

EF <sub>CT</sub>	=	emission factor, estimated at actual P/PE accounting for climate and topography in an ecodistrict, kg N <sub>2</sub> O-N/kg N ( <i>See Figure A3-2</i> )
EF <sub>CT, P/PE</sub>	=	emission factor estimated at P/PE = 1, 0.017 kg N <sub>2</sub> O-N/kg N
F <sub>TOPO</sub>	=	fraction of the ecodistrict area in the lower section of the toposequence See Rochette et al. (2008)
P	=	long-term mean precipitation from May to October in an ecodistrict, mm
PE	=	long-term mean potential evapotranspiration from May to October, mm

---

64. Mottles are the product of intermittent oxidation/reduction cycles of (generally) iron present in the soil profile. Prevalence, size, and colour of mottles are indicative of the soil materials being intermittently saturated for significant periods of time.

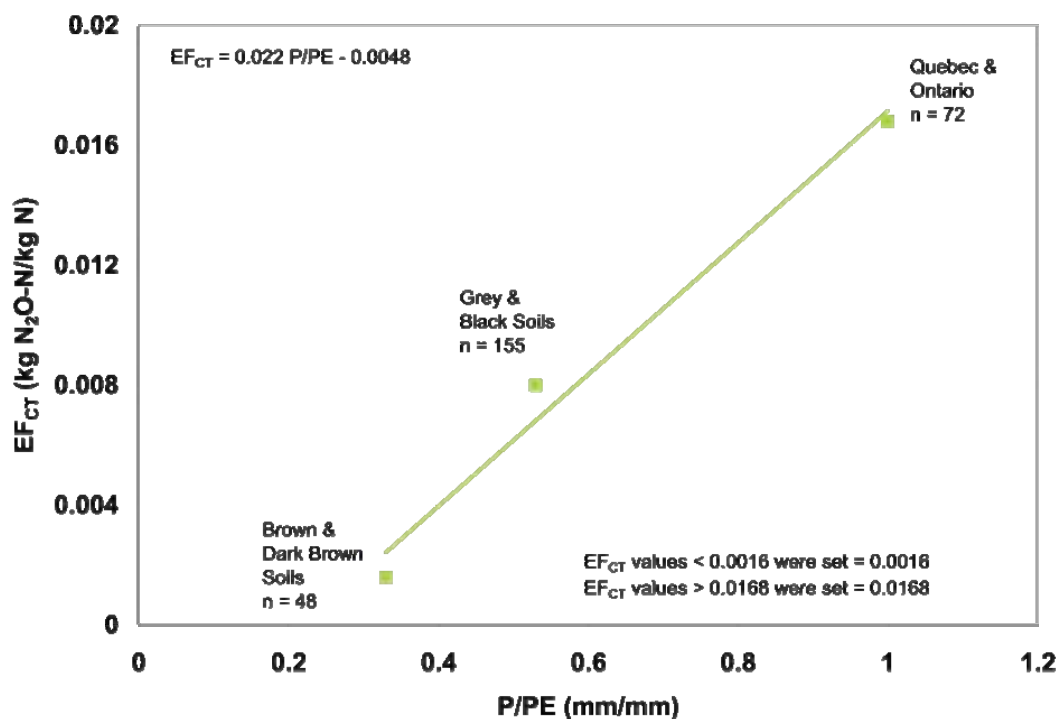


Figure A3-2: N<sub>2</sub>O Emissions as a function of long-term ratio of precipitation over potential evapotranspiration (P/PE) from 1971 to 2000

### *N<sub>2</sub>O Emissions during Winter and Spring Thaw*

Average annual snowfall in eastern Canada varies between 1 and 4.5 m (Environment Canada 2002). Snowmelt water in the spring creates wet soil conditions that often stimulate N<sub>2</sub>O production (Wagner-Riddle and Thurtell 1998). The intensity of soil freezing was also found to influence spring thaw emissions (Wagner-Riddle et al. 2007). Accordingly, results from micrometeorological studies showed that significant N<sub>2</sub>O emissions can occur during winter and spring thaw in Ontario (Wagner-Riddle and Thurtell 1998; Grant and Pattey 1999) and limiting emission estimates to the snow-free period underestimates total annual N<sub>2</sub>O emissions in that region. Rochette et al. (2008) reported mean N<sub>2</sub>O emissions during winter and spring thaw in Southern Ontario to be 1.2 kg N<sub>2</sub>O-N ha<sup>-1</sup> (Wagner-Riddle et al. 2007; Wagner-Riddle and Thurtell 1998); these emissions were included for deriving the relationship between EF<sub>CT</sub> and P/PE shown in Figure A3-2.

Spring thaw emissions also occur in the Prairies but are usually smaller than in eastern Canada (Lemke et al. 1999). Chamber flux measurements used to estimate EF<sub>CT</sub> in the Prairies include spring thaw emissions, because low snow accumulation in that region allows chamber deployments during that period. Therefore, no adjustment to the EF<sub>CT</sub> for the spring thaw emissions is required in the Prairies.

### **Soil Texture and N<sub>2</sub>O Emissions**

Soil texture does not directly influence N<sub>2</sub>O production in soils. However, it correlates with several physical and chemical parameters that control N<sub>2</sub>O production and transport in the soil

profile (Arrouays et al. 2006; da Silva and Kay 1997; Minasny et al. 1999). Accordingly, soil texture-related variables often correlate with N<sub>2</sub>O emissions from agricultural soils (Hénault et al. 1998; Corre et al. 1999; Chadwick et al. 1999; Bouwman et al. 2002; Freibauer 2003).

The impact of soil texture on N<sub>2</sub>O emissions from agricultural soils was estimated using a ratio factor (RF<sub>TEXTURE</sub>) defined as the ratio of N<sub>2</sub>O emissions on soils of a given textural class to the mean emissions from soils of all textures. A value of 0.8 was assigned to the RF<sub>TEXTURE-COARSE</sub>, 1.0 for RF<sub>TEXTURE-MEDIUM</sub> and 1.2 for RF<sub>TEXTURE-FINE</sub> (Rochette et al. 2008). RF<sub>TEXTURE</sub> could not be estimated in regions other than Quebec, Ontario, and the Atlantic Provinces. Small influence of soil texture on N<sub>2</sub>O emissions (RF<sub>TEXTURE</sub> = 1) is likely justified under dry climates such as in the Prairie region, where low soil water content results in low N<sub>2</sub>O emissions regardless of the soil texture.

#### Equation A3-15:

$$RF_{TEXTURE,i} = (RF_{TEXTURE-FINE,i} \times FRAC_{TEXTURE-FINE,i}) + (RF_{TEXTURE-COARSE,i} \times FRAC_{TEXTURE-COARSE,i}) + (RF_{TEXTURE-MEDIUM,i} \times FRAC_{TEXTURE-MEDIUM,i})$$

where:

RF <sub>TEXTURE,i</sub>	=	a weighted soil texture ratio factor of N <sub>2</sub> O for an ecodistrict i for Ontario, Quebec, and the Atlantic provinces
RF <sub>TEXTURE-FINE, i</sub>	=	a ratio factor of N <sub>2</sub> O for fine-textured soils for an ecodistrict i
FRAC <sub>TEXTURE-FINE, i</sub>	=	fraction of fine-textured soils in an ecodistrict i
RF <sub>TEXTURE-COARSE, i</sub>	=	a ratio factor of N <sub>2</sub> O for coarse-textured soils for an ecodistrict i
FRAC <sub>TEXTURE-COARSE, i</sub>	=	fraction of coarse-textured soils in an ecodistrict i
RF <sub>TEXTURE-MEDIUM, i</sub>	=	a ratio factor of N <sub>2</sub> O for medium-textured soils for an ecodistrict i
FRAC <sub>TEXTURE-MEDIUM, i</sub>	=	fraction of medium-textured soils in an ecodistrict i

### Synthetic Nitrogen Fertilizers

Canada's method to estimate N<sub>2</sub>O emissions from synthetic N fertilizer application on agricultural soils takes into account local climate regimes and topographic conditions. Equation A3-16 is used to estimate N<sub>2</sub>O emissions by ecodistricts<sup>65</sup>. Emission estimates at the provincial and national scales are obtained by aggregating estimates at the ecodistrict level.

65. "Ecodistrict" is defined as a subdivision of an ecoregion characterized by a distinctive assemblage of relief, landforms, geology, soil, vegetation, water bodies, and fauna ([http://gcmd.nasa.gov/records/CANADA-CGDI\\_Canada\\_AAFC\\_Eco.html](http://gcmd.nasa.gov/records/CANADA-CGDI_Canada_AAFC_Eco.html))

**Equation A3-16:**

$$N_2O_{SFN} = \sum (N_{FERT,i} \times EF_{BASE,i} \times RF_{TEXTURE,i}) \times \frac{44}{28}$$

where:

$N_2O_{SFN}$	=	emissions from synthetic N fertilizers, kg $N_2O$ /year
$N_{FERT,i}$	=	total synthetic fertilizer consumption at the $i^{th}$ ecodistrict, kg N/year. $N_{FERT}$ at an ecodistrict level is estimated using Equation A3-20.
$EF_{BASE,i}$	=	a weighted average of emission factors at the $i^{th}$ ecodistrict, which is a function of local climate (ratio of precipitation over potential evapotranspiration) and landforms, kg $N_2O$ -N/kg N-year
$RF_{TEXTURE,i}$	=	a weighted soil texture ratio factor of $N_2O$ emission for an ecodistrict, $i$
$44/28$	=	weight ratio of $N_2O$ to N

Data for synthetic N fertilizer sales are available by province only and needed to be disaggregated to the ecodistrict level. The approach was based on the assumption that the amount of synthetic N fertilizers applied ( $N_{APPLDP}$ ) is equal to the difference between recommended N rates ( $N_{RCMD}$ ) and manure N available for application on cropland ( $N_{MAN-AV,CROPS}$ ).

**Equation A3-17:**

$$N_{APPLDP,i} = N_{RCMD,i} - N_{MAN-AV,CROPS,i}$$

where:

$N_{APPLDP,i}$	=	total N fertilizer potentially applied in ecodistrict $i$ , kg N/year
$N_{RCMD,i}$	=	recommended fertilizer application in ecodistrict $i$ , kg N/year
$N_{MAN-AV,CROPS,i}$	=	available N from manure applied to crops in ecodistrict $i$ , kg N/year

$N_{RCMD}$  was estimated as the sum of the products of each crop type and the recommended fertilizer application rate for that crop in that ecodistrict (Yang et al. 2007):

**Equation A3-18:**

$$N_{RCMD,i} = \sum (CROPA_{ij} \cdot N_{RECR,j})$$

where:

$CROPA_{ij}$	=	area of crop type $j$ in ecodistrict $i$ , ha
$N_{RECR,j}$	=	recommended annual N application rate for crop type $j$ in ecodistrict $i$ , kg N/ha-year

$N_{\text{MAN-AV,CROPS}}$  was calculated as the sum of all manure N from all farm animals in the ecodistrict as follows:

**Equation A3-19:**

$$N_{\text{MAN-AV,CROPS},i} = \sum_{j,k} [(\text{AnimalNo}_{ji} \cdot N_{\text{EX},j}) (1 - N_{\text{PRP},j}) (1 - \text{FRAC}_{(\text{LossMS})jk} - \text{UNAV})]$$

where:

$\text{AnimalNo}_{ji}$	=	animal population of category j in ecodistrict i, number of heads ( <i>see section A3.3.1</i> )
$N_{\text{EX},j}$	=	annual N excretion rate for animal category j, kg N/head-year ( <i>see Table A3-25 and Table A3-26</i> )
$N_{\text{PRP},j}$	=	fraction of manure N that is deposited on pasture by grazing animals for animal category j ( <i>see Table A3-22</i> ).
$\text{FRAC}_{(\text{LossMS})jk}$	=	fraction of manure N that is lost during manure storage and handling in manure management system k for animal category j ( <i>See Table A3-27</i> )
UNAV	=	fraction of manure N that is either in organic form or unavailable for crops: 0.35 (Yang et al. 2007).

**Table A3-27: Total N and  $\text{NH}_3$ - and  $\text{NO}_x$ -N Losses Associated with Various Livestock and Manure Management Systems**

Animal Category	Manure Management Systems	Total Manure N Loss (%) <sup>2</sup> ( $\text{FRAC}_{(\text{LossMS})}$ )	$\text{NH}_3$ -N and $\text{NO}_x$ -N Loss (%) <sup>2</sup> ( $\text{FRAC}_{\text{GASM}}$ )
Dairy Cow	Liquid	40 (15–45)	40 (15–45)
	Solid Storage	35 (10–55)	25 (10–40)
	Pasture and Range		20 (5–50)
Non-Dairy Cattle	Liquid	40 (15–45)	40 (15–45)
	Solid Storage	40 (20–50)	30 (20–50)
	Pasture and Range		20 (5–50)
Swine	Liquid	48 (15–60)	48 (15–60)
	Solid Storage	50 (20–70)	45 (10–65)
Sheep, Lamb, Llamas and Alpacas	Solid Storage	15 (5–20)	12 (5–20)
	Pasture and Range		20 (5–50)
Goat and Horse	Solid Storage	15 (5–20)	12 (5–20)
	Pasture and Range		20 (5–50)
Poultry	Liquid	50	50
	Solid Storage	53 (20–80)	48 (10–60)
	Pasture and Range		20 (5–50)

Notes:

1. Numbers in parentheses indicate a range.
2. Data sources: Hutchings et al. (2001); EPA (2004); Rotz (2004).

Because the potential amount of fertilizer needs to be reconciled with the total amount sold in the province ( $N_{\text{SALES}}$ ) to estimate the actual amount applied ( $N_{\text{FERT}}$ ),  $N_{\text{APPLDP}}$  is adjusted in each ecodistrict as follows:

**Equation A3-20:**

$$N_{\text{FERT},i} = N_{\text{APPLDP},i} \times \left[ \frac{\left( \sum_{ip} N_{\text{APPLDP}p} \right)}{N_{\text{SALES}p}} \right]$$

where:

$N_{\text{FERT},i}$	=	total fertilizer N actually applied to all crops in ecodistrict i, kg
$N_{\text{APPLDP},i}$	=	total fertilizer N applied to all crops in ecodistrict i, kg
$\sum_{ip} N_{\text{APPLDP}p}$	=	sum of all fertilizer N potentially applied in province p, kg
$N_{\text{SALES}p}$	=	total amount of fertilizer N sold in province p, kg

In ecodistricts where  $N_{\text{MAN-AV,CROPS}}$  exceeded  $N_{\text{RCMD}}$ ,  $N_{\text{FERT}}$  was set to 0. For years between two consecutive Census years (e.g. 1991, 1996 and 2001),  $N_{\text{RCMD}}$  was linearly interpolated to successively estimate annual values of  $N_{\text{APPLDP}}$  and  $N_{\text{FERT}}$  at the ecodistrict level.

The Farm Input Markets Unit of the Farm Income and Adaptation Policy Directorate of Agriculture and Agri-Food Canada collected annual fertilizer N consumption data at the provincial level and published *Canadian Fertilizer Consumption, Shipments and Trade from 1990 to 2002* (Korol 2003). Since 2003, fertilizer N data have been collected and published by the Canadian Fertilizer Institute<sup>66</sup>.

There are 958 weather stations in the AAFC-archived weather database. These stations (80°00'N–41°55'N, 139°08'W–52°40'W) across Canada (758 stations) and the United States (200 stations) were used to interpolate monthly precipitation and potential evapotranspiration from May to October from 1970 to 2000 to the ecodistrict centroids. AAFC-archived weather data were provided by the Meteorological Service of Canada, Environment Canada.

### Manure Applied as Fertilizer

Emissions of  $\text{N}_2\text{O}$  from manure applied as fertilizer include  $\text{N}_2\text{O}$  produced from the application of manure from drylot or solid storage, liquid and other waste management systems on agricultural soils. Similarly to synthetic fertilizer  $\text{N}_2\text{O}$  emissions, a country-specific Tier 2 methodology is used for estimating  $\text{N}_2\text{O}$  emissions from manure applied as fertilizer. The methodology is based on the quantity of manure N produced by domestic animals and country-specific  $\text{EF}_{\text{BASE}}$  taking into account local climate moisture and topographic conditions at the ecodistrict level.  $\text{N}_2\text{O}$  emission estimates from this source are calculated using Equation A3-21.

---

66. Available online at [http://www.cfi.ca/Publications/Statistical\\_Documents.asp](http://www.cfi.ca/Publications/Statistical_Documents.asp)



**Equation A3-21:**

$$N_2O_{MAN} = \sum (N_{MAN,CROPS,i} \times EF_{BASE,i} \times RF_{TEXTURE,i}) \times \frac{44}{28}$$

where:

$N_2O_{MAN}$	=	emissions from animal manure applied to cropland as fertilizers, kg N <sub>2</sub> O/year
$N_{MAN,CROPS,i}$	=	total amount of animal manure N applied as fertilizer to cropland in ecodistrict i, kg N/year ( <i>see Equation A3-22</i> )
$EF_{BASE,i}$	=	a weighted average emission factor for ecodistrict i accounting for climate and topography, kg N <sub>2</sub> O-N/kg N-year
$RF_{TEXTURE,i}$	=	a weighted average of soil texture ratio factor of N <sub>2</sub> O emission for an ecodistrict, i
44/28	=	weight ratio of N <sub>2</sub> O to N

**Equation A3-22:**

$$N_{MAN,CROPS,i} = \sum_T [(N_T \times N_{EX,T}) \times (1 - N_{PRP,T}) \times (1 - FRAC_{(LOSSMS,T)})]$$

where:

$N_{MAN,CROPS,i}$	=	animal manure applied as N fertilizers on cropland in ecodistrict i, kg N/year
$N_T$	=	population for the T <sup>th</sup> animal category or subcategory ( <i>see section A3.3.1</i> )
$N_{EX,T}$	=	N excretion rate for the T <sup>th</sup> animal category or subcategory ( <i>Table A3-25 and Table A3-26</i> )
$N_{PRP,T}$	=	fraction of manure N on pasture, range, and paddock for each animal category T in ecodistrict i ( <i>See Table A3-22</i> )
$FRAC_{(LOSSMS,T)}$	=	fraction of total losses of manure N for each animal category T excluding pasture, range, and paddock in ecodistrict i ( <i>See Table A3-27</i> )

Animal population data sources and population accounts are detailed in Section A3.3.1.

**Biological Nitrogen Fixation**

Biological N fixation by the legume–rhizobium association, a major source of N<sub>2</sub>O in the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997), is not included in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006). This decision is supported by the findings of Rochette and Janzen (2005) that there is no evidence that measurable amounts of N<sub>2</sub>O are produced during the N fixation process itself. Therefore, Canada decided to report this source as “not occurring.” However, the contribution of legume N to N<sub>2</sub>O emissions is included as a source of N<sub>2</sub>O emissions from crop residue decomposition on agricultural soils (N<sub>RES</sub>).

**Crop Residue Decomposition**

The transformations (nitrification and denitrification) of the N released during the decomposition of crop residues result in N<sub>2</sub>O emissions into the atmosphere. A country-specific Tier 2 methodology similar to that for fertilizer and manure applied as fertilizer is used to estimate N<sub>2</sub>O emissions from crop residues, based on Equation A3-23, Equation A3-24 and Equation A3-25:

**Equation A3-23:**

$$N_2O_{RES} = \sum (N_{RES,i} \times EF_{BASE,i} \times RF_{TEXTURE,i}) \times \frac{44}{28}$$

where:

$N_2O_{RES}$	=	emissions from crop residue decomposition, kg $N_2O$ /year
$EF_{BASE,i}$	=	a weighted average of emission factors for ecodistrict i, kg $N_2O$ -N/kg Nyear
$44/28$	=	weight ratio of $N_2O$ to N
$N_{RES,i}$	=	total amount of crop residue N that is returned to the cropland annually for ecodistrict i, kg N/year ( <i>See Equation A3-24</i> )
$RF_{TEXTURE,i}$	=	a weighted average of soil texture ratio factor of $N_2O$ emission for an ecodistrict, i

**Equation A3-24:**

$$N_{RES,i} = \sum_T [P_{T,i} \times FRAC_{RENEW,T,i} \times (R_{AG,T} \times N_{AG,T} + R_{BG,T} \times N_{BG,T})]$$

where:

$FRAC_{RENEW,T,i}$	=	fraction of total area under crop T that is renewed annually in ecodistrict i
$R_{AG,T}$	=	ratio of above-ground residues to harvested yield for crop T, kg dry matter (DM)/kg
$N_{AG,T}$	=	N content of above-ground residues for crop T, kg N/kg DM
$R_{BG,T}$	=	ratio of below-ground residues to harvested yield for crop T, kg DM/kg
$N_{BG,T}$	=	N content of below-ground residues for crop T, kg N/kg DM
T	=	crop/forage type
$P_{T,i}$	=	total production of the Tth crop type that is renewed annually in ecodistrict i, kg DM/year ( <i>See Equation A3-25</i> ).

**Equation A3-25:**

$$P_{T,i} = \frac{A_{T,i} \times Y_{T,i}}{\sum_{i=1}^N (A_{T,i} \times Y_{T,i})} \times P_{T,p} \times (1 - H_2O_T)$$

where:

$A_{T,i}$	=	area under crop type T in ecodistrict i, ha
$Y_{T,i}$	=	average crop yield for crop type T in ecodistrict i, kg/ha-year
$H_2O_T$	=	water content of harvested crop T, kg/kg
$P_{T,p}$	=	total crop production for crop type T in province p, kg DM/year

Statistics Canada (2006) (Statistics Canada #22-002) collects and publishes annual field crop production data by province. Crops include wheat, barley, corn/maize, oats, rye, mixed grains, flax seed, canola, buckwheat, mustard seed, sunflower seed, canary seeds, fodder corn, sugar beets, tame hay, dry peas, soybean, dry white beans, coloured beans, chick peas, and lentils. Area and production of each crop are reported at the Census Agricultural Region and provincial levels, and yields have been allocated to Soil Landscapes of Canada (SLC) polygons through area overlays by Agriculture and Agri-Food Canada. Specific parameters for each crop type are listed in Janzen et al. (2003).

## Cultivation of Organic Soils (Histosols)

Cultivation of organic soil (histosols) for annual crop production produces N<sub>2</sub>O. The IPCC Tier 1 methodology is used to estimate N<sub>2</sub>O emissions from cultivated organic soils (Equation A3-26).

### Equation A3-26:

$$N_2O_H = \sum (A_{os,i} \times EF_{HIST}) \times \frac{44}{28}$$

where:

N <sub>2</sub> O <sub>H</sub>	=	N <sub>2</sub> O emissions from cultivated histosols, kg N <sub>2</sub> O-N/year
A <sub>os,i</sub>	=	total area of cultivated organic soils in each province, ha
EF <sub>HIST</sub>	=	IPCC default emission factor for mid-latitude organic soils, 8.0 kg N <sub>2</sub> O-N/ha-year (IPCC 2000)
44/28	=	weight ratio of N <sub>2</sub> O to N

Areas of cultivated histosols at a provincial level are not collected as part of the Census of Agriculture. Consultations with numerous soil and crop specialists across Canada indicate that the total area of cultivated organic soils from 1990 to 2006 in Canada was 16 200 ha (G. Padbury and G. Patterson, AAFC, personal communication, unreferenced).

## N<sub>2</sub>O Emissions or Removals from Adoption of No-Till and Reduced Tillage

This category is specific to Canada. It does not derive from additional N input such as fertilizer, manure, and crop residue N, but reflects how changes in tillage practices affect N<sub>2</sub>O emissions. For example, compared with conventional or intensive tillage (IT), direct seeding (NT) and reduced tillage (RT) affect the decomposition of soil organic matter, soil carbon and N availability, soil bulk density, and water content, and thus N<sub>2</sub>O emissions.

Field studies in Quebec and Ontario showed that NT practices increased N<sub>2</sub>O emissions, whereas in the Prairies the opposite was observed. To quantify the impact of tillage practices on N<sub>2</sub>O, a tillage ratio factor (F<sub>TILL</sub>) defined as the ratio of mean N<sub>2</sub>O fluxes on NT or RT to mean N<sub>2</sub>O fluxes on IT (N<sub>2</sub>O<sub>NT</sub>/N<sub>2</sub>O<sub>IT</sub>), is used as follows (Rochette et al. 2008):

**Equation A3-27:**

$$N_2O_{TILL} = \sum \left[ (N_{FERT,i} + N_{MAN,CROPS,i} + N_{RES,i}) \times (EF_{BASE,i} \times FRAC_{NT-RT,i} (F_{TILL} - 1)) \right] \times \frac{44}{28}$$

where:

$N_2O_{TILL}$	=	$N_2O$ emissions or removals resulting from the adoption of NT and RT, kg $N_2O$ /year
$N_{FERT,i}$	=	total synthetic fertilizer N consumption in ecodistrict i, kg N/year
$N_{MAN,CROPS,i}$	=	total amount of animal manure N applied as fertilizer to cropland in ecodistrict i, kg N/year
$N_{RES,i}$	=	total amount of crop residue N that is returned to the cropland annually for ecodistrict i, kg N/year
$EF_{BASE,i}$	=	a weighted average emission factor for ecodistrict i, kg $N_2O$ -N/kg N-year
$FRAC_{NT-RT,i}$	=	fraction of cropland on NT and RT in ecodistrict i, %
$F_{TILL}$	=	a ratio factor adjusting $EF_{BASE}$ due to the adoption of NT and RT: $F_{TILL} = 1.1$ in eastern Canada; $F_{TILL} = 0.8$ in the Prairies (Rochette et al. 2008)
44/28	=	weight ratio of $N_2O$ to N

The fraction of cropland under NT and RT ( $FRAC_{NT-RT}$ ) for each ecodistrict originated from the Census of Agriculture and is identical to that used in the LULUCF Cropland Remaining Cropland category for NT and RT practices (Statistics Canada 1992, 1997, 2002). These data are published at the Census Agricultural Region, Census Division, provincial, and national levels. Annual  $FRAC_{NT-RT}$  between the two consecutive Census years is adjusted through interpolation.

 **$N_2O$  Emissions Resulting from Summerfallowing**

Summerfallowing is a farming practice typically used in the Prairie region to conserve soil moisture by leaving the soil unseeded for an entire growing season in a crop rotation. During the fallow year, several factors may stimulate  $N_2O$  emissions relative to a cropped situation, such as higher soil water content, temperature, and available carbon and N (Campbell et al. 1990). Experimental studies have shown that  $N_2O$  emissions in fallow fields are similar to emissions from continuously cropped fields (Rochette et al. 2008). In order to account for these emissions not captured by the default IPCC input-driven approach, the following country-specific methodology is used to estimate the effect of summerfallowing on  $N_2O$  emissions with the assumption that during a crop year, direct  $N_2O$  emissions from a given field are summarized as follows:

**Equation A3-28:**

$$N_2O_{CROP} = N_2O_{BACK} + N_2O_{SFN} + N_2O_{MAN} + N_2O_{RES}$$

where  $N_2O_{SFN}$ ,  $N_2O_{MAN}$ , and  $N_2O_{RES}$  are defined in the previous sections.  $N_2O_{BACK}$  are the background soil  $N_2O$  emissions that are not due to crop residue-N, fertilizer-N or manure-N additions.

During a fallow year, no fertilizer or manure is applied. In the absence of external N inputs,  $N_2O$  emissions during the fallow year ( $N_2O_{FALLOW}$ ) can be seen as consisting of 1) background" emissions that would have occurred regardless of fallow ( $N_2O_{BACK}$ ) and 2) emissions due to the modifications to the soil environment by the practice of summerfallow ( $N_2O_{FALLOW-EFFECT}$ ):

**Equation A3-29:**

$$N_2O_{\text{FALLOW}} = N_2O_{\text{BACK}} + N_2O_{\text{FALLOW-EFFECT}}$$

Since  $N_2O$  emissions are assumed equal during fallow and cropped years ( $N_2O_{\text{CROP}} = N_2O_{\text{FALLOW}}$ ) and assuming that  $N_2O_{\text{BACK}}$  is the same in cropped and fallow situations,  $N_2O_{\text{FALLOW-EFFECT}}$  can be estimated as follows:

**Equation A3-30:**

$$N_2O_{\text{SFN}} + N_2O_{\text{MAN}} + N_2O_{\text{RES}} = N_2O_{\text{FALLOW-EFFECT}}$$

The  $N_2O$  emissions due to the practice of summerfallow are therefore calculated for each ecodistrict by applying emissions from N inputs to annual crops (crop residues, fertilizers and manure) to the area of that ecodistrict under summerfallow:

**Equation A3-31:**

$$N_2O_{\text{FALLOW}} = \sum [(N_2O_{\text{SFN},i} + N_2O_{\text{RES},i} + N_2O_{\text{MAN},i}) \times \text{FRAC}_{\text{FALLOW},i}]$$

where:

$N_2O_{\text{FALLOW}}$	=	emissions due to the effect of summerfallow
$N_2O_{\text{SFN},i}$	=	emissions from synthetic N fertilization in ecodistrict i, kg $N_2O$ -N
$N_2O_{\text{RES},i}$	=	emissions from crop residue decomposition in ecodistrict i, kg $N_2O$ -N
$N_2O_{\text{MAN},i}$	=	emissions from animal manure applied as fertilizers to cropland in ecodistrict i, kg $N_2O$ -N
$\text{FRAC}_{\text{FALLOW},i}$	=	fraction of cropland in ecodistrict i that is under summerfallow, %

Estimates of  $N_2O_{\text{SFN}}$ ,  $N_2O_{\text{RES}}$  and  $N_2O_{\text{MAN}}$  at an ecodistrict level are those derived from synthetic fertilizers, manure applied as fertilizers and crop residues.  $\text{FRAC}_{\text{FALLOW}}$  is derived from the Census of Agriculture for each ecodistrict (Statistics Canada 1992; 1997; 2002) and is identical to that used in the LULUCF Cropland Remaining Cropland category for the summerfallow practice. Annual  $\text{FRAC}_{\text{FALLOW}}$  between the two consecutive census years is adjusted through interpolation.

 **$N_2O$  Emissions from Irrigation**

Higher soil water content under irrigation increases  $N_2O$  emissions by increasing biological activity and reducing soil aeration (Jambert et al. 1997). Accordingly, highest  $N_2O$  emissions from agricultural soils in the northwestern United States (Liebig et al. 2005) and western Canada (Hao et al. 2001) were observed on irrigated cropland, followed by non-irrigated cropland and rangeland. Field studies directly comparing  $N_2O$  emissions under irrigated and non-irrigated situations are lacking in Canada. Therefore, an approach was used based on the assumptions that 1) the irrigation water stimulates  $N_2O$  production in a way similar to rainfall water, and 2) irrigation is applied to eliminate any moisture deficit such that “precipitation + irrigation water = potential evapotranspiration.” Consequently, the effect of irrigation on  $N_2O$  emissions from agricultural soils was accounted for using an  $EF_{\text{BASE}}$  estimated at a  $P/PE = 1$  (e.g.  $EF_{\text{BASE}} = 0.017 \text{ } N_2O\text{-N/kg N}$ ) for the irrigated areas of an ecodistrict:

**Equation A3-32:**

$$N_2O_{IRRI} = \sum \left[ (N_{FERT,i} + N_{MAN,CROPS,i} + N_{RES,i}) \times (0.017 - EF_{BASE,i}) \times FRAC_{IRRI,i} \right] \times \frac{44}{28}$$

where:

$N_2O_{IRRI}$	=	emissions from irrigation, kg $N_2O$ /year
$N_{FERT,i}$	=	total synthetic fertilizer N consumption in ecodistrict i, kg N/year
$N_{MAN,CROPS,i}$	=	total amount of animal manure N applied as fertilizer to cropland in ecodistrict i, kg N/year
$N_{RES,i}$	=	total amount of crop residue N that is returned to the cropland annually for ecodistrict i, kg N/year
0.017	=	value attributed to $EF_{BASE}$ for irrigated land, kg $N_2O$ -N/kg N-year
$EF_{BASE,i}$	=	a weighted average emission factor for ecodistrict i, kg $N_2O$ -N/kg N-year for ecodistrict i
$FRAC_{IRRI,i}$	=	fraction of irrigated cropland in ecodistrict i,
44/28	=	weight ratio of $N_2O$ to N

$FRAC_{IRRI}$  is derived from the Census of Agriculture for each ecodistrict (Statistics Canada 1992; 1997; 2002). Annual  $FRAC_{IRRI}$  between the two consecutive census years is adjusted through interpolation.

### A3.3.6.2 *Manure on Pasture, Range, and Paddock from Grazing Animals*

The IPCC Tier 1 methodology is used to estimate  $N_2O$  emissions from manure on pasture, range, and paddock. The IPCC methodology is based on the quantity of manure N produced by domestic animals on pasture, range, and paddock, and  $N_2O$  emissions are calculated using Equation A3-33.

**Equation A3-33:**

$$N_2O_{PRP} = \sum_T (N_T \times N_{EX,T} \times N_{PRP,T} \times EF_{PRP,T}) \times \frac{44}{28}$$

where:

$N_2O_{PRP}$	=	emissions from manure on pasture, range, and paddock from grazing animals, kg $N_2O$ /year
$N_T$	=	animal population of the animal category T in a province, head (Section A3.3.1)
$N_{EX,T}$	=	annual N excretion rate for the animal category T, kg N/head-year (Table A3-25 and Table A3-26)
$N_{PRP,T}$	=	fraction of manure N excreted on pasture, range, and paddock by animal category T (Table A3-22).
$EF_{PRP,T}$	=	emission factor for manure N deposited by animals on pasture, range, and paddock: 0.02 kg $N_2O$ -N/kg N for dairy cattle, non-dairy cattle, buffalo, swine, and poultry, and 0.01 kg $N_2O$ -N/kg N for sheep, llamas, alpacas, lamb, goat, and horse (IPCC 2006) (Annex 12)
44/28	=	weight ratio of $N_2O$ to N

Animal population data and data sources are detailed in Section A3.3.1.

### A3.3.6.3 Indirect N<sub>2</sub>O Emissions from Soils

#### Volatilization and Redeposition of Nitrogen

The IPCC Tier 1 methodology is used to estimate indirect N<sub>2</sub>O emissions due to volatilization and redeposition of fertilizer and manure N applied to agricultural soils. The emission calculation is shown in Equation A3-34:

#### Equation A3-34:

$$N_2O_{VD} = \sum \left[ (N_{FERT,i} \times FRAC_{GASF}) + (N_{MAN,CROPS,i} \times FRAC_{GASM}) + N_{MAN-VOLAT,i} \right] \times EF_{VD} \times \frac{44}{28}$$

where:

$N_2O_{VD}$	=	emissions due to volatilization and redeposition of N, kg N <sub>2</sub> O/year
$N_{FERT,i}$	=	synthetic N fertilizer consumption in ecodistrict i, kg N/year
$FRAC_{GASF}$	=	fraction of synthetic fertilizer N applied to soils that volatilizes as NH <sub>3</sub> - and NO <sub>x</sub> -N: 0.1 kg (NH <sub>3</sub> -N + NO <sub>x</sub> -N)/kg N (IPCC 2006)
$N_{MAN,CROPS,i}$	=	total amount of animal manure N applied as fertilizer to cropland in ecodistrict i, kg N/year
$FRAC_{GASM}$	=	fraction of volatilized manure N applied as fertilizers to cropland: 0.2 kg (NH <sub>3</sub> -N + NO <sub>x</sub> -N)/kg N (IPCC 2006)
$EF_{VD}$	=	emission factor due to volatilization and redeposition: 0.01 kg N <sub>2</sub> O-N/kg N (IPCC/OECD/IEA 1997)
44/28	=	weight ratio of N <sub>2</sub> O to N
$N_{MAN-VOLAT,i}$	=	total manure N lost as NH <sub>3</sub> -N and NO <sub>x</sub> -N from livestock excretion in ecodistrict i, kg N (Equation A3-35)

#### Equation A3-35:

$$N_{MAN-VOLAT,i} = \sum_{mT} (N_T \times N_{EX,T} \times AWMS_{m,T} \times FRAC_{GASMm,T})$$

where:

$N_T$	=	animal population for animal category T, head
$N_{EX,T}$	=	N excretion from animal category T, kg N/year (Section A3.3.5.1.)
$AWMS_{m,T}$	=	fraction of manure N from animal category T managed under manure management system m (Table A3-22)
$FRAC_{GASMm,T}$	=	fraction of manure N excreted by animal category T and managed under manure management system m that volatilizes as NH <sub>3</sub> -N and NO <sub>x</sub> -N (Table A3-27)

Data sources for estimating  $N_{FERT}$  and  $N_{MAN-VOLAT}$  at an ecodistrict level are provided in the previous sections (Section 3.3.6.1 and Table A3-27).

## Leaching, Erosion and Runoff

A modified IPCC Tier 1 methodology is used to estimate N<sub>2</sub>O emissions from leaching, runoff, and erosion of fertilizer, manure, and crop residue N from agricultural soils:

### Equation A3-36:

$$N_2O_L = \sum [(N_{FERT,i} + N_{MAN,CROPS,i} + N_{PRP,i} + N_{RES,i}) \times FRAC_{LEACH,i} \times EF_{LEACH}] \times \frac{44}{28}$$

where:

$N_2O_L$	=	emissions due to leaching and runoff, kg N <sub>2</sub> O/year
$N_{FERT,i}$	=	synthetic N fertilizers applied for ecodistrict i, kg N
$N_{MAN,CROPS,i}$	=	manure N applied as fertilizers for ecodistrict i, kg N
$N_{PRP,i}$	=	manure N on pasture, range, and paddock for ecodistrict i, kg N
$N_{RES,i}$	=	crop residue N for ecodistrict i, kg N
$FRAC_{LEACH,i}$	=	fraction of N that is lost through leaching and runoff for ecodistrict i, as defined below
$EF_{LEACH}$	=	leaching/runoff emission factor: 0.025 kg N <sub>2</sub> O-N/kg N (IPCC 2000)
44/28	=	weight ratio of N <sub>2</sub> O to N

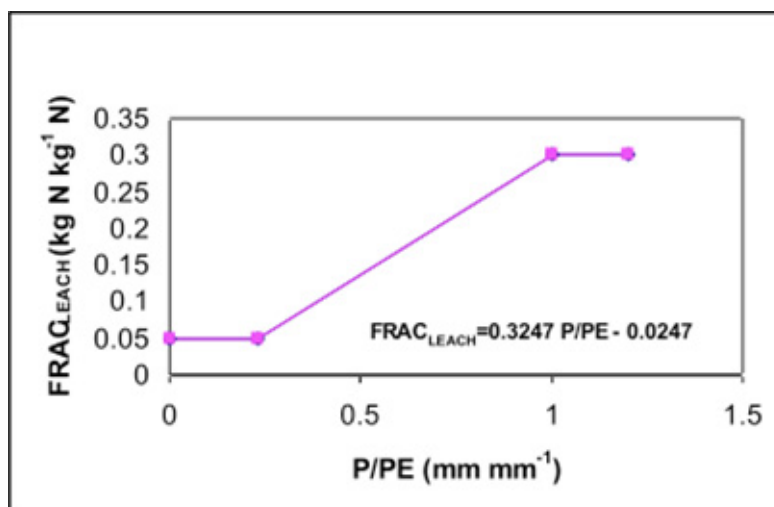
### *Determining the Fraction of Nitrogen that is Leached (FRAC<sub>LEACH</sub>) at the Ecodistrict Level in Canada*

In Canada, leaching losses of N vary widely among regions. High N inputs in humid conditions may lead to losses greater than 100 kg N/ha-year in some farming systems of southern British Columbia (Paul and Zebarth 1997; Zebarth et al. 1998). Such losses, however, represent only a small fraction of Canadian agroecosystems. In Ontario, Goss and Goorahoo (1995) predicted leaching losses of 0–37 kg N ha<sup>-1</sup>, accounting for 0–20% of N inputs from seed, fertilizer, manure, animals, N fixation, and atmospheric deposition. Leaching losses in most of the Prairie region may be smaller due to lower precipitation and lower N inputs on an areal basis. Based on a long-term experiment in central Alberta, Nyborg et al. (1995) suggested that leaching losses were minimal, and Chang and Janzen (1996) found no evidence of N leaching in non-irrigated, heavily manured plots, despite large accumulations of soil nitrate in the soil profile.

The default value for FRAC<sub>LEACH</sub> in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997) was 0.3. FRAC<sub>LEACH</sub> can reach values as low as 0.05 in regions where rainfall is much lower than potential evapotranspiration (IPCC 2006), such as in the Prairie region of Canada. Accordingly, it was assumed that FRAC<sub>LEACH</sub>, depending on the ecodistrict, would vary from a low of 0.05 to a high of 0.3.

For ecodistricts with a P/PE value for the growing season (May through October) greater than or equal to 1, the maximum FRAC<sub>LEACH</sub> value recommended by the *IPCC 2006 Guidelines for National Greenhouse Gas Inventories* (IPCC 2006) of 0.3 was assigned. For ecodistricts with the lowest P/PE value (0.23), a minimum FRAC<sub>LEACH</sub> value of 0.05 was assigned. For ecodistricts with a P/PE value that ranged between 0.23 and 1, FRAC<sub>LEACH</sub> was estimated by the linear function that joins the points (P/PE, FRAC<sub>LEACH</sub>) = (1,0.3; 0.23,0.05) (Figure A3-3).





-----  
**Figure A3-3: Determination of the Ecodistrict FRAC<sub>LEACH</sub> Values**  
 -----

Data sources for  $N_{\text{FERT}}$  (Section A3.3.6.1),  $N_{\text{MAN,CROPS}}$  (section A3.3.6.1),  $N_{\text{PRP}}$  (Section A3.3.6.2), and  $N_{\text{RES}}$  (Section A3.3.6.1) at an ecodistrict level are provided in the previous sections.

Long-term normals of monthly precipitation and potential evapotranspiration from May to October, 1971–2000 (AAFC-archived database; S. Gameda, personal communication, unreferenced), were used to calculate FRAC<sub>LEACH</sub> at an ecodistrict level.

### **A3.4 Methodology for Land Use, Land-Use Change and Forestry**

The LULUCF sector of the inventory includes the GHG emissions/removals associated with managed lands and with land conversion to different land categories.

As in Chapter 7, the structure of this annex attempts to maintain the land-based reporting categories, while grouping related data collection and estimate development methodologies. Section A3.4.1 summarizes the spatial framework for estimate development and area reconciliation. The general approach for estimating carbon stock changes, emissions, and removals in all forest-related categories, including managed forests, forest conversion to other lands, and lands converted to forests, is briefly described in Section A3.4.2. Sections A3.4.3 to A3.4.6 provide similar information for Cropland, Grassland, Wetlands, and Settlements.

Several approaches to the estimation of delayed emissions due to carbon storage in HWPs are briefly described in Section A3.4.7, along with implications for Canada.

#### **A3.4.1 Spatial Framework for LULUCF Estimate Development and Area Reconciliation**

The enhanced complexity of estimate development and active participation of several scientists and experts creates a complex institutional framework within which close collaboration is essential. At the same time, the approaches, methods, tools, and data that are available and most suitable to monitor one land activity are not always appropriate for another. Important differences exist in the spatial framework specific to each land category, with the risk that activity data and estimates become spatially inconsistent. A hierarchical spatial framework was agreed upon by all

partners of the national LULUCF MARS, to ensure the highest possible consistency and spatial integrity of the GHG inventory.

At the finest level of spatial resolution are analysis units, which are specific to each estimation system. In managed forests, the analysis units are the management units found in provincial and territorial forest inventories. For the purpose of this assessment, managed forests were classified into some 577 analysis units across 12 provinces and territories (Table A3-28). Analysis units typically result from the intersection of administrative areas used for timber management and ecological boundaries.

**Table A3-28: Spatial Analysis Units of Managed Forests**

Province / Territory	Number of Analysis Units
Newfoundland and Labrador	25
Nova Scotia	12
Prince Edward Island	1
New Brunswick	1
Quebec	151
Ontario	52
Manitoba	70
Saskatchewan	45
Alberta	69
British Columbia	98
Yukon	13
Northwest Territories	40
<b>Canada</b>	<b>577</b>

The most suitable spatial framework for GHG monitoring of agricultural lands (Cropland) is the National Soil Database of the Canadian Soil Information System<sup>67</sup> and its underlying soil landscapes. The full array of attributes that describe a distinct type of soil and its associated landscapes, such as surface form, slope, typical soil carbon content under native and dominant agricultural land use, and water table depth, is called a soil landscape. Soil landscapes are spatially associated with SLC polygons (the analysis units), that may contain one or more distinct soil landscape components. Note that the precise locations of particular soil landscapes within a polygon, of particular forest stands within a forest management analysis unit, or of forest conversion events within a deforestation analysis unit are not defined or spatially explicit; by convention, the expression “spatially referenced” refers to locational information associated with the boundaries of such spatial units. The SLC polygons are in the order of 1 000 to 1 000 000 ha in area and are appropriate for mapping at the scale of 1:1 million.

SLC polygons are also the basic units of Canada’s National Ecological Framework, a hierarchical, spatially consistent national context within which ecosystems at various levels of generalization can be described, monitored, and reported on (Marshall and Schut 1999). The 12 353 SLC polygons are nested in the next level of generalization (1 021 ecodistricts), which are further grouped in 194 ecoregions and 15 ecozones.

Analysis units for estimating the areas of forest converted to other uses were based on expected deforestation rates and characteristics, as well as administrative boundaries.

---

67. Available online at <http://sis2.agr.gc.ca/cansis/>

The LULUCF sector of the GHG inventory reports information in 18 reporting zones (Chapter 7, Figure 7-1). These reporting zones are essentially the same as ecozones of the National Ecological Framework, with three exceptions: the Boreal Shield and Taiga Shield ecozones are split into their east and west components to form four reporting zones; and the Prairies ecozone is divided into a semi-arid and a subhumid component. These subdivisions do not alter the hierarchical nature of the spatial framework. Table A3-29 provides the land and water areas of each reporting zone, as well as the estimated area of managed forest and cropland for the 2006 inventory year. Methods and data sources used for developing this information are described in McGovern (2007).

**Table A3-29: Estimates of Land, Water, Managed Forest and Cropland Areas in 2006**

Reporting Zone Number and Name		Total Area (ha)	Total Land Area (ha)	Total Fresh Water Area (ha)	Managed Forest Area (ha)	Cropland Area (ha)
1	Arctic Cordillera	24 277 684	23 991 749	285 935		
2	Northern Arctic	151 022 874	142 416 424	86 06 450		
3	Southern Arctic	84 636 177	74 608 974	10 027 203		
4	Taiga Shield East	74 834 455	65 668 565	9 165 890	1 102 862	
5	Boreal Shield East	111 056 710	99 129 131	11 927 579	55 575 314	680 161
6	Atlantic Maritime	20 938 606	19 736 815	1 201 791	15 927 782	1 167 667
7	Mixedwood Plains	16 780 897	11 014 617	5 766 280	2 721 688	5 401 380
8	Hudson Plains	37 371 084	36 393 778	977 306	302 259	
9	Boreal Shield West	83 951 074	71 111 613	12 839 461	28 769 212	207 311
10	Boreal Plains	73 611 950	67 185 834	6 426 116	36 181 296	11 487 126
11	Subhumid Prairies	22 341 203	21 598 791	742 412	1 823 554	16 720 367
12	Semiarid Prairies	23 966 465	23 493 794	472 671	24 170	14 023 832
13	Taiga Plains	65 803 607	58 218 579	7 585 028	20 043 380	10 308
14	Montane Cordillera	48 470 844	47 226 428	1 244 416	35 439 899	1 175 103
15	Pacific Maritime	20 809 934	20 487 877	322 057	13 223 977	119 977
16	Boreal Cordillera	46 785 399	45 841 568	943 831	16 618 191	372
17	Taiga Cordillera	26 530 375	26 373 796	156 579	412 084	
18	Taiga Shield West	63 167 721	52 178 220	10 989 501	1 829 553	

Activity data originating from different sources cannot be harmonized at the level of analysis units, since analysis units used in different land categories often overlap, and the exact location of events, stands, or activities within a unit is not known. The spatial harmonization is conducted within 60 reconciliation units, which are derived from the spatial intersection of reporting zones (Figure 7-1) with provincial and territorial boundaries. QC and QA procedures are conducted at the levels of analysis units during estimate development and of reconciliation units during estimate compilation.

### **A3.4.2 Forest Land and Forest-Related Land-Use Change**

#### *A3.4.2.1 Carbon Modelling*

The estimation of carbon stock changes, emissions from and removals by managed forests, forest conversion to other land uses, and land converted to forests was conducted with version 3 of CBM-CFS3, the most recent of a family of models whose development goes back to the late 1980s (Kurz et al. 1992). The model integrates forest inventory information (forest age, area, and species composition), libraries of merchantable volume over age curves, equations to convert stand merchantable volume into total biomass, data on natural and anthropogenic disturbances, and simulations of carbon transfers between pools associated with ecosystem processes, exchanges with the atmosphere, and losses to forest products.

The ecosystem processes modelled by the CBM-CFS3 to generate the estimates submitted here are growth, litter fall, natural tree mortality, and decomposition. Events include management activities, wildfires, insect infestations, and forest conversion. Management activities represented are commercial thinning (since 2000), clear-cutting, partial cutting, and salvage cutting.<sup>68</sup> Different practices of forest conversion are also simulated, including controlled burning.

The forest carbon pools represented in the CBM-CFS3 can be matched to the IPCC forest carbon pools (Table A3-30). Living biomass pools are further subdivided into two sets, for each of hardwood and softwood tree species. The first 16 carbon pools were implemented for the national estimation.

**Table A3-30: Forest Carbon Pools in IPCC and CBM-CFS3**

IPCC Carbon Pools		Pool Names in CBM-CFS3
<b>Living Biomass</b>	Above-ground biomass	Merchantable stemwood Other (submerchantable stemwood, tops, branches, stumps, non-merchantable trees) Foliage
	Below-ground biomass	Fine roots Coarse roots
<b>Dead Organic Matter (DOM)</b>	Dead wood	Above-ground fast Below-ground fast Medium Softwood stem snag Softwood branch snag Hardwood stem snag Hardwood branch snag
	Litter	Above-ground very fast Above-ground slow
<b>Soils</b>	Soil organic matter	Below-ground very fast <sup>1</sup> Below-ground slow Black carbon <sup>2</sup> Peat <sup>2</sup>

Notes:

1. Below-ground very fast pool includes dead and decaying fine roots, which in practice cannot be separated from soil.
2. Black carbon and peat are currently not represented.

Carbon transfers between pools as shown in Figure A3-4 are simulated either as annual processes or as disturbance events.

Annual processes comprise growth, litter fall, mortality, and decomposition and are simulated as simultaneous carbon transfers executed at each time step (annually) in every inventory record. During annual processes, carbon is taken up in the biomass pool and some biomass carbon is transferred to dead organic matter (DOM) pools. The decay of DOM carbon results in its transfer to another DOM pool (e.g. stem snags to medium deadwood pool), to a slow soil pool, or to the atmosphere. More information on pool structure and decay rates is provided in Kurz et al. (in preparation). Rates of carbon transfer are defined for each pool, based on pool-specific turnover rates (for biomass pools) or decay rates (DOM and soil pools). Turnover rates can be very high (e.g. 95% for hardwood foliage) or very low (e.g. <1% for stemwood). Annual decay rates are

68. Salvage cutting is the removal of merchantable timber left after a natural disturbance. Whenever possible, salvage logging is distinguished from conventional harvesting operations so as not to overstate the total area affected by the combination of natural and anthropogenic disturbances.

defined for a reference mean annual temperature of 10°C; they vary between 50% (very fast DOM pools, such as dead fine roots) and 0.0032% (slow soil pool).

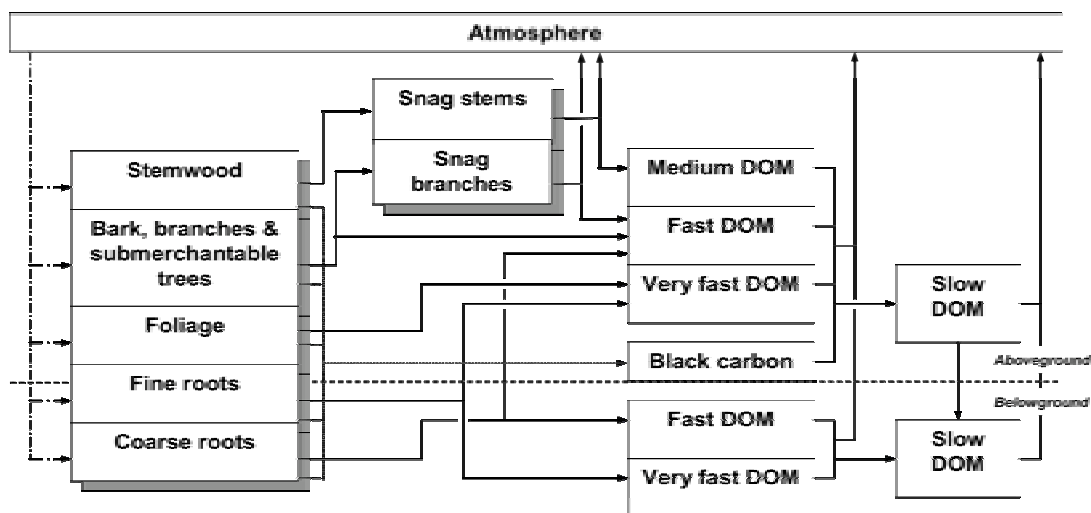


Figure A3-4: Carbon Transfers Between Pools at Each Annual Time Step as Modelled in CBM-CFS3

Growth is simulated as an annual process. Every record in the forest inventory used in each of the 577 analysis units is associated with a growth curve that defines the dynamics of merchantable volume over time. Assignment of an inventory record to the appropriate growth curve is based on a classifier set that includes province, ecological stratum, leading species, site productivity class, and several other classifiers that differ between provinces and territories. Growth curve libraries for each province and territory in Canada are derived from permanent or temporary sample plots or from forest inventory information.

Conversion of merchantable volume curves to above-ground biomass curves is performed with a set of equations developed for Canada's National Forest Inventory (Boudewyn et al. 2007). These equations estimate, for each province/territory, ecozone, leading species, or forest type, the above-ground biomass of each stand component from merchantable stemwood volume (per hectare). Finally, below-ground biomass pools are estimated using regression equations (Li et al. 2003). Mean annual increments are not used in the estimation.

Disturbances trigger different combinations of carbon transfers, based on the disturbance type and severity, the forest ecosystem affected, and the ecological region. For modelling purposes, different practices of forest conversion are also implemented as disturbances. The impact of a disturbance is defined in a disturbance matrix, which specifies for one or more disturbance types the proportion of each pool in the ecosystem that is transferred to other pools, released to the atmosphere (in different GHGs), or transferred to HWP. Figure A3-5 illustrates one such matrix, simulating forest conversion in the Boreal Shield West, during which the wood is harvested and residues (slash) are burned. In the 2008 submission, the impact of wildfires and insect infestations is represented with 15 different disturbance types. Management activities are represented with 15 disturbance types, and land-use change practices, with 31 such types. Including the adjustment of parameter values for ecozones, the simulation uses a total of 236 disturbance matrices to simulate the impact of disturbances. The number of different disturbance matrices is dependent on the availability of activity data (e.g. the spatial and temporal resolution of data sources used to document disturbances) and the knowledge required to parameterize the matrices.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	CO <sub>2</sub>	CH <sub>4</sub>	CO	Products		
1.Softwood merchantable																	0.027	0.083							0.15C	0.318	0.002	0.803	
2.Softwood foliage													0.123					0.010								0.60C	0.364	0.006	
3.Softwood others														0.320				0.010								0.60C	0.364	0.006	
4.Softwood submerchantable														0.803												0.35C	0.345	0.005	
5.Softwood coarse roots															0.500	0.500													
6.Softwood line roots													0.401	0.4C1												0.18C	0.318		
7.Hardwood merchantable																	0.027	0.083								0.15C	0.318	0.002	0.803
8.Hardwood foliage													0.123					0.010								0.60C	0.364	0.006	
9.Hardwood others														0.320				0.010								0.60C	0.364	0.006	
10.Hardwood submerchantable														0.803												0.35C	0.345	0.005	
11.Hardwood coarse roots															0.500	0.500													
12.Hardwood line roots													0.401	0.4C1												0.18C	0.318		
13.Aboveground Very Fast DOM C													0.803													0.18C	0.318	0.002	
14.Belowground Very Fast DOM C														0.803												0.18C	0.318	0.002	
15.Aboveground Fast DOM C															0.500											0.12C	0.318	0.002	
16.Belowground Fast DOM C																0.803										0.18C	0.318	0.002	
17.Medium DOM C																	0.400									0.09C	0.308	0.001	
18.Aboveground Slow DOM C																		1.000											
19.Belowground Slow DOM C																			1.000										
20.Softwood Stem Snag																	0.400									0.09C	0.308	0.001	
21.Softwood Branch Snag															0.903											0.18C	0.318	0.002	
22.Hardwood Stem Snag																	0.400									0.09C	0.308	0.001	
23.Hardwood Branch Snag															0.903											0.12C	0.318	0.002	

Figure A3-5:Disturbance Matrix Simulating the Carbon Transfers Associated with Forest Conversion with Harvest and Slash Burning, Applied to Forest Conversion in Reporting Zone 9 (Boreal Shield West)

The proportion of CO<sub>2</sub>-C emitted from each pool, documented in each disturbance matrix, can be specific to the pool, the types of forest and disturbance intensity, and the ecological zone; there are therefore no CO<sub>2</sub> emission factors applicable to all fires. With a few exceptions, the proportion of total carbon emitted in each carbon-containing GHG (CO<sub>2</sub>, CO, and CH<sub>4</sub>) is constant: 90% of carbon is emitted as CO<sub>2</sub>, 9% as CO, and 1% as CH<sub>4</sub> (B. Stocks, personal communication to W. Kurz, unreferenced).

While the CBM-CFS3 can model carbon fluxes at various spatial scales, generating national estimates involved harmonizing, integrating, and ingesting vast quantities of data from a great diversity of sources. The next section documents the key data sources used for this submission.

#### *A3.4.2.2 Data Sources*

##### **Managed Forest Land**

The Canadian provincial and territorial governments, whose jurisdiction includes natural resource management, provided essential information, notably detailed forest inventory data and, when available, details on forest management activities and practices, disturbances and disturbance prevention or control, regional yield tables (volume/age curve) for dominant tree species and site indices, as well as regional expertise (Table A3-31). The forest inventory data in Canada's National Forest Inventory (CanFI 2001) were used for Labrador, Nova Scotia, New Brunswick, Manitoba, Saskatchewan, Alberta, Yukon, and the Northwest Territories. More recent and higher-resolution inventory data were provided by Prince Edward Island, Quebec, Ontario, British Columbia, and Newfoundland. Considerable efforts were necessary to harmonize, format, and compile the detailed inventory information into input data for the CBM-CFS3. A series of "method papers" describe the compilation process for each provincial and territorial forest inventory. Since forest inventory data were not collected in the same years, additional steps were necessary to synchronize the inventory data to the year 1990 (Stinson et al. 2006a).

**Table A3-31: Main Sources of Information and Data, Managed Forests**

<b>Description</b>	<b>Source</b>	<b>Spatial Resolution</b>	<b>Temporal Coverage</b>	<b>Reference</b>
Fire data	Canadian Wildland Fire Information System	Spatially explicit	2004 and 2006	Expert <a href="http://cwfis.cfs.nrcan.gc.ca/">http://cwfis.cfs.nrcan.gc.ca/</a>
	Canadian Large Fire Database	Spatially referenced	1959–2003	<a href="http://fire.cfs.nrcan.gc.ca/research/climate_change/lfdb_e.htm">http://fire.cfs.nrcan.gc.ca/research/climate_change/lfdb_e.htm</a>
Forest inventories	Canada's National Forest Inventory (CanFI)	CanFI grid cell	1949–2004	<a href="http://cfs.nrcan.gc.ca/subsite/canfi/home">http://cfs.nrcan.gc.ca/subsite/canfi/home</a>
	Alberta	Analysis units	N/A	Growth curves from provincial expert
	British Columbia	Analysis units	2000	Provincial expert
	Newfoundland	Analysis units	2000	Provincial expert
	Ontario	Analysis units	2000	Provincial expert
	Prince Edward Island	Analysis units	2000	Provincial expert
Harvest data	Quebec	Analysis units	2000	Provincial expert
	National Forestry Database	Provincial boundaries	1990–2004	<a href="http://nfdp.ccfm.org/">http://nfdp.ccfm.org/</a>
	Alberta	Analysis units	2003–2005	Provincial expert
	British Columbia	Analysis units	2003–2005	Provincial expert
	Newfoundland	Analysis units	1990–2005	Provincial expert
	Manitoba	Analysis units	2003–2005	Provincial expert
	New Brunswick	Analysis units	2003–2005	Provincial expert
	Northwest Territories	Analysis units	2003–2005	Territorial expert
	Nova Scotia	Analysis units	2003–2005	Provincial expert
	Ontario	Analysis units	2000–2005	Provincial expert
	Prince Edward Island	Analysis units	2000–2005	Provincial expert
	Quebec	Analysis units	1990–2005	Provincial expert
	Saskatchewan	Analysis units	2003–2005	Provincial expert
	Yukon	Analysis units	2003–2005	Territorial expert
Insect data	Forest Insect and Disease Survey	Spatially explicit	1990–2000	Atlantic Forestry Centre
	Spruce Budworm Decision Support System	Reconciliation units	1970–2003	Expert
	British Columbia	Spatially explicit	1990–2005	Provincial expert
	Saskatchewan	Spatially explicit	1990–2002	Provincial expert
Climate data	CFS	Reconciliation units	1961–1990 normals	McKenney (2005)

Note: N/A = not available

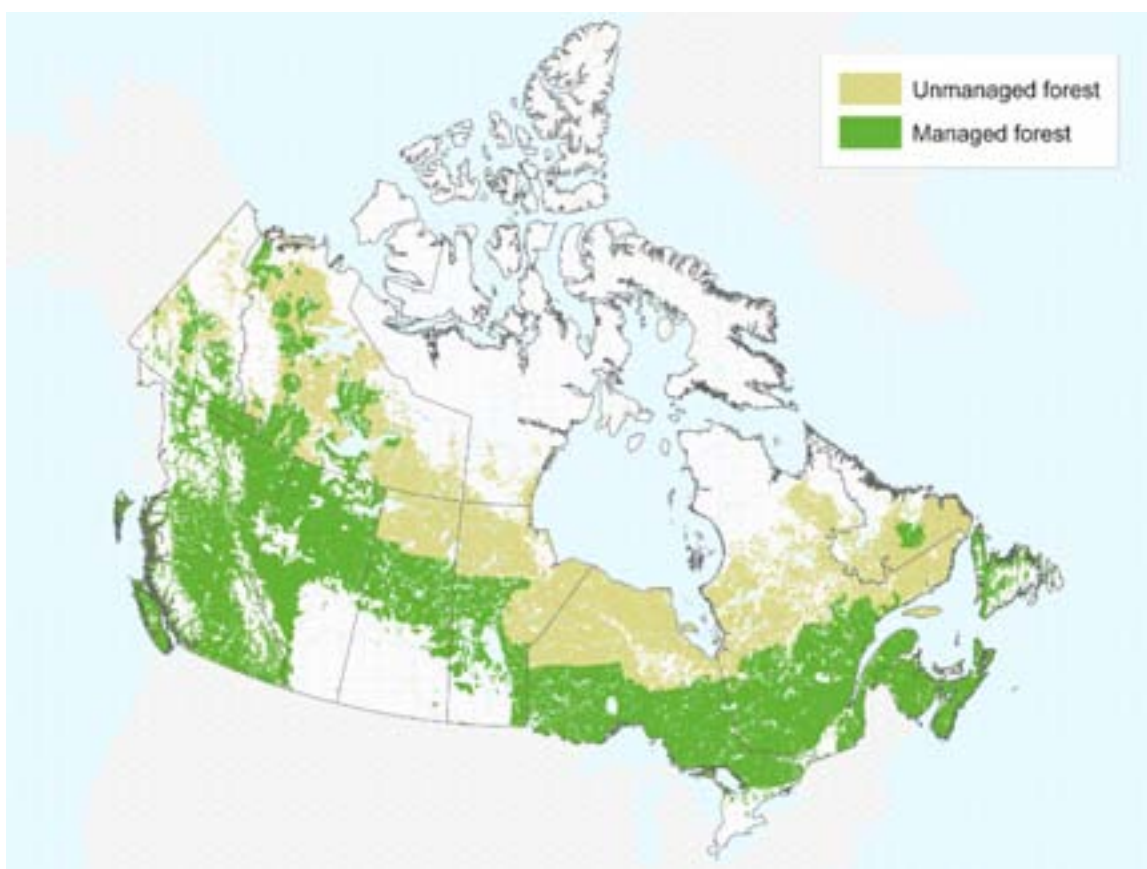
The estimation of the managed forest area required the spatial delineation and combination of boundaries of many different forest areas, including all operational forest management units, timber supply areas, tree farm licences, industrial freehold timberland, private woodlots, and any other Forest Land where there is active management for timber or non-timber resources, as well as forest areas where there is intensive protection against natural disturbances. All these layers are aggregated and intersected with underlying forest inventory data. The process is documented in



Stinson et al. (2006b). Figure A3-6 illustrates the location of managed and unmanaged forests in Canada, for the purpose of GHG estimation and reporting. In 2006, the total area of managed forests was 229 995 kha, of which 67% lies in the four reporting zones: Boreal Shield East, Montane Cordillera, Boreal Plains, and Boreal Shield West (Table A3-29).

Forest management activities are documented in the National Forestry Database; additional information on specific activities is obtained directly from provincial and territorial forest management agencies.

Historical data on areas disturbed by wildfires were extracted from the Canadian Large Fire Database. These were supplemented by provincial and territorial data for the years 1990–2003 and by the Canadian Wildland Fire Information System for the years 2004 to 2006 (Table A3-31).



-----  
**Figure A3-6: Managed and Unmanaged Forests in Canada**  
 -----

Insect disturbances are monitored on aerial surveys (Table A3-31). The gross annual areas are converted into effective impact areas, which represent the area disturbed net of unaffected forested areas (non-treed areas or treed areas with non-host species). Effective impact areas are assigned to analysis units and are further broken down by impact severity: stand-replacing mortality, partial mortality, and growth reduction.

## Forest Conversion

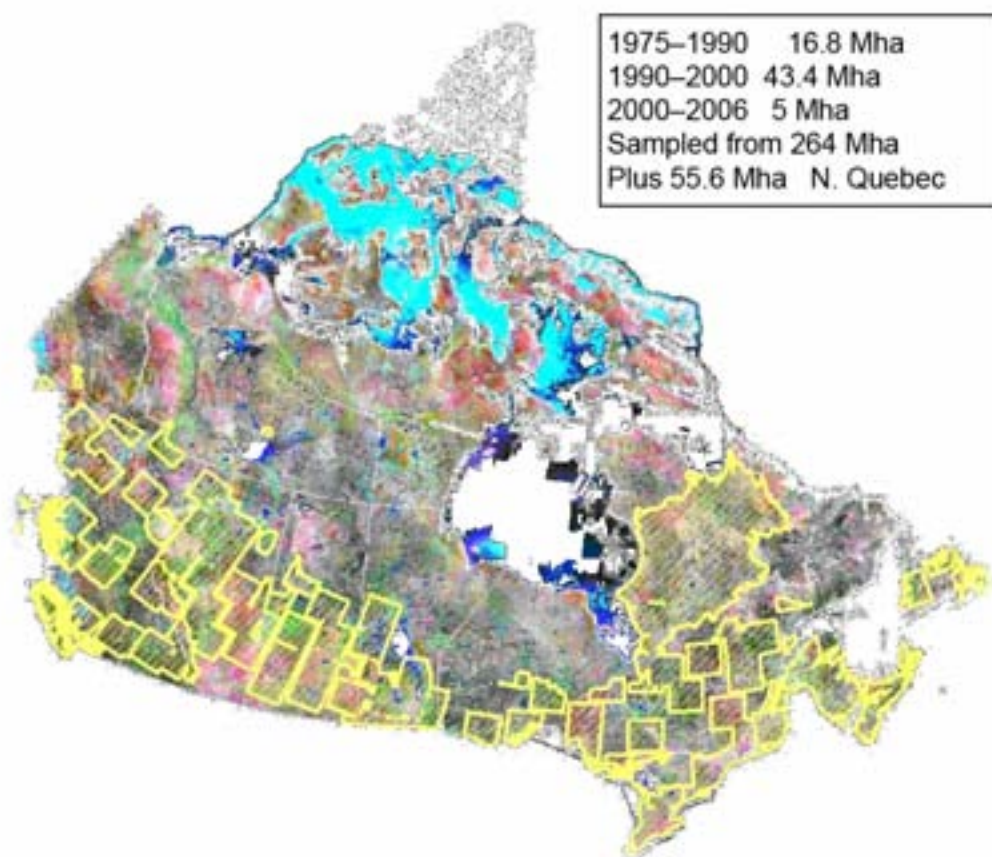
In order to account for the long residual effects of forest conversion, conversion rates were estimated starting in 1970. The approach for estimating forest areas converted to other uses—or “deforested areas”—is based on three main information sources: systematic or representative sampling of remote sensing imagery, records, and expert judgement/opinion. The basic methods have been tested in several pilot projects (CFS 2006a), and the methodology has now reached a consistent level of success in estimating deforestation activity.

The core method involves remote sensing mapping of deforestation on samples from Landsat images dated circa 1975, 1990, and 2000. Change enhancements between two dates of imagery are produced to highlight areas of forest clearing and identify possible deforestation events (i.e. candidate events). The imagery is then interpreted to determine if the land cover of the candidate event was forest initially (at Time 1) and is a land cover change or land-use change at Time 2 (Leckie et al. 2002; Paradine et al. 2004). This deforestation interpretation process is strongly supported by other remote sensing data, including digitized aerial photographs; snow-covered, leaf-off, winter Landsat imagery; secondary Landsat images from other dates and years; ancillary data, such as maps of road networks, settlements, wetlands, woodland coverage, and mine and gravel pit locations; and specialized databases giving locations of oil and gas pipelines and well pads (Leckie et al. 2006). When readily available, detailed forest inventory information is also used.

Each deforestation event identified in the images as greater than 1 ha is manually delineated. The broad forest type prior to deforestation is interpreted,<sup>69</sup> and the post-deforestation land use recorded (“post-class”). Confidence ratings on the land use at Time 1 and Time 2 are used in subsequent QC and field validation procedures.

---

69. See Chapter 7 for the definitional parameters of “forest.”



-----  
**Figure A3-7: Deforestation Strata and Areas Sampled for the 2006 and 2007 Submissions**  
 -----

The forested areas of Canada are broadly stratified into regions of expected forest conversion level and dominant cause, which dictates the targeted sampling intensity. Depending on the expected spatial pattern and rates of forest conversion events, sampling approaches ranged from complete mapping to systematic sampling over the entire spatial unit of interest to representative selection of sample cells within a systematic grid. For example, in populated areas of southern Quebec and in the Prairie fringe, a 12.3% sampling rate was generally achieved, with  $3.5 \times 3.5$  km sample cells on a systematic 10-km grid (Figure A3-8). In practice, resource constraints limit the size of the remote sensing sample used for the deforestation estimates. The total areas, either fully mapped or sampled, cover approximately 320 Mha, of which over 16 Mha were actually mapped for 1975-1990 and 43 Mha for 1990-2000.

## NIR 2006 Sample Plot Design

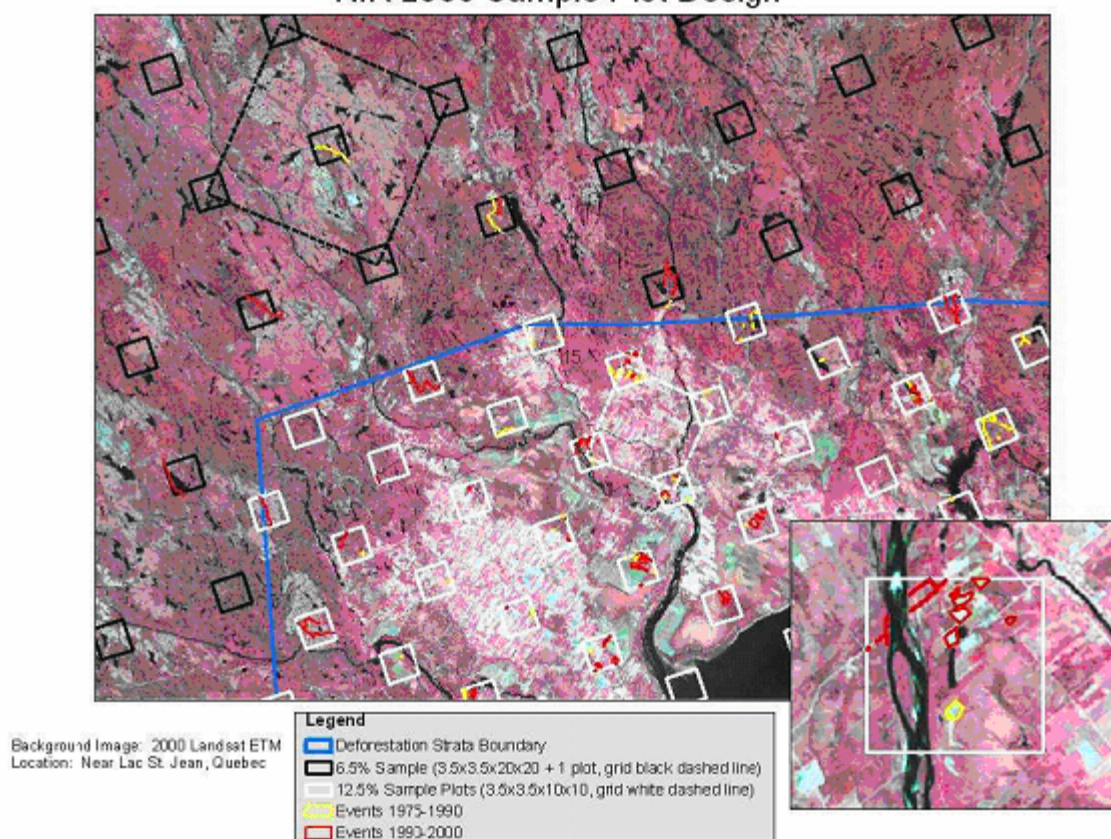


Figure A3-8: Sampling Grids over Imagery for Forest Conversion Mapping and Delineated Forest Conversion Events

Representative samples are used in areas of moderate expected deforestation (e.g. eastern woodlots in the Maritimes; the Eastern Townships in Quebec; the Lower Mainland of British Columbia; the south agricultural zone of the Prairies). The forest activity stratum is a large region of Canada with a low population density; the main economic activities consist of forestry and other resource extraction. Again, a representative sampling approach is used, augmented with additional samples (e.g. pilot studies) in Quebec, Ontario, and British Columbia. Special cases of known, localized, and large deforestation activities were also identified, such as hydroelectric reservoirs and the Alberta oil sands developments. These are handled as single events, with spatially complete mapping.<sup>70</sup> The extent of forests affected by land submersion is estimated by multiplying the area of land flooded by the proportion of forest cover in the region surrounding the reservoir, determined by a Landsat image classification forest cover map (Wulder et al. 2004).

Records were gathered when available. They consist mostly of information on forest roads, power lines, oil and gas infrastructure, and hydroelectric reservoirs (Leckie et al. 2006). Temporal coverage, availability, and appropriateness of these records are used to make decisions as to the

70. In the case of hydroelectric reservoirs, some records are also used to determine flooded area.

data sources (records or imagery) on which to ultimately rely. Records from six provinces are used for forestry roads and from three provinces for power lines. The assessment of forest conversion in Alberta<sup>71</sup> due to the pipeline component of the oil and gas infrastructure is based on a commercial GIS database of pipelines and well pads and a separate database on the width of pipeline corridors. Approximately 95% of pipeline right-of-ways are less than 20 m wide, and most are 14 to 16 m wide; the remainder are 20 m wide or slightly more. In most cases, records provide only the total area of land converted to pipelines, regardless of the preconversion land category. To obtain consistent estimates, all pipeline rights-of-way were assigned a 20-m width; 5% of the area thus obtained was determined as potential forest conversion area. When preconversion land use is missing, records from Canada's National Forest Inventory (CanFI 1991) are used to determine the proportion of land converted to pipelines that was forest.

Expert opinion is called upon when records data are unavailable or of poor quality or the remote sensing sample is insufficient. Expert judgement is also used to reconcile differences among records and remote sensing information and to resolve large discrepancies between the 1975–1990 and 1990–2000 area estimates. In such cases, available expert opinion and data sources are brought together, remote sensing and records data are reviewed, and decisions made (CFS 2006b). Most estimates, certainly those where the land-use change categories had the largest impacts, are derived directly from remote sensing samples.

The deforestation data are compiled and summarized on the basis of deforestation strata and reconciliation units. All deforestation events are assembled into a large deforestation event database. A compilation system summarizes events for each deforestation stratum and aggregate deforestation rates to reconciliation units. Compilation also involves insertion of records data and expert judgement. In the course of these procedures, each deforestation event is compiled to yield a local deforestation rate (ha/year) based on the time interval between the images. Since the available imagery was not necessarily dated 1975, 1990, or 2000, the deforestation rates cover different time periods. At the data compilation phase, each forest conversion event is assigned to one of two time periods (1975–1990 or 1990–2000), and the corresponding deforestation rate is assigned to that period. For example, a 7.0-ha event encountered on imagery from the period 1975–1989 would yield a 0.5 ha/year rate (7.0 ha/14 years) and then would be assigned to the period 1975–1990. The total area interpreted in a stratum for that time period is then used to determine a relative deforestation rate ((ha/year)/km<sup>2</sup> interpreted) for all events of the same type. Relative deforestation rates are scaled up for each stratum. Data are finally grouped by post-class (e.g. the change rate for agricultural crop or rural residential) and in turn, are summarized by broader categories when recompiled by reconciliation unit.

The remote sensing data are derived using the circa 1975, 1990, and 2000 imagery, whereas records data are annual or summarized over time periods. As explained above, the remote sensing core method provides two distinct forest conversion rates, for 1975–1990 and for 1990–2000, but no annual estimates of these rates. The preparation of annual forest conversion rates for 1970–2005 requires the simultaneous application of two procedures: 1) extrapolation of annual rates prior to 1975 and beyond 2000; and 2) interpolation between the 1975–1990 and 1990–2000 data. In the absence of documented and tested procedures, the simplest approach is to assign the 1975–1990 rate to each year from 1970 to 1983 and the 1990–2000 rate to each year from 1995 to 2005 (the extrapolation). A linear interpolation is applied between the two temporal anchor points

---

71. In British Columbia and Saskatchewan, where oil and gas development is also significant, the basic remote sensing method was used because of poor record quality.



(1983 and 1995), which resulted in an estimate of the annual deforestation rate for each intervening year. The procedure is illustrated in Figure A3-9. Noted exceptions to this procedure are individual large events such as hydroelectric reservoirs, for which year of flooding is known, and some records-based events.

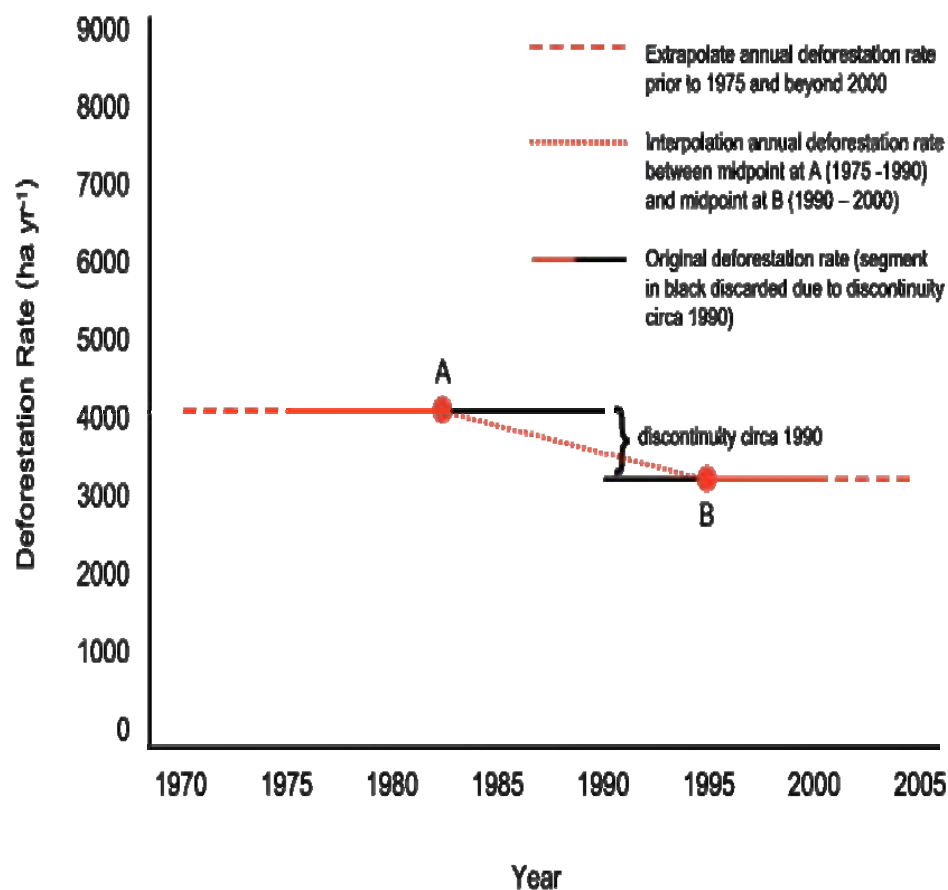


Figure A3-9: Procedure to Develop a Consistent Time Series of Rates of Forest Conversion

Figure A3-10 displays the annual rates of forest conversion by selected end uses: forest land to cropland (FLCL), forest land to settlements (FLSL), and forest land to wetlands (FLWL). Forest land conversion to settlements includes forest roads, all infrastructure development, mining, and oil and gas extraction, as well as urban, commercial, industrial, and recreational areas. Note that these figures differ from the ones reported in the CRF tables, which are cumulative areas in the Land converted to categories.

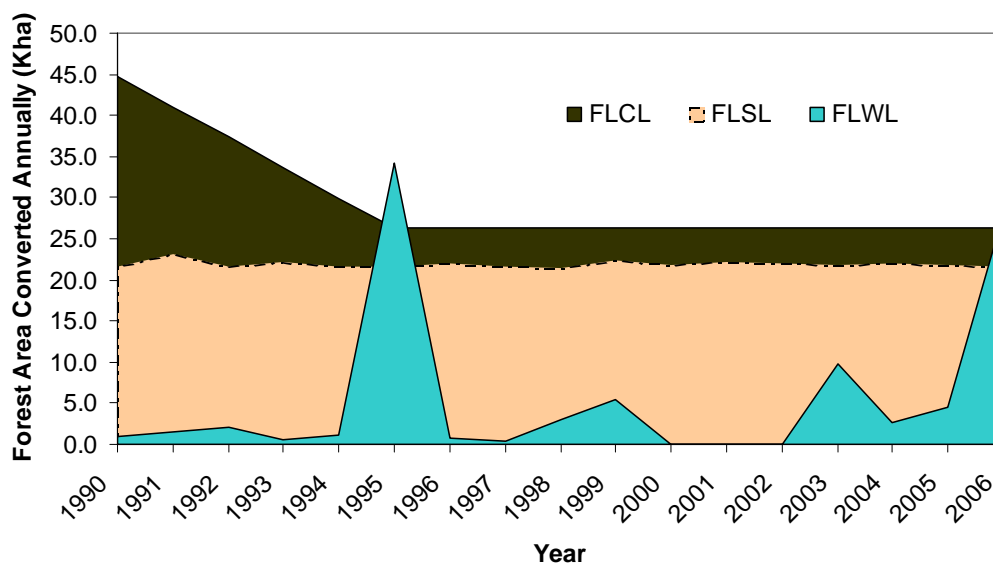


Figure A3-10: Annual Rates of Forest Conversion in Canada

### *QA/QC of Forest Conversion Data*

Great care was taken in understanding the records data, their suitability, and their limitations. Documentation of the records data was examined, personnel involved in managing and implementing the data collection and storage were interviewed and, where available, numbers were checked against independent data sources and the expectations of experts.

The remote sensing interpretation follows defined practices (Paradine et al. 2004) although it is conducted by a variety of organizations, including provincial government forestry or geomatics groups, remote sensing or mapping companies, research and development organizations, and inhouse government staff. The basic QC process includes internal checks within the mapping agency or company by a senior person; real-time QA by Forest Service specialists during interpretation, with feedback provided within days of an interpretation of an area; and a final QA or vetting of the interpretation by the Canadian Forest Service. Field checking was undertaken on established pilot projects. Each QC point and revision were documented within the GIS databases of deforestation event data. One independent QA procedure was completed on a large sample of interpretations.

Records of decision as to data used, expert judgement applied, and resolution of contradictory data were documented (CFS 2006b) and updated for the 2008 submission. Data sources and limitations were recorded, and remote sensing data and interpretations were archived. Calculations and expert judgement are traceable through the compilation system.

## Uncertainty of Forest Conversion Data

There are three main sources of uncertainty in the estimates of forest area converted to other land categories:

- omission and commission;
- sampling error; and
- boundary delineation error.

The deforestation mapping process also involves three additional sources of uncertainty impacting the emission estimates:

1. forest type being removed;
2. post-conversion land category; and
3. event timing.

This section will discuss the first three uncertainty sources. Ongoing work to estimate emission uncertainties will include the last three factors. Complete results will be presented in future submissions.

In estimates derived from remote sensing, the quantification of omission errors (missing forest conversion events) and commission errors (including events that are not forest conversion) takes into account the entire mapping process, including image interpretation, QC, field validation, and other vetting activities. Key uncertainty sources in the 1975–1990 forest conversion events stem from the lower resolution and poorer quality of 1975 imagery and lack of ancillary information. Over the entire time series, there is a tendency for omissions to be small in size, whereas commission errors are usually from a misinterpretation rather than an oversight and thus are less size dependent. Commission errors arise from either mistakenly calling an area forest at Time 1 (e.g. if the vegetation cover prior to change did not meet the forest definition) or mistakenly labelling as “non-forest,” the Time 2 land category (e.g. after a harvest). Over the entire process, commission errors are more likely than omission errors; hence, the estimate of total forest area converted derived from image interpretations is more likely to be overestimated than underestimated. Records, used mostly for roads and power lines, are more likely to omit events than to misattribute them. Expert judgement concluded that a  $\pm 20\%$  range was an acceptable and conservative estimate of the total uncertainty due to omission/commission errors.

Sampling is a mixture of wall-to-wall mapping of regions, systematic samples completely covering regions, samples from representative areas, and complete mapping of selected local areas. In some areas, the sample coverage and design differed between 1975–1990 and 1990–2000. Uncertainty due to the sampling is therefore regionally variable and, since some types of forest conversion are more prevalent in different regions, the uncertainty by type is also complex and variable. The sampling uncertainties were not estimated by region or type of forest conversion, but rather on a global basis by expert judgement, taking into account regional differences in forest conversion activities and sampling intensity. The sampling error for the total forest area converted was estimated at  $\pm 25\%$ .

Boundary delineation error is the displacement of the boundary outline from the true boundary, resulting in incorrect area estimation. Both area overestimation and underestimation can occur, depending on the landscape spatial patterns. In the absence of quantitative evidence, it was



assumed that delineation errors did not cause either positive or negative bias and that a  $\pm 20\%$  range best represented the uncertainty associated with this type of error.

The overall uncertainty is a combination of the boundary delineation, omission and commission, and sampling errors. The simplified estimates of uncertainty made for each one were combined using a simple error propagation method:  $(0.2^2 + 0.2^2 + 0.25^2)^{1/2} = 0.38$ .

The  $\pm 38\%$  uncertainty about the estimate of the total forest area converted annually in Canada places with 95% confidence the true value of this area for 2006 between 35 kha and 77 kha.

Owing to availability of data sources and lower deforestation mapping sample intensity, the uncertainty in the 1970–1990 estimates is expected to be larger than that for the 1990–2005 period, and there may be some tendency towards overestimation of deforestation in 1970–1990. This would affect the uncertainty range for these and subsequent years. Caution should also be exerted in applying the 38% range to the cumulative area of Forest Land converted to another category over the last 20 years (land areas reported in the CRF tables). This issue will be considered in the future.

### ***Planned Improvements in Forest Conversion***

Planned improvements will be incremental, with an emphasis on their efficiency in reducing uncertainties and improving specific estimates. Improvement strategies combine a greater remote sensing coverage, expanded records compilation, more complete QC, and field verification. Imagery for a target date of 2006 is currently being obtained and assembled to enable updated estimates for a post-circa-2000 period. This new data and data from circa 2008 and beyond will be added to the mapping and records data as reporting progresses.

### **Land Converted to Forest Land**

Records of land conversion to forest land in Canada were available for 1990–2002 from the FAACS<sup>72</sup> initiative (White and Kurz 2005). Conversion activities for 1970–1989 and 2003–2005 were estimated based on activity rates observed in the FAACS data. Additional information from the Forest 2020 Plantation Demonstration Assessment<sup>73</sup> was included for 2004 and 2005. Each event, regardless of date, source, type, or location, was converted to an inventory record for the purposes of carbon analysis. All events were compiled in a single data set of afforestation activity in Canada from 1970 to 2005.

For 1990–2002, the area planted was stratified by ecozone, province, and species. Total area planted by province and ecozone, in conjunction with the proportion of species planted for each province, was used to calculate area planted by species, resulting in estimates of the area converted to forest, by species, for each reconciliation unit.

Yield curves are not always available for some plantation species or growing conditions (stocking level or site history); those used to estimate growth increments were taken from a variety of sources, most often directly from provincial experts. Where species do not have their own yield curve, they are given the yield curve of another species with similar growth characteristics or the species most likely to have been present in that area. Changes in soil carbon stocks are highly

72. <http://cfs.nrcan.gc.ca/subsite/afforestation/feasibilityafforestation>

73. <http://cfs.nrcan.gc.ca/subsite/afforestation/forest2020pda/forest2020pda>

uncertain, because of difficulties in locating data about the carbon stocks prior to plantation. It was assumed that the ecosystem would generally accumulate soil carbon at a slow rate; the limited time frame of this analysis and the scale of the activity relative to other land-use and land-use change activities suggest that the impact of this uncertainty, if any, is minimal.

#### A3.4.2.3 *Estimation of Carbon Stock Changes, Emissions, and Removals*

At the beginning of each annual time step, the CBM-CFS3 first assigns land-use change activities to inventory records and redistributes these records to ensure that the impacts of land-use change (conversion to forests and conversion of forests) are reported in the new land category. Forest disturbances are simulated only after the land-use conversions have been completed. The selection of forest stands affected by land-use change and non-land-use change disturbances is based on documented eligibility rules (Kurz et al. in preparation).

Once the model has computed the immediate effect of disturbances on all forest stands, it applies the sets of carbon transfers associated with annual processes to all records (managed forest, land converted to forest, and land converted from forest), including both stocked and non-stocked stands. As explained above, annual processes combine growth, turnover, and decay processes, applied to the entire area of managed forests. The outputs consist of net GHG balance of managed forests, including growth; immediate emissions due to disturbances (carbon stock changes, carbon losses to the atmosphere and to forest products); and decay of both DOM and soil organic matter, including on stands affected by disturbances. During this stage, inventory records that have been in a Land converted to category for 20 years are converted into the Land remaining category.

The same data output is available on converted forest lands (except tree growth), but is reported in the new land category—e.g. Land converted to cropland (CRF Table 5.B Row 2), Land converted to wetlands (CRF Table 5.D Row 2), and Land converted to settlements (CRF Table 5.E Row 2). Estimates of soil organic matter emissions on forest land converted to cropland and peatlands were developed separately; methods are described in Section A3.4.3.3 and A3.4.5.1. Likewise, estimation methods for emissions (as opposed to carbon stock changes) from forest land converted to flooded lands are described in Section A3.4.5.2.

Note that the immediate effect of disturbances is identifiable in the output data sets for the year of the disturbance. In subsequent years, post-disturbance emissions and removals are simulated as annual processes. The CBM-CFS3 does not distinguish decomposition releases from DOM accumulated prior to or during a disturbance; hence, long-term impact of disturbances cannot be fully identified.

Table A3-32 gives 2006 estimates of the broad components of the GHG emissions and removals in managed forests generated by the CBM-CFS3. The largest fluxes are carbon uptake by biomass and its release by DOM decay. The first is largely influenced by the age-class distribution of the managed forests; organic matter decay is controlled by input from litter fall, mortality, and the disturbances that occurred prior to the inventory year. Insect disturbances have very limited immediate impact; however, depending on the severity of infestations and insect damage, they may result in large carbon transfers from biomass to DOM and influence the long-term trend of organic matter decay (see Chapter 7). Emissions from the DOM pool account for over 76% of all wildfire emissions.

**Table A3-32: GHG Emissions/Removals of Managed Forests, 2006**

Process/Event	GHG Balance (Gg CO <sub>2</sub> eq)				
	Biomass	DOM	Soil	N <sub>2</sub> O	Ecosystem Net Balance
Annual processes	-2 939 473	2 077 267	616 966	0	-245 239
Harvesting	148 230	15 600	0	0	163 830
Wildfires	19 011	81 714	0	4 480	105 205
Insects <sup>1</sup>	0	0		0	0
Total	-2 772 232	2 174 581	616 966	4 480	23 795

Notes:

1. "0" emissions indicate that insects do not consume or deplete carbon as do fires and harvest. Rather, they kill biomass that is transferred to DOM.

Carbon in CH<sub>4</sub> and CO emissions is included in each pool's assessment, but N<sub>2</sub>O emissions are computed separately from total CO<sub>2</sub> emissions (Annex 13).

#### *A3.4.2.4 Uncertainties*

Constraints of time and resources continue to prevent the timely development of formal uncertainty estimates for the Forest Land category. Important sources of uncertainty about forest land remaining forest land estimates are discussed below.

### **Area of Managed Forests**

Despite important efforts to obtain, harmonize, and integrate the most accurate forest inventory information available across the country, some intractable uncertainties remain. Forest inventories are prepared and maintained by jurisdictions for purposes other than for GHG estimation and reporting, primarily for use in timber supply planning. Methods, standards, definitions, and quality differ by jurisdiction, depending on their objectives for the inventory. All of the inventories used were developed prior to Canada's adopting a standard for the definition of forest of 1 ha, 25% crown closure, and 5 m minimum height at maturity. Although documentation on the different inventory techniques and procedures used across the country is usually available, it seldom contains any quantitative assessment of uncertainty.

The current approach ensures consistency between GHG estimates and forest management planning and reporting statistics generated by each jurisdiction. Despite this care and attention, two areas of uncertainty remain:

*Completeness:* Forest inventories are focused on data needed for timber supply planning and may contain less information about stands that, while meeting the definition of forest used for GHG accounting, are not of interest for timber supply planning purposes. This uncertainty has been addressed by considering additional sources of data where available.

*Accuracy:* Forest inventory information is costly to gather and can be collected over a span of multiple years. The inventories are usually prepared on a 10-year or longer cycle, typically with a forward-looking focus. Uncertainty in this respect is primarily related to the vintage of the industry inventory and concerns over whether it has been updated for depletions since it was prepared.

The methods used to reconcile and compile forest inventory data in support of GHG estimate development do not at present allow a quantification of the uncertainties about managed forest areas.

### **Key Model Parameters and Assumptions**

Emissions and removals are sensitive to the assumptions about the age-class distribution of managed forests and model parameters governing turnover, transfers, and decay in each carbon pool. For example, the uncertainty about the age of a forest stand (or age-class structure of a forest landscape) may affect the simulated stand (or landscape) productivity, depending on the shape of the growth curve and the particular location of a given age category along that curve (or the regional average age in relation to a regional average growth curve). Likewise, the age class (or the uncertainty about it) of a stand killed by a fire disturbance may influence the quantity of biomass and DOM affected (or its uncertainty) and the resulting emissions.

Soil and slow-decaying DOM pools contain a considerable amount of carbon. Even though the rates of soil organic matter decay modelled by the annual processes are very low, they do, by virtue of the pool size and forest areas, strongly influence emissions from annual processes. Similarly, the transfers of DOM carbon to the atmosphere modelled in the disturbance matrices, applied over the vast areas affected by disturbances, amount to significant emissions. The recalibration of DOM decay rates for the 2007 submission, which affected the size of all DOM and soil carbon pools, the immediate emissions from wildfires, and residual emissions post-disturbance illustrate the complexity of the system.

The initial soil and DOM pool sizes are in turn sensitive to assumptions about historic disturbance regimes. Work is under way to improve the ability to quantify the sensitivity of DOM dynamics in CBM-CFS3 to assumptions about historic disturbances and to refine the assumptions themselves.

### **A3.4.3 Cropland**

The methodologies described in this section apply to carbon stock changes in mineral soils subject to cropland management, the conversion of Forest and Grassland to Cropland, CO<sub>2</sub> emissions/removals from liming and changes in woody perennial crops, as well as N<sub>2</sub>O emissions from soil disturbance upon conversion to cropland. The estimation methodologies for carbon stock changes and GHG emissions from the biomass and DOM pools upon conversion of forest land to cropland are provided in Section A3.4.2.3.

#### ***A3.4.3.1 Cropland Remaining Cropland***

A detailed description of the methodologies used for this category can be found in McConkey et al. (2007a).

### **Change in Carbon Stocks in Mineral Soils**

#### ***Changing Management Practices***

The amount of organic carbon retained in soil represents the balance between the rates of input by crop primary production and losses through soil organic carbon (SOC) decomposition. How the soil is managed determines whether the amount of SOC stored in a soil is increasing or decreasing. The IPCC (2003) approach, which guided the development of the CO<sub>2</sub> estimate methodology, is based on the premise that changes in soil carbon stocks over time occur

following changes in soil management that influence the rates of either carbon additions to, or carbon losses from, the soil. If no change in management practices has occurred, the carbon stocks are assumed to be at equilibrium, and hence the change in carbon stocks is deemed to be zero.

A number of management practices are generally known to increase SOC in cultivated cropland, such as reduction in tillage intensity, intensification of cropping systems, adoption of yield-promoting practices, and re-establishment of perennial vegetation (Janzen et al. 1997; Bruce et al. 1999). Adoption of practices with reduced tillage (RT) or no-till (NT) can result in significant accumulation of SOC compared with intensive tillage (IT) (Campbell et al. 1995; 1996a; 1996b; Janzen et al. 1998; McConkey et al. 2003). Many cropping systems can be intensified by increasing the duration of photosynthetic activity through a reduction of summerfallow (Campbell et al. 2000; 2005; McConkey et al. 2003) and greater use of perennial forage (Biederbeck et al. 1984; Bremer et al. 1994; Campbell et al. 1998). Intensification of cropping systems not only increases the amount of carbon entering the soil, but may also reduce decomposition rates by cooling the soil through shading and by drying the soil. Conversely, switching from conservative to conventional tillage or from intensive to extensive cropping systems will reduce carbon input and increase the decomposition, thereby reducing SOC.

VandenBygaart et al. (2003) compiled published data from long-term studies in Canada to assess the effect of agricultural management practices on SOC. This compendium, as well as the availability of activity data from the Census of Agriculture, provided the basis for identifying the key management practices and management changes used to estimate changes in soil carbon stocks. Emissions and removals of CO<sub>2</sub> from mineral soils were estimated for the following land management changes (LMCs):

1. Change in mixture of crop type:
2. Increase in perennial crops
3. Increase in annual crops
4. Change in tillage practices:
5. IT to RT
6. IT to NT
7. RT to IT
8. RT to NT
9. NT to IT
10. NT to RT
11. Change in area of summerfallow
12. Increase in area of summerfallow
13. Decrease in area of summerfallow

Where nutrients are greatly limiting, proper fertilization can increase SOC; in such conditions, however, fertilizer or other nutrient-enhancing practices are generally already applied. Land irrigation in semi-arid areas can affect SOC, but the impact is unclear, and the area of irrigated land has been relatively constant in Canada. Therefore, it was assumed that the selected LMCs represented the most important and consistent influences on SOC contents in mineral soils.

### ***Carbon Stock Change Factor***

To estimate carbon emissions or removals, a SOC stock change factor specific to each combination of SLC polygon (the analysis unit) and management change is multiplied by the area of change. The factor is the average rate of SOC change per year and per unit of area of LMC.

**Equation A3-37:**

$$\Delta C = F \times A$$

where:

- $\Delta C$  = change in SOC stock for inventory year, Mg C  
 $F$  = average annual change in SOC subject to LMC, Mg C/ha per year  
 $A$  = LMC area, ha

Areas of LMC (i.e. changes in tillage, crop type and fallow) were obtained from the Census of Agriculture. Census data provide information on the net change in area during five-year Census periods. In practice, land probably both enters and leaves a land management practice, and combinations of management changes occur. However, because only net change data are available, two assumptions were made: additivity and reversibility of SOC factors. Reversibility assumes that the factor associated with an LMC from A to B is the opposite of that associated with the LMC from B to A. Additivity assumes that the carbon changes from each individual LMC occurring on the same piece of land are independent and therefore additive. This assumption is supported by the findings of McConkey et al. (2003), who reported that the impact of tillage and crop rotations on SOC is generally additive.

There is a relatively large set of Canadian observations of long-term changes in SOC for LMC such as adoption of NT and reduced frequency of summerfallow (VandenBygaart et al. 2003; Campbell et al. 2005). However, even this large data set does not cover the whole geographical extent of Canadian agriculture. In addition, there are problems associated with measurement data: 1) treatments often vary among research sites, making comparisons difficult; 2) difficulty in determining duration of effect; 3) difficulty in estimating full uncertainty from a range of interactions with initial soil state and combination of different practices; and 4) difficulty in determining the variability of soil carbon stocks without management change.

Because of these limitations, a well-calibrated and validated model of SOC dynamics, the Century model (Parton et al. 1987; 1988), was used to derive SOC factors for changes between NT and IT, RT and IT, RT and NT, annual and perennial crops, and area of summerfallow. The Century model has been used to simulate SOC change for Canadian conditions (Voroney and Angers 1995; Liang et al. 1996; Monreal et al. 1997; Campbell et al. 2000; 2005; Pennock and Frick 2001; Carter et al. 2003; Bolinder 2004).

Smith et al. (1997; 2000; 2001) developed an approach using the Century model to estimate SOC change on agricultural land in Canada. The model underwent an extensive calibration and validation process. To estimate carbon change, it was necessary to develop a generalized description of land use and management from 1910 onwards on cropland for a sample of soil types and climates across Canada. These scenarios were generated from a mixture of expert knowledge and agricultural statistics of land management, including crop types, fallow, and fertilizer applied (Smith et al. 1997, 2000). These have been used for the first comprehensive assessments of SOC change on agricultural land within a broader assessment of soil health (McCrae et al. 2000).

Initial SOC in 1910 was estimated as 1.25 times the SOC in the SLC polygon attribute database (CanSIS). These database SOC values were derived from measurements made for soil surveys and land resource studies (Tarnocai 1997) and were assumed to represent average SOC on cropland in 1985. SOC change factors were estimated using the difference in SOC stocks over time between simulation of a generalized land use and management scenario with and without the LMC of interest (Smith et al. 2001).

A 10-year crop-and-tillage system (CTS) was developed for each analysis unit and census year, using data from the Census of Agriculture. The CTS focused on seven crops and crop types (grain, oilseeds, pulses, alfalfa, root crops, perennial crops, and summerfallow) and three tillage practices (IT, RT, and NT). Essentially, each CTS represents a mix of crops and tillage practices in space as a mix of crops and tillage practices in time. Under this scheme, a polygon with 20% of cropland area in grain and 20% of cropland area in NT, for example, has 2 of 10 years in grain and 2 of 10 years in NT. Temporal sequences of crop and tillage practices were developed from expert-defined rule-sets, such as “summerfallow never follows summerfallow” and “wheat typically follows soybeans.” The construction allows a base CTS and substitutions of LMCs in the CTS to be readily input to the Century model.

The SOC change factor was determined as  $\text{Factor} = (\text{carbon for CTS with LMC substitutions} - \text{carbon for base CTS}) / [(\text{fraction of CTS substituted with the LMC}) \times (\text{duration considered})]$ . If a land management system is defined as a particular mix of crops and tillage practices on a specified land area, a change in SOC due to an LMC ( $\Delta C_{\text{LMC}}$ ) can be estimated as the difference in SOC stock between two land management systems divided by the proportional amount of LMC between the two land management systems.

**Equation A3-38:**

$$\Delta C_{\text{LMC}}(t) = \frac{\Delta C}{P_{\text{LMC}}}$$

where:

- $\Delta C_{\text{LMC}}(t)$  = the difference in SOC between land management systems from year to year (Mg SOC/ha),
- $P_{\text{LMC}}$  = the proportion of the land area under a given land management system subject to the LMC.

This proportion can be derived as the proportion of the particular LM in the base system less the amount of the LM in the new system after LMC. That is,

**Equation A3-39:**

$$P_{\text{LMC}} = P_{\text{LMbase}} - P_{\text{LMnew}}$$

where:

- $P_{\text{LMbase}}$  = the proportion of the base land management system and
- $P_{\text{LMnew}}$  = the proportion of the new land management system.

The following provides an example of Century runs for a Lethbridge Loam (Orthic Dark Brown Chernozem) in the Semi-Arid Prairies reporting zone. A base model run was made using a 10 year base mix of crops based on the 1996 Census of Agriculture and weather data based on 1951–2001. Century simulations of SOC were made by substituting perennial crops for the seven annual crops in the base mixture. As a separate exercise, NT was substituted for four years of IT in the base mixture (Figure A3-11). The next step was to calculate the  $\Delta C_{\text{LMC}}(t)$  function by subtracting the simulated SOC values for the base mix values from those imposed by the LMC (Figure A3-12). Finally, the  $\Delta C_{\text{LMC}}(t)$  was calculated as the proportion of area of farming system divided by the  $p_{\text{LMC}}$  (Equation A3-39). The respective values of  $p_{\text{LMC}}$  for the IT to NT reduction and for the addition of perennial crops were 4/10 and 7/10.

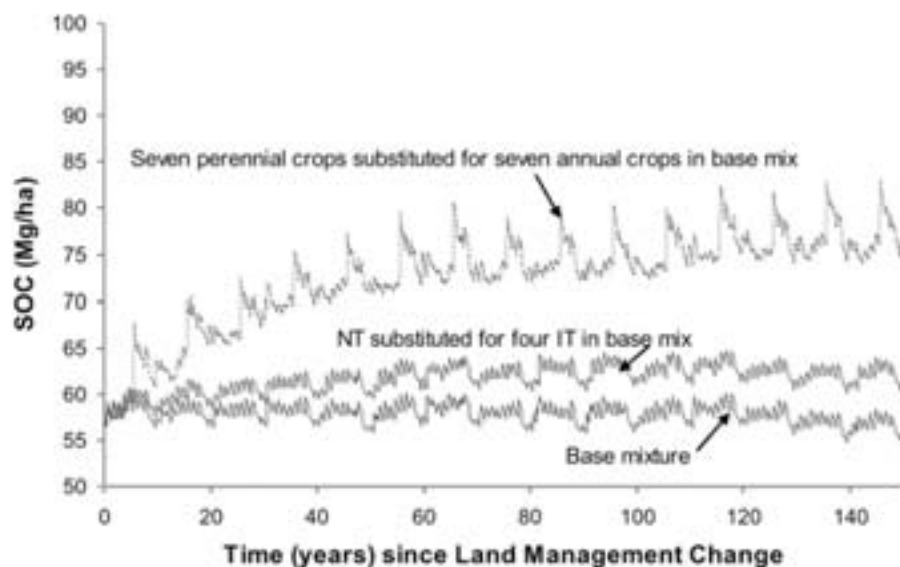


Figure A3-11: Soil Organic Carbon (SOC) for a Base Crop Mix, for Perennial (Alfalfa) Substituted for Annual Crops (Wheat), and for No-Till (NT) Substituted for Intensive Till (IT) Based on Century Runs for a Lethbridge Loam

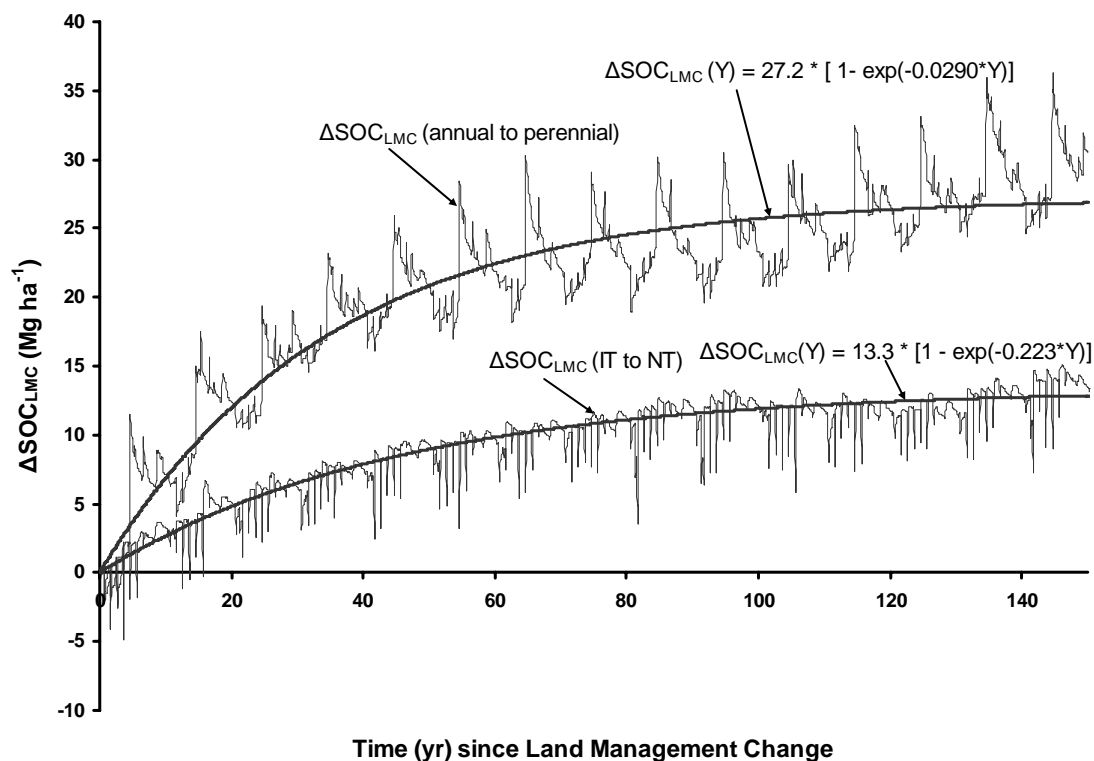


Figure A3-12: Change in SOC for Simulations with Substitutions Relative to Simulations with Base Crop Mix



SOC dynamics are believed to be governed by first-order kinetics, and thus carbon change can be expressed as:

**Equation A3-40:**

$$\Delta C_{LMC}(t) = \Delta C_{LMCmax} \times [1 - \exp^{(-k \times t)}]$$

where:

$\Delta C_{LMCmax}$	=	the maximum SOC change induced by the LMC
$k$	=	the rate constant
$t$	=	year

In practice, the exponential equations are fit statistically using standard statistical analysis software by methods of least squares. The slope of the exponential equation has units of Mg C/ha per year and is the instantaneous factor value. Since the estimation is based on annual changes, the equation used for estimating the factor for annual change from the previous year (i.e. from year  $t-1$  to year  $t$ ) is:

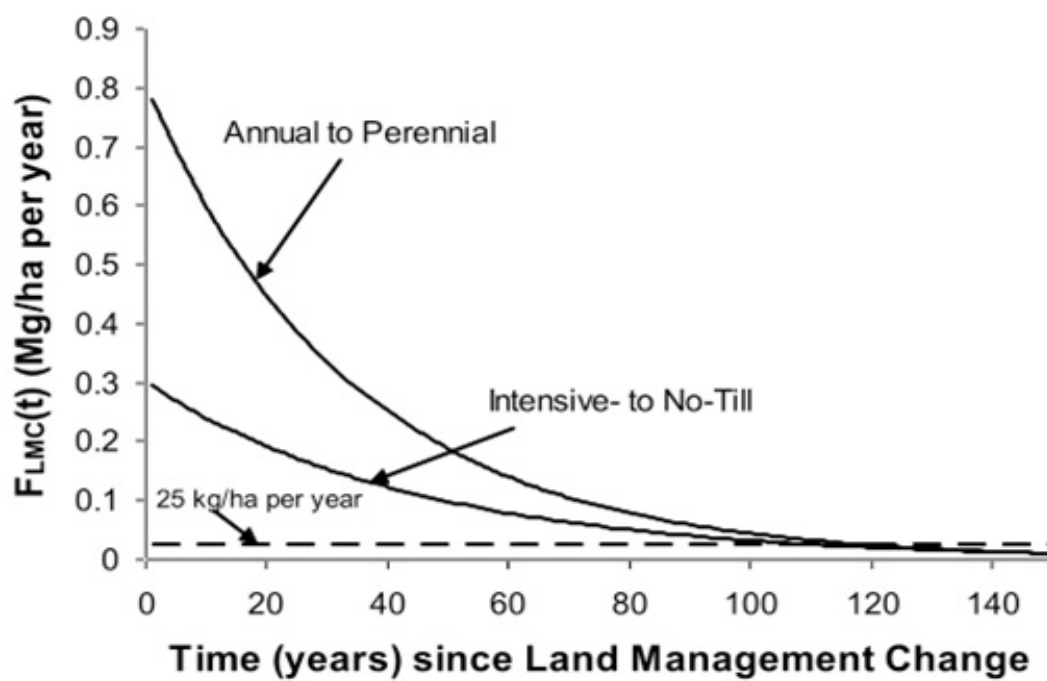
**Equation A3-41:**

$$F_{LMC}(t) = \Delta C_{LMCmax} \times [\exp^{(-k \times [t-1])} - \exp^{(-k \times t)}]$$

Since perfect steady-state conditions are never reached, the exponential equation should theoretically apply forever. In practice, however, the exponential equation was truncated when the  $F_{LMC}(t)$  dropped to 25 kg C/ha per year. This rate was below a practical measurement limit (Figure A3-13).

***Estimating Mean  $k$  and  $\Delta C_{LMCmax}$  for Practical Factor Calculations***

The  $\Delta C_{LMCmax}$  and  $k$  parameters were determined for all 11 602 soil components. These soil components represented a wide range of initial SOC states and combinations of base crop mixtures and amounts of substitutions. The parameter values were estimated for each reporting zone as the mean across these soil components, weighted by area of agriculture on each component (Table A3-33). The geometric mean was used for  $k$ , since its distribution was positively skewed. These means were calculated by three general soil texture classes (sandy, loamy, and clayey) and applied to each soil component based on its textural class. Occasionally,  $k$  values less than 0 or greater than 0.15 resulted from the fit to  $\Delta C_{LMC}$ ; the  $k$  and  $\Delta C_{LMCmax}$  from these fits were excluded from the reporting zone means.



-----  
 Figure A3-13:  $F_{LMC}$  from Exponential Equation  
 -----

**Table A3-33: Generalized Values of Parameters for  $F_{LMC}(t) = \Delta C_{LMCmax} \times [1 - \exp^{(-k \times t)}]$  to Predict Change from Land Management Change (LMC) and Effective Linear Coefficients of SOC Change**

Zone <sup>1</sup>	LMC <sup>2</sup>	k (/year)	$\Delta C_{LMCmax}$ (Mg/ha)	Final Year of Effect after LMC <sup>3</sup>	Mean annual Linear Coefficient over Duration of Effect of LMC (Mg/ha per year)	Mean Annual Linear Coefficient over First 20 years after LMC (Mg/ha per year)
East Atlantic	IT to NT	0.0216	3.5	52	0.05	0.06
	IT to RT	0.0251	2.4	36	0.04	0.05
	RT to NT	0.0233	1.1	1	0.03	0.00
	Decrease fallow	0.0305	13.1	91	0.14	0.30
	Increase perennial	0.0217	43.4	167	0.25	0.77
East Central	IT to NT	0.0250	5.0	65	0.06	0.10
	IT to RT	0.0261	1.9	25	0.04	0.04
	RT to NT	0.0255	3.2	46	0.05	0.06
	Decrease fallow	0.0305	13.1	91	0.14	0.30
	Increase perennial	0.0247	38.2	147	0.25	0.74
Parkland	IT to NT	0.0286	6.5	70	0.08	0.14
	IT to RT	0.0242	2.8	41	0.04	0.05
	RT to NT	0.0263	3.7	51	0.05	0.07
	Decrease fallow	0.0305	13.1	91	0.14	0.30
	Increase perennial	0.0233	29.4	142	0.20	0.55
Semi-Arid Prairies	IT to NT	0.0261	4.9	63	0.06	0.10
	IT to RT	0.0188	2.3	30	0.03	0.04
	RT to NT	0.0222	2.5	37	0.04	0.05
	Decrease fallow	0.0305	13.1	91	0.14	0.30
	Increase perennial	0.0281	26.1	120	0.21	0.56
West	IT to NT	0.0122	4.8	69	0.04	0.05
	IT to RT	0.0116	0.8	0	0.00	0.00
	RT to NT	0.0119	3.9	53	0.03	0.04
	Decrease fallow	0.0305	13.1	91	0.14	0.30
	Increase perennial	0.0155	34.4	198	0.17	0.46

Notes:

1. Area-weighted summary: East Atlantic is the Atlantic Maritime reporting zone plus the Boreal Shield reporting zone in Newfoundland and Labrador, East Central is the Mixedwood Plains reporting zone plus the Boreal Shield East reporting zone in Ontario and Quebec, Parkland is the Subhumid Prairies, Boreal Shield West, and Boreal Plains reporting zones plus those parts of the Montane Cordillera reporting zone with agricultural activity contiguous to agricultural activity within the rest of the Parkland zone, and West is the Pacific Maritime reporting zone plus the Montane Cordillera reporting zone excepting that portion of the latter that is included in the Parkland zone as described above.
2. For LMCs in the opposite direction to that listed, the  $F_{LMCmax}$  will be the negative of the value listed.
3. No further carbon change once the absolute value of the rate of change is less than 25 kg C/ha per year.

The dynamics of SOC change in summerfallow have been well studied in Canada. Therefore, rather than using the value for  $\Delta C_{LMCmax}$  from the Century simulations, the  $\Delta C_{LMCmax}$  value was set so that F was 150 C/ha per year (Campbell et al. 2005) at 20 years based on a  $p_{LMC}$  of 0.5 (for example a change from 50% fallow to no use of fallow). The k value was derived from the Century simulations as described above.

Generally, rates of SOC losses may be expected to be greater upon an LMC than rates of SOC gain upon the reverse LMC. However, this effect depends greatly on the relative SOC amount at the time of the LMC. The factors are assumed reversible. Reversibility requires that the SOC effect of an LMC in one direction is exactly the negative of the SOC effect of the practice change in the opposite direction.

### ***Soil Carbon Factor Validation***

SOC change factors for LMCs used in the inventory were compared with empirical coefficients in VandenBygaart et al. (2008). They showed that empirical data comparing SOC change between IT and NT were highly variable, particularly for eastern Canada. Nonetheless, the modelled factors were still within the range derived from the empirical data. The mean IT-NT factor for experiments in the Subhumid Prairies reporting zone was over four times that of the Semi-Arid Prairies reporting zone. The mean Century model-derived factor for the Semi-Arid Prairies reporting zone was similar to the factor derived from the field experiments. However, the Century-derived IT-NT factor for the Subhumid Prairies reporting zone was about 30% lower than the factor derived from the field experiments. When considering the switch from annual to perennial cropping, the mean empirical factor was 0.59 Mg C/ha per year, and this compared favourably with the range of 0.46–0.56 Mg SOC/ha per year in the modelled factors in western Canadian soil zones. In eastern Canada, only two empirical change factors were available, but they appeared to be in line with the modelled values (0.60–1.07 Mg SOC/ha per year empirical versus 0.74–0.77 Mg C/ha per year modelled). For conversion of crop fallow to continuous cropping, the rate of C storage (0.33 Mg/ha per year) was more than double the average rate of  $0.15 \pm 0.06$  Mg/ha per year derived from two independent assessments of the literature. This difference led to the decision to use empirically based factors for changes in summerfallow in the inventory. Soil carbon change factors for cropland soils in Canada would be greatly improved by a reduction in the high variability usually associated with the empirical data and by improved simulation of the Century model under varying management conditions and initial SOC.

### ***Estimates of Change in Soil Carbon Stocks***

SOC changes as a result of LMC were reported for 1990–2006. Because the effect of LMCs declines over time, a vintage or time when change was deemed to have occurred is maintained for each LMC. The carbon change factor was multiplied by the area of LMC and summed across soil components to produce an estimate of SOC change for the SLC polygon. This is the smallest georeferenced unit of SOC stocks and SOC stock changes, with accounting using an IPCC Tier 2 approach as follows:

#### **Equation A3-42:**

$$\Delta C_{\text{LMC},t} = \sum_{t1, t2 \text{ ALLSLC}} (\Delta C_{\text{TILL}} + \Delta C_{\text{SF}} + \Delta C_{\text{CROPPING}})$$

where:

$\Delta C_{\text{LMC},t}$	=	change in SOC stocks due to LMC for a specific year (t2) since 1951 (t1)
$\Delta C_{\text{TILL}}$	=	change in SOC stocks due to change in tillage practices from each SLC, since each particular tillage change
$\Delta C_{\text{SF}}$	=	change in SOC stocks due to the change in summerfallow in each SLC
$\Delta C_{\text{CROPPING}}$	=	change in soil C stocks due to the change in annual and perennial crops in each SLC

Land management data from the Census of Agriculture were available in 1951, 1961, 1971, 1976, 1981, 1986, 1991, 1996, and 2001. Land management data for years between census years were estimated using linear interpolation. From 2002 to 2006, land management data were set at the same level as in 2001.

## **Data Sources**

There are two types of data used for either deriving carbon factors (modelling) or computing the actual estimates of carbon stock change. The data mainly used for modelling carbon factors include SLC, CTS derived from the Census of Agriculture data, and crop yields, climate data, and activity data from other surveys and databases.

## **Land Information and Activity**

The SLC is a national-scale spatial database describing the types of soils associated with landforms, displayed as polygons at an intended scale of representation of 1:1 million<sup>74</sup>. The advantage of using SLC Version 3.0 for the LULUCF inventory is that all SLC polygons are “nested” within the 1995 National Ecological Framework, making it possible to scale up or scale down data and estimates, as required.

In all provinces within the agricultural region of Canada, detailed soil survey information (map scales greater than 1:1 million) was used to delineate the SLC polygons and compile the associated database files. The SLC Component Soil Names Files and Soil Layer Files provided specific input data (soil carbon content, soil texture, pH, bulk density, and soil hydraulic properties) for modelling carbon factors with Century. The SLC polygon provides the spatial basis for allocating land management practices (tillage practices and cropping systems from the Census of Agriculture) and Cropland converted from Forest and Grassland to modelled carbon factors.

## **Analysis Units**

There are 3 264 SLC polygons that have agricultural activities. Since the SLC polygons have several soil landscape components, the finest spatial resolution for analysis of agricultural activities is 11 602 unique combinations of soil components within SLC polygons. These unique combinations represent the basic analysis units. The location of land management and soil components is not spatially explicit but rather spatially referenced to SLC polygons.

A procedure was developed to assign agricultural activities to SLC based on the suitability of each component of a soil polygon. The soil components have different inherent properties that make them more or less likely to have different types of agricultural activities. Each soil component within the SLC attribute file has a suitability rating of high, moderate, or low likelihood for being under annual crop production. Annual crop production is linked to those components with a high rating of likelihood of being under annual crop production. If there was insufficient area with high likelihood of being under annual cropland for area of annual crops, the remaining annual crop production was linked to components with moderate likelihood of being under annual crop production and, if required, to low-ranked components. After linking the annual crop production area, perennial forages and seeded pasture area were linked to the remaining components in the same manner, starting with components with the highest likelihood of being in annual crops and ending with components with the lowest likelihood of being cropped.

---

74. Available online at <http://sis.agr.gc.ca/cansis/nsdb/slc/v1/intro.html>

## Crop Yields

Crop yields at an ecodistrict level were developed from Statistics Canada surveys. Statistics Canada conducts annual surveys of up to 31 000 farmers, stratified by region, to compile estimates of the area, yield, production, and stocks of the principal field crops grown in Canada. Eight publications are released at strategic points in the crop year; the first area report contains the planting intentions of producers, whereas the June estimates are made after most of the seeding has been completed. Yields and levels of production by province are estimated twice, based on expectations to the end of harvest, whereas the November estimate is released after the harvest. The data are released at the Census Agricultural Region level, providing crop yields for approximately 70 spatial units in the country. Census Agricultural Region boundaries were overlain on SLC boundaries in a GIS, and a yield value for each crop in each soil polygon was assigned based on majority proportion. Data used for accounting included 1975–2006 yield data for wheat, barley, oats, corn, soybeans, potatoes, and canola. These yields were used to calibrate the Century crop growth submodel.

## Climatic Data

There are 958 weather stations in the AAFC-archived weather database. Long-term normals of monthly maximum and minimum temperatures (°C) and precipitation (mm) from 1951 to 2001 for all ecodistricts were used for modelling carbon factors. AAFC-archived weather data were provided by the Meteorological Service of Canada, Environment Canada.

## Census of Agriculture

Activity data for accounting in cropland remaining cropland rely mainly on data from the Census of Agriculture (Statistics Canada 1992, 1997a, 2002). The smallest area for which Statistics Canada will release data externally for confidentiality reasons is the Dissemination/Enumeration Area level (approximately 52 000 in Canada). AAFC has reconfigured Census data for 1981, 1986, 1991, 1996, and 2001 from Dissemination Area units to SLC polygons (and higher-level ecostratification units) using a procedure involving geographic overlays of the relevant boundary files.

Data on tillage practices were taken from the Census according to the following categories: 1) IT—tillage that incorporates most of the crop residue into the soil, 2) RT—tillage that retains most of the crop residue on the surface, and 3) NT—no-till seeding or zero-till seeding. For summerfallow, the following tillage categories were used: 1) NT—the area on which “chemicals only were used for weed control, 2) IT—the area on which tillage only was used, and 3) RT—the area on which a combination of tillage and chemicals was used. There are two limitations with the Census data pertaining to tillage practices that resulted in uncertainties: 1) Statistics Canada and expert opinion indicate that the conservation components tend to be underestimated, and 2) tillage distributions as reported for a region must be applied equally to all crops within that region.

## Uncertainty

Uncertainty was estimated using analytical uncertainty analysis (Coleman and Steele 1999). The uncertainties associated with estimates of CO<sub>2</sub> emissions or removals mainly involve estimates of uncertainties for area and carbon factors of management changes for fallow, tillage, and annual/perennial crops (McConkey et al. 2007b).

The uncertainty of area of change was determined for ecodistricts (one level of spatial aggregation above SLC), and the average area of agricultural land within an ecodistrict is 138 kha. Ecodistricts were considered sufficiently large that the areas of different managements were considered independent of the areas of those managements in other, including adjacent ecodistricts. Errors in the areas of management practices in each ecodistrict were assumed to represent inherent uncertainty that was unaffected by the uncertainty of that management practice in other ecodistricts. Further, the ecodistrict area is sufficiently large that a null report of an activity can be assumed to mean that activity is not occurring within the ecodistrict. Therefore, area uncertainty can be more reliably considered in relative terms for an ecodistrict than for a SLC polygon.

The uncertainty of the area in a management practice at any time for an average ecodistrict was based on the relative proportion of the area of that management practice in that ecodistrict. The relative uncertainty of the area of management practice (expressed as standard deviation of an assumed normal population) decreased from 10% of the area to 1.25% of the area as the relative area of that practice increased (T. Huffman, personal communication, unreferenced).

The uncertainties associated with carbon change factors for fallow, tillage, and annual/perennial crops were assumed to arise from two main influences: 1) process uncertainty in carbon change due to inaccuracies in predicting carbon change even if the situation of the management practice were to be defined perfectly, and 2) situational uncertainty in carbon change due to variation in the situation of the management practice.

Process uncertainty includes the effect of uncertainty in the model. This includes the uncertainty in the model predictions from uncertain model parameters and from inaccurate and/or incomplete representation of all relevant processes by the model. Where empirical data are used, process uncertainty includes inadequacies in measurement techniques, analysis error, poor representativeness of measurements, and/or components of carbon change not measured. To estimate the process error, the variation from measured carbon change for controlled experiments was used. It was assumed that this represents the inherent uncertainty even when the situation is accurately described. Since models of SOC dynamics are validated and calibrated against such data, it was also assumed that this variability provides an estimate of model process error. Process uncertainty scaling coefficients for tillage and fallow were derived for Canada from VandenBygaart et al. (2003).

Situational uncertainty includes the effect of uncertainty within the situation as described. This includes the effect of interactions with past or concurrent changes to land use or land management, variability in the weather or soil properties, variability in crop management, and/or continuity of LMCs. The situational uncertainty scaling coefficients for fallow change, tillage change, and annual–perennial crop change were estimated from the observed variability of Century-simulated carbon change for all the soil component–management–climate combinations within the reconciliation unit. The initial SOC content was based on measured database values that in turn reflected the effect of the range of past histories on soil carbon. There were many combinations of management within which carbon change was calculated. There was also a range of historical ecodistrict weather that was included in the Century simulations. The situational uncertainty also includes the additional variability of the regional factors introduced by the imposition of reversibility of carbon change. Average situational uncertainty scaling coefficients were derived for Canada (McConkey et al. 2007b).

Although process and situational uncertainty are expected to interact, given the complexity of the large number of possible interactions between deviations due to process uncertainty and those due

to situation uncertainty, it is infeasible to describe their relationship. Hence, it was assumed that the total deviation in total carbon change was the sum of the deviation from process and situational uncertainty. Details of uncertainty estimate development are provided in McConkey et al. (2007b).

### CO<sub>2</sub> Emissions from Agricultural Lime Application

Limestone (CaCO<sub>3</sub>) and dolomite (CaMg(CO<sub>3</sub>)<sub>2</sub>) are often used to neutralize acidic soils, increase the availability of soil nutrients, in particular phosphorus, reduce the toxicity of heavy metals, such as aluminium, and improve the crop growth environment. During this neutralization process, CO<sub>2</sub> is released in bicarbonate equilibrium reactions that take place in the soil.

The rate of release varies with soil conditions and the types of compounds applied. In most cases where lime is applied, applications are repeated every few years. Thus, for the purposes of the inventory, it is assumed that the addition rate of lime is in near equilibrium with the consumption of lime applied in previous years. Emissions associated with use of lime are calculated from the amount and composition of the lime applied annually.

The amount of carbon released as a result of limestone application is calculated using the default IPCC Tier 1 approach:

#### Equation A3-43:

$$C = \sum (A_i \times 12/100)$$

where:

$A_i$  = annual limestone consumption in province i, Mg/year  
 12/100 = ratio of molecular weight of C to molecular weight of limestone

Similarly, the amount of carbon released as a result of dolomite application is calculated as:

#### Equation A3-44:

$$C = \sum (A_i \times 12/184.3)$$

where:

$A_i$  = annual consumption of dolomitic lime in province i, Mg/year  
 12/184.3 = ratio of molecular weight of carbon to molecular weight of dolomite

If the type of lime was not known, the lime was assumed to be composed of 50% calcitic lime and 50% dolomitic lime.

There is no single source of data for lime application on agricultural soils. The quantity of lime used for agricultural purposes is not collected by Statistics Canada or by the Canadian Fertilizer Association. Lime usage data were retrieved from Western Canada, Atlantic, Ontario, and Quebec Fertilizer Associations.



## *Uncertainty*

The 95% confidence limits associated with annual lime consumption data were estimated to be  $\pm 50\%$  (B. McConkey, personal communication, unreferenced). This uncertainty was assumed to include the uncertainty of lime sales, uncertainty in proportion of dolomite to calcite, uncertainty of when lime sold is actually applied, and uncertainty in the timing of emissions from applied lime. The uncertainty in the emission factor was not considered because the chemical conversion is deemed complete, and the maximum value of the emission factor was used.

## **CO<sub>2</sub> Emissions and Removals from Woody Biomass**

Vineyards, fruit orchards, and Christmas tree farms are intensively managed for sustained yields. Vineyards are pruned each year, leaving only the trunk and one-year-old stems. Similarly, fruit trees are pruned annually to maintain the desired canopy shape and size. Old plants are replaced on a rotating basis, for disease prevention, stock improvement, or introduction of new varieties. Typically, Christmas trees are harvested at about 10 years of age. For all three crops, it was assumed that, because of these rotating practices and the requirements for sustained yield, a uniform age-class distribution is generally found on production farms. Hence, there would be no net increase or decrease in biomass carbon within existing farms, as carbon lost from harvest or replacement would be balanced by gains due to new plant growth. The approach was therefore limited to detecting changes in areas under vineyards, fruit orchards, and Christmas tree plantations and estimating the corresponding carbon stock changes in total biomass.

There are no Canadian studies on the above-ground or below-ground carbon dynamics of vineyards or fruit trees. However, results from other studies are considered valid inasmuch as varieties, field production techniques, and even root stocks are often the same. Canadian literature on Christmas tree plantations is used whenever suitable.

On average, vines are replaced at 28 years of age and that the average vine is therefore 14 years old (Mailvaganam 2002). Because of intensive pruning, the biomass of shoots and leaves is set at the constant value of 4 Mg/ha, whereas linear rates of above-ground and below-ground biomass accumulation in trunks and roots were 0.4 and 0.3 Mg/ha per year, respectively (Nendel and Kersebaum 2004). These were converted to carbon values using a 50% carbon content in biomass. Upon a decrease in vineyard areas, an instantaneous loss of 6.9 Mg C/ha is assumed, equal to the average standing biomass for 14-year-old vines (McConkey et al. 2007a).

While the average biomass of a mature tree ranged between 18 kg for an apple tree and 72 kg for a peach tree, because of different standard planting densities, the range of standing biomass per area was narrower, between 36 and 40 Mg/ha (McConkey et al. 2007a). This similarity is expected since, regardless of tree size and planting density, the tree shapes and canopies are manipulated to maximize net photosynthesis per area. An annual rate of carbon sequestration was calculated over a 12-year growth period at 1.6 Mg C/ha per year. The same rate, multiplied by a root:shoot ratio of 0.40 (Bartelink 1998), was used to estimate carbon sequestration in below-ground biomass. It was assumed that, on new orchard areas, trees accumulate biomass at a linear rate for 10 years (the average tree age on a plantation). Instantaneous carbon loss upon a decrease of orchards was equal to 50% of the total biomass of a 10-year-old tree (22.4 Mg C/ha).

Christmas trees are marketed at about 10 years of age (McConkey et al. (2007a). Wood accounts for approximately 70% of Christmas tree biomass, and fresh wood has a moisture content of 60–80%. With typical spacing and an expected market mass of 10 kg, a plantation of marketable trees is estimated to have an above-ground biomass density of 17.1 Mg/ha. With a root:shoot ratio of

0.3 (Bartelink 1998; Litton et al. 2003; Xiao and Ceulemans 2004), the total carbon biomass of a marketable tree plantation is estimated at 11.1 Mg C/ha. Carbon sequestration in biomass of new Christmas tree plantations is calculated for five years at rates of 0.85 and 0.26 Mg C/ha for above-ground and below-ground biomass, respectively. A decrease of plantation area would result in the immediate loss of 5.6 Mg C/ha.

### ***Uncertainty***

Poorly growing plants are regularly removed and replaced. Frequently, fruit trees and vineyards are irrigated to maintain desired growth during dry periods. Consequently, the variability in carbon stock changes should be less than that for other agricultural activities.

For loss of area, all carbon in woody biomass is assumed to be immediately released. There are no Canadian-specific data on this uncertainty. Therefore, the default uncertainty of  $\pm 75\%$  for woody biomass on Cropland from IPCC *Good Practice Guidance for Land Use, Land-Use Change and Forestry* (IPCC 2003) was used. If the loss in area of fruit trees, vineyards, or Christmas trees is estimated to have gone to annual crops, there is also a deemed perennial to annual crop conversion with associated carbon change uncertainty that contributes to carbon change uncertainty for a reporting zone.

### **Cultivation of Organic Soils**

Cultivation of histosols for annual crop production usually involves drainage, tillage, and fertilization. All these practices increase decomposition of SOC and, thus, release of CO<sub>2</sub> to the atmosphere.

### ***Methodology***

The IPCC Tier 1 methodology is based on the rate of C released per unit land area:

#### **Equation A3-45:**

$$C = \sum (A_i \times EF)$$

where:

$A_i$	=	area of organic soils that is cultivated for annual crop production in province i, ha
EF	=	carbon emission factor, Mg C loss/ha per year. The default EF of 5.0 Mg C/ha per year was used (IPCC 2006).

### ***Data Sources***

Areas of cultivated histosols at a provincial level are not included in the Census of Agriculture, which is conducted regularly at five-year intervals by Statistics Canada. In the absence of these data, consultations with numerous soil and crop specialists across Canada were undertaken. Based on these consultations, the total area of cultivated organic soils in Canada was 16 200 ha (G. Padbury and G. Patterson, Agriculture and Agri-Food Canada, personal communication, unreferenced).

### ***Uncertainty***

The uncertainty associated with emissions from this source is due to the uncertainties associated with the area estimates for the cultivated histosols and of the emission factor. The 95%

confidence limits associated with the area estimate of cultivated histosols are assessed to be  $\pm 50\%$  (Hutchinson et al. 2007). The 95% confidence limits of the emission factor provided in the *IPCC 2006 Guidelines for National Greenhouse Gas Inventories* (IPCC 2006) is  $\pm 90\%$ .

#### A3.4.3.2 Grassland Converted to Cropland

Conversion of native Grassland to Cropland generally results in losses of OC and organic nitrogen and in turn leads to emissions of CO<sub>2</sub> and N<sub>2</sub>O to the atmosphere.

A number of studies on changes of SOC and soil organic nitrogen in Grassland converted to Cropland have been carried out on the Brown, Dark Brown, and Black soil zones of the Canadian Prairies, and these results are summarized by McConkey et al. (2007a).

### Losses of Soil Organic Carbon

The average loss of SOC based on field observations was 22% (McConkey et al. 2007a). Many of the studies involved comparisons within 30 years of breaking, whereas others were 70 or more years from breaking. Since many of these studies did not specify the period since breaking, it is assumed that the 22% SOC loss would refer to about 50–60 years after breaking.

The SOC dynamics from breaking of Grassland to Cropland for the Brown and Dark Brown Chernozemic soils (Figure A3-14) can be estimated with the Century model (Version 4.0). Shortly after breaking, there is an increase in soil organic matter, as below-ground biomass of the grass becomes part of SOC. After a few years, SOC declines below the amount of SOC that existed under Grassland. The rate of SOC decline gradually decreases with time. Neglecting the initial SOC increase due to carbon added from recently killed roots, simulated SOC dynamics can be described by the following equation:

#### Equation A3-46:

$$\Delta\text{SOC}(t) = \Delta\text{SOC}_{\text{Bmax}} \times \left[ 1 - \exp\left(-k_B \times [t - t_{\text{lag}}]\right) \right]$$

where:

- $\Delta\text{SOC}(t)$  = change in SOC for the  $t^{\text{th}}$  year after conversion, Mg C/ha
- $\Delta\text{SOC}_{\text{Bmax}}$  = maximum ultimate change in SOC from Grassland to Cropland, Mg C/ha
- $k_B$  = rate constant for describing the decomposition
- $t$  = time since breaking of Grassland, years
- $t_{\text{lag}}$  = time lag before  $\Delta\text{SOC}$  becomes negative, years

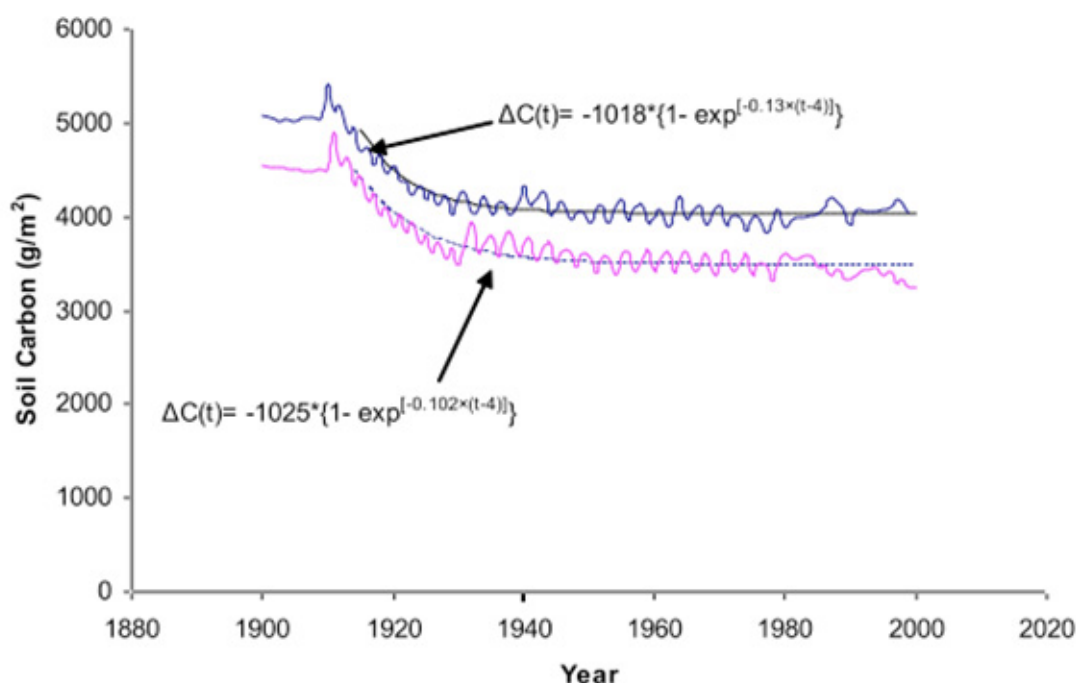


Figure A3-14: Century-simulated SOC dynamics after breaking of Grassland to Cropland for the Brown (pink) and Dark Brown (black) Chernozemic soils

Assuming that the 22% loss at about 50–60 years after initial breaking represented the total loss, the  $\Delta\text{SOC}_{\text{Bmax}}$  is  $0.22/(1-0.22) = 28\%$  of the stabilized SOC under agriculture. Given the uncertainty of actual dynamics, it was assumed no time lag in SOC loss from breaking Grassland, so that SOC starts to decline immediately upon breaking. With these assumptions, the general equation for predicting SOC loss from breaking Grassland becomes:

**Equation A3-47:**

$$\Delta\text{SOC}(t) = 0.28 \times \text{SOC}_{\text{agric}} \times [1 - \exp^{(-0.12 \times t)}]$$

where:

- $\Delta\text{SOC}(t)$  = change in SOC for the  $t^{\text{th}}$  year after conversion, Mg C/ha
- $t$  = time since breaking, years
- $\text{SOC}_{\text{agric}}$  = 0- to 30-cm SOC from the National Soil Database within CanSIS for the soil profile under an agricultural land use (Cropland), Mg C/ha

Thus, the total losses of SOC in Grassland converted to Cropland were calculated using an IPCC Tier 2 approach:

**Equation A3-48:**

$$\Delta C_{GL-CL} = \sum_{1951-2006} \sum_{ALLSLC} \sum_t (\Delta SOC_t \times AREA_{GL-CL})$$

where:

$\Delta C_{GL-CL}$	=	losses of SOC subject to conversion of Grassland to Cropland since 1951, Mg C
ALL SLC	=	all soil polygons that contain grassland
t	=	time after grassland conversion, years
$\Delta SOC_t$	=	change in SOC for the t <sup>th</sup> year after conversion, Mg C/ha
$AREA_{GL-CL}$	=	area of Grassland converted to Cropland, ha

**Losses of Soil Organic N and N<sub>2</sub>O Emissions**

Change in soil organic nitrogen is estimated as a fixed proportion of carbon losses. Where changes in both soil organic nitrogen and SOC were determined, the average change in soil organic nitrogen was 0.06 kg N lost/kg C lost (McConkey et al. 2007a). Thus, the emissions of N<sub>2</sub>O in Grassland converted to Cropland were calculated using an IPCC Tier 2 approach:

**Equation A3-49:**

$$N_2O_{GL-CL} = \sum_{1951-2006} \sum_{ALLSLC} \sum_t (\Delta SOC_t \times AREA_{GL-CL} \times 0.06 \times EF_{BASE}) \times \frac{44}{28}$$

where:

$N_2O_{GL-CL}$	=	emissions of N <sub>2</sub> O subject to conversion of Grassland to Cropland since 1951, kt
ALL SLC	=	all soil polygons that contain Grassland
t	=	time after Grassland conversion, years
$\Delta SOC_t$	=	change in SOC for the t <sup>th</sup> year after conversion, Mg C/ha
$AREA_{GL-CL}$	=	area of Grassland converted to Cropland, ha
0.06	=	conversion of carbon to nitrogen
$EF_{BASE}$	=	base emission factor, defined as a function of long-term climate normals (monthly precipitation divided by potential evapotranspiration from May to October; P/PE) at an ecodistrict level (Section A3.3 of Annex 3)
44/28	=	molecular weight ratio of N <sub>2</sub> O to N <sub>2</sub>

**Data Sources**

For the census years of 1981, 1986, 1991, 1996, and 2001, unimproved pasture areas at the SLC level were obtained by “reconfiguring” Census of Agriculture database to SLC polygons. For 1951, 1961, and 1971, provincial totals for unimproved pasture were disaggregated to SLCs based on the distribution in 1981. Within an SLC, unimproved pasture was allocated to soil components identified as “low” for “likelihood of being cropped.” Once allocated to SLC polygons, area totals for unimproved pasture were aggregated to an ecodistrict or reconciliation unit level as required in each year from 1990.

### *Uncertainty*

The conversion from agricultural Grassland to Cropland is allowed, but the conversion in the other direction is not allowed. The uncertainty of the area of this conversion in a given ecodistrict cannot be larger than the uncertainty of the final area of cropland or the initial area of Grassland. Therefore, the uncertainty of the area of conversion was set to the lower of the uncertainty of the area of Cropland or Grassland. The factor scaling coefficient was assumed to be the same as for annual–perennial crop conversions (McConkey et al. 2007b).

#### *A3.4.3.3 Forest Converted to Cropland*

### **CO<sub>2</sub> and N<sub>2</sub>O Emissions from Soils**

Clearing forest to increase agricultural land is a declining but still significant practice in Canada. This section describes the methodology for estimating CO<sub>2</sub> and N<sub>2</sub>O emissions associated with the soil disturbance. The method for estimating emissions from biomass upon conversion is presented in Section A3.4.2.3. For SOC change, there is a need to differentiate between the eastern and the western parts of the country.

#### *Eastern Canada*

There are many observations that compare SOC for land under forest with adjacent land under agriculture in Eastern Canada. The mean loss of carbon was 20.3% for a depth of approximately 30 cm (McConkey et al. 2007a). This value is comparable with the soil database in CanSIS (Table A3-34), indicating that, on average, SOC for the uppermost 30 cm of soil under agriculture was 20.5% less than under forest.

**Table A3-34: SOC for Forested and Agricultural Land in Eastern and Western Canada from the Canadian Soil Information System Database (0- to 30-cm soil depth)**

Soil Texture	Soil Organic Carbon (Mg C/ha)		Difference (%)
	Forested Land <sup>1</sup>	Cropland <sup>1</sup>	
Eastern Canada			
Coarse	85 (26)	68 (42)	-2E+01
Medium	99 (38)	77 (35)	-2E+01
Fine	99 (58)	78 (36)	-2E+01
Western Canada			
Coarse	73 (39)	74 (38)	0
Medium	66 (30)	73 (30)	4
Fine	74 (38)	77 (25)	1

Note:

1. Standard deviation in parentheses.

Although the SOC for forested land in Table A3-34 accounts for carbon in the litter layer above mineral soil, in practice, there is always uncertainty in quantifying the litter layer carbon and carbon within soil debris (Paul et al. 2002). Soil erosion, which is generally assumed to increase under agriculture, also reduces measured SOC on agricultural land.

The Century model (Version 4.0) was used to estimate the SOC dynamics from forest conversion, and Figure A3-15 shows an example of such dynamics. In the first years after deforestation, there is an increase in soil organic matter, as litter and above-ground and below-ground DOM become

part of SOC. After a few years, SOC declines below the amount of SOC that existed before deforestation. The rate of SOC decline gradually decreases with time.

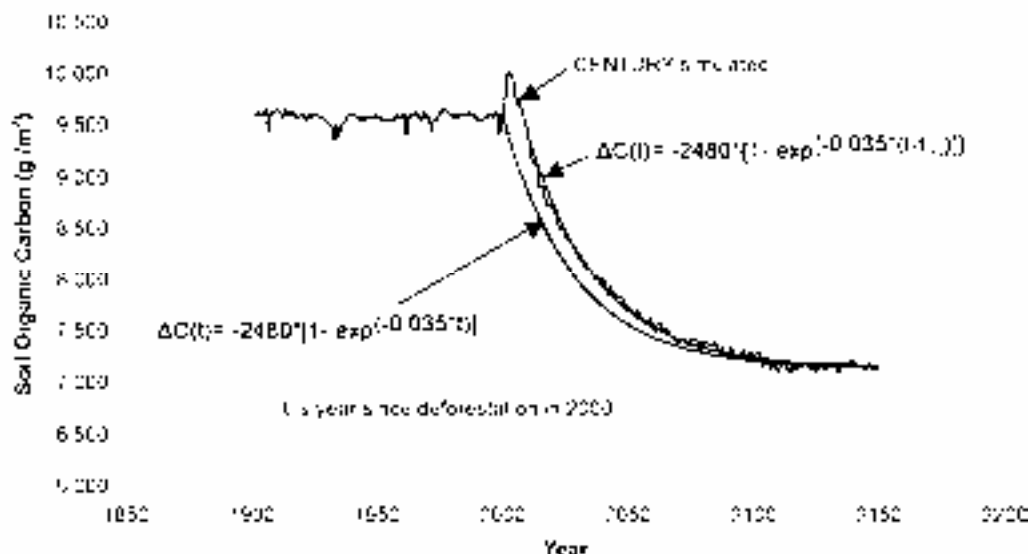


Figure A3-15: Century-Simulated SOC Following Deforestation of Long-Term Deciduous Forest to Cropland

The following equation was fit to the Century results in Figure A3-15, neglecting the initial SOC increase:

**Equation A3-50:**

$$\Delta\text{SOC}(t) = \Delta\text{SOC}_{\text{Dmax}} \times \left[ 1 - \exp^{(-k_D \times [t - t_{\text{lag}}])} \right]$$

where:

$\text{N}_2\text{OGL-CL}$	=	emissions of $\text{N}_2\text{O}$ subject to conversion of Grassland to Cropland since 1951, kt
$\Delta\text{SOC}(t)$	=	change in SOC for the $t^{\text{th}}$ year after conversion, Mg C/ha
$\Delta\text{SOC}_{\text{Dmax}}$	=	ultimate change in SOC from deforestation to agriculture, Mg C/ha
$k_D$	=	rate constant for describing the decomposition, /year
$t$	=	time since deforestation, years
$t_{\text{lag}}$	=	time lag before $\Delta\text{SOC}$ becomes negative, years

For the example shown in Figure A3-15, 25% of carbon losses occur within 20 years of deforestation and 90% within 100 years. Given the uncertainty of actual dynamics, it was assumed that there is no time lag in SOC loss from deforestation, so that SOC starts to decline immediately upon deforestation: i.e. the fitted SOC loss (Equation A3-50) is used to estimate SOC loss with time lag set to 0 after fitting. Fitting Equation A3-50 to the simulations shown in Figure A3-15 produces a mean  $k_D$  of 0.0262/year. Using this value, 92.7% of SOC loss would occur by 100 years after deforestation.

The mean loss of 20.5% of SOC resulting from deforestation to cropland for eastern Canada based on CanSIS information was assumed to correspond to about 100 years after deforestation, so the  $\Delta\text{SOC}_{\text{Dmax}}$  is 1/0.927 times this value, or 22.1% of SOC under long-term forest. As the CanSIS soil database has more data on SOC for conditions under long-term cropland than of SOC under long-term forest in areas where cropland exists, the maximal SOC losses were calculated relative to stabilized cropland SOC (i.e. loss =  $0.221/(1-0.221) \times \text{SOC}$  or loss =  $0.284 \times \text{SOC}$  under agriculture). Therefore, the final equation for estimating SOC loss for deforestation to cropland in eastern Canada is

**Equation A3-51:**

$$\Delta\text{SOC}(t) = 0.284 \times \text{SOC}_{\text{agric}} \times [1 - \exp^{(-0.0262 \times t)}]$$

where:

$\Delta\text{SOC}(t)$	=	change in SOC for the $t^{\text{th}}$ year after conversion, Mg C/ha
$\text{SOC}_{\text{agric}}$	=	0- to 30-cm SOC from CanSIS for a cropland soil profile, Mg C/ha
-0.0262	=	rate constant for describing the decomposition, /year
$t$	=	time since deforestation, years

Thus, the total amount of SOC lost from forest land converted to cropland is estimated to be

**Equation A3-52:**

$$\Delta\text{C}_{\text{FL-CL}} = \sum_{\text{ALLSLC}} \sum_{t1, t2} \sum_{t1+1, t2} (\Delta\text{SOC}_t \times \text{AREA}_{\text{FL-CL}, t})$$

where:

$\Delta\text{C}_{\text{FL-CL}}$	=	total carbon loss in forest land converted to cropland annually since 1970 ( $t1$ ), Mg C/ha
$t_2$	=	most recent year
$\Delta\text{SOC}_t$	=	change in SOC for the $t^{\text{th}}$ year after conversion, Mg C/ha ( <i>See Equation A3-51</i> )
$\text{AREA}_{\text{FL-CL}, t}$	=	area of forested land converted to cropland annually since 1970, ha

Note that the SOC loss predicted by Equation A3-52 is in addition to carbon stock changes in tree biomass and woody DOM that existed in the forest at the time of deforestation.

Based on the field observations, average nitrogen change in eastern Canada was -5.2%, representing 0.4 Mg N/ha (McConkey et al. 2007a). For those comparisons where both nitrogen and carbon losses were determined, the corresponding carbon loss was 19.9 Mg C/ha, and carbon loss was 50 times nitrogen loss. For simplicity, it was assumed that nitrogen loss was a constant 2% of C loss. Thus,  $\text{N}_2\text{O}$  emissions from forest land converted to cropland are estimated as



**Equation A3-53:**

$$N_2O_{FL-CL} = \sum_{1951-2006} \sum_{ALL\ SLC} \sum_t (\Delta SOC_t \times AREA_{FL-CL} \times 0.02 \times EF_{BASE}) \times \frac{44}{28}$$

where:

$N_2O_{FL-CL}$	=	emissions of $N_2O$ subject to conversion of forest to cropland since 1951, kt
ALL SLC	=	all soil polygons that contain forest land conversion
$\Delta SOC_t$	=	change in SOC for the tth year after conversion, Mg C/ha per year
$AREA_{FL-CL}$	=	area of forest land converted to cropland, ha
0.02	=	conversion of C to nitrogen
$EF_{BASE}$	=	base emission factor, defined as a function of long-term climate normals (monthly precipitation divided by potential evapotranspiration from May to October; P/PE) at an ecodistrict level ( <i>See Section A3.3.6 of Annex 3</i> )
44/28	=	molecular weight ratio of $N_2O$ to $N_2$

**Western Canada**

Much of the current agricultural soil in western Canada was Grassland prior to cultivation. Hence, deforestation has been primarily of forest that adjoins Grassland areas. There is also limited deforestation of secondary forest that has grown on former Grassland since the suppression of wildfires with agricultural development. Since deforestation has been less important in western Canada than in eastern Canada, there are fewer comparisons of SOC under forest and agriculture in the literature.

The CanSIS data provide the most numerous comparisons of SOC under forest with that under cropland (Table A3-34). On average, these data indicate that there is no loss of SOC from deforestation. This indicates that, in the long term, the balance between carbon input and SOC mineralization remains similar under agriculture to what it was under forest. It is important to recognize that the northern fringe of western Canadian agricultural areas, where most deforestation is occurring, is marginal for arable agriculture, and pasture and forage crops are the primary agricultural uses after clearing. In general, loss of carbon from forest to agriculture is least where agricultural land contains forages and pastures.

For western Canada, no loss of SOC over the long term was assumed from deforestation to cropland. Therefore, the carbon loss from deforestation in western Canada would be from losses of carbon in above- and below-ground tree biomass and coarse woody DOM that existed in the forest at the time of deforestation. Similarly, average organic nitrogen change in western Canada for sites at least 50 years from breaking was +52% (McConkey et al. 2007a), reflecting substantial added nitrogen in agricultural systems compared with forests. However, recognizing the uncertainty about actual soil carbon–nitrogen dynamics upon deforestation, forest land converted to cropland was assumed not to be a source of  $N_2O$  from the soil pool.  $N_2O$  emissions are reported wherever biomass burning occurs during conversion (see section A3.4.2.1).

**Data Sources**

The approach used to estimate the area of forest land converted to cropland is described in Section A3.4.2.2. The annual forest conversion by reconciliation unit was disaggregated to SLC polygons on the basis of concurrent changes in the area of cropland within SLC polygons. Only polygons that showed an increase in cropland area for the appropriate time period were allocated

deforestation, and the amount allocated was equivalent to that polygon's proportion of the total cropland increase within the reconciliation unit.

### ***Uncertainty***

The uncertainty of carbon change in each reporting zone was estimated differently for eastern and western Canada because of differences in carbon change estimation methods (McConkey et al. 2007b). For western Canada, an uncertainty of carbon change was estimated, although the mean value of SOC change factor was 0. The assumption was that the uncertainty of SOC change after forest land to cropland conversion in western Canada would follow a similar pattern as that for eastern Canada.

### **A3.4.4 Grassland**

Agricultural Grassland is defined as “unimproved pasture” used for grazing domestic livestock in geographical areas where Grassland would not naturally grow into forest if abandoned: southern Saskatchewan and Alberta and a small area of southern British Columbia. These grasslands developed under millennia of grazing by large animals such as bison and periodic burning. Essentially, “agricultural Grassland” as defined is extensively managed native range.

The primary direct human activities on agricultural grassland in Canada are fire suppression, seeding new plant species into the Grassland, and adjusting the amount, duration, and timing of grazing by domestic livestock.

#### ***A3.4.4.1 Data Sources***

The activity data are developed from various data sources, including the Census of Agriculture, which enumerates all farms every five years, and other data collected by governments and industry associations. The amount of managed Grassland is identified as land that farmers in the identified SLC polygons call “unimproved pasture” when participating in the Census. The existence of native Grassland remaining grassland areas within SLC polygons outside the Prairies ecozone is based on the presence of certain soil types by expert knowledge. The occurrence of Chernozems, Sombric Brunisols, and Melanic Brunisols under native conditions in the SLC component file, primarily within British Columbia, was assumed to indicate areas of native Grassland.

For 1981, 1986, 1991, 1996, and 2001, unimproved pasture values at the SLC level were obtained from the Census of Agriculture database. For 1951, 1961, and 1971, provincial totals of unimproved pasture were disaggregated to SLCs based on the distribution in 1981. Within an SLC, unimproved pasture was allocated to soil components with a low likelihood of being cropped. Once allocated to SLC polygons, area totals for unimproved pasture were aggregated to an ecodistrict or reporting zone level as required in each year from 1990.

#### ***A3.4.4.2 General Approach and Methods***

### **State of Grassland**

The Prairie Farm Rehabilitation Administration (2000) conducted an assessment of range in the Prairies ecozone from public land agencies and expert opinion of rangeland professionals and reported that about half of the range in Canada was in poor condition. They also noted that range management systems had improved over the past several decades. The major challenge is to improve range in poor to good condition as opposed to preventing further decline of range

condition. The advantages of good condition are better productivity in terms of grazing and improved biodiversity. The invasion of Grassland with tame grass species is an important problem for Canadian Grassland because of negative effects on biodiversity (Bai et al. 2001). However, there is no clear relationship between range condition, invasion of Grassland with tame grass species and SOC (McConkey et al. 2007a).

According to the IPCC *Good Practice Guidance for Land Use, Land-Use Change and Forestry* (IPCC 2003), Grassland in temperate/boreal regions in degraded conditions has 95% of the SOC of that in non-degraded conditions, indicating an opportunity to increase SOC by improving conditions of the Grassland. However, this estimate includes mostly Grassland types, especially seeded pastures, not representative of Canadian Grassland as defined for GHG inventory purposes. Much of the potential SOC gain from grazing management on rangeland has been from increasing grazing on Grassland that has previously been ungrazed or lightly grazed (Conant et al. 2001; Schuman et al. 2002; Liebig et al. 2005), but that opportunity is small in Canada, as its agricultural Grassland is already grazed (Lynch et al. 2005). Bruce et al. (1999) estimated that there was no opportunity to increase SOC from grazing management improvements on extensively managed rangeland in North America.

### **Effect of Grassland Management on SOC**

There are a number of studies of the effects of grazing versus no grazing on SOC. The effects of grazing compared with those of no grazing are inconsistent (McConkey et al. 2007a). Although the productivity of heavily grazed pasture is lower, which may lead to a decline in range conditions, this was not related to declines in SOC (Biondini and Manske 1996). The effect of grazing regime is complex, because of the effects of grazing on plant community and effects on carbon input to soil from both above- and below-ground plant growth (Schuman et al. 2002; Liebig et al. 2005). An additional influence of grazing regime is the increased return of carbon in fecal matter as stocking rate increases (Baron et al. 2002). Dormaar et al. (1997) concluded that soil under native Grassland is very resilient to grazing pressure with regard to SOC.

Prior to agricultural development, the Grassland burned regularly, but burning is now aggressively suppressed. Burning of range increased SOC in Canada (Anderson and Bailey 1980). This effect has been widely observed globally through the production of relatively stable black carbon (Gonzalez-Perez et al. 2004). However, because of the stability of such black carbon, which is responsible for net SOC increases from periodic burning, current suppression of fire may be preventing further increases in SOC. Nevertheless, there is no evidence to the effect that fire suppression is producing significant decreases in SOC. Annual CO<sub>2</sub> fluxes indicate that grazed Grassland with no burning does not appear to be either a source or sink of CO<sub>2</sub> in the long term (Frank 2002).

The addition of organic amendments and inorganic fertilizer will increase the productivity of native Grassland (Smoliak 1965), suggesting that these practices could increase SOC through greater carbon inputs. However, such practices are basically of academic interest, as the only economically practical management options for semi-arid Grasslands are altering grazing regime, burning, and introducing new plant species (Liebig et al. 2005).

There are no detailed comprehensive activity data on management change for Canadian agricultural Grassland. However, even if there were such data, there is no indication that this Grassland is or will be losing or gaining SOC in response to direct human activity. Therefore, Canada has chosen not to estimate carbon change on its agricultural Grassland.

### **A3.4.5 Wetlands**

#### *A3.4.5.1 Peatlands*

Approximately 16 kha of peatlands are currently managed in Canada for the production of horticultural peat. The cumulative area of peatlands ever managed for this purpose amounts to 19 kha, the difference being peatlands that are no longer under production. The production consists of horticultural peat only; Canada does not produce peat for use as a fuel.

Virtually all peat extraction in Canada relies on the vacuum harvest technology. However, many abandoned peat extraction fields were once exploited with the cut-block method; this influences the post-abandonment dynamics of vegetation regrowth.

Owing to the extraction technology and desired properties of sphagnum peat, at the time of site selection, preference is given, among other factors, to peatlands with thin woody vegetation, which nevertheless meets the definition of “forest” for the purpose of GHG reporting (Canadian Sphagnum Peat Moss Association<sup>75</sup>).

### **General Approach and Methods**

Only CO<sub>2</sub> emissions from land converted to wetlands (peatlands) and peatlands remaining peatlands were estimated. The estimation included the following sources: vegetation clearing and subsequent decomposition, decay of soil organic matter on sites drained during the inventory year and from fields under production, peat stockpiles, abandoned peat fields, and restored peatlands. A description of the approach can be found in Waddington et al. (in preparation)

In any inventory year, emissions from land converted for peat extraction are expressed by Equation A3-54:

---

75. Available online at <http://www.peatmoss.com/pm-harvest.php>

**Equation A3-54:**

$$\text{CO}_2 - \text{C}_{\text{L\_Peat}} = \text{CO}_2 - \text{C}_{\text{BIOMASS}} + \text{CO}_2 - \text{C}_{\text{DOM residual}} + \text{CO}_2 - \text{C}_{\text{SOILS drained}} + \text{CO}_2 - \text{C}_{\text{SOILS extraction}} + \text{CO}_2 - \text{C}_{\text{SOILS stockpiles}}$$

where:

$\text{CO}_2 - \text{C}_{\text{L\_Peat}}$	=	total carbon emissions as $\text{CO}_2$ from Land converted to wetlands (for peat extraction)
$\text{CO}_2 - \text{C}_{\text{BIOMASS}}$	=	carbon emissions as $\text{CO}_2$ from the loss of carbon to forest products upon forest clearing
$\text{CO}_2 - \text{C}_{\text{DOM residual}}$	=	carbon emissions as $\text{CO}_2$ from the decay of vegetation cleared no more than 20 years prior to the inventory year
$\text{CO}_2 - \text{C}_{\text{SOILS drained}}$	=	carbon emissions as $\text{CO}_2$ from the oxidation of soil organic matter on peatland drained during the inventory year
$\text{CO}_2 - \text{C}_{\text{SOILS extraction}}$	=	carbon emissions as $\text{CO}_2$ from the oxidation of soil organic matter on productive peatlands converted for no more than 20 years
$\text{CO}_2 - \text{C}_{\text{SOILS stockpiles}}$	=	carbon emissions as $\text{CO}_2$ from the oxidation of stockpiled peat on productive peatlands converted for no more than 20 years

Preconversion biomass (or biomass cleared) is estimated at an average 20 t C/ha. Upon clearing, all biomass carbon is transferred to forest products or DOM; the latter begins to decay on the same year, following an exponential decay curve.

On wetlands remaining wetlands (peatlands), emissions are expressed as in Equation A3-55:

**Equation A3-55:**

$$\text{CO}_2 - \text{C}_{\text{Peat}} = \text{CO}_2 - \text{C}_{\text{DOM residual}} + \text{CO}_2 - \text{C}_{\text{SOILS extraction}} + \text{CO}_2 - \text{C}_{\text{SOILS stockpiles}} + \text{CO}_2 - \text{C}_{\text{SOILS abandoned}} + \text{CO}_2 - \text{C}_{\text{SOILS restored}}$$

where:

$\text{CO}_2 - \text{C}_{\text{Peat}}$	=	total carbon emissions as $\text{CO}_2$ from wetlands remaining wetlands (peatlands)
$\text{CO}_2 - \text{C}_{\text{DOM residual}}$	=	carbon emissions as $\text{CO}_2$ from the decay of biomass cleared more than 20 years ago
$\text{CO}_2 - \text{C}_{\text{SOILS extraction}}$	=	carbon emissions as $\text{CO}_2$ from the oxidation of soil organic matter on peatlands converted for more than 20 years
$\text{CO}_2 - \text{C}_{\text{SOILS stockpiles}}$	=	carbon emissions as $\text{CO}_2$ from the oxidation of stockpiled peat on peatlands converted for more than 20 years
$\text{CO}_2 - \text{C}_{\text{SOILS abandoned}}$	=	carbon emissions/removals as $\text{CO}_2$ resulting from the net ecosystem production on abandoned peatlands
$\text{CO}_2 - \text{C}_{\text{SOILS restored}}$	=	carbon emissions/removals as $\text{CO}_2$ resulting from the net ecosystem production on restored peatlands

Soil emissions from a productive peat field “ $\text{CO}_2 - \text{C}_{\text{SOILS extraction}}$ ” are estimated with a single emission factor reflecting peat oxidation rates. Emissions from peat stockpiles are calculated as an exponential decay for half a year.

Abandoned peat fields remain a persistent source of atmospheric  $\text{CO}_2$  (Waddington and McNeil 2002), until carbon uptake by regrowing vegetation exceeds soil and residual DOM decay. In the current model, the emission factor on abandoned fields is reduced by a fixed annual amount to

reflect the effect of gradual vegetation establishment and the slow decrease of emissions over several decades.

Current restoration practices consist of blocking drainage ditches, sowing the field with fresh moss spores, and spreading a layer of straw on abandoned peat fields (to prevent desiccation). In the initial years of restoration, straw decomposition may further increase CO<sub>2</sub> emissions, until vegetation re-establishes. Net carbon sequestration on restored peat fields is assumed to occur after five years, and its rate is subsequently maintained constant.

It is assumed that the non-growing season is six months long. In that period, emissions represent 15% of the annual total ecosystem CO<sub>2</sub> respiration, and gross primary production is zero during the non-growing season. Table A3-35 lists the main parameter values applied in estimate development. Uncertainty estimates were obtained from expert judgement.

**Table A3-35: Parameters and Emission Factors for Estimating CO<sub>2</sub>-C Emissions from Wetlands (Peatlands)**

Emission Factor/Parameter	Unit	Value	Uncertainty (%)
Biomass cleared	t C/ha	20	100
Exponential decay constant, DOM		0.05	75
Emission factor on newly drained fields	g CO <sub>2</sub> -C/m <sup>2</sup> per year	351	75
Emission factor on productive fields	g CO <sub>2</sub> -C/m <sup>2</sup> per year	1019	75
Exponential decay constant, stockpiles		0.05	75
Annual decrease in emission factor, abandoned fields			
Vacuum-harvested	g CO <sub>2</sub> -C/m <sup>2</sup> per year	15	75
Block-cut	g CO <sub>2</sub> -C/m <sup>2</sup> per year	35	75
Emission factor, restored peatlands			
First year	g CO <sub>2</sub> -C/m <sup>2</sup> per year	1753	75
>Five years	g CO <sub>2</sub> -C/m <sup>2</sup> per year	-8E+01	75

### **Data Sources**

Little information on the area of peat production in Canada is available. The Canadian Sphagnum Peat Moss Association confirmed that 14 000 ha were under production in 2004 (derived from Cleary 2003) and that a total of 18 000 ha were either active or decommissioned. A 76% increase in peat production since 1990 was used to back-calculate areas under production in previous years with a simple linear regression. The annual area drained for peat extraction was assumed to be equal to the difference in total production areas between successive years, less abandoned and restored peatlands. With the vacuum harvest technology, the average lifetime of a productive peat field is approximately 35 years (Cleary 2003). By default, land converted for more than 20 years is reported in the category Wetlands (peatlands) remaining wetlands (peatlands).

### **Uncertainties**

Emission factors were derived from flux measurements made mostly over abandoned peatlands, which introduces significant uncertainty when applied to actively managed peatlands, and peat stockpiles. All measurements were conducted in eastern Canada, adding uncertainties to estimates in western Canada. A single estimate of preconversion biomass carbon density (20 t C/ha) was assumed, corresponding to poorly stocked forest stands.

### A3.4.5.2 *Flooded Lands*

#### **General Approach and Methods**

Following IPCC *Good Practice Guidance for Land Use, Land-Use Change and Forestry* (IPCC 2003), emissions from land converted to wetlands (creation of flooded lands, namely reservoirs) are estimated for all known reservoirs flooded for 10 years or less. Only CO<sub>2</sub> emissions are reported. An IPCC Tier 2 method was used, whereby country-specific CO<sub>2</sub> emission factors were developed based on measurements, as described below. Details can be found in Blain et al. (2007). It is believed that the default approach, assuming that all biomass carbon would be emitted upon flooding, would overestimate immediate deforestation emissions from reservoir creation, because the majority of submerged forest biomass does not decay for an extended period of time.

Two complementary estimation methodologies are used to account for GHG fluxes from flooded lands, depending on land conversion practices. When there is evidence of forest clearing and/or burning prior to flooding, immediate and residual emissions from all carbon pools are estimated as in all forest conversion events since 1970, with the CBM-CFS3 (see Section A3.4.2.1). Note that emissions from forest clearing for infrastructure development are reported under Forest converted to settlements.

In the absence of such evidence, it was assumed that all vegetation was simply flooded, leading to the emission—as CO<sub>2</sub>—of a fraction of the submerged carbon from the surface of the reservoir. The proportion of the area flooded that was previously forested was used to attribute these emissions to either Forest land converted to wetlands or Other land converted to wetlands.

Since 1993, measurements of CO<sub>2</sub> fluxes have been made above some 57 hydroelectric reservoirs in four different provinces: Quebec, Manitoba, British Columbia, and Newfoundland and Labrador (Duchemin 2006). In most studies, the reservoirs were located in watersheds little affected by human activities, with the notable exception of Manitoba. In almost all cases, only diffusive fluxes of CO<sub>2</sub>, CH<sub>4</sub>, or N<sub>2</sub>O (in order of frequency) were measured. Studies on ebullition, degassing emissions, and winter emissions are rare and insufficient to support the development of domestic emission factors. Out of these measured reservoirs, a subset of 25 was selected to develop two separate regional emission curves for the 20-year period following impoundment. For the Taiga/Boreal/Hudson Plains regions (reporting zones 4, 5, 8, and 10), an emission curve was developed from nine reservoirs and a total of 17 measurements (Figure A3-16a). The emission curve for the Montane Cordillera (reporting zone 14) was developed from 16 reservoirs and a total of 16 measurements (Figure A3-16b). It is important to note that each of these measurements (data points in Figure A3-16) represents on average the integration of between 8 and 28 flux samples per reservoir.

Non-linear regression analysis was used to parameterize the emission curves, of the form:

#### **Equation A3-56:**

$$\text{CO}_2 \text{ rate } L_{\text{reservoir}} = b_0 + b_1 \times \ln(t)$$

where:

CO <sub>2</sub> rate L <sub>reservoir</sub>	=	rate of CO <sub>2</sub> emissions from land converted to wetlands (reservoirs), mg/m <sup>2</sup> per day
b <sub>0</sub> , b <sub>1</sub>	=	curve parameters, unitless
t	=	time since flooding, years

The relations between diffuse CO<sub>2</sub> flux and age of reservoir were weaker and less significant for the Montane Cordillera. Of particular note is that there were only two sample flux measurements less than 20 years of age in the model fit for the Montane Cordillera.

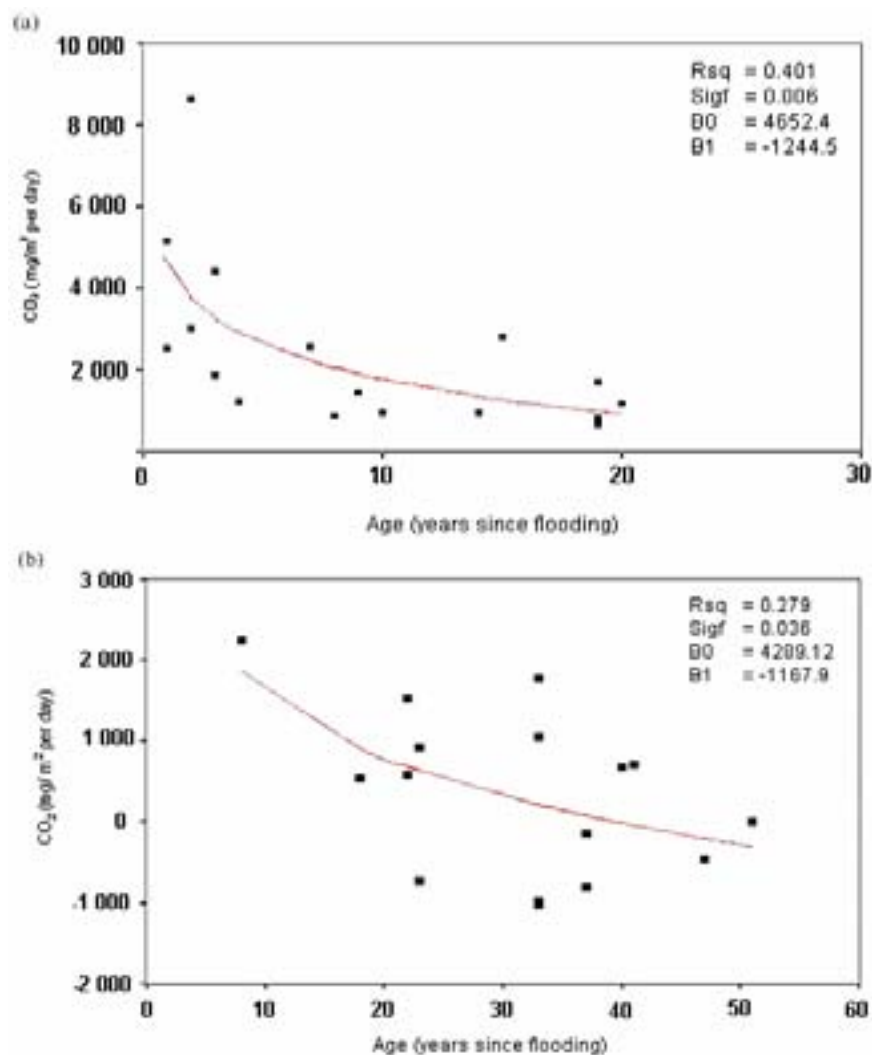


Figure A3-16: Logarithmic Curve Fits for a) Taiga/Boreal/Hudson Plain Reservoirs and b) Montane Cordillera Reservoirs

Note:

Curve parameters are provided, as well as the coefficients of determination and their significance.

Total CO<sub>2</sub> emissions from the surface of reservoirs were estimated as the sum of all emissions from reservoirs flooded for 10 years or less:



**Equation A3-57:**

$$\text{CO}_2 \text{ L}_{\text{reservoirs}} = \sum (\text{CO}_2 \text{ rate L}_{\text{reservoir}} \times A_{\text{reservoir}} \times \text{Days}_{\text{ice free}} \times 10^{-8})$$

where:

$\text{CO}_2 \text{ L}_{\text{reservoirs}}$	=	emissions from lands converted to flooded lands (reservoirs), Gg $\text{CO}_2/\text{year}$
$\text{CO}_2 \text{ rate L}_{\text{reservoir}}$	=	rate of $\text{CO}_2$ emissions for each reservoir, $\text{mg}/\text{m}^2$ per day
$A_{\text{reservoir}}$	=	reservoir area, ha
$\text{Days}_{\text{ice free}}$	=	number of days without ice, days

$A_{\text{reservoir}}$  was used as the best available estimate of the area converted to managed wetlands (reservoirs), although in reality reservoirs may contain islands, i.e. emergent land areas. “Ice-free period” was defined as the average number of days between the observed freeze date and the breakup date of ice cover on a body of water (Magnuson et al. 2000). In the case of hydroelectric reservoirs, locations were mapped and estimates of the ice-free period were generated from the lakes–ice-free period isoline map of Canada (Natural Resources Canada 1974).

Emissions were calculated starting from the year that flooding to fill the reservoir is complete. Reservoirs take a minimum of one year to fill following dam completion, unless otherwise confirmed.

**Data Sources**

The two main data sources used to develop area estimates were 1) information received on forest conversion due to reservoir impoundment in reporting zones 4 and 5 (see Section A3.4.2.2, Forest Conversion); and 2) the Canadian Reservoir Database (Duchemin 2002). The database contains 421 records of hydro reservoirs dating back to 1876. Of these reservoirs, 110 have a known surface area totalling 3 452 786 ha. The average reservoir size is 31 kha. The distribution of reservoir area is skewed, with 25% of the largest reservoirs representing over 95% of all reservoir area in the database.

Since  $\text{CO}_2$  emissions from the surface of reservoirs are reported only for the 10 years following impoundment, all flooding events since 1980 were identified. Information from provincial and private hydroelectric utilities was accessed to update the database and cross-check the date of reservoir construction and the total reservoir area for all these reservoirs. In some instances, the database reported as new facilities some small, refurbished hydroelectric generation sites in the province of Quebec that entered into production under a new ownership. As a result, a separate category was added to the database to document both the original construction and commissioning of a dam and the date when a hydroelectric facility was refurbished but no changes occurred to the reservoir area.

The trend in area flooded is characterized by two distinct periods (Figure A3-17). The first, prior to 1994, was marked by large-scale flooding, which occurred in the early 1980s and still appeared as Land converted to wetlands in the 1990–1993 inventory years. After 10 years, these reservoirs were removed from the accounting, and there was a corresponding decrease in the area to a low in 1994. From 1994 to 2005, there was a small but consistent increase in new reservoir areas, with the occurrence of several small to medium-scale flooding events. Three reservoirs (Toulmoustou, Peribonka, and Eastmain-1) have been recently created; flooding for Peribonka and Eastmain-1 reservoirs was completed in 2006. Accounting of reservoir emissions for Toulmoustou started in 2006; the 2008 submission includes emissions from both the forest clearing and associated flooding for these three sites.

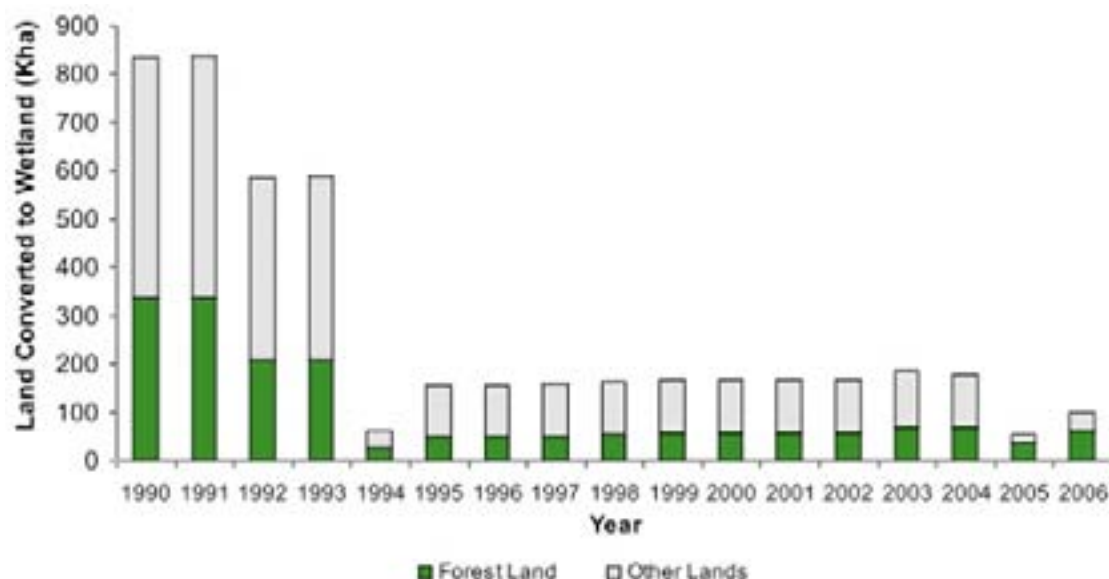


Figure A3-17: Cumulative Areas in the Lands Converted to Wetlands (Flooded Lands) Category

It is important to note that fluctuations in the area of Lands converted to Wetlands (reservoirs) reported in the CRF tables are not indicative of changes in current conversion rates, but reflect the difference between land areas recently (< 10 years ago) converted to reservoirs and older reservoirs (> 10 years), whose areas are thus transferred out of the accounting. The reporting system does not encompass all the reservoir areas in Canada, which are monitored separately in the Canadian Reservoir Database.

### Uncertainty

A temporal curve better reflects the decreasing trends of emission rates after impoundment than a unique emission factor. Hence, the domestic approach is believed to reduce the uncertainty in estimation factors. However, important remaining sources of uncertainty are:

*The use of two emission curves to represent all recently flooded reservoirs in Canada.* While in eastern Canada the time since flooding explains approximately 80% of inter-reservoir variability in CO<sub>2</sub> emissions, in the west, the same parameter accounts for only 50% of the variability (Duchemin 2006). However, the relative contribution of western reservoirs to the total emissions represents less than 2% of total emissions during the reporting period.

*Seasonal variability.* Some reservoirs display marked seasonal variability in CO<sub>2</sub> fluxes, which are not taken into account in estimate development. Anecdotal evidence suggests that algal bloom in the spring could be associated with this variability, especially in reservoirs subjected to anthropogenic nutrient inputs.

*The omission of potentially important CO<sub>2</sub> emission pathways (e.g. degassing).*

## Planned Improvements

Planned improvements include developing improved estimates of the preconversion standing biomass, better understanding of conversion practices for both peat extraction and reservoir flooding, and integrating new emission measurements to the curve as they become available.

### A3.4.6 Settlements

Emissions and removals in this category comprise urban tree growth (settlements remaining settlements) and emissions from land conversion to settlements. This submission reports emissions from the conversion of forest land to settlements and of tundra to settlements.

To estimate the very small sink from urban tree growth, a Tier 1 methodology was used. An average growth of 0.05 t biomass/ha per year every year over 1990–2005 was computed and applied to 1800 kha of non-built-up urban surface areas (Statistics Canada 1997b).

Approaches, methods, and data sources for estimating emissions from the conversion of forest land to settlements are covered in Section A3.5.2. This section describes estimate development for the conversion of non-forest land to settlements in the Canadian Arctic and sub-Arctic.

#### A3.4.6.1 *General Approach and Methods*

The Canadian northern regions (Arctic and sub-Arctic) cover nearly half of Canada's land mass and include five land categories (IPCC 2003), except Cropland. This assessment covered an area of about 359 million hectares and included reporting zones 1, 2, 3, and 17, as well as reporting zones 13 and 18 north of 60°N latitude. The challenge was to capture land-use change and estimate associated emissions in this vast and remote landscape. An approach was developed specifically for this task and included the following components:

Map non-forest land-use change in Canada's Arctic/sub-Arctic prior to and including 1990 and between 1990 and 2000.

Estimate annual GHG emissions (above-ground biomass only) from non-forest land-use change in Canada's Arctic/sub-Arctic for the period 1990–2000.

A comprehensive, wall-to-wall analysis over this area was clearly impractical, as this would require on the order of 100 Landsat satellite scenes for each date. Similarly, random sampling would likely not capture enough land-use change events to allow a reliable assessment. Instead, GIS data sets denoting the occurrence of cultural, mining, and other human development were used to reduce and optimize the domain of investigation, by flagging areas with high probability of occurrence of land-use changes. These areas of concentrated land-use change potential were targeted for change detection analysis (change vector analysis; Johnson and Kasischke 1998) using 23 Worldwide Reference System Landsat frames from circa 1985, 1990, and 2000. The scenes cover more than 8.7 million hectares, 56% of the potential land-use change area identified using the GIS data sets, or 70% of potential land-use change area if seismic survey lines are not included.<sup>76</sup> All 23 frames were located in the western Arctic and sub-Arctic regions.

---

76. Recent, low-impact seismic lines have a narrow swath of approximately 2 m width, as opposed to conventional ones, which were much larger (~8 m). Low-impact seismic lines were widely adopted over the past decade and considerably reduce the environmental impact of seismic exploration.

The Land Use Change Mapping System for Canada's North (Butson and Fraser 2005), can be described as a hybrid change detection method based on two separate techniques: change vector analysis for identifying changed areas and constrained signature extension for labelling those changes (Olthof et al. 2005). A detailed description of how the Land Use Change Mapping System for Canada's North was used for the purpose of capturing non-forest land-use change in Canada's north is available in Fraser et al. (2005). The average rate of land-use change between 1985 and 2000 over the assessed area was 666 ha/year, and 70% of land-use change areas occurred in reporting zone 13. Lack of available imagery prevented the implementation of the system beyond 2000; therefore, the same annual rate of land-use change was applied for the years 2001–2005.

A series of above-ground biomass maps in 2000 were developed for the main land-use change areas, using relationships between above-ground biomass and remote sensing data constructed from and calibrated with ground measurements (Figure A3-18). These maps were used to determine CO<sub>2</sub> emissions from the clearing of above-ground biomass.

The dominant land cover types in the two study areas are rock, lichen, low–high shrub, grass, and sparse woodland.



Figure A3-18: Study Areas for the Determination of Above-Ground Biomass

Multiple regressions were conducted between  $\ln(\text{above-ground biomass})$  and a combination of image signals for all vegetation covers combined (grass, shrub, sparse woodland). The best least-square approximation had an  $r^2 = 0.72\text{--}0.78$ , dependent on approaches used, a relative mean square error of 75–80%, and a median value of the absolute percentage error of 33–53%. Biomass regressions were applied to the preconversion imagery for all land-use change areas to yield an estimate of the biomass cleared. All land-use change activities involved conversion of tundra vegetation to settlements, and all preconversion biomass carbon was deemed emitted upon clearing.

Since the 2007 submission, additional imagery was analyzed with the change detection method used for deforestation area estimation. Reporting zone 4 and part of reporting zone 8 were fully mapped for both forest and non-forest conversion to settlements, adding 55 Mha to the area already mapped. The above-ground biomass of non-forest vegetation was derived from a

literature search and estimated at 6 kt/ha (or 3 t C/ha). For this region, there was an average rate of non-forest land-use change of 133 ha/year for the period 1990–2006.

When only the above-ground biomass component is considered, land-use change activities over Canada's north released an estimated 152 kt CO<sub>2</sub> eq per year in the 1990–2005 period.

#### *A3.4.6.2 Uncertainty*

The uncertainty in land-use change area covered by the 23 Landsat scenes is estimated to be within 20% (Fraser et al. 2005). The biomass equations developed from field measurements in the Dawson City study area were validated on the other study areas of Yellowknife and the Lupin mine. The median values of the absolute percentage error in above-ground biomass estimation for both study areas are 33–53%.

A Monte Carlo simulation method was used to quantify the overall error in carbon emissions caused by uncertainties in land-use change area and biomass estimation. At the 95% confidence level, the percentage error varies from 218% if there is only one land-use change site within a reporting zone to 15% if a reporting zone has 75 or more land-use change sites. The error in the total above-ground biomass carbon stock change estimate, if considered as one reporting area, is about 15%. A full discussion of uncertainty can be found in Chen et al. (2005).

### **A3.4.7 Estimation of Delayed CO<sub>2</sub> Emissions from Harvested Wood Products (HWPs)**

In addition to the default method, four alternative approaches for carbon accounting in HWPs have been proposed: stock change, production, atmospheric flow, and simple decay. Box A3-1 provides a brief description of each approach. Although these approaches would yield the same net carbon exchange with the atmosphere if applied at the global level, they differ on a national level in the way in which they account for the time and place of emissions.

As a basis for comparison, the annual emissions of carbon in harvested wood are estimated using the default and three alternative approaches. When warranted, the delayed emissions from domestic wood consumption (stock change and atmospheric flow) or domestic production (production and decay) since 1960 are included. These harvest emissions (HE) are calculated as follows:

IPCC Default:

$$HE_{\text{Default}} = RW + \text{Firewood}$$

Stock Change:

$$HE_{\text{Stock Change}} = RW + \text{Firewood} - \text{Domestic Long-Lived Commodity} + \text{Inherited Emissions from Long-Lived Commodity Consumption}$$

Production:

$$HE_{\text{Production}} = RW + \text{Firewood} - \text{Long-Lived Commodity Production} + \text{Inherited Emissions from Long-Lived Commodity Production}$$

## Atmospheric Flow:

$$\text{HEAtm. Flow} = \text{Firewood} + \text{Processing Wastes} + \text{Inherited Emissions from Long-Lived Commodity Consumption}$$

where:

HE	=	carbon emitted outside managed forests during the inventory year from material harvested and/or consumed in previous and current years
RW	=	carbon in industrial roundwood and fuelwood harvested in the current inventory year
Firewood	=	carbon in residential firewood consumed in the current inventory year
Consumption	=	production + imports – exports
Production	=	domestic production
Processing Wastes	=	total industrial wood biomass consumption – commodity production

For Canada, CO<sub>2</sub> emissions outside of managed forests in 2006, resulting from either domestically consumed or domestically produced HWPs, varied from 176 Mt (IPCC default) to 92 (atmospheric flow), 136 (production), or 159 Mt (stock change), depending on the approach selected.

Note that delay in carbon emissions due to storage in HWPs is taken into account only for long-lived (> 5 years) commodities. The carbon stored in short-lived commodities, including fuelwood and firewood, is assumed to be emitted upon harvest. To date, the calculations have included only semi-processed commodities (e.g. sawnwood, pulpwood, wood-based panels, paper and paperboard, and other industrial roundwood). It is not feasible at present to develop a system that would monitor the paths of carbon stored in HWPs (HWP-C) from harvest to consumer products.

Further elaboration of these approaches is planned, based on the IPCC *Good Practice Guidance for Land Use, Land-Use Change and Forestry* (IPCC 2003) and the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006). Work has been initiated in 2007 to update the Forest Product Sector module of the Carbon Budget Model.

**Box A3–1: Overview of Approaches to Account for Carbon Storage in Harvested Wood Products**

In the **IPCC default approach**, only the net change in forest carbon stocks is accounted for. Emissions from harvests are treated as though they are 100% released as CO<sub>2</sub> to the atmosphere in the year and country of harvest. Carbon storage in wood products is not considered.

The **atmospheric flow** approach tracks carbon emissions and removals associated with the harvest, manufacturing, and consumption of wood products within national boundaries. Its intent is similar to the general methodology for estimating fossil fuel emissions, and it provides a more accurate reflection of when and where harvest emissions actually occur.

The **stock change** approach accounts only for the net carbon stock change in the domestic wood product reservoir, e.g. HWP-C in all long-lived commodities within the national territory, after imports and exports. The difference between the stock change and atmospheric flow accounting lies in the treatment of exported products (which are significant in Canada). In the stock change approach, carbon in all exported wood products and commodities exits the domestic stock and hence is considered an emission to the atmosphere.

The **production** approach accounts for the changes in carbon stocks of domestically harvested wood and commodities derived from this domestic wood, regardless of their actual location. The accounting boundaries hence encompass the entire export market.

The **simple decay** approach also accounts for the delayed emissions from all HWP-C from domestically harvested wood, but in a simplified way, by applying decay curves standardized by product categories.

**A3.5 Methodology for Waste**

The Waste Sector consists of three sources of emissions: solid waste disposal on land (landfills), wastewater treatment, and waste incineration. This section of Annex 3 details the accounting methodologies that are used to describe the GHG emission estimates for the following categories from the Waste Sector:

- CH<sub>4</sub> emissions from solid waste disposal on land;
- CH<sub>4</sub> and N<sub>2</sub>O emissions from wastewater treatment; and
- CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O emissions from waste incineration.

**A3.5.1 CH<sub>4</sub> Emissions from Solid Waste Disposal on Land****A3.5.1.1 Methodology**

Emissions are estimated from two types of landfills in Canada:

- municipal solid waste (MSW) landfills; and
- wood waste landfills.

The Scholl Canyon model is used to estimate CH<sub>4</sub> generation from landfills using the following first-order decay equation (IPCC/OECD/IEA 1997):

**Equation A3-58:**

$$Q_{T,x} = kM_x L_0 e^{-k(T-x)}$$

where:

$Q_{T,x}$	=	the amount of CH <sub>4</sub> generated in the current year (T) by the waste M <sub>x</sub> , kt CH <sub>4</sub> /year
$x$	=	the year of waste input
$M_x$	=	the amount of waste disposed of in year x, Mt
$k$	=	CH <sub>4</sub> generation rate constant, /yr
$L_0$	=	CH <sub>4</sub> generation potential, kg CH <sub>4</sub> /t waste
$T$	=	current year

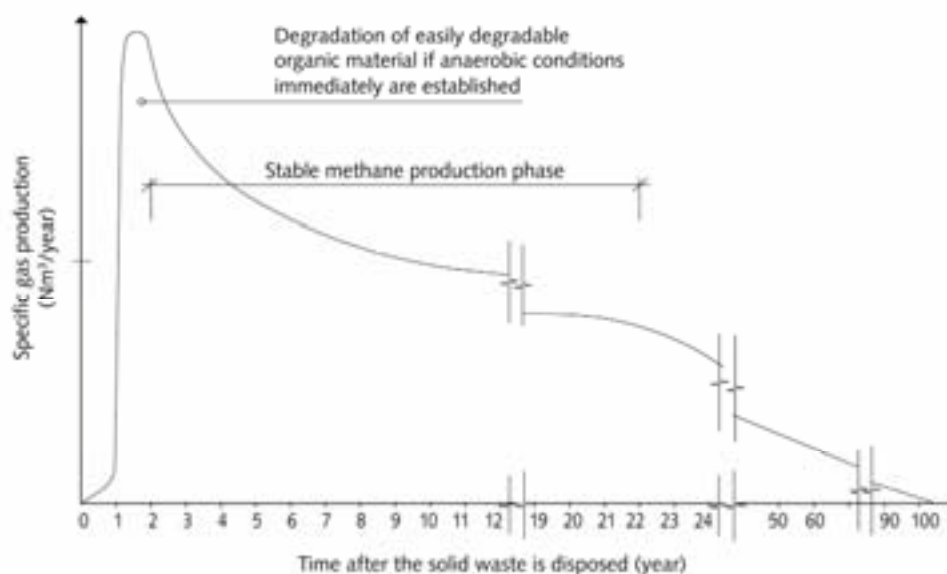
**Equation A3-59:**

$$Q_T = \sum Q_{T,x}$$

where:

$Q_T$	=	the amount of CH <sub>4</sub> generated in the current year (T), kt CH <sub>4</sub> /year
-------	---	---

The Scholl Canyon model assumes that CH<sub>4</sub> production is highest in the early phase, followed by a slow steady decline in annual production rates, as shown in Figure A3-19. The Canadian model assumes that the initial lag time where anaerobic conditions are established is negligible, as shown in Figure A3-19.



-----  
**Figure A3- 19: Scholl Canyon Model Representation of Landfill Degradation**  
 -----

Note:

Figure is from Jensen and Pipatti (2003) and is shown as published without modification.



In order to estimate CH<sub>4</sub> emissions from landfills, information on several of the factors described above is needed. To calculate the net emissions for a specific year, the sum of  $Q_{T,x}$  for every section of waste landfilled in past years is taken, the captured gas quantities subtracted, and the CH<sub>4</sub> emitted from the incomplete combustion of the flared portion of captured gas is added. A computerized model has been developed to estimate aggregate emissions on a regional basis in Canada.

## **Waste Disposed of Each Year ( $M_x$ )**

### ***MSW Landfills***

Two primary sources are used in obtaining landfill data for the GHG inventory. The amount of MSW landfilled in the years 1941 through 1990 was estimated by Levelton (1991). For the years 1998, 2000, 2002, and 2004, MSW disposal data are obtained from the *Waste Management Industry Survey*, which is conducted by Statistics Canada on a biennial basis (Statistics Canada, 2000, 2003, 2004, 2007a). MSW disposal values for the subsequent odd years (1999, 2001, and 2003) are obtained by taking an average of the adjacent even years. Disposal, with respect to the Statistics Canada data, refers to the combination of waste incinerated and waste landfilled. Therefore, in order to obtain the amount of waste landfilled, incinerated waste is subtracted from the Statistics Canada disposal values for 1998, 2000, 2002, and 2004. As well, exported waste is subtracted from the 2000, 2002, and 2004 Statistics Canada disposal data, since the amount of waste exported is included in the waste disposal values for the Statistics Canada 2000 survey year and subsequent years (Marshall, personal communication, 2006, 2007).

Over the period 1991–1997 and 2005, with the exception of Prince Edward Island and the Northwest, Nunavut, and Yukon Territories, MSW landfill values are estimated by fitting a polynomial to the Levelton (1991) and Statistics Canada (2000, 2003, 2004, 2007a) MSW landfill values. The 2006 data were trended from earlier waste quantity values. To estimate the coefficients in the polynomial, a multiple linear regression application (Microsoft Excel LINEST statistical tool for an array) is used. The choice of how many coefficients to use for the polynomial function depended on how well the data fit the lower-order polynomials. Generally, the polynomial fit was improved with increasing number of coefficients. A polynomial of the order 13 is used in the inventory MSW estimates. This multiple linear regression method of estimation is consistent with the IPCC interpolation method (IPCC 2000). Table A3-36 shows the polynomial coefficients generated by the multiple linear regression method for each of the provinces.

**Table A3-36: Multiple Linear Regression Polynomial Coefficients Used in Estimating the Amount of MSW Landfilled for 1991–1997 and 2005**

	NL	NS	NB	QC	ON	MB	SK	AB	BC
C	6.87E+09	8.60E+09	-1.87E+10	2.18E+11	-2.91E+10	-8.47E+09	3.96E+10	-4.35E+11	1.70E+12
C <sub>1</sub>	-1.97E+06	-3.22E+06	4.22E+06	-4.70E+08	-2.37E+07	3.28E+06	6.20E+06	4.13E+08	-1.17E+09
C <sub>2</sub>	3.14E+03	-1.02E+04	-7.88E+02	8.18E+05	2.49E+04	5.10E+03	-1.39E+04	-4.96E+04	2.53E+04
C <sub>3</sub>	1.62E+00	2.65E+00	2.26E+00	-3.18E+02	1.50E+01	-5.77E-01	-1.75E+01	-3.04E+01	-1.65E+02
C <sub>4</sub>	8.20E-06	-1.59E-03	1.30E-03	-2.15E-01	-5.96E-03	-1.51E-03	3.28E-03	-4.42E-03	8.23E-02
C <sub>5</sub>	-9.81E-08	2.46E-06	-5.70E-07	4.76E-05	-1.68E-06	-2.78E-07	3.72E-06	2.21E-05	1.52E-06
C <sub>6</sub>	-1.63E-10	8.20E-10	3.21E-10	4.16E-08	1.13E-09	1.51E-10	7.74E-10	-1.55E-08	3.39E-08
C <sub>7</sub>	-8.88E-14	-2.11E-13	-2.43E-14	5.93E-12	-3.00E-14	2.72E-13	-4.58E-13	-1.02E-12	-5.11E-12
C <sub>8</sub>	-6.34E-17	-1.50E-16	-1.09E-16	6.56E-15	-8.94E-16	-7.69E-17	8.21E-17	4.03E-15	-2.76E-15
C <sub>9</sub>	5.40E-20	-2.03E-19	-2.03E-20	-5.89E-18	-2.33E-19	-5.56E-20	7.12E-20	-1.61E-18	-2.24E-19
C <sub>10</sub>	-1.48E-24	3.34E-24	-1.30E-23	-1.91E-21	2.36E-22	1.74E-23	-1.54E-22	4.04E-22	3.44E-22
C <sub>11</sub>	-6.62E-28	2.48E-26	9.41E-27	1.61E-25	1.08E-25	8.89E-27	6.66E-26	8.76E-26	-9.63E-25
C <sub>12</sub>	3.03E-30	2.21E-29	2.63E-30	5.53E-28	-2.26E-29	-3.09E-30	-2.86E-29	-9.54E-29	3.59E-28
C <sub>13</sub>	-1.32E-33	-7.77E-33	-3.92E-34	-1.00E-31	-1.03E-32	-6.66E-35	7.64E-33	1.57E-32	-6.11E-33

Note:

Coefficients have been rounded and may not result in the correct totals for MSW landfilled.

The amounts of MSW landfilled for the years 1991–1997 and 2005 are calculated according to the following equation:

**Equation A3-60:**

$$M_X = (C_{13} \times X^{13}) + (C_{12} \times X^{12}) + (C_{11} \times X^{11}) + (C_{10} \times X^{10}) + (C_9 \times X^9) + (C_8 \times X^8) + (C_7 \times X^7) + (C_6 \times X^6) + (C_5 \times X^5) + (C_4 \times X^4) + (C_3 \times X^3) + (C_2 \times X^2) + (C_1 \times X) + C$$

where:

M <sub>X</sub>	=	MSW landfilled in year X, t
C <sub>i</sub>	=	coefficient of the <i>i</i> th order ( <i>see Table A3-36</i> )
X	=	year of interest

Statistics Canada MSW disposal data are unavailable for Prince Edward Island and the Northwest, Nunavut, and the Yukon Territories. Thus, MSW landfill values for this province and these territories for the period 1991–2006 are obtained by trending historical landfill data with the provincial populations for 1971–2006 (Statistics Canada 2006b, 2007b). Three sources of landfill data are used to estimate the MSW landfill amounts for 1991–2006. The first set of data was provided by Levelton (1991) for 1971–1990. The second set of landfill data was provided by the Hazardous Waste Branch of Environment Canada for 1992 (Environment Canada 1996b). The third set of landfill data involves multiplying the 1992 percentage of waste landfilled for Prince Edward Island and the Northwest Territories, Nunavut, and the Yukon (Environment Canada 1996b) by the surplus of waste landfilled provided by Statistics Canada for 1998, 2000, 2002, and 2004 (Statistics Canada 2000, 2003, 2004, 2007a). The surplus of waste landfilled for 1998, 2000, 2002, and 2004 is calculated by subtracting the sum of the provided provincial landfill values from the total Canadian landfill value. Table A3-37 shows the amount of MSW landfilled for the period 1990–2006.

**Table A3-37: MSW Landfilled for 1990–2006<sup>4</sup>**

Year	Waste Landfilled (t)											
	NL	PE	NS	NB	QC	ON	MB	SK	AB	BC	NT & NU	YT
1990 <sup>1</sup>	366 004	51 293	493 010	462 391	3 699 833	5 957 104	696 174	638 942	1 577 585	1 760 621	34 493	16 608
1991	400 159	68 830	540 341	489 539	4 073 027	6 287 557	741 706	720 035	1 790 701	1 990 162	37 237	18 975
1992	402 670	74 800	533 426	488 826	4 152 266	6 390 940	755 034	729 362	1 837 539	2 012 191	35 300	17 200
1993	403 918	72 414	523 456	485 805	4 230 976	6 479 872	767 869	736 993	1 881 860	2 028 235	39 284	20 578
1994	403 775	74 900	510 179	480 262	4 309 123	6 552 824	780 167	742 752	1 923 350	2 037 746	40 600	19 846
1995	402 110	76 834	493 335	471 972	4 386 673	6 608 214	791 881	746 453	1 961 687	2 040 161	41 768	20 676
1996	398 783	79 457	472 655	460 706	4 463 598	6 644 405	802 966	747 906	1 996 538	2 034 895	42 597	21 713
1997	393 651	80 155	447 861	446 225	4 539 872	6 659 708	813 373	746 914	2 027 558	2 021 350	42 682	22 165
1998 <sup>2</sup>	366 280	104 825	407 095	425 626	4 568 910	5 963 525	855 666	780 700	1 874 276	1 789 252	49 469	24 104
1999	369 650	80 520	357 703	387 656	4 799 511	6 283 801	875 695	741 743	2 006 801	1 843 849	42 646	21 043
2000 <sup>2</sup>	373 020	92 586	308 311	349 685	5 030 113	6 604 076 <sup>3</sup>	895 724	702 786	2 139 327	1 898 445	43 694	21 290
2001	364 808	81 254	306 310	354 002	5 057 840	6 554 891	857 145	711 293	2 193 015	1 882 903	43 858	20 326
2002 <sup>2</sup>	356 595	82 280	304 309	358 318	5 085 567	6 505 705 <sup>3</sup>	818 566	719 801	2 246 704	1 867 362	38 830	18 920
2003	367 700	82 528	309 104	366 047	5 290 543	6 346 012	839 021	734 066	2 346 984	1 993 321	45 883	20 818
2004 <sup>2</sup>	378 804	91 318	313 899	373 776	5 495 519	6 186 319 <sup>3</sup>	859 475	748 331	2 447 264	2 119 281	43 095	20 998
2005	375 542	84 213	306 272	373 734	5 807 178	5 964 694	864 443	747 396	2 551 536	2 117 746	46 990	21 346
2006	373 680	83 898	277 339	353 289	5 835 975	6 230 720	845 984	730 523	2 633 941	2 150 407	47 043	21 523

## Notes:

1. Levelton (1991) data.

2. Statistics Canada disposal data (Statistics Canada, 2000, 2003, 2004, 2007a).

3. Exported MSW subtracted from the Statistics Canada disposal data (Pope, personal communication, 2006, 2007).

4. The data represented above were chosen from selected years. MSW landfill data from 1941 to 1990 (Levelton, 1991) were used in the multiple linear regression method for estimation of MSW landfilled for 1991–2006.

### ***Wood Waste Landfills***

The amount of wood waste landfilled in the years 1970 through 1992 is estimated at a national level based on the Wood Residue Data Base (NRCan 1997). Data for the years 1998 and 2004 are provided by subsequent publications (NRCan 1999, 2005). A linear regression trend analysis is conducted to interpolate the amount of wood residue landfilled in the years 1993–1997, 1999–2003, 2005 and 2006. This interpolation method is selected, as it is most suitable for the data distribution.

The breakdown in the amount of wood residue disposed of (defined as residue that is not further used in a product, used as a source of fuel, or converted into a chemical) for the solid wood operations and the pulp and paper industries is estimated based on information in a study of pulp and paper mill waste (MWA Consultants Paprican 1998). The proportion of wood waste disposal is estimated at 80% for solid wood operations and 20% for pulp and paper mills.

The breakdown of the portion of the wood residue directed to landfills from the solid wood and pulp and paper industry operations is estimated based on the Wood Residue Data Base (NRCan 1997). The allocation of wood waste landfilled in private landfills is estimated at 15% for solid wood operations and 86% for pulp and paper mills. To avoid double-counting, since emissions from public landfills are already accounted for in the emissions from MSW landfills, the ratio of wood waste landfilled in private versus public landfills, obtained from NRCan (1997) is used to isolate the quantity landfilled in dedicated private wood waste landfills. This portion is assumed to be also true for the years 1970–2006. Table A3-38 shows the amount of wood waste disposed of and landfilled for the period 1990–2006.

**Table A3-38: Wood Waste Generated and Landfilled in Canada for 1990–2006**

Year	Wood Waste Disposed of (bone dry tonnes)		Wood Waste Landfilled (bone dry tonnes)		
	Pulp & Paper	Solid Wood Industry	Pulp & Paper	Solid Wood Industry	Total
1990	1 811 062	7 244 248	1 557 513	1 086 637	2 644 151
1991	1 811 062	7 244 248	1 557 513	1 086 637	2 644 151
1992	1 811 062	7 244 248	1 557 513	1 086 637	2 644 151
1993	1 537 557	6 150 226	1 322 299	922 534	2 244 833
1994	1 447 245	5 788 981	1 244 631	868 347	2 112 978
1995	1 356 934	5 427 736	1 166 963	814 160	1 981 124
1996	1 266 623	5 066 491	1 089 296	759 974	1 849 269
1997	1 176 311	4 705 246	1 011 628	705 787	1 717 415
1998	1 080 000	4 320 000	928 800	648 000	1 576 800
1999	995 689	3 982 755	856 292	597 413	1 453 706
2000	905 378	3 621 510	778 625	543 227	1 321 851
2001	815 066	3 260 265	700 957	489 040	1 189 997
2002	724 755	2 899 020	623 289	434 853	1 058 142
2003	634 444	2 537 775	545 622	380 666	926 288
2004	547 561	2 190 244	470 902	328 537	799 439
2005	453 821	1 815 284	390 286	272 293	662 579
2006	363 510	1 454 039	312 618	218 106	530 724

## CH<sub>4</sub> Generation Rate Constant (k)

The CH<sub>4</sub> generation rate constant *k* represents the first-order rate at which CH<sub>4</sub> is generated after waste has been landfilled. The value of *k* is affected by four factors: moisture content, availability of nutrients, pH, and temperature. In calculating provincial decay rates, however, the ambient temperature should not be considered, as the landfill temperature is independent of the ambient temperature at depths exceeding 2 m. The moisture content should be the sole parameter considered (Maurice and Lagerkvist 2003; Thompson and Tanapat 2005).

### *MSW Landfills*

The *k* values used to estimate emissions from MSW landfills originate from a study conducted by the University of Manitoba that employed the provincial precipitation data from 1971 to 2000 (Thompson et al. 2006). The provincial locations estimating the average annual precipitation were based on those chosen by Levelton (1991). The EPA (2001) default decay values were used in conjunction with the Environment Canada annual precipitation data, and a graph was plotted showing a linear relationship between annual precipitation and decay rate. The U.S. EPA assigns a default decay value of 0.02/year to areas with an annual precipitation of less than 635 mm and 0.04/year to areas with an annual precipitation greater than 635 mm. Using this relationship, provincial landfill decay rates were calculated (Thompson et al. 2006).

Table A3-39 shows the mean annual precipitation and decay values assigned for each of the provincial landfill sites chosen by Levelton (1991).

**Table A3-39: Mean Annual Precipitation and MSW Landfill *k* Value Estimates for Provincial Landfill Sites**

Region	Mean Annual Precipitation (mm)	Kinetic Rate Constant <i>k</i> (/year)
<b>Newfoundland and Labrador</b>		
Carbonear	N/A	N/A
Corner Brook	1 270.8	0.048
St. John's	1 513.7	0.055
<i>Average</i>	<i>1 392.3</i>	<i>0.052</i>
<b>Prince Edward Island</b>		
Charlottetown	1 173.3	0.045
Summerside	1 078.0	0.042
<i>Average</i>	<i>1 125.7</i>	<i>0.044</i>
<b>Nova Scotia</b>		
Dartmouth	N/A	N/A
Halifax	1 452.2	0.054
Lunenburg	N/A	N/A
New Glasgow	N/A	N/A
Sydney	1 504.9	0.055
Truro	1 202.1	0.046
<i>Average</i>	<i>1 386.4</i>	<i>0.056</i>
<b>New Brunswick</b>		
Bathurst	1 058.6	0.042
Campbellton	N/A	N/A
Edmundston	N/A	N/A

<b>Region</b>	<b>Mean Annual Precipitation (mm)</b>	<b>Kinetic Rate Constant k (/year)</b>
Fredericton	1 143.3	0.044
Moncton	1 143.5	0.044
Saint John	1 390.3	0.052
<i>Average</i>	<i>1 184.0</i>	<i>0.046</i>
<b>Québec</b>		
Montréal	1 064.6	0.042
Québec	1 230.3	0.047
Rimouski	9 15.0	0.037
Saint-Étienne	N/A	N/A
Saint Tite-des-Caps	N/A	N/A
St. Cécile	N/A	N/A
St. Sophie	N/A	N/A
<i>Average</i>	<i>1 070.0</i>	<i>0.042</i>
<b>Ontario</b>		
Barrie	938.5	0.038
Belleville	891.6	0.037
Brantford	892.3	0.037
Brockville	983.4	0.040
Cornwall	1 002.0	0.040
Guelph	923.2	0.038
Hamilton	910.1	0.037
Kingston	968.4	0.039
Kitchener	N/A	N/A
London	987.1	0.040
North Bay	1 007.7	0.040
Oshawa	877.9	0.036
Ottawa-Hull	N/A	N/A
Peterborough	840.3	0.035
St. Catharines	873.6	0.036
Sarnia	846.8	0.035
Sudbury	899.3	0.037
Thunder Bay	711.6	0.031
Timmins	831.3	0.035
Toronto	834.0	0.035
Windsor	918.3	0.038
<i>Average</i>	<i>902.0</i>	<i>0.037</i>
<b>Manitoba</b>		
Brandon	472.0	0.024
Portage la Prairie	514.5	0.025
Thompson	517.4	0.026
Winnipeg	513.7	0.025
<i>Average</i>	<i>504.4</i>	<i>0.025</i>
<b>Saskatchewan</b>		
Moose Jaw	365.1	0.021
Prince Albert	424.3	0.023

Region	Mean Annual Precipitation (mm)	Kinetic Rate Constant k (/year)
Regina	388.1	0.022
Saskatoon	350.0	0.021
Swift Current	377.1	0.021
Yorkton	450.9	0.024
<i>Average</i>	<i>392.6</i>	<i>0.022</i>
<b>Alberta</b>		
Calgary	412.6	0.022
Edmonton	482.7	0.024
Fort McMurray	455.5	0.024
Lethbridge	386.3	0.022
Medicine Hat	333.8	0.020
Red Deer	487.2	0.025
<i>Average</i>	<i>426.4</i>	<i>0.023</i>
<b>British Columbia</b>		
Campbell River	1 451.5	0.054
Chilliwack	1 501.3	0.055
Courtney	N/A	N/A
Kamloops	305.1	0.019
Matsqui	N/A	N/A
Port Alberni	1 910.7	0.067
Prince Rupert	2 593.6	0.088
Vancouver	1 199.0	0.046
Vernon	409.9	0.022
Victoria	883.3	0.036
<i>Average</i>	<i>1 280.7</i>	<i>0.048</i>
<b>Yukon</b>		
Whitehorse	267.4	0.018
<i>Average</i>	<i>267.4</i>	<i>0.018</i>
<b>Northwest Territories &amp; Nunavut</b>		
Yellowknife	280.7	0.018
<i>Average</i>	<i>280.7</i>	<i>0.018</i>

Note: N/A = Not available

The k values used to estimate emissions from MSW landfills at a provincial level are derived from taking the average of k value estimates for each province (Thompson et al. 2006). These values are provided in Table A3-40.

**Table A3-40: MSW Landfill k Value Estimates for Each Province**

k Value (/year)											
NL	PE	NS	NB	QC	ON	MB	SK	AB	BC	YT	NT & NU
0.052	0.044	0.056	0.046	0.042	0.037	0.025	0.022	0.023	0.048	0.018	0.018

### Wood Waste Landfills

Based upon the default value for estimating wood products industry landfill CH<sub>4</sub> emissions recommended by the National Council for Air and Stream Improvement, Inc., a k value of 0.03/year was assumed to represent the CH<sub>4</sub> generation rate constant for all of the wood waste landfills in Canada (NCASI 2003).

### CH<sub>4</sub> Generation Potential (L<sub>0</sub>)

#### MSW Landfills

The CH<sub>4</sub> generation potential (L<sub>0</sub>) represents the amount of CH<sub>4</sub> that could be theoretically produced per tonne of waste landfilled. The following equation, as presented in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, is used to calculate the CH<sub>4</sub> generation potential for MSW landfills (IPCC/OECD/IEA 1997):

#### Equation A3-61:

$$L_0 = \text{MCF} \times \text{DOC} \times \text{DOC}_F \times F \times \frac{16}{12} \times 1000 \frac{\text{kgCH}_4}{\text{tCH}_4}$$

where:

L <sub>0</sub>	=	CH <sub>4</sub> generation potential, kg CH <sub>4</sub> /t waste
MCF	=	CH <sub>4</sub> correction factor, fraction
DOC	=	degradable organic carbon, t C/t waste
DOC <sub>F</sub>	=	fraction of DOC dissimilated
F	=	fraction of CH <sub>4</sub> in landfill gas
16/12	=	stoichiometric factor to convert CH <sub>4</sub> to carbon

MCF accounts for the proportion of managed to unmanaged solid waste disposal sites. Unmanaged solid waste disposal sites produce less CH<sub>4</sub>, since a larger fraction of waste decomposes aerobically in the top layers of the site. The IPCC default value for MCF for managed landfill sites is chosen to represent the MCF for MSW landfills, since it is assumed that all landfills covered by the data collected are engineered landfills. The IPCC default values for MCF are shown in Table A3-41 (IPCC/OECD/IEA 1997).

**Table A3-41: Solid Waste Disposal Site CH<sub>4</sub> Correction Factors**

Type of Site	MCF Default Values
Managed	1.0
Unmanaged: deep (≥ 5 m waste)	0.8
Unmanaged: shallow (<5 m waste)	0.4
Default value: uncategorized solid waste disposal sites	0.6

The IPCC default value for the fraction of CH<sub>4</sub> in landfill gas (F) ranges between 0.4 and 0.6. It can vary based on certain factors, including waste age and composition and potential air dilution effects that can lower the actual concentration of CH<sub>4</sub> in the landfill gas. The average value 0.5 is chosen for the fraction of CH<sub>4</sub> in landfill gas.

DOC<sub>F</sub> represents the amount of organic carbon that is ultimately degraded and released from the solid waste disposal site. It accounts for the fact that some of the organic carbon does not degrade or



degrades very slowly. A value of 0.6 was selected from the IPCC  $\text{DOC}_F$  default range, for waste that includes lignin, of 0.5 to 0.6 (IPCC/OECD/IEA 2000). This value, taken from the upper end of this range, i.e., more easily degraded, best represents the Canadian situation where the majority of the wood wastes, that by definition have high lignin concentrations, from saw mills and pulp and paper industries, are disposed of in dedicated private landfills.

DOC represents the amount of organic carbon that is accessible to biochemical decomposition and is based on the composition of the waste. Waste composition percentages from across Canada are used to calculate the provincial DOC values according to the following equation (IPCC/OECD/IEA 1997).

**Equation A3-62:**

$$\% \text{ DOC (by wet weight)} = (0.4 \times A) + (0.17 \times B) + (0.15 \times C) + (0.3 \times D)$$

where:

- A = % of MSW that is paper and textiles
- B = % of MSW that is garden or park waste
- C = % of MSW that is food waste
- D = % of MSW that is wood or straw

The provincial and territorial DOCs were calculated from waste disposal composition values for three distinct time periods: 1941–1975, 1976–1989 and 1990 to 2006. Using waste composition data obtained from a Natural Resources Canada (NRCan) study, which were based on the 2002 data year (NRCan 2006), DOC values were derived and assumed to be constant over the period 1990 to 2004. Since the waste diversion programs were not significant prior to 1990, a second set of DOCs were developed to represent the waste composition at disposal from 1976 to 1989 by adding the NRCan landfill data to the 2004 Statistics Canada recycled waste composition data (Statistics Canada 2007a). A third set of DOCs were developed from a 1967 national study to cover the period from 1941 to 1975 (CRC Press 1973). Provincial and territorial DOCs and  $L_0$ s are summarized in Table A3-42.

**Table A3-42: Provincial and Territorial  $\text{CH}_4$  Generation Potential ( $L_0$ ) Values**

Province/Territory	2002 Organic Waste Diversion <sup>a</sup> (%)	1941 to 1975		1976 to 1989		1990 to Present	
		DOC	$L_0$ (kg $\text{CH}_4$ / t waste)	DOC	$L_0$ (kg $\text{CH}_4$ / t waste)	DOC	$L_0$ (kg $\text{CH}_4$ / t waste)
British Columbia	23.3	0.28	111.86	0.17	69.89	0.16	63.71
Alberta	16.7	0.39	157.63	0.26	104.46	0.18	71.87
Saskatchewan	4.3	0.36	143.92	0.22	86.39	0.22	86.75
Manitoba	4.9	0.33	131.37	0.19	76.82	0.19	76.59
Ontario	16.4	0.36	143.74	0.21	82.75	0.21	83.00
Quebec	13.7	0.36	144.45	0.21	82.52	0.20	81.23
New Brunswick	19.8	0.23	93.91	0.16	65.91	0.16	63.22
Nova Scotia	29.7	0.25	100.89	0.16	62.35	0.16	64.10
Prince Edward Island	NA	0.27	108.74	0.17	67.19	0.16	64.63
Newfoundland	NA	0.28	112.62	0.18	73.28	0.18	73.35
Territories (YT, NT & NU)	NA	0.22	87.59	0.15	58.54	0.16	65.13

Notes:

Sources: Derived from data obtained from NRCan (2006), Statistics Canada (2007a) and CRC Press (1973).

a. Thompson et al. (2006).

From the NRCan 2006 document, the quantities for each standard category of waste from residential and ICI origins were added together to reflect the true composition at disposal at the MSW landfill sites. Therefore, by this methodology, the ICI biodegradability as well as that of the

residential waste are accounted for in the MSW waste composition. The NRCan report uses a consistent methodology to estimate the MSW waste composition at disposal for all provinces and territories.

Since significant results from waste diversion projects only began to be made manifest in the early 1990s in Canada, as supported by this document and expert opinion in the field, these provincial/territorial DOCs are used in the estimation of  $L_0$ s and ultimately in the provincial/territorial specific methane emission generation for the period 1990–2006, inclusively.

For the period 1976–1989, DOC values were calculated based on the assumption that the waste composition at disposal could be represented by the generation waste composition for the year 2002. This was accomplished by summing the MSW (residential and ICI) waste quantities (NRCan 2006) at disposal for each waste category with the recycled quantities for the corresponding category for each province and territory. The latter data was obtained from Statistics Canada report *Waste Management Industry Survey Business and Government Sectors 2004* (Statistics Canada 2008). a). Where gaps were identified in the Statistics Canada report, due to confidentiality issues, regional factors (western, central and maritime provinces and northern territories) were used to populate the missing data.

The years 1941 to 1975 are covered by an  $L_0$  developed by a third set of DOC values, based on national waste compositions provided in Table 1.1-9 of CRC Press (1973). The data from this table are derived from the article “World Survey Finds Less Organic Matter” (Anon. 1967a). MSW data from Table 1: Waste Composition Data for Ontario, of the report *Residential Waste Composition Study, Volume 1* of the Ontario Waste composition Study (Ontario Ministry of the Environment 1991); for waste audit studies dated 1976, 1978 and 1980, gave paper, wood, food wastes, textile and yard waste percentages that average values (40%, 2.6%, 22%, 3.4% and 13%, respectively); that are comparable to those from the 2002 generated estimates used for the 1976 to 1989 period. The 1967 article data (Anon. 1967a) gave paper and organic matter compositions of 70% and 10%, respectively. Therefore, 1975–1976 was judged to be an appropriate transition point to use to allow for a realistic change between the significantly different 1967 data set and the data derived from the 2002 waste composition without waste diversion employed to represent the waste composition for the late 70s and 80s. The breakdown of organic matter percentage (10%), obtained from Table 1.1-9, into food and yard waste was based upon the waste composition (10.2% and 8.6%, respectively) given for Montréal, Quebec, from the same CRC Press (1973) text, Table 1.1-10, where the data was obtained from a separate 1967 article (Anon. 1967b). The information on percentage of wood (2.4%) came from an article by the American Public Works Association (1964), and was presented in Table 1.1-2.8: Composition and Analysis of Average Municipal Refuse (CRC Press 1973).

A provincial profile was developed from the 1967 national average by pro-rating each of its DOC waste categories to match the same provincial profile as for the 1976 to 1989 period. Table A3-43 presents the landfilled waste composition by the *IPCC 2006 Guidelines for National Greenhouse Gas Inventories* 1996 defined categories for the provinces and territories as derived from the data sources.

**Table A3-43: Provincial and Territorial CH<sub>4</sub> Generation Potential (L<sub>0</sub>) Values**

British Columbia		DOC Parameters 1941 to 1975	DOC Parameters 1976 to 1989	DOC Parameters 1990 to present
		(%)	(%)	(%)
	A	61.4	28.4	20.8
	B	4.1	13.4	15.5
	C	5.1	16.4	19.0
	D	6.5	4.6	7.1
	DOC	0.280	0.175	0.159
	L <sub>0</sub>	111.9	69.9	63.7

Alberta		DOC Parameters 1941 to 1975	DOC Parameters 1976 to 1989	DOC Parameters 1990 to present
		(%)	(%)	(%)
	A	87.4	40.4	27.0
	B	7.5	24.6	17.0
	C	9.3	30.0	20.7
	D	6.0	4.2	3.9
	DOC	0.394	0.261	0.180
	L <sub>0</sub>	157.6	104.5	71.9

Saskatchewan		DOC Parameters 1941 to 1975	DOC Parameters 1976 to 1989	DOC Parameters 1990 to present
		(%)	(%)	(%)
	A	84.3	39.0	37.1
	B	4.8	15.9	18.1
	C	6.0	19.5	22.2
	D	1.7	1.2	1.4
	DOC	0.360	0.216	0.217
	L <sub>0</sub>	143.9	86.4	86.7

Manitoba		DOC Parameters 1941 to 1975	DOC Parameters 1976 to 1989	DOC Parameters 1990 to present
		(%)	(%)	(%)
	A	76.7	35.5	32.7
	B	3.8	12.6	15.1
	C	4.8	15.4	18.4
	D	2.7	1.9	2.4
	DOC	0.328	0.192	0.191
	L <sub>0</sub>	131.4	76.8	76.6

Ontario		DOC Parameters 1941 to 1975	DOC Parameters 1976 to 1989	DOC Parameters 1990 to present
		(%)	(%)	(%)
	A	83.2	38.5	37.2
	B	4.2	13.9	14.8
	C	4.1	13.4	14.2
	D	4.4	3.1	4.1
	DOC	0.359	0.207	0.207
	L <sub>0</sub>	143.7	82.7	83.0

Quebec		DOC Parameters 1941 to 1975	DOC Parameters 1976 to 1989	DOC Parameters 1990 to present
		(%)	(%)	(%)
	A	84.7	39.2	35.0
	B	4.2	13.8	17.2
	C	4.1	13.2	16.6
	D	3.0	2.1	3.0
	DOC	0.361	0.206	0.203
	L <sub>0</sub>	144.4	82.5	81.2

New Brunswick		DOC Parameters 1941 to 1975	DOC Parameters 1976 to 1989	DOC Parameters 1990 to present
		(%)	(%)	(%)
	A	53.2	24.6	26.4
	B	6.3	20.7	16.0
	C	6.2	19.8	15.4
	D	0.7	0.5	0.7
	DOC	0.235	0.165	0.158
	L <sub>0</sub>	93.9	65.9	63.2

Nova Scotia		DOC Parameters 1941 to 1975	DOC Parameters 1976 to 1989	DOC Parameters 1990 to present
		(%)	(%)	(%)
	A	59.6	27.5	32.3
	B	4.4	14.6	9.9
	C	4.3	14.0	9.5
	D	0.0	0.0	0.0
	DOC	0.252	0.156	0.160
	L <sub>0</sub>	100.9	62.4	64.1

P.E.I.	DOC Parameters 1941 to 1975	DOC Parameters 1976 to 1989	DOC Parameters 1990 to present
	(%)	(%)	(%)
A	64.2	29.7	34.2
B	4.8	15.7	7.9
C	4.7	15.1	7.6
D	0.0	0.0	0.0
DOC	0.272	0.168	0.162
L <sub>0</sub>	108.7	67.2	64.6

NFL	DOC Parameters 1941 to 1975	DOC Parameters 1976 to 1989	DOC Parameters 1990 to present
	(%)	(%)	(%)
A	64.7	29.9	30.9
B	5.9	19.3	18.0
C	5.7	18.5	17.3
D	1.4	1.0	1.1
DOC	0.282	0.183	0.183
L <sub>0</sub>	112.6	73.3	73.4

Territories	DOC Parameters 1941 to 1975	DOC Parameters 1976 to 1989	DOC Parameters 1990 to present
	(%)	(%)	(%)
A	50.7	23.5	26.1
B	5.1	16.7	18.6
C	5.0	16.1	17.9
D	0.0	0.0	0.0
DOC	0.219	0.146	0.163
L <sub>0</sub>	87.6	58.5	65.1

Data Sources: CRC Press (1973), NRCan (2006), Statistics Canada (2007a).

### **Wood Waste Landfills**

Equation A3-58, as presented in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, is used to calculate the CH<sub>4</sub> generation potential for wood waste landfills (IPCC/OECD/IEA 1997). The IPCC default value for MCF for unmanaged deep landfill sites (0.8) is chosen to represent the MCF, as it best represents industry practices.

The value 0.5 is chosen for the fraction of CH<sub>4</sub> in landfill gas (F) from the IPCC default range of 0.4 to 0.6.

DOC<sub>F</sub> represents the amount of organic carbon that is ultimately degraded and released from the solid waste disposal sites. It accounts for the fact that some of the organic carbon does not degrade or degrades very slowly. The *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* provides default values in the order of 0.5–0.6 for waste sites that include lignin. The lower end of this range, 0.5, is used in the calculation for the CH<sub>4</sub> generation potential to better represent the high lignin content in wood waste (IPCC/OECD/IEA 1997).

DOC represents the amount of organic carbon that is accessible to biochemical decomposition. Equation A3-62 is used to calculate the national wood waste DOC value, assuming a 100% wood composition (IPCC/OECD/IEA 1997).

Based on these considerations, a  $L_0$  of 80 kg CH<sub>4</sub>/t of wood waste is calculated from Equation A3-61.

### Captured Landfill Gas

At many large MSW landfill facilities, landfill gas is captured to be flared or utilized, or both. Owing to the relatively high concentration of CH<sub>4</sub> in the landfill gas, the gas can be combusted for electricity or heat generation. To a lesser extent, in recent years, the captured gas is simply collected and vented. If not utilized, the captured landfill gas is flared. For the purposes of the inventory, captured gas includes only the gas that is flared or utilized. In order to calculate the net CH<sub>4</sub> emissions from landfills, the amount of captured CH<sub>4</sub> is subtracted from the CH<sub>4</sub> generated as estimated by the Scholl Canyon model, and then this value is added to the portion of CH<sub>4</sub> emitted from the flaring operation. GHG emissions affiliated with the use of landfill gas for energy recovery are accounted for in the Energy Sector. The calculation of net CH<sub>4</sub> emissions is shown in the following equation:

#### Equation A3-63:

$$\text{CH}_4(\text{NET}) = \text{CH}_4(\text{generated}) - \text{CH}_4(\text{captured}) + \text{CH}_4(\text{emitted-F})$$

where:

CH <sub>4</sub> (NET)	=	net CH <sub>4</sub> emissions from MSW landfills, t
CH <sub>4</sub> (generated)	=	CH <sub>4</sub> emissions generated from MSW landfills, t
CH <sub>4</sub> (captured)	=	CH <sub>4</sub> emissions captured from MSW landfills, t
CH <sub>4</sub> (emitted-F)	=	CH <sub>4</sub> emissions emitted from flaring of captured MSW landfill gas, t

A flaring emission control efficiency of 99.7% is used to determine the amount of CH<sub>4</sub> emitted. This value is obtained from Table 2.4-3 of Chapter 2.4 of EPA AP 42 (EPA 1995). The amount of CH<sub>4</sub> emitted from flaring of landfill gas is calculated as follows:

#### Equation A3-64:

$$\text{CH}_4(\text{emitted-F}) = \text{CH}_4(\text{flared}) \times (1 - \text{Eff}_{(\text{flare-control})})$$

where:

CH <sub>4</sub> (emitted-F)	=	CH <sub>4</sub> emissions emitted from flaring of MSW CH <sub>4</sub> gas, t/year
CH <sub>4</sub> (flared)	=	CH <sub>4</sub> gas flared, t/year
Eff <sub>(flare-control)</sub>	=	flare emission control efficiency, fraction

The quantities of CH<sub>4</sub> gas collected from 1983 to 1996 were obtained from ad hoc surveys conducted by Environment Canada (Perkin, personal communication, 1998) and for the years 1997–2003 were collected directly from individual landfill operators biennially by Environment Canada's National Office of Pollution Prevention (Environment Canada 2003a). CH<sub>4</sub> gas capture data for 2005 were obtained through a study prepared for Environment Canada (Environment

Canada 2007). Data for 2006 are assumed to be unchanged from 2005. Since the CH<sub>4</sub> capture data are collected every odd-numbered year, for the purposes of the national GHG inventory, the CH<sub>4</sub> capture data for the even-numbered years are averaged from the adjacent odd-numbered years from 1997. This biennial survey is now assumed directly by the Greenhouse Gas Division. Table A3-44 shows the amount of CH<sub>4</sub> captured and flared from 1990 to 2006.<sup>77</sup>

**Table A3-44: Estimated MSW CH<sub>4</sub> Captured, Flared, and Emitted for 1990–2006**

Year	CH <sub>4</sub> Generated (kt)	CH <sub>4</sub> Captured (kt)	CH <sub>4</sub> Flared (kt)	CH <sub>4</sub> Emitted from Flare (kt)	CH <sub>4</sub> Emitted (kt)
1990	880.870	192.661	23.614	0.071	688.280
1991	897.620	195.641	27.175	0.082	702.061
1992	914.518	204.782	35.291	0.106	709.842
1993	931.455	209.390	44.461	0.133	722.199
1994	948.332	223.362	56.729	0.170	725.139
1995	965.038	243.442	69.355	0.208	721.804
1996	981.460	264.551	78.672	0.236	717.146
1997	997.469	267.803	81.001	0.243	729.909
1998	1 009.810	271.817	90.797	0.272	738.266
1999	1 023.478	275.830	100.593	0.302	747.950
2000	1 038.543	294.287	117.904	0.354	744.610
2001	1 052.941	312.743	135.214	0.406	740.603
2002	1 066.726	312.561	137.063	0.411	754.577
2003	1 080.945	312.378	139.342	0.418	768.985
2004	1 095.585	312.950	146.918	0.441	783.076
2005	1 110.204	313.523	154.493	0.463	797.145
2006	1 125.208	313.523	154.493	0.463	812.149

### A3.5.1.2 Data Sources

Waste disposal data are collected from a Statistics Canada biennial waste survey (Statistics Canada 2000, 2003, 2004, 2007a). The Statistics Canada data for 1998, 2000, 2002, and 2004 waste disposal are used in developing its MSW estimates for the national GHG inventory.

Landfill gas capture and flare data for 1997–2003 were collected directly from individual landfill operators biennially by Environment Canada’s National Office of Pollution Prevention (Environment Canada 2003a). CH<sub>4</sub> gas capture data for 2005 were obtained through the study entitled “An Inventory of Landfill Gas Recovery and Utilization in Canada,” prepared for Environment Canada (Environment Canada 2007).

77. The following landfill gas capture facilities did not provide data by February 2007: Highway 101 Landfill (NS), Bestan inc. (QC), Eastview Road Landfill Site (ON), Aurora Landfill (ON), and Cottonwood Landfill (BC). Thus, data provided in the 2003 inventory were assumed to be held constant for the 2005 inventory.

### A3.5.2 CH<sub>4</sub> Emissions from Wastewater Treatment

#### A3.5.2.1 Methodology

##### Municipal Wastewater Treatment

The IPCC default method for calculating CH<sub>4</sub> emissions from domestic wastewater handling is not used because the required data (i.e. volumes of wastewater treated) are not available. Instead, a method developed for Environment Canada (ORTECH Corporation 1994) is used to calculate an emission factor. This method assumes that the CH<sub>4</sub> generation rate from the anaerobic decomposition of organic matter in wastewater is 0.22 kg CH<sub>4</sub>/kg BOD<sub>5</sub> (the five-day biochemical oxygen demand), and the daily per capita BOD<sub>5</sub> loading rate is 0.050 kg BOD<sub>5</sub>/person per day. Based on these two assumptions, it is estimated that 4.015 kg CH<sub>4</sub>/person per year could potentially be emitted from anaerobically treated wastewater. The derivation of the CH<sub>4</sub> emission factor is shown below.

##### Equation A3-65:

$$\begin{aligned} \text{EF}_{\text{CH}_4} \text{ (kg CH}_4\text{/ capita per year)} &= (\text{per capita BOD}_5\text{ loading rate}) \times (\text{CH}_4\text{ generation rate}) \\ &= \left( \frac{0.05 \text{ kg BOD}_5}{\text{capita} \times \text{day}} \right) \times \left( 365 \frac{\text{days}}{\text{year}} \right) \times \left( 0.22 \frac{\text{kg CH}_4}{\text{kg BOD}_5} \right) \\ &= \left( 4.015 \frac{\text{kg CH}_4}{\text{capita} \times \text{year}} \right) \end{aligned}$$

The percentage of wastewater that is treated aerobically (primary and secondary wastewater treatment) and anaerobically (waste stabilization pond treatment) is obtained from the Municipal Water Use Data Base for the following years: 1983, 1986, 1989, 1991, 1994, 1996, and 1999 (Environment Canada 1983–1999). Given that municipal effluent volumetric flow rates are strongly correlated with population, the corresponding missing years for the period 1983–1999 are estimated by trending the water use values (Environment Canada 1983–1999) with the provincial populations for 1983–1999 (Statistics Canada 2006b, 2007b). This method of estimation is consistent with the IPCC surrogate method (IPCC 2000). The percentage of wastewater treated for 2000–2006 is estimated by applying a growth function to the 1983–1999 Municipal Water Use Data Base values using the provincial populations for 1983–2006 (Statistics Canada 2006b, 2007b). This method of estimation is consistent with the IPCC method of extrapolation (IPCC 2000).

Emissions are calculated by multiplying the emission factors by the population of the respective province (Statistics Canada 2006b, 2007b) and the fraction of wastewater that is anaerobically treated.

##### Equation A3-66:

$$\text{CH}_{4(x)} = \text{EF}_{\text{CH}_4} \times P_x \times \text{Frac}_{\text{AN}(x)}$$

where:

CH <sub>4(x)</sub>	=	CH <sub>4</sub> emissions from wastewater treatment for province x, t/year
EF <sub>CH<sub>4</sub></sub>	=	CH <sub>4</sub> emission factor for wastewater treatment, t/capita per year
P <sub>x</sub>	=	population of province x
Frac <sub>AN(x)</sub>	=	fraction of wastewater treated anaerobically for province x



CH<sub>4</sub> emissions are also calculated using the IPCC check method for CH<sub>4</sub> emissions from domestic wastewater treatment (IPCC 2000). The check method calculation is shown below:

**Equation A3-67:**

$$WM = P \times D \times SBF \times EF \times FTA \times 365 \times 10^{-12}$$

where:

WM	=	annual CH <sub>4</sub> emissions per country from domestic wastewater, Tg
P	=	population of country
D	=	organic load in biochemical oxygen demand per person, g BOD/person per day: 60 g BOD/person per day was used (Table 6.5 of the Revised 1996 <i>IPCC Guidelines for National Greenhouse Gas Inventories</i> ; IPCC/OECD/IEA 1997)
SBF	=	fraction of BOD that readily settles: default = 0.5
EF	=	emission factor, g CH <sub>4</sub> /g BOD: default = 0.6
FTA	=	fraction of BOD in sludge that degrades anaerobically: default = 0.8

The IPCC check method states that for countries that employ exclusively aerobic processes, the fraction of BOD in sludge that degrades anaerobically (FTA) would be significantly lower or zero. In these cases, IPCC recommends using the full Good Practice Guidance *and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000). Canada falls into this category. However, owing to the lack of required data, the check method is used to check the accuracy of the method developed by ORTECH Corporation (1994). The FTA is determined by taking a weighted average of the percentage of people served by anaerobic treatment as follows:

**Equation A3-68:**

$$FT_i = \sum_x \frac{\% AN_{x,i} \times P_{x,i}}{P_{tot,i}}$$

where:

FT <sub>i</sub>	=	fraction of BOD in sludge that degrades anaerobically for year i
%AN <sub>x,i</sub>	=	percentage of the population served by anaerobic wastewater treatment for province x in year i
P <sub>x,i</sub>	=	population of province x for year i
P <sub>tot,i</sub>	=	population of Canada for year i

The difference in CH<sub>4</sub> emissions between the IPCC check method and the method developed by ORTECH Corporation (1994) is primarily due to the choice of emission factor. The IPCC default emission factor is shown as 0.6 g CH<sub>4</sub>/g BOD. The emission factor used in the method developed by ORTECH Corporation (1994) (0.22 g CH<sub>4</sub>/g BOD) is obtained from a study performed by Thorneloe (1993).

There may be some anaerobic treatment within the category of secondary wastewater treatment. However, although the percentage of wastewater in secondary treatment that is treated anaerobically is not quantified within the Municipal Water Use Data Base (Environment Canada 1983–1999), it is not expected to be significant.

Table A3-45 shows the percentage of wastewater treated anaerobically (waste stabilization ponds) for 1983–2006. The remaining percentage of wastewater is treated aerobically (primary and secondary wastewater treatment). Waste stabilization ponds (facultative lagoons) are

assumed to be anaerobic, since they are primarily anaerobic systems with an aerobic top layer that reverts to anaerobic conditions during the night (Rich 2005).

**Table A3-45: Percentage of Wastewater Treated Anaerobically by Province**

Year	Wastewater Treatment (% Anaerobic)											
	NL	PE	NS	NB	QC	ON	MB	SK	AB	BC	NT & NU	YT
1983	2.4	18.6	16.8	37.2	10.2	2.1	10.9	22.6	20.8	9.0	46.4	100.0
1986	2.3	13.6	16.9	37.1	8.5	2.2	11.1	20.9	20.6	8.4	43.0	100.0
1989	3.8	11.2	9.6	41.5	13.0	3.1	11.2	19.7	13.4	8.8	83.7	100.0
1990	2.7	10.4	10.1	41.9	13.3	3.2	11.2	21.8	10.2	8.7	83.7	100.0
1991	12.9	15.8	4.8	32.5	10.1	2.7	10.1	21.2	12.5	9.6	95.6	100.0
1992	7.7	11.7	6.1	37.7	12.4	3.1	10.8	21.7	7.9	9.3	100.0	100.0
1993	7.6	10.0	5.0	37.7	12.7	3.2	10.8	21.5	6.1	9.4	100.0	100.0
1994	11.0	15.8	14.3	29.5	13.8	2.4	9.9	18.8	12.2	5.6	97.5	100.0
1995	5.4	10.7	6.8	35.6	13.3	3.1	10.5	20.8	5.8	7.8	100.0	100.0
1996	19.8	13.8	11.6	28.9	16.3	2.2	9.2	20.0	12.7	6.1	97.7	91.2
1997	19.7	11.2	7.2	34.2	14.3	3.0	10.1	20.5	5.2	7.0	97.9	97.7
1998	25.3	11.3	7.3	34.5	14.5	3.0	10.0	20.5	3.1	6.9	97.6	98.0
1999	40.0	12.3	13.4	39.1	18.3	2.2	11.0	17.6	11.6	5.8	97.7	90.4
2000	36.3	11.2	7.9	35.1	15.6	2.9	10.1	20.9	3.0	6.5	98.1	89.5
2001	39.2	11.2	8.1	35.2	15.9	3.0	10.0	21.5	1.8	6.4	98.6	86.0
2002	40.4	11.1	7.8	35.1	16.4	3.0	9.9	21.8	0.3	6.3	99.0	86.1
2003	40.9	10.9	7.6	35.0	16.8	3.0	9.9	21.9	0.0	6.2	99.3	91.0
2004	41.4	10.7	7.4	34.9	17.3	3.0	9.7	21.9	0.0	6.1	99.5	93.3
2005	42.9	10.6	7.6	35.0	17.7	3.1	9.7	22.2	0.0	5.9	99.5	94.4
2006	44.7	10.6	7.8	35.3	18.1	3.1	9.6	22.4	0.0	5.7	99.6	95.2

## Industrial Wastewater Treatment

Presently, there are no emissions estimated from this subsector. However, the following methodology will be used once the activity data is available.

A top-down modified IPCC Guidelines approach, as described in Figure 5.4 of the *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000), is used for the calculation of CH<sub>4</sub> emissions from industrial wastewater handling. CH<sub>4</sub> from Industrial Wastewater is not currently a key source category; thus, Box 1 of the decision tree in Figure 5.4 (IPCC 2000) is the chosen methodology for calculation of CH<sub>4</sub> emissions.

The IPCC default value of 0.25 kg CH<sub>4</sub>/kg chemical oxygen demand (COD) is used in the estimation of CH<sub>4</sub> emissions from industrial wastewater treatment (IPCC 2000). The volume of industrial wastewater treated is obtained from surveys conducted by Environment Canada for the years 1986, 1991, and 1996 (Environment Canada 1986, 1991, 1996a). The volume of industrial wastewater treated for 1997–2006 is forecasted by applying a growth function to the 1986, 1991, and 1996 Municipal Water Use Data Base values. This forecasting method is consistent with the IPCC trend extrapolation method (IPCC 2000). The corresponding missing years for the period

1987–1996 are estimated by fitting a polynomial to the Environment Canada data (Environment Canada 1986, 1991, 1996a) and the forecasted data 1997–2006. To estimate the coefficients in the polynomial, a multiple linear regression method is used. A polynomial of the order 6 provides the best fit. Table A3-46 shows the polynomial coefficients generated by the multiple linear regression method for each of the industry groups.

**Table A3-46: Multiple Linear Regression Polynomial Coefficients Used in Estimating the Amount of Industrial Wastewater Treated for 1987–1990 and 1992–1995**

	C	C <sub>1</sub>	C <sub>2</sub>	C <sub>3</sub>	C <sub>4</sub>	C <sub>5</sub>	C <sub>6</sub>
<b>Food</b>	5.05E+07	0	0	0	-4.75E-05	3.80E-08	-7.93E-12
<b>Beverages</b>	-4.11E+06	0	0	0	3.86E-06	-3.09E-09	6.43E-13
<b>Rubber Products</b>	1.02E+06	0	0	0	-9.58E-07	7.67E-10	-1.60E-13
<b>Plastic Products</b>	2.50E+05	0	0	0	-2.35E-07	1.88E-10	-3.92E-14
<b>Total Textiles</b>	-1.73E+07	0	0	0	1.64E-05	-1.31E-08	2.74E-12
<b>Paper &amp; Allied Products</b>	-7.56E+07	0	0	0	7.17E-05	-5.76E-08	1.20E-11
<b>Petroleum &amp; Coal Products</b>	-5.54E+06	0	0	0	5.23E-06	-4.19E-09	8.75E-13
<b>Chemical Products</b>	1.54E+07	0	0	0	-1.46E-05	1.17E-08	-2.44E-12

Note: Coefficients have been rounded and may not result in the correct totals for the volume of industrial wastewater treated.

The volumes of industrial wastewater treated for the years 1987–1990 and 1992–1995 are calculated according to the following equation:

**Equation A3-69:**

$$V_x = (C_6 \times X^6) + (C_5 \times X^5) + (C_4 \times X^4) + (C_3 \times X^3) + (C_2 \times X^2) + (C_1 \times X) + C$$

where:

V <sub>x</sub>	=	volume of industrial wastewater treated in year X, million cubic metres
C <sub>i</sub>	=	coefficient of the ith order
X	=	year of interest

Table A3-47 shows the amount of industrial wastewater treated per industry group for 1986–2006.

**Table A3-47: Volume of Wastewater Treated per Industry Type for 1986–2006**

Year	Volume of Wastewater Treated (million cubic metres)							
	Food	Beverages	Rubber Products	Plastic Products	Total Textile	Paper & Allied Products	Petroleum & Coal Products	Chemicals & Chemical Products
1986	352	15	5	7	25	2 286	33	208
1987	295.3	20.1	4.2	6.7	36.2	2 287.0	36.7	199.0
1988	251.0	24.4	3.6	6.5	42.5	2 260.2	38.8	194.9
1989	214.6	28.0	3.2	6.3	46.6	2 226.3	40.2	192.8
1990	185.2	30.9	3.0	6.2	48.8	2 186.5	40.9	192.6
1991	147.5	33.9	2.3	6	58.3	2 214.3	44	183.9
1992	144.8	35.3	2.8	6.0	48.2	2 093.6	40.8	196.5
1993	132.3	36.8	2.8	5.9	46.1	2 042.8	40.0	200.2
1994	123.9	37.9	2.9	5.9	43.0	1 990.5	39.0	204.9
1995	118.9	38.7	3.1	5.9	39.2	1 938.0	37.7	210.1
1996	128.6	38.4	3.6	5.9	28.3	1 847.5	34.4	220.9
1997	125.1	39.4	3.9	5.9	24.5	1 781.8	32.7	229.1
1998	121.7	40.4	4.3	5.9	21.2	1 718.4	31.2	237.7
1999	118.4	41.4	4.7	5.8	18.3	1 657.3	29.7	246.6
2000	115.2	42.4	5.2	5.8	15.9	1 598.3	28.3	255.8
2001	112.1	43.5	5.6	5.8	13.7	1 541.5	26.9	265.3
2002	109.1	44.6	6.2	5.8	11.9	1 486.6	25.6	275.3
2003	106.1	45.7	6.7	5.8	10.3	1 433.7	24.4	285.5
2004	103.3	46.9	7.4	5.7	8.9	1 382.7	23.2	296.2
2005	100.5	48.1	8.1	5.7	7.7	1 333.6	22.1	307.3
2006	97.8	49.3	8.8	5.7	6.7	1 286.1	21.0	318.7

CH<sub>4</sub> emissions are calculated by multiplying the volume of wastewater treated per industry type by the corresponding COD value, followed by the default emission factor of 0.25 kg CH<sub>4</sub>/kg COD (IPCC 2000) and the fraction of wastewater that was treated anaerobically. Prior to 2006, from the information available there were no major industries treating their effluent waters anaerobically (Hicke, personal communication, 2006; Flynn, personal communication, 2006). However, we are now aware of some anaerobic treatment units in operation in 2006 but no quantitative information is presently available. IPCC COD default values (IPCC 2000) are used where possible (i.e. where IPCC industry sectors matched the industry sectors included in the Environment Canada surveys). The industry groups shown in Table A3-47 are selected from the total group of industry waste streams provided in the Environment Canada reports (Environment Canada, 1986, 1991, 1996a) due to the availability of COD values for a select number of industry groups (IPCC 2000). Table A3-48 shows the industry sectors included within the Environment Canada surveys (Environment Canada 1986, 1991, and 1996a) and the corresponding IPCC default COD values that are chosen to represent the industry sectors (IPCC 2000).

**Table A3-48: COD Values Used in CH<sub>4</sub> Emission Estimates per Industry Type**

Industry Group	IPCC Industry Type	IPCC Degradable Organic Component—COD (g/L)
Food	Vegetables, Fruits, & Juices	5.0
Beverages	Soft Drinks	2.0
Rubber Products	Organic Chemicals	3.0
Plastic Products	Plastics and Resins	3.7
Primary Textiles & Textile Products	Textiles (Natural)	0.9
Wood Products	N/A	N/A
Paper & Allied Products	Pulp & Paper (Combined)	9.0
Primary Metals	N/A	N/A
Fabricated Metals	N/A	N/A
Transportation Equipment	N/A	N/A
Non-Metallic Mineral Products	N/A	N/A
Petroleum & Coal Products	Petroleum Refineries	1.0
Chemicals & Chemical Products	Organic Chemicals	3.0

Notes:

Sources: IPCC (2000), except for Industry Group, which is from Environment Canada (1986, 1991, 1996a).

N/A = not available

CH<sub>4</sub> emissions for industrial wastewater treatment are calculated on a national level as follows:

**Equation A3-70:**

$$\text{CH}_4(\text{Industry Type}) = V_{(\text{Industry Type})} \times \text{COD}_{(\text{Industry Type})} \times \text{EF}_{\text{CH}_4} \times \text{Frac}_{(\text{Anaerobic})}$$

where:

CH <sub>4</sub> (IndustryType)	=	CH <sub>4</sub> emissions generated per industry type, t/year
V <sub>(IndustryType)</sub>	=	volume of wastewater treated, L/year
COD <sub>(IndustryType)</sub>	=	chemical oxygen demand per industry type, kg/L
EF <sub>CH<sub>4</sub></sub>	=	CH <sub>4</sub> emission factor: IPCC default value = 0.000 25 t CH <sub>4</sub> /kg COD
Frac <sub>(Anaerobic)</sub>	=	fraction of anaerobically treated wastewater

### A3.5.2.2 Data Sources

The percentage of municipal wastewater that is treated aerobically (primary and secondary wastewater treatment) and anaerobically (waste stabilization pond treatment) is obtained from the Municipal Water Use Data Base for the following years: 1983, 1986, 1989, 1991, 1994, 1996, and 1999 (Environment Canada 1983–1999).

The volume of industrial wastewater treated is obtained from surveys conducted by Environment Canada for the years 1986, 1991, and 1996.

## A3.5.3 N<sub>2</sub>O Emissions from Wastewater Treatment

### A3.5.3.1 Methodology

The N<sub>2</sub>O emissions from municipal wastewater treatment facilities are calculated using the IPCC default method (IPCC/OECD/IEA 1997). This method estimates emissions based on the amount of nitrogen in sewage and the assumption that 0.01 kg N<sub>2</sub>O-N/kg sewage nitrogen will be generated.

To estimate the amount of nitrogen in sewage, it is assumed that protein is 16% nitrogen (IPCC/OECD/IEA 1997). The Canadian protein consumption is obtained from the annual food statistics publication (Statistics Canada 2005, 2006a), as shown in Table A3-49. Data are provided for the years 1991, 1996, and 2001–2006. Protein consumption data for missing years are estimated by applying a multiple linear regression application to the Statistics Canada data.

**Table A3-49: Canadian Protein Consumption**

Year	Protein Consumption (g/capita per day)
1990	70.53
1991 <sup>a</sup>	68.48
1992	71.26
1993	71.64
1994	72.02
1995	72.39
1996 <sup>a</sup>	71.22
1997	73.09
1998	73.40
1999	73.67
2000	73.91
2001 <sup>a</sup>	75.94
2002 <sup>a</sup>	75.44
2003 <sup>a</sup>	74.43
2004 <sup>a</sup>	75.10
2005 <sup>a</sup>	74.47
2006 <sup>b</sup>	72.34

Sources

a. Statistics Canada (2005). The data have been adjusted for retail, household, cooking, and plate loss.

b. Statistics Canada (2006a). The data have been adjusted for retail, household, cooking, and plate loss.

The N<sub>2</sub>O emission factor is calculated as follows:

**Equation A3-71:**

$$EF_{N_2O} = PC \times EF_{N_2O-N} \times \text{Frac}_{NPR} \times \frac{44}{28}$$

where:

EF <sub>N<sub>2</sub>O</sub>	=	emission factor: kg N <sub>2</sub> O/capita per year
PC	=	annual per capita protein consumption, kg/capita per year (Statistics Canada, 2005 and 2006a)
EF <sub>N<sub>2</sub>O-N</sub>	=	emission factor: default 0.01 (0.002–0.12) kg N <sub>2</sub> O-N/kg sewage nitrogen produced
Frac <sub>NPR</sub>	=	fraction of nitrogen in protein: default = 0.16 kg N/kg protein
44/28	=	stoichimetric factor to convert nitrogen to N <sub>2</sub> O

Emissions are calculated by multiplying the emission factor by the population of the respective provinces (Statistics Canada 2006b, 2007b):

**Equation A3-72:**

$$N_2O_s = EF_{N_2O} \times NR_{PEOPLE}$$

where:

$N_2O_s$	=	$N_2O$ emissions from human sewage, kg $N_2O$ /year
$EF_{N_2O}$	=	emission factor: kg $N_2O$ /capita per year (Equation A3-71).
$NR_{PEOPLE}$	=	number of people in country

### A3.5.3.2 Data Sources

The Canadian protein consumption data are obtained from the annual food statistics publication (Statistics Canada 2005, 2006a).

The provincial populations are obtained from Statistics Canada (Statistics Canada 2006b, 2007b).

## A3.5.4 CO<sub>2</sub> Emissions from Municipal Waste Incineration

### A3.5.4.1 Methodology

The IPCC decision tree in Figure 5.5 of IPCC (2000) for CO<sub>2</sub> emissions from waste incineration defines good practice in adapting the methods in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997). Country-specific carbon contents are not available; thus, Box 2 of the decision tree in Figure 5.5 (IPCC) is the chosen methodology for calculation of CO<sub>2</sub> emissions.

The following steps detail the methodology for the estimation of CO<sub>2</sub> emissions from waste incineration:

*Calculating the Amount of Waste Incinerated:* The amount of waste incinerated each year is based on two primary sources. The amount of MSW incinerated in the year 1992 was estimated based on a study performed by the Hazardous Waste Branch of Environment Canada (Environment Canada 1996b). The amount of MSW incinerated for the years 1999, 2000, and 2001 was estimated based on the study “Municipal Solid Waste Incineration in Canada: An Update on Operations 1999–2001, performed by A.J. Chandler & Associates Ltd. for Environment Canada (Environment Canada 2003b). A polynomial curve-fitting equation is employed to estimate the amount of MSW incinerated over the period 1991–1998 based on the values provided by A.J. Chandler & Associates Ltd. and Environment Canada. To estimate the coefficients in the polynomial, a multiple linear regression application (Microsoft Excel LINEST statistical tool for an array) is used. A polynomial of the order 13 provides the best fit. This multiple linear regression method of estimation is consistent with the IPCC interpolation method (IPCC 2000). To estimate the amount of MSW incinerated for 2002–2006, a trend extrapolation was performed with the A.J. Chandler & Associates Ltd. and Environment Canada MSW incineration values for all relevant provinces except Quebec and Ontario, for which only the former MSW incineration values were used. In the province of Ontario, one of the incineration plants closed at the end of 2001. Therefore, the amount of waste incinerated in Ontario for the period 2002–2006 is estimated by trending the A.J. Chandler & Associates Ltd. incineration values for 1999–2001 with population (Statistics Canada 2006b, 2007b), assuming that the Ontario incineration plant was closed for this period.

MSW incineration estimates for the period 1990–2006 are shown in Table A3-50.

**Table A3-50: Estimated MSW Incinerated by Province for 1990–2006**

Year	MSW Incinerated (t)					
	NL	PE	NS	QC	ON	BC
1990	0	32 000	76 500	619 522	258 700	239 752
1991	0	32 000	53 458	564 219	266 361	252 214
1992	35 500	29 800	56 700	541 100	277 000	257 500
1993	0	32 000	57 953	530 107	255 272	262 964
1994	0	32 000	57 564	508 308	251 779	265 179
1995	0	32 000	55 924	483 314	249 873	265 668
1996	0	32 000	53 421	455 098	249 719	264 723
1997	0	32 000	50 443	423 631	251 484	262 637
1998	0	32 000	47 385	388 882	255 337	259 705
1999	0	32 212	45 000	298 904	258 429	254 800
2000	0	33 000	42 000	303 887	270 811	256 400
2001	0	32 224	42 000	303 910	281 671	246 700
2002	0	32 687	41 965	307 941	165 943 <sup>1</sup>	251 783
2003	0	32 870	40 013	311 166	180 435 <sup>1</sup>	251 401
2004	0	33 122	38 606	314 743	194 675 <sup>1</sup>	250 937
2005	0	33 274	40 522	317 975	207 781 <sup>1</sup>	250 397
2006	0	33 199	41 436	321 466	220 410 <sup>1</sup>	249 823

Note:

1. Ontario incineration plant closed as of 2001 year end.

*Developing Emission Factors:* Provincial CO<sub>2</sub> emission factors are developed based on a study performed by the Hazardous Waste Branch of Environment Canada (Environment Canada 1996b). The CO<sub>2</sub> emission factors are founded on the assumption that carbon contained in waste undergoes complete oxidation to CO<sub>2</sub>.

The provincial breakdown in the type of waste incinerated for 1992 was estimated by the Hazardous Waste Branch of Environment Canada (Environment Canada 1996b). The quantity of waste incinerated was divided into three categories: paper, plastics, and organics. Consistent with the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997), only CO<sub>2</sub> emissions resulting from the incineration of carbon in waste of fossil origin (e.g. plastics, certain textiles, rubber, liquid solvents, and waste oil) are included in emission estimates (IPCC 2000). Therefore, it is necessary to estimate the fossil origin portion of the waste in order to develop an emission factor that excludes emissions due to the incineration of biomass. The breakdown in organic composition is estimated by averaging waste composition data from three published documents (Environment Canada 1994, 1995a, 1995b). Table A3-51 shows the averaged breakdown in organic composition.

**Table A3-51: Estimated MSW Organic Composition**

Component	% Composition of Total Organics
Yard/Garden Waste	41
Food Waste	31
Wood Waste	16
Textiles	10
Rubber	2
Other	0
Total Organics	100



The amount of fossil fuel-based carbon available in the waste incinerated is determined using typical percent weight carbon content values. Carbon and moisture content values were provided by Tchobanoglous et al. (1993) and Peavy et al. (1985). The amount of carbon per tonne of waste is estimated by subtracting the moisture content from the mass of fossil origin waste and multiplying by the carbon content value of the waste type. The fossil origin portion of the organic waste is determined by multiplying the organic waste by the percent fossil origin composition as follows:

**Equation A3-73:**

$$\text{Waste Type}_{\text{Fossil-Origin}} = M_{\text{Total}} \times (1 - \% \text{ Organic}_{\text{Comp}})$$

where:

$\text{Waste Type}_{\text{Fossil-Origin}}$	=	amount of fossil fuel-based waste incinerated, t (1992 data provided by Environment Canada 1996b)
$M_{\text{Total}}$	=	amount of waste incinerated, t (1992 data provided by Environment Canada)
$\% \text{ Organic}_{\text{Comp}}$	=	% organic composition per waste type (Environment Canada 1994, 1995a, 1995b)

The amount of fossil fuel-based carbon is converted to tonnes of CO<sub>2</sub> per tonne of waste by multiplying by the ratio of the molecular mass of CO<sub>2</sub> to that of carbon. The derivation of the CO<sub>2</sub> emission factor is shown in the following equations:

**Equation A3-74:**

$$C_{\text{Avail}(y)} = (\text{Waste Type}_{\text{Fossil-Origin}}) \times (1 - \% \text{ Moisture}) \times \% C_{\text{Waste Type}}$$

where:

$C_{\text{Avail}(y)}$	=	available carbon per waste type for province y, t
$\text{Waste Type}_{\text{Fossil-Origin}}$	=	amount of fossil fuel-based waste incinerated, t (1992 data provided by Environment Canada)
$\% \text{ Moisture}$	=	% moisture content per waste type (Tchobanoglous et al. 1993)
$\% C_{\text{Waste Type}}$	=	% carbon content per waste type (dry basis) (Tchobanoglous et al. 1993)

**Equation A3-75:**

$$\text{EF}_{\text{CO}_2 - 1992(y)} = \left( \frac{\sum C_{\text{Avail}(y)}}{M_{\text{Inc}(y)}} \right) \times \frac{44}{12}$$

where:

$\text{EF}_{\text{CO}_2 - 1992(y)}$	=	1992 CO <sub>2</sub> emission factor for incineration for province y, t CO <sub>2</sub> /t waste incinerated
$C_{\text{Avail}(y)}$	=	available carbon per waste type for province y, t ( <i>See Equation A3-74</i> )
$M_{\text{Inc}(y)}$	=	total mass waste incinerated in 1992 for province y, t
44/12	=	stoichiometric factor to convert carbon to CO <sub>2</sub>

*Calculating CO<sub>2</sub> Emissions:* Emissions were calculated on a provincial level by multiplying the amount of waste incinerated by the appropriate emission factors.

**Equation A3-76:**

$$\text{CO}_{2(x)} = \text{EF}_{\text{CO}_2-1992} \times (\text{M}_{\text{Inc}(x)/\text{province}})$$

where:

$\text{CO}_{2(x)}$	=	$\text{CO}_2$ emissions from waste incineration in year x, t/province per year
$\text{EF}_{\text{CO}_2-1992}$	=	1992 provincial $\text{CO}_2$ emission factor for incineration, t $\text{CO}_2$ /t incinerated
$\text{M}_{\text{Inc}(x)/\text{province}}$	=	mass waste incinerated per province in year x, t/year

**A3.5.4.2 Data Sources**

The amount of MSW incinerated in the year 1992 was estimated by the Hazardous Waste Branch of Environment Canada (Environment Canada 1996b). The amount of MSW incinerated for the years 1999, 2000, and 2001 was estimated by A.J. Chandler & Associates Ltd. for Environment Canada (Environment Canada 2003b).

The amount of fossil fuel-based carbon available in the waste incinerated is determined using typical percent weight carbon constants. Carbon constants and moisture contents were provided by Tchobanoglous et al. (1993) and Peavy et al. (1985).

**A3.5.5 N<sub>2</sub>O Emissions from Waste Incineration****A3.5.5.1 Methodology****Municipal Solid Waste Incineration**

Emissions of  $\text{N}_2\text{O}$  from MSW incineration are estimated using the assumption that the IPCC five-stoker facility factors are most representative. The average  $\text{N}_2\text{O}$  emission factor over the range given as IPCC default values for MSW five-stoker facilities is 0.148 kg/t waste incinerated (IPCC/OECD/IEA 1997). To estimate emissions, the calculated factor is multiplied by the amount of waste incinerated by each province. The national emission values are then determined as the summation of these emissions for all provinces.

**Equation A3-77:**

$$\text{N}_2\text{O}_{\text{MSW}} = \text{M}_{\text{MSW}} \times \text{EF}_{\text{N}_2\text{O-MSW}}$$

where:

$\text{N}_2\text{O}_{\text{MSW}}$	=	$\text{N}_2\text{O}$ emissions from municipal solid waste incineration, t/year
$\text{M}_{\text{MSW}}$	=	mass of municipal solid waste incinerated, t/year
$\text{EF}_{\text{N}_2\text{O-MSW}}$	=	MSW $\text{N}_2\text{O}$ emission factor (0.148 kg $\text{N}_2\text{O}$ /t MSW incinerated / 1000 kg/t)

**Sewage Sludge Incineration**

Emissions of  $\text{N}_2\text{O}$  from sewage sludge incineration are estimated using the IPCC default emission factor for fluidized beds, 0.8 kg/t of dried sewage sludge incinerated (IPCC 2000). To estimate emissions, the calculated factor is multiplied by the amount of waste incinerated by each province. The national emission values are then determined as the summation of these emissions for all provinces.

**Equation A3-78:**

$$N_2O_{SS} = M_{SS} \times EF_{N_2O-SS}$$

where:

$N_2O_{SS}$	=	$N_2O$ emissions from sewage sludge incineration, t/year
$M_{SS}$	=	mass of dried sewage sludge incinerated, t/year
$EF_{N_2O-SS}$	=	sewage sludge $N_2O$ emission factor (0.8 kg $N_2O$ /t dried sludge incinerated / 1000 kg/t)

**A3.5.5.2 Data Sources**

Data sources for MSW incineration are described in Section A.3.5.4.2.

Estimates of the amount of dried solids in the sewage sludge incinerated in the years 1990–1992 are based on a study completed in 1994 (Fettes, personal communication, 1994). Data for the years 1993–1996 were acquired through telephone surveys of facilities that incinerate sewage sludge (Environment Canada 1997). Data for the years 1997 and 1998 are based on a study prepared by Compass Environmental Inc. for Environment Canada (Environment Canada 1999). Activity data for the years 1999, 2000, and 2001 are taken from a study prepared by A.J. Chandler & Associates Ltd. for Environment Canada (Environment Canada 2003b).

**A3.5.6 CH<sub>4</sub> Emissions from Waste Incineration****A3.5.6.1 Methodology**

CH<sub>4</sub> emissions from the incineration of MSW are assumed to be negligible. However, waste incineration of the biosolids resulting from municipal wastewater treatment does produce CH<sub>4</sub> emissions. The IPCC does not provide a methodology for CH<sub>4</sub> emissions from waste incineration, but recommends that national experts use existing published methods (IPCC 2000).

Emissions of CH<sub>4</sub> are estimated based on emission factors obtained from the U.S. EPA (EPA 1995). The emission factors are 1.6 t/kt of total dried solids for fluidized bed sewage incinerators and 3.2 t/kt of dried solids for multiple hearth incinerators, both equipped with venturi scrubbers. It is assumed that all incinerators are of the fluidized bed type.

CH<sub>4</sub> emissions from sewage sludge incineration are dependent on the amount of dried solids incinerated. To calculate the CH<sub>4</sub> emissions, the amount of dried solids incinerated is multiplied by an appropriate emission factor. Estimates of the amount of dried solids in the sewage sludge incinerated in the years 1990–1992 are based on a study completed in 1994 (Fettes, personal communication, 1994). Data for the years 1993–1996 were acquired through telephone surveys of facilities that incinerate sewage sludge (Environment Canada 1997). Data for the years 1997 and 1998 are based on a study prepared by Compass Environmental Inc. for Environment Canada (Environment Canada 1999). Activity data for the years 1999, 2000, and 2001 are taken from a study prepared by A.J. Chandler & Associates Ltd. for Environment Canada (Environment Canada 2003b). To estimate the amount of sewage sludge incinerated in the years 2002–2006, a linear regression analysis is completed using the A.J. Chandler & Associates Ltd. and Compass Environmental Inc. MSW incineration values.

In view of the relatively small number of facilities that incinerate sewage sludge in Canada, we believe that all relevant facilities were contacted, and we expect that the activity data collected from all three sources of information are complete. As such, our approach in estimating the amount of sewage sludge incinerated over the time series years is consistent.

Sewage sludge incineration estimates for the period 1990–2006 are shown in Table A3-52.

**Table A3-52: Estimated Sewage Sludge Incinerated for 1990–2006**

Year	Sewage Sludge Incinerated (t, dry basis)				
	QC	ON	SK	AB	National Total
1990	49 200	222 795	1 840	0	273 835
1991	59 400	222 795	1 840	0	284 035
1992	79 800	222 795	1 840	0	304 435
1993	64 833	129 125	71	0	194 029
1994	100 181	93 072	59	0	193 311
1995	101 356	113 985	152	0	215 493
1996	93 276	112 697 <sup>1</sup>	70	0	206 043
1997	15 424	0	0	4 885	20 310
1998	18 341	0	0	4 951	23 292
1999	22 032	0	0	0	22 032
2000	24 651	0	0	0	24 651
2001	27 960	0	0	0	27 960
2002	31 096	0	0	0	31 096
2003	34 234	0	0	0	34 234
2004	37 373	0	0	0	37 373
2005	40 511	0	0	0	40 511
2006	43 649	0	0	0	43 649

Note:

1. A large step change is observed in the quantities of sewage sludge incinerated in Ontario for the period 1996–1997. This is as a result of two pilot projects that were approved in the mid-1990s for the non-incineration waste disposal of sewage sludge. The first project involved the spreading of treated sewage sludge on farmers' fields outside of Toronto, and the second project involved the transportation of sewage sludge to be spread on mine tailings. Both projects proved to have difficulties, owing to odour problems and the large quantities of waste that were to be spread on farmers' fields. From 1996 to 2000, Toronto sludge was stored during periods when excess quantities of waste were unable to be applied on land. In 2001, a new contract commenced that involved the spread of biosolids on Ontario farmers' fields, with excess biosolids being shipped to U.S. landfill sites.

CH<sub>4</sub> emissions are calculated as follows:

**Equation A3-79:**

$$\text{CH}_{4(s)} = S_{\text{Inc}} \times \text{EF}_{\text{CH}_4 - \text{FB}}$$

where:

CH <sub>4(s)</sub>	=	CH <sub>4</sub> emissions from waste incineration, t/year
S <sub>Inc</sub>	=	sewage sludge incinerated, dry t/year
EF <sub>CH<sub>4</sub>-FB</sub>	=	CH <sub>4</sub> emission factor for fluidized bed incinerators: 1.6 t CH <sub>4</sub> /kt sewage sludge incinerated / 1000 kg/t

### A3.5.6.2 Data Sources

Estimates of the amount of dried solids in the sewage sludge incinerated in the years 1990–1992 are based on a study completed in 1994 (Fettes, personal communication, 1994). Data for the years 1993–1996 were acquired through telephone surveys of facilities that incinerate sewage sludge (Environment Canada 1997). Data for the years 1997 and 1998 are based on a study prepared by Compass Environmental Inc. for Environment Canada (Environment Canada 1999).

Activity data for the years 1999, 2000, and 2001 are taken from a study prepared by A.J. Chandler & Associates Ltd. for Environment Canada (Environment Canada 2003b).

## ***References***

### **A3.1, METHODOLOGY FOR FUGITIVE EMISSIONS FROM FOSSIL FUEL PRODUCTION, PROCESSING, TRANSMISSION, AND DISTRIBUTION**

---

[AEUB] Alberta Energy and Utilities Board. 2006. Alberta Drilling Activity: Monthly Statistics. Available online at: <http://www.ercb.ca/docs/products/STs/st59/st59-2006.pdf>

[AEUB] Alberta Energy and Utilities Board. EUB Provincial Surveillance and Compliance Summary 2006: ST99-2007. Available online at: [http://www.ercb.ca/docs/products/STs/st99\\_current.pdf](http://www.ercb.ca/docs/products/STs/st99_current.pdf)

[AEUB] Alberta Energy and Utilities Board. ST-43: Mineable Alberta Oil Sands Annual Statistics. Available online at: [http://www.ercb.ca/portal/server.pt/gateway/PTARGS\\_0\\_0\\_308\\_0\\_0\\_43/http%3B/ercbContent/publishedcontent/publish/ercb\\_home/publications\\_catalogue/publications\\_available/serial\\_publications/st43.aspx](http://www.ercb.ca/portal/server.pt/gateway/PTARGS_0_0_308_0_0_43/http%3B/ercbContent/publishedcontent/publish/ercb_home/publications_catalogue/publications_available/serial_publications/st43.aspx)

British Columbia Ministry of Energy and Mines. 2007. Oil and Gas Production and Activity in British Columbia: Statistics and Resource Potential 1996-2006. Available online at: [http://www.em.gov.bc.ca/subwebs/oilandgas/pub/5839\\_OilnGas\\_Bro.pdf](http://www.em.gov.bc.ca/subwebs/oilandgas/pub/5839_OilnGas_Bro.pdf)

Canada-Newfoundland and Labrador Offshore Petroleum Board. 2007. Development Wells - Hibernia. Available online at: <http://www.cnlopb.nl.ca/>

Canada-Newfoundland and Labrador Offshore Petroleum Board. 2007. Development Wells - Terra Nova. Available online at: <http://www.cnlopb.nl.ca/>

Canada-Newfoundland and Labrador Offshore Petroleum Board. 2007. Development Wells - White Rose. Available online at: <http://www.cnlopb.nl.ca/>

[CAPP] Canadian Association of Petroleum Producers. 1999. CH<sub>4</sub> and VOC Emissions from the Canadian Upstream Oil and Gas Industry, Vols. 1 and 2. Prepared for the Canadian Association of Petroleum Producers. Calgary (AB): Clearstone Engineering Ltd. Publication No. 1999-0010.

[CAPP] Canadian Association of Petroleum Producers. 2005a. A National Inventory of Greenhouse Gas (GHG), Criteria Air Contaminant (CAC) and Hydrogen Sulphide (H<sub>2</sub>S) Emissions by the Upstream Oil and Gas Industry, Vols. 1-5. Calgary (AB): Clearstone Engineering Ltd. January.

[CAPP] Canadian Association of Petroleum Producers. 2005b. Extrapolation of the 2000 UOG Emission Inventory to 2001, 2002 and 2003. Calgary (AB): Clearstone Engineering Ltd.

[CAPP] Canadian Association of Petroleum Producers. 2006. An Inventory of GHGs, CACs, and H<sub>2</sub>S Emissions by the Canadian Bitumen Industry: 1990 to 2003. Calgary (AB): Clearstone Engineering Ltd.

[CAPP] Canadian Association of Petroleum Producers. 2007. Industry Facts and Information by Region and Province 2006. Available online at: [http://www.capp.ca/default.asp?V\\_DOC\\_ID=6](http://www.capp.ca/default.asp?V_DOC_ID=6)

[CGA] Canadian Gas Association. 1997. 1995 Air Inventory of the Canadian Natural Gas Industry. Calgary (AB): Radian International LLC.

[CPPI] Canadian Petroleum Products Institute. 2004. Economic and Environmental Impacts of Removing Sulphur from Canadian Gasoline and Distillate Production. Calgary (AB): Levelton Consultants Ltd. in association with Purvin & Gertz Inc. August.

Environment Canada. 2007. Bitumen-Oil Sands Extrapolation Model – Rev 3. Calgary (AB): Clearstone Engineering Ltd.

Hollingshead B. 1990. Methane Emissions from Canadian Coal Operations: A Quantitative Estimate. Devon (AB): Coal Mining Research Company. Report CI 8936.

King B. 1994. Management of Methane Emissions from Coal Mines: Environmental, Engineering, Economic and Institutional Implications of Options. Report prepared by Neill and Gunter for Environment Canada.

Manitoba Science, Technology, Energy and Mines. Manitoba Petroleum Statistics. Available online at: <http://www.gov.mb.ca/iedm/petroleum/stats/index.html>

[NEB] National Energy Board. Estimated Production of Canadian Crude Oil and Equivalent. Available online at: <http://www.neb-one.gc.ca/clf-nsi/rnrgynfmrtn/sttsc/crdlndptrlmprdct/stmtdprdctn-eng.html>

Saskatchewan Industry and Resources. 2006-2007 Annual Report. Government of Saskatchewan. Available online at: <http://www.ir.gov.sk.ca/default.aspx?DN=4157,3087,2936,Documents>

Saskatchewan Industry and Resources. Monthly Production and Disposition of Crude Oil at the Producer Level, Ending Month 12.

Statistics Canada. Confidential communication with Statistics Canada.

Statistics Canada. Report on Energy Supply–Demand in Canada (Annual). Catalogue # 57-003-XIB.

Statistics Canada. Coal and Coke Statistics. Catalogue # 45-002.

Statistics Canada. Natural Gas Transportation and Distribution. Catalogue # 57-205.

Statistics Canada. Table 126-0001 - Supply and disposition of crude oil and equivalent, monthly (cubic metres). CANSIM. Available online at: <http://cansim2.statcan.ca/>

Statistics Canada. Table 131-0001 – Supply and disposition of natural gas, monthly (cubic metres). CANSIM. Available online at: <http://cansim2.statcan.ca/>

### **A3.2, Methodology for Industrial Processes**

---

Cheminfo Services. 2005. Improvements to Canada's Greenhouse Gas Emissions Inventory Related to Non-Energy Use of Hydrocarbon Products. Final Report, Markham, Ontario, Canada, March.

Cheminfo Services. 2006. Improvements and Updates to Certain Industrial Process and Solvent Use-Related Sections in Canada's Greenhouse Gas Inventory. Final Report, Markham, Ontario, Canada, September.

[IPCC] Intergovernmental Panel on Climate Change. 2000. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at: <http://www.ipcc-nggip.iges.or.jp/public/gp/english/>

[IPCC/OECD/IEA] Intergovernmental Panel on Climate Change, Organisation for Economic Co-operation and Development, and International Energy Agency. 1997. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Available online at: <http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm>

Jaques AP. 1992. Canada's Greenhouse Gas Emissions: Estimates for 1990, Environmental Protection, Conservation and Protection, Environment Canada. Report EPS 5/AP/4.

Lowenheim FA, Moran M. 1980. (Faith, Keyes and Clark's) Industrial Chemicals. J. Wiley & Sons, New York, N.Y., U.S.A.

McCann TJ. 2000. 1998 Fossil Fuel and Derivative Factors, Prepared by T.J. McCann and Associates for Environment Canada, March.

Statistics Canada. Industrial Chemicals and Synthetic Resins, 1990–2005 (Monthly). Catalogue # 46-002-XIE.

Statistics Canada. Report on Energy Supply–Demand in Canada (Annual). Catalogue # 57-003-XIB.

### **A3.3, AGRICULTURE**

---

[AAFRD] Alberta Agriculture, Food and Rural Development. 2001. Alberta Cow–Calf Audit, 1997/1998 Production Indicators and Management Practices over the Last 10 Years. Edmonton, Alberta, Canada.

[AAFRD and University of Alberta] Alberta Agriculture, Food and Rural Development and University of Alberta. 2003. Development of a Farm-Level Greenhouse Gas Assessment: Identification of Knowledge Gaps and Development of a Science Plan, Alberta Agricultural Research Institute (AARI) Project No. 2001J204.

Agriculture and Agri-Food Canada. 1990-2006. Annual Livestock and Meat Report. Available online at: <http://www.agr.gc.ca/redmeat/almr/calendar.htm>

Agriculture and Agri-Food Canada. 2005a. Dairy Animal Improvement Statistics. Dairy Section, Animal Industry Division, Agriculture and Agri-Food Canada.

Agriculture and Agri-Food Canada. 2005b. Statistics of the Canadian Dairy Industry. Dairy Section, Animal Industry Division, Agriculture and Agri-Food Canada.

Agriculture and Agri-Food Canada. 2006. Statistics of the Canadian dairy industry. Dairy Section, Animal Industry Division. Available online at <http://www.dairyinfo.gc.ca>

Arrouays D, Saby N, Walter C, Lemerrier B, Schwart C. 2006. Relationships between particle-size distribution and organic carbon in French arable topsoils. *Soil Use Manag.* 22:48–51.

Boadi DA, Ominski KH, Fulawka DL, Wittenberg KM. 2004. Improving Estimates of Methane Emissions Associated with Enteric Fermentation of Cattle in Canada by Adopting an IPCC (Intergovernmental Panel on Climate Change) Tier-2 Methodology. Final report submitted to the Greenhouse Gas Division, Environment Canada, by the Department of Animal Science, University of Manitoba, Winnipeg, Manitoba, Canada.

Bouwman AF, Boumans LJM, Batjes NH. 2002. Emissions of N<sub>2</sub>O and NO from fertilized fields: Summary of available data. *Global Biogeochem. Cycles* 16:doi:10.1029/2001GB001811.

Bouwman AF. 1996. Direct emission of nitrous oxide from agricultural soils. *Nutrient Cycling in Agroecosystems.* 46: 53–70.

Campbell CA, Zentner RP, Janzen HH, Bowren KE. 1990. Crop Rotation Studies on the Canadian Prairie. Canadian Government Publishing Centre. Ottawa, Ontario, Canada.

[CANSIM] Canadian Socio-Economic Information Management System [database on the Internet]. Statistics Canada; [updated daily; cited 2008 January 10]. Available online at: <http://cansim2.statcan.ca/>

Chadwick DR, Sneath RW, Phillips VR, Pain BF. 1999. A UK inventory of nitrous oxide emissions from farmed livestock. *Atmos. Environ.* 33:3345–3354.

Chang C, Janzen HH. 1996. Long-term fate of nitrogen from annual feedlot manure applications. *Journal of Environmental Quality.* 25: 785–790.

Christensen DA, Steacy G, Crowe WL. 1977. Nutritive value of whole crop cereal silages. *Canadian Journal of Animal Science,* 57: 803–805.

Corre MD, Van Kessel C, Pennock DJ. 1996. Landscape and seasonal patterns of nitrous oxide emissions in a semiarid region. *Soil Science Society of America Journal.* 60: 1806–1815.

Corre MD, Pennock DJ, Van Kessel C, Elliott DK. 1999. Estimation of annual nitrous oxide emissions from a transitional Grassland–Forest region in Saskatchewan, Canada. *Biogeochemistry.* 44: 29–49.

[CRAAQ] Centre de référence en agriculture et agroalimentaire du Québec. 1999. Chèvres laitières—Budget: Production laitière. Centre de Référence en Agriculture et Agroalimentaire du Québec. Agdex 435/821. Comité de références économiques en agriculture du Québec. Group GRÉAGRI inc.

da Sylva AP, Kay BD. 1997. Estimating the least limiting water range of soils from properties and management. *Soil Science Society of American Journal.* 61:877–883.



Decisioneering. 2000. Crystal Ball®, Decisioneering Inc., Denver, Colorado, U.S.A. Available online at: <http://www.crystalball.com>

Dobbie KE, McTaggart IP, Smith KP. 1999. Nitrous oxide emissions from intensive agricultural systems: Variations between crops and seasons, key driving variables and mean emission factors. *Journal of Geophysical Research*. 104: 26891–26899.

Environment Canada. 2002. Canadian Climate Normals—Precipitation. Available online at: [http://www.climate.weatheroffice.ec.gc.ca/prods\\_servs/cdcd\\_iso\\_e.html?&](http://www.climate.weatheroffice.ec.gc.ca/prods_servs/cdcd_iso_e.html?&)

[EPA] United States Environmental Protection Agency. 2004. National Emission Inventory—Ammonia Emissions from Animal Husbandry Operations. Draft report. U.S. Environmental Protection Agency. Washington, D.C., U.S.A., January 30.

Flynn HC, Smith JO, Smith KA, Wright J, Smith P, Massheder J. 2005. Climate- and crop-responsive emission factors significantly alter estimates of current and future nitrous oxide emissions from fertilizer use. *Global Change Biology*. 11: 1522–1536.

Freibauer A. 2003. Regionalized inventory of biogenic greenhouse gas emissions from European agriculture. *Europ. J. Agron*. 19:135-160.

Goss MJ, Goorahoo D. 1995. Nitrate contamination of groundwater: measurement and prediction. *Fertilizer Research*. 42: 331–338.

Grant R, Pattey E. 1999. Mathematical modeling of nitrous oxide emissions from an agricultural field during spring thaw. *Glob. Biogeochem. Cycles* 13: 679–694.

Gregorich EG, Rochette P, VandenBygaart AJ, Angers DA. 2005. Greenhouse gas contributions of agricultural soils and potential mitigation practices in eastern Canada. *Soil & Tillage Research*. 76: 1–20.

Hao X, Chang C, Carefoot JM, Janzen HH, Ellert BH. 2001. Nitrous oxide emissions from an irrigated soil as affected by fertilizer and straw management. *Nutrient Cycling in Agroecosystems*, 60: 1–8.

Hashimoto AG, Varel VH, Chen YR. 1981. Ultimate methane yield from beef cattle manure: effect of temperature, ration constituents, antibiotics and manure age. *Agricultural Wastes*. 3: 241–256.

Hénault C, Devis X, Page S, Justes E, Reau R, Germon J-C. 1998. Nitrous oxide emissions under different soil and land management conditions. *Biology and Fertility of Soils*. 26: 199–207.

Hutchings NJ, Sommer SG, Andersen JM, Asman WAH. 2001. A detailed ammonia emission inventory for Denmark. *Atmospheric Environment*. 35: 1959–1968.

Hybrid Turkeys. 2001. Hybrid Converter—Commercial Hens and Toms. Available online at: <http://www.hybridturkeys.com/Pages/converter.html>

[IPCC] Intergovernmental Panel on Climate Change. 2000. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Intergovernmental Panel on

Climate Change National Greenhouse Gas Inventories Programme. Available online at: <http://www.ipcc-nggip.iges.or.jp/public/gp/english/>

[IPCC] Intergovernmental Panel on Climate Change. 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4: Agriculture, Forestry and Other Land Use. Intergovernmental Panel on Climate Change. Available online at: <http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.htm>

[IPCC/OECD/IEA] Intergovernmental Panel on Climate Change, Organisation for Economic Co-operation and Development, and International Energy Agency. 1997. Revised 1996 IPCC Guidelines for Greenhouse Gas Inventories. Available online at: <http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm>

Izaurrealde RC, Lemke RL, Goddard TW, McConkey B, Zhang Z. 2004. Nitrous oxide emissions from agricultural toposequences in Alberta and Saskatchewan. *Soil Science Society of America Journal*. 68: 1285–1294.

Jambert C, Delmas R, Serça D, Thouron L, Labroue L, Delprat L. 1997. N<sub>2</sub>O and CH<sub>4</sub> emissions from fertilized agricultural soils in southwest France. *Nutrient Cycling in Agroecosystems*. 48: 105–114.

Janzen HH, Beauchemin KA, Bruinsma Y, Campbell CA, Desjardins RL, Ellert BH, Smith EG. 2003. The fate of nitrogen in agroecosystems: an illustration using Canadian estimates. *Nutrient Cycling in Agroecosystems*. 67: 85–102.

Kononoff PJ, Mustafa AF, Christensen DA, McKinnon JJ. 2000. Effects of barley silage particle length and effective fiber on yield and composition of milk from dairy cows. *Canadian Journal of Animal Science*. 80: 749–752.

Kopp JC, Wittenberg KM, McCaughey WP. 2004. Management strategies to improve cow–calf productivity on meadow brome grass pastures. *Canadian Journal of Animal Science*. 84(3): 529–535.

Korol M. 2003. Canadian Fertilizer Consumption, Shipments and Trade (2002/2003). Farm Input Markets Unit. Farm Income and Adaptation Policy Directorate. Agriculture and Agri-Food Canada.

Lemke RL, Izaurrealde RC, Nyborg M, Solberg ED. 1999. Tillage and N-source influence soil-emitted nitrous oxide in the Alberta Parkland Region. *Canadian Journal of Soil Science*. 79: 15–24.

Liebig MA, Morgan JA, Reeder JD, Ellert BH, Gollany HT, Schuman GE. 2005. Greenhouse gas contributions and mitigation potential of agricultural practices in northwestern USA and western Canada. *Soil & Tillage Research*. 83: 25–52.

MacMillan RA, Pettapiece WW. 2000. Alberta Landforms: Quantitative Morphometric Descriptions and Classification of Typical Alberta Landforms, Semiarid Prairie Agricultural Research Centre, Research Branch, Agriculture and Agri-Food Canada, Swift Current, Saskatchewan, Canada, Technical Bulletin No. 2000-2E, 118 pp.

Manitoba Agriculture and Food. 2000. Manitoba Cattle on Feed 1999/2000. Market Analysis and Statistics Section, Program and Policy Analysis Branch, Manitoba Agriculture and Food.

Marinier M, Clark K, Wagner-Riddle C. 2004. Improving Estimates of Methane Emissions Associated with Animal Waste Management Systems in Canada by Adopting an IPCC Tier-2 Methodology. Final report submitted to the Greenhouse Gas Division, Environment Canada, by the Department of Land Resource Science, University of Guelph, Guelph, Ontario, Canada.

Minasny B, McBratney AB, Bristow KL. 1999. Comparison of different approaches to the development of pedotransfer functions for water-retention curves. *Geoderma*. 93: 225–253.

[NRC] United States National Research Council. 1981. Nutrient Requirements of Goats. National Research Council, National Academy Press, Washington, D.C., U.S.A.

[NRC] United States National Research Council. 1985. Nutrient Requirements of Sheep, 6th Revised Edition. National Research Council, National Academy Press, Washington, D.C., U.S.A.

[NRC] United States National Research Council. 1989. Nutrient Requirements of Horses, 5th Revised Edition. National Research Council, National Academy Press, Washington, D.C., U.S.A.

[NRC] United States National Research Council. 1998. Nutrient Requirements of Swine, 10th Revised Edition. National Research Council, National Academy Press. Washington, D.C., U.S.A.

[NRC] United States National Research Council. 2001. Nutrient Requirements of Dairy Cattle, 7th Revised Edition. National Research Council. National Academy Press. Washington, D.C., U.S.A.

Nyborg M, Solberg ED, Izaurrealde RC, Malhi SS, Molina-Ayala M. 1995. Influence of long-term tillage, straw and N fertilizer on barley yield, plant-N uptake and soil-N balance. *Soil & Tillage Research*. 36: 165–174.

Okine EK, Mathison GW. 1991. Effects of feed intake on particle distribution, passage of digesta, and extent of digestion in the gastrointestinal tract of cattle. *Journal of Animal Science*. 69: 3435–3445.

Paul JW, Zebarth BJ. 1997. Denitrification and nitrate leaching during the fall and winter following dairy cattle slurry application. *Canadian Journal of Soil Science*. 77: 231–240.

Pennock DJ, Corre MD. 2001. Development and application of landform segmentation procedures. *Soil & Tillage Research*. 58: 151–162.

Petit HV, Dewhurst RJ, Proulx JG, Khalid M, Haresign W, Twagiramungu H. 2001. Milk production, milk composition, and reproductive function of dairy cows fed different fats. *Canadian Journal of Animal Science*. 81: 263–271.

Rochette P, Janzen HH. 2005. Towards a revised coefficient for estimating N<sub>2</sub>O from legumes. *Nutrient Cycling in Agroecosystems*. 73: 171–179.

Rochette P, Worth DE, Lemke RL, McConkey BG, Pennock DJ, Wagner-Riddle C, Desjardins RL. 2008. An IPCC Tier II methodology for estimating N<sub>2</sub>O emissions from agricultural soils in Canada. *Canadian Journal of Soil Science* (In press).

Rotz CA. 2004. Management to reduce nitrogen losses in animal production. *Journal of Animal Science*. 82(Suppl.): E119–E137.

Safely LM Jr, Casada MF, Woodbury JW, Roos KF. 1992. Global Methane Emissions from Livestock and Poultry Manure. Research Report. U.S. Environmental Protection Agency, Washington, D.C., U.S.A.

Small JA, McCaughey WP. 1999. Beef cattle management in Manitoba. *Canadian Journal of Animal Science*. 79: 539–544.

Statistics Canada. 1987. Agriculture, Census Canada 1986. Statistics Canada. Catalogue 96-102.

Statistics Canada. 1992. Agricultural Profile of Canada in 1991. Census of Agriculture. Catalogue # 93350.

Statistics Canada. 1997. Agricultural Profile of Canada in 1996. Census of Agriculture. Catalogue # 93356.

Statistics Canada. 2002. Agricultural Profile of Canada in 2001. Census of Agriculture. Catalogue # 95F0301XIE.

Statistics Canada. 2006. Field Crop Reporting Series, 1990–2006 (Annual). Catalogue # 22-002.

Statistics Canada. 2007. Selected Historical Data from the Census of Agriculture. Catalogue # 95-632.

Statistics Canada. 2008. Alternative Livestock on Canadian Farms. Census years 1981, 1986, 1991, 1996, 2001 and 2006. Catalogue # 23-502-X.

Wagner-Riddle C, Furon A, McLaughlin NL, Lee I, Barbeau J, Jayasundara S, Parkin G, von Bertoldi P, Warland J. 2007. Intensive measurement of nitrous oxide emissions from a corn soybean wheat rotation under two contrasting management systems over 5 years. *Global Change Biol*. 13:1722-1736.

Wagner-Riddle C, Thurtel GW. 1998. Nitrous oxide emissions from agricultural fields during winter and spring thaw as affected by management practices. *Nutrient Cycling in Agroecosystems*. 52: 151–163.

Western Canadian Dairy Herd Improvement Services. 2002. 2002 Herd Improvement Report. Edmonton, Alberta, Canada. 16 pp.

Weston RH. 2002. Constraints on feed intake by grazing sheep. In: M. Freer and H. Dove (Eds.) *Sheep Nutrition*. CSIRO Publishing. Collingwood, Australia.

Yang JY, De Jong R, Drury CF, Huffman E, Kirkwood V, Yang XM. 2007. Development of a Canadian agricultural nitrogen model (CANB v2.0): simulation of the nitrogen indicators and integrated modeling for policy scenarios. *Canadian Journal of Soil Science*. 87: 153–165.

Zebarth BJ, Hii B, Liebscher H, Chipperfield K, Paul JW, Grove G, Szeto SY. 1998. Agricultural land use practices and nitrate contamination in the Abbotsford aquifer, British Columbia, Canada. *Agriculture, Ecosystems & Environment*. 69: 99–112.

### A3.4, LULUCF

---

- Anderson HG, Bailey AW. 1980. Effects of annual burning on grassland in the aspen parkland of east-central Alberta. *Canadian Journal of Botany*. 58(8): 985–996.
- Bai Y, Abouguendia Z, Redmann RE. 2001. Relationship between plant species diversity and grassland condition. *Journal of Range Management*. 54: 177–183.
- Baron VS, Mapfumo E, Dick AC, Naeth MA, Okine EK, Chanasyk DS. 2002. Grazing intensity impacts on pasture carbon and nitrogen flow. *Journal of Range Management*. 55(6): 535–541.
- Bartelink HH. 1998. A model of dry matter partitioning in trees. *Tree Physiology*. 18(2): 91–101.
- Blain D, Seed E, Lindsay M. 2007. Forest Land and Other Land Conversion to Wetlands (Reservoirs) Estimation and Reporting of CO<sub>2</sub> Emissions. Draft report. Greenhouse Gas Division, Environment Canada.
- Biederbeck VO, Campbell CA, Zentner RP. 1984. Effect of crop rotation and fertilization on some biological properties of a loam in southwestern Saskatchewan. *Canadian Journal of Soil Science*. 64: 355–367.
- Biondini ME, Manske L. 1996. Grazing frequency and ecosystem processes in a northern mixed prairie, USA. *Ecological Applications*. 6(1): 239–256.
- Bolinder MA. 2004. Contribution aux connaissances de la dynamique du C dans les systèmes sol-plante de l'est du Canada. Ph.D. Thesis, Université Laval, Ste-Foy, Quebec, Canada.
- Boudewyn P, Song X, Magnussen S, Gillis, M, 2007, Model-based, volume-to-biomass conversion MD A.I. for forested and vegetated land in Canada, Natural Resources Canada. Canadian Forest Service, Information Report – BC-X-411
- Bremer E, Janzen HH, Johnston AM. 1994. Sensitivity of total, light fraction and mineralizable organic matter to management practices in a Lethbridge soil. *Canadian Journal of Soil Science*. 74: 131–138.
- Bruce JP, Frome M, Haites E, Janzen H, Lal R, Paustian K. 1999. Carbon sequestration in soils. *Journal of Soil Water Conservation*. 54: 382–389.
- Butson C, Fraser R. 2005. Mapping land cover change and terrestrial dynamics over northern Canada using multi-temporal Landsat imagery. In: *Proceedings of MultiTemp 2005, The Third International Workshop on the Analysis of Multi-temporal Remote Sensing Images*, May 16–18, 2005, Biloxi, Mississippi, U.S.A., Institute of Electrical and Electronics Engineers.
- Campbell CA, McConkey BG, Zentner RP, Dyck RP, Selles F, Curtin D. 1995. Carbon sequestration in a Brown Chernozem as affected by tillage and rotation. *Canadian Journal of Soil Science*. 75: 449–458.
- Campbell CA, McConkey BG, Zentner RP, Selles F, Curtin D. 1996a. Longterm effects of tillage and crop rotations on soil organic C and total N in a clay soil in southwestern Saskatchewan. *Canadian Journal of Soil Science*. 76: 395–401.

- Campbell CA, McConkey BG, Zentner RP, Selles F, Curtin D. 1996b. Tillage and crop rotation effects on soil organic matter in a coarse-textured Typic Haploboroll in southwestern Saskatchewan. *Soil & Tillage Research*. 37: 3–14.
- Campbell CA, Selles F, LaFond GP, McConkey BG, Hahn D. 1998. Effect of crop management on C and N in long-term crop rotations after adopting no-tillage management: Comparison of soil sampling strategies. *Canadian Journal of Soil Science*. 78: 155–162.
- Campbell CA, Zentner RP, Liang BC, Roloff G, Gregorich EG, Blomert B. 2000. Organic C accumulation in soil over 30 years in semiarid southwestern Saskatchewan—Effect of crop rotations and fertilizers. *Canadian Journal of Soil Science*. 80: 179–192.
- Campbell CA, Janzen HH, Paustian K, Gregorich EG, Sherrod L, Liang BC, Zentner RP. 2005. Carbon storage in soils of the North American Great Plains: Effect of cropping frequency. *Agronomy Journal*. 97: 349–363.
- [CanFI]. 1991. Canada's National Forest Inventory, 1994 version. See Low et al. (1994).
- [CanFI] 2001. Canada's National Forest Inventory. Available online at: <http://cfs.nrcan.gc.ca/subsite/canfi/home>. See also Power et al. (2006)
- Carter MR, Kunelius HT, Sanderson JB, Kimpinski J, Platt HW, Bolinder MA. 2003. Trends in productivity parameters and soil health under long-term two-year potato rotations. *Soil & Tillage Research (Special Issue)*. 72: 153–168.
- [CFS] Canadian Forest Service. 2006a. Deforestation Monitoring Pilot Project Reports. Internal report. Pacific Forestry Centre, Canadian Forest Service, Natural Resources Canada, Victoria, British Columbia, Canada.
- [CFS] Canadian Forest Service. 2006b. NIR 2006 Deforestation Area Estimation: Records of Decision. Internal report. Pacific Forestry Centre, Canadian Forest Service, Natural Resources Canada, Victoria, British Columbia, Canada.
- Chen W, Blain D, Li J, Fraser R, Zhang Y, Leblanc S, Keohler K, Zhang Y, Butson C, Olthof I, Oraziatti J, Girouard G, Wang J, Pavlic G, McGovern M, Seed ED. 2005. Estimation of Greenhouse Gas Removals/Emissions due to Land Use Changes over Canada's North during 1985–1990 and 1990–2000. Summary report. Submitted to the Greenhouse Gas Division, Environment Canada.
- Cleary J. 2003. Greenhouse Gas Emissions from Peat Extraction in Canada: A Life Cycle Perspective. M.Sc. Thesis, McGill University, Montréal, Quebec, Canada. C2GCR Report No. 2003-1.
- Coleman HW, Steele JWG. 1999. Experimentation and Uncertainty Analysis for Engineers. John Wiley and Sons, New York, N.Y., U.S.A.
- Conant RT, Paustian K, Elliott ET. 2001. Grassland management and conversion into grassland: Effects on soil carbon. *Ecological Applications*. 11(2): 343–355.

Dormaar JF, Johnston AM, Smoliak S. 1977. Seasonal variation in chemical characteristics of soil organic matter of grazed and ungrazed mixed prairie and fescue grassland. *Journal of Range Management*. 30(3): 195–198.

Duchemin É. 2002. Canadian Reservoir Database / Répertoire des réservoirs canadiens (Computer file). Environment Canada and DREXenvironment (distributor).

Duchemin É. 2006. Émissions de gaz provoquant l'effet de serre à partir des terres inondées au Canada. Final report submitted to the Greenhouse Gas Division, Environment Canada.

Frank AB. 2002. Carbon dioxide fluxes over a grazed prairie and seeded pasture in the Northern Great Plains. *Environmental Pollution*. 116: 397–403.

Fraser R, Olthof I, Girouard G, Pavlic G, Clouston A, Pouliot D, Chen W. 2005. Remote Sensing Based Estimate of Land Use Change Area in Canada's Arctic/Sub-Arctic. Draft final report to the Greenhouse Gas Division, Environment Canada.

Gonzalez-Perez JA, Gonzalez-Vila FJ, Almendros G, Knicker H. 2004. The effect of fire on soil organic matter—a review. *Environment International*. 30(6): 855–870.

Hutchinson JJ, Rochette P, Vergé X, Worth D, Desjardins R. 2007. Uncertainties in Methane and Nitrous Oxide Emissions Estimates from Canadian Agroecosystems Using Crystal Ball. Preliminary report submitted to the Greenhouse Gas Division, Environment Canada, by the Research Branch, Agriculture and Agri-Food Canada.

[IPCC] Intergovernmental Panel on Climate Change. 2003. Good Practice Guidance for Land Use, Land-Use Change and Forestry, Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at: <http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf.htm>

[IPCC] Intergovernmental Panel on Climate Change. 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4: Agriculture, Forestry and Other Land Use, Intergovernmental Panel on Climate Change. Available online at: <http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.htm>

Janzen HH, Campbell CA, Gregorich EG, Ellert BH. 1997. Soil carbon dynamics in Canadian agroecosystems. In: Lal R, Kimble JM, Follett RF, Stewart BA (Eds.) *Soil Processes and Carbon Cycles*. Boca Raton, Florida (US): CRC Press. pp. 57–80.

Janzen HH, Campbell CA, Izaurrealde RC, Ellert BH, Juma N, McGill WB, Zentner RP. 1998. Management effects on soil C storage in the Canadian prairies. *Soil & Tillage Research*. 47: 181–195.

Johnson RD, Kasischke ES. 1998. Change vector analysis: a technique for the multispectral monitoring of land cover and condition. *International Journal of Remote Sensing*. 19: 411–426.

Kurz WA, Apps MJ, Webb TM, McNamee PJ. 1992. The Carbon Budget of the Canadian Forest Sector: Phase 1. Northern Forestry Centre, Forestry Canada, Edmonton, Alberta, Canada. Information Report NOR-X-326.

Kurz WA et al. (in preparation). Operational-Scale Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3) Version 1.0: Scientific Description. Canadian Forest Service, Natural Resources Canada.

Leckie DG, Gillis MD, Wulder MA. 2002. Deforestation estimation for Canada under the Kyoto Protocol: A design study. *Canadian Journal of Remote Sensing*. 28(5): 672–678.

Leckie D, Paradine D, Hardman D, Tinis S. 2006. NIR 2006 Deforestation Area Estimation: Methods Summary. Internal report. Canadian Forest Service, Natural Resources Canada, Victoria, British Columbia, Canada. 13 pp.

Li Z, Kurz WA, Apps MJ, Beukema SJ. 2003. Belowground biomass dynamics in the Carbon Budget Model of the Canadian Forest Sector: recent improvements and implications for the estimation of NPP and NEP. *Canadian Journal of Forest Research*. 33: 126–136.

Liang BC, Gregorich EG, MacKenzie AF. 1996. Modelling the effects of inorganic and organic amendments on organic matter in a Quebec soil. *Soil Science*. 161: 109–114.

Liebig MA, Morgan JA, Reeder JD, Ellert BH, Gollany HT, Schuman GE. 2005. Greenhouse gas contributions and mitigation potential of agricultural practices in northwestern USA and western Canada. *Soil & Tillage Research*. 83(1): 25–52.

Litton CM, Ryan MG, Tinker DB, Knight DH. 2003. Belowground and aboveground biomass in young postfire lodgepole pine forests of contrasting tree density. *Canadian Journal of Forest Research*. 33(2): 351–363.

Lynch DH, Cohen RDH, Fredeen A, Patterson G, Martin RC. 2005. Management of Canadian prairie region grazed grasslands: Soil C sequestration, livestock productivity and profitability. *Canadian Journal of Soil Science*. 85(2): 183–192.

Magnuson JL, Robertson DM, Benson BJ, Wynne RH, Livingstone DM, Arai T, Assel TA, Barry RG, Card V, Kuusisto E, Granin NG, Prowse TD, Stewart KM, Vuglinski VS. 2000. Historical trends in lake and river ice cover in the northern hemisphere. *Science*. 289: 1743–1746.

Mailvaganam S. 2002. 2001 Ontario Grape Vine Survey. Ontario Ministry of Agriculture and Food. Available online at:  
<http://www.omafr.gov.on.ca/english/stats/hort/grapevine01/ogvs01.html>

Marshall IB, Schut PH. 1999. A National Ecological Framework for Canada—Overview. Prepared by Environment Canada and Agriculture and Agri-Food Canada. Available online at:  
<http://sis.agr.gc.ca/cansis/nsdb/ecostrat/intro.html>

McConkey BG, Liang BC, Campbell CA, Curtin D, Moulin A, Brandt SA, Lafond GP. 2003. Crop rotation and tillage impact on carbon sequestration in Canadian prairie soils. *Soil & Tillage Research*. 74: 81–90.

McConkey B, Angers D, Bentham M, Boehm M, Brierley T, Cerkowniak D, Liang BC, Collas P, de Gooijer H, Desjardins R, Gameda S, Grant B, Huffman T, Hutchinson J, Hill L, Krug P, Martin T, Patterson G, Rochette P, Smith W, VandenBygaart B, Vergé X, Worth D. 2007a. CanAG-MARS Methodology and Greenhouse Gas Estimates for Agricultural Land in the



- LULUCF Sector for NIR 2006. Report submitted to the Greenhouse Gas Division, Environment Canada, by the Research Branch of Agriculture and Agri-Food Canada, April.
- McConkey BG, VandenByGaart B, Hutchinson J, Huffman T, Martin T. 2007b. Uncertainty Analysis for Carbon Change—Cropland Remaining Cropland. Report submitted to Environment Canada by the Research Branch of Agriculture and Agri-Food Canada.
- McCrae T, Smith CAS, Gregorich LJ. 2000. Environmental Sustainability of Canadian Agriculture: Report of the Agri-Environmental Indicator Project. Agriculture and Agri-Food Canada, Ottawa, Ontario, Canada. Publication 2022/E.
- McGovern M. 2007. Reporting Zones – GHG Spatial Reporting Structure for Canada. Greenhouse Gas Division, Environment Canada.
- McKenney D. 2005. Regional, National and International Climate Modeling. Canadian Forest Service, Natural Resources Canada, Ottawa, Ontario, Canada. Available online at: [http://www.glfc.cfs.nrcan.gc.ca/landscape/climate\\_models\\_e.html](http://www.glfc.cfs.nrcan.gc.ca/landscape/climate_models_e.html)
- Monreal CM, Zentner RP, Robertson JA. 1997. An analysis of soil organic matter dynamics in relation to management, erosion and yield of wheat in long-term crop rotation plots. *Canadian Journal of Soil Science*. 77: 553–563.
- Natural Resources Canada. 1974. Lakes—Ice Free Period [map], 1:35,000,000. In: National Atlas of Canada, 4th Edition. Available online at: [http://atlas.gc.ca/site/english/maps/archives/4thedition/environment/water/013\\_14](http://atlas.gc.ca/site/english/maps/archives/4thedition/environment/water/013_14)
- Nendel C, Kersebaum KC. 2004. A simple model approach to simulate nitrogen dynamics in vineyard soils. *Ecological Modelling*. 177: 1–5.
- Olthof I, Butson C, Fraser R. 2005. Signature extension through space for northern landcover classification: a comparison of radiometric correction methods. *Remote Sensing of Environment*. 95: 290–302.
- Paradine D, Leckie D, Tinis S. 2004. Deforestation Interpretation Guide KP 3.7 V1.0. Internal document. Canadian Forest Service, Natural Resources Canada, Victoria, British Columbia, Canada.
- Parton WJ, Schimel DS, Cole CV, Ojima DS. 1987. Analysis of factors controlling soil organic matter levels in Great Plains grasslands. *Soil Science Society of America Journal*. 51: 1173–1179.
- Parton WJ, Stewart JWB, Cole CV. 1988. Dynamics of C, N, P and S in grassland soils: a model. *Biogeochemistry*. 5: 109–131.
- Paul KI, Polglase PJ, Nyakuengama JG, Khanna PK. 2002. Change in soil carbon following afforestation. *Forest Ecology and Management*. 168(1–3): 241–257.
- Pennock DJ, Frick AH. 2001. The role of field studies in landscape-scale applications of process models: an example of soil redistribution and soil organic carbon modeling using CENTURY. *Soil & Tillage Research*. 58(3/4): 183–191.

- Power K, Gillis MD, Boudewyn P. 2006. Canada's Forest Inventory 2001. Canadian Forest Service, Natural Resources Canada. Information Report PFC-X-### (in review).
- Prairie Farm Rehabilitation Administration. 2000. Prairie Agricultural Landscapes. Prairie Farm Rehabilitation Administration, Agriculture and Agri-Food Canada, Regina, Saskatchewan, Canada.
- Schuman GE, Reeder JD, Manley JT, Hart RH, Manley WA. 1999. Impact of grazing management on the carbon and nitrogen balance of a mixed-grass rangeland. *Ecological Applications*. 9: 65–71.
- Schuman GE, Janzen HH, Herrick JE. 2002. Soil carbon dynamics and potential carbon sequestration by rangelands. *Environmental Pollution*. 116: 391–396.
- Smith WN, Rochette P, Monreal C, Desjardins RL, Pattey E, Jaques A. 1997. The rate of carbon change in agricultural soils in Canada at the landscape level. *Canadian Journal of Soil Science*. 77: 219–229.
- Smith WN, Desjardins RL, Pattey E. 2000. The net flux of carbon from agricultural soils in Canada 1970–2010, *Global Change Biology*. 6(5): 558–568.
- Smith WN, Desjardins RL, Grant B. 2001. Estimated changes in soil carbon associated with agricultural practices in Canada. *Canadian Journal of Soil Science*. 81: 221–227.
- Smoliak S. 1965. Effects of manure, straw and inorganic fertilizers on Northern Great Plains ranges. *Journal of Range Management*. 18: 11–14.
- Statistics Canada. 1992. Agricultural Profile of Canada in 1991. Census of Agriculture. Catalogue # 93350.
- Statistics Canada. 1997a. Agricultural Profile of Canada in 1996. Census of Agriculture. Catalogue # 93356.
- Statistics Canada. 1997b. Econnections—Indicators and Detailed Statistics 1997. National Accounts and Environment Division, Statistics Canada, Ottawa, Ontario, Canada. Catalogue #. 16-200-XKE.
- Statistics Canada. 2002. Agricultural Profile of Canada in 2001. Census of Agriculture. Catalogue # 95F0301XIE.
- Stinson G, Zhang G, Rampley G, Dymond C, White T, Kurz WA. 2006a. Forest Inventory Rollback Tool for CBM-CFS3. Internal report. Greenhouse Gas Division, Environment Canada, Ottawa, Ontario, Canada.
- Stinson G, White T, Kurz WA, Dymond C. 2006b. Delineating Canada's Managed Forest for NIR 2007. Internal report. Greenhouse Gas Division, Environment Canada, Ottawa, Ontario, Canada.
- Tarnocai C. 1997. The amount of organic carbon in various soil orders and ecological provinces in Canada. In: Lal R, Kimble JM, Follett RF, Stewart BA (Eds.) *Soil Processes and the Carbon Cycle*. Boca Raton, Florida (US): CRC Press. pp. 81–92.

- VandenBygaart AJ, Gregorich EG, Angers DA. 2003. Influence of agricultural management on soil organic carbon: A compendium and assessment of Canadian studies. *Canadian Journal of Soil Science*. 83: 363–380.
- VandenBygaart AJ, McConkey BG, Angers DA, Smith W, De Gooijer H, Bentham M, Martin T. 2008. Soil carbon change factors for the Canadian agriculture national greenhouse gas inventory. *Canadian Journal of Soil Science* (under review).
- Voroney RP, Angers DA. 1995. Analysis of the short-term effects of management on soil organic matter using the CENTURY model. In: Lal R, Kimble J, Levine E and Stewart BA (Eds.) *Soil Management and the Greenhouse Effect*. New York, N.Y. (US): Springer-Verlag. pp. 113–120.
- Waddington JM, McNeil P. 2002. Peat oxidation in an abandoned cutover peatland. *Canadian Journal of Soil Science*. 82: 279–286.
- Waddington JM, Blain D, Seed ED. (In preparation). *Practices of Peatland Management and Greenhouse Gas Emissions and Removals in Canada*.
- White T, and Kurz WA. 2005. Afforestation on private land in Canada from 1990 to 2002 estimated from historical records. *The Forestry Chronicle*. 81(4): 491–497.
- White T, Luckai N, Larocque GR, Kurz WA, Smyth C. 2008. A practical approach for assessing the sensitivity of the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3). *Ecological Modelling* (in press).
- Wulder M, Cranny M, Dechka J, White J. 2004. *An Illustrated Methodology for Land Cover Mapping of Forests with Landsat-7 ETM+ Data: Methods in Support of EOSD Land Cover, Version 3*. Pacific Forestry Centre, Canadian Forest Service, Natural Resources Canada, Victoria, British Columbia, Canada, March. 35 pp.
- Xiao CW, Ceulemans R. 2004. Allometric relationships for below- and aboveground biomass of young Scots pines. *Forest Ecology and Management*. 203(1–3): 177–186.

### **A3.5, WASTE**

---

- American Public Works Association. 1964. Characteristics of municipal reference. In: *Proceedings of the National Conference on Solid Waste Research*. February 1964.
- Anon. 1967. World survey finds less organic matter. *Refuse Removal Journal* 10: 26. September.
- Anon. 1967. Can garbage become a national asset? *Compost Science*. 8(1): 3.
- CRC Press. 1973. *National Waste Composition (1967)*, Table 1.1-9: Summary of International Refuse Composition of the Handbook of Environmental Control, Volume II: Solid Waste; Table 1.1-10: Composition of Household Garbage and Table 1.1-28: Composition and Analysis of Average Municipal Refuse.
- Environment Canada. 1983–1999. *Municipal Water Use Data Base*. Available online at: [http://www.ec.gc.ca/water/en/manage/use/e\\_data.htm](http://www.ec.gc.ca/water/en/manage/use/e_data.htm).

Environment Canada. 1986, 1991, 1996a. Water Use in Canadian Industry. Prepared by D. Scharf et al., Environmental Economics Branch, Environment Canada.

Environment Canada. 1994. Options for Managing Emissions from Solid Waste Landfills. Prepared by Hickling for Environment Canada in association with Emcon Associates.

Environment Canada. 1995a. Estimation of the Effects of Various Municipal Waste Management Strategies on Greenhouse Gas Emissions. Report EPS 2/AP/1.

Environment Canada. 1995b. Waste Analysis, Sampling, Testing and Evaluation (WASTE) Program: The Effect of Waste Stream Characteristics on Municipal Solid Waste Incineration—The Fate and Behaviour of Trace Metals, Vol. I. Report EPS 3/HA/10.

Environment Canada. 1996b. Perspectives on Solid Waste Management in Canada: An Assessment of the Physical, Economic and Energy Dimensions of Solid Waste Management in Canada. Vol. I. Prepared by Resource Integration Systems Ltd. March.

Environment Canada. 1997. Telephone survey conducted by Environment Canada.

Environment Canada. 1999. Municipal Solid Waste Incineration in Canada: An Update on Operations 1997–1998. Prepared by Compass Environmental Inc. for Environment Canada and Federal Panel on Energy Research Development.

Environment Canada. 2003a. Inventory of Landfill Gas Recovery and Utilization in Canada. National Office of Pollution Prevention, Environment Canada.

Environment Canada. 2003b. Municipal Solid Waste Incineration in Canada: An Update on Operations 1999–2001. Prepared by A.J. Chandler & Associates in conjunction with Compass Environmental Inc. for Environment Canada.

Environment Canada. 2007. An Inventory of Landfill Gas Recovery and Utilization in Canada 2005. Unpublished report prepared by the Greenhouse Gas Division of Environment Canada with the support of the University of Manitoba.

[EPA] United States Environmental Protection Agency. 1995. Compilation of Air Pollutant Emission Factors. Vol. I—Stationary Point and Area Sources. AP 42, 5th Edition. Chapter 2, Solid Waste Disposal. U.S. Environmental Protection Agency. Available online at: <http://www.epa.gov/ttn/chief/ap42/ch02>

[EPA] United States Environmental Protection Agency. 2001. Conventional and Emerging Technology Applications for Utilizing Landfill Gas. U.S. Environmental Protection Agency.

Fettes W. 1994. Personal communication between Senes Consultants and Puitan Bennet. February.

Flynn F. 2006. Personal communication. Service de l'assainissement des eaux, Direction des politiques du secteur industriel, Ministère de l'Environnement du Québec.

Hicke K. 2006. Personal communication (email dated March 8, 2006). Environmental Management Officer, British Columbia Ministry of Environment.

[IPCC] Intergovernmental Panel on Climate Change. 2000. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at: <http://www.ipcc-nggip.iges.or.jp/public/gp/english/>

[IPCC/OECD/IEA] Intergovernmental Panel on Climate Change, Organisation for Economic Co-operation and Development, and International Energy Agency. 1997. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Available online at: <http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm>

Jensen EF, Pipatti R. 2003. CH<sub>4</sub> Emissions from Solid Waste Disposal, February. Available online at: [http://www.ipcc-nggip.iges.or.jp/public/gp/bgp/5\\_1\\_CH4\\_Solid\\_Waste.pdf](http://www.ipcc-nggip.iges.or.jp/public/gp/bgp/5_1_CH4_Solid_Waste.pdf)

Levelton BH. 1991. Inventory of Methane Emissions from Landfills in Canada. Unpublished report prepared for Environment Canada by Levelton & Associates.

Marshall J. 2006. Personal communication (February 2006). Manager of the Waste Management Industry Survey: Business and Government Sectors, 2002 Report. Statistics Canada.

Marshall J. 2007. Personal communication (email dated February 21, 2006). Manager of the Waste Management Industry Survey: Business and Government Sectors, 2004 Report. Statistics Canada.

Maurice C, Lagerkvist A. 2003. LFG emission measurements in cold climatic conditions: seasonal variations and methane emissions mitigation. *Cold Regions Science and Technology*. 36: 37–46.

MWA Consultants Paprican. 1998. Increased Use of Wood Residue for Energy: Potential Barriers to Implementation. Final draft. Prepared for the Canadian Petroleum Producers Association (confidential internal document).

[NCASI] National Council for Air and Stream Improvement. 2003. Calculation Tools for Estimating Greenhouse Gas Emissions from Wood Products Manufacturing Facilities. National Council for Air and Stream Improvement, Inc.

[NRCan] Natural Resources Canada. 1997. National Wood Residue Data Base. Natural Resources Canada (printouts from J. Roberts).

[NRCan] Natural Resources Canada. 1999. Canada's Wood Residues: A Profile of Current Surplus and Regional Concentrations. Prepared by the Canadian Forest Service, Industry, Economics and Programs Branch, Natural Resources Canada for the National Climate Change Process Forest Sector Table. March.

[NRCan] Natural Resources Canada. 2005. Estimated Production, Consumption and Surplus Mill Wood Residues in Canada—2004. Prepared by the Forest Products Association of Canada for Natural Resources Canada.

[NRCan] Natural Resources Canada. 2006. Provincial/Territorial Disposal Waste Compositions (2002), an Analysis of Resource Recovery Opportunities in Canada and the Projection of Greenhouse Gas Emission Implications. Natural Resources Canada. March 2006.

Ontario Ministry of the Environment. 1991. Residential waste composition study : Volume 1 of the Ontario Waste Composition Study, prepared by Gore and Storrie Limited., Decima Research Limited for the Ontario Ministry of the Environment, Toronto. January 1991

ORTECH Corporation. 1994. Inventory Methods Manual for Estimating Canadian Emissions of Greenhouse Gases. Unpublished report prepared for the Regulatory Affairs and Program Integration Branch, Conservation and Protection, Environment Canada. Report No. 93-T61-P7013-FG.

Peavy HS, Rowe DR, Tchobanoglous G. 1985. Environmental Engineering. New York (NY): McGraw Hill Book Company.

Perkin ME. 1998. Personal communication (letter dated July 1998). National Office of Pollution Prevention, Environment Canada.

Pope B. 2006. Personal communication (February 2006). Waste Management Analyst, Ontario Ministry of the Environment.

Pope B. 2007. Personal communication (January 2006). Waste Management Analyst, Ontario Ministry of the Environment.

Rich LG. 2005. Technical Note Number 8. Facultative Lagoons: A Different Technology. Clemson (SC): Clemson University. Available online at: <http://www.lagoonsonline.com/technote8.htm>

Statistics Canada. 2000, 2003, 2004, 2007a. Waste Management Industry Survey: Business and Government Sectors. System of National Accounts, Statistics Canada. Catalogue# 16F0023XIE.

Statistics Canada. 2005. Food Statistics. Catalogue # 21-020-XIE. October 2006

Statistics Canada. 2006a. Food Statistics. Catalogue #. 21-020-XIE. May 2007

Statistics Canada. 2006b. Annual Demographic Statistics. Catalogue #. 91-213-XIB.

Statistics Canada. 2007b. Annual Demographic Estimates: Canada, Provinces and Territories. Demography Division, Statistics Canada, 2007 – Revised December 2007. Catalogue # 91-215-X.

Tchobanoglous G, Theisen H, Vigil S. 1993. Integrated Solid Waste Management, Engineering Principles and Management Issues. New York (NY): McGraw Hill.

Thompson S, Tanapat S. 2005. Waste management options for greenhouse gas reduction. Journal of Environmental Informatics. 6(1): 16–24.

Thompson S, Sawyer J, Bonam RK, Smith S. 2006. Recommendations for Improving the Canadian Methane Generation Model for Landfills. Winnipeg (MB): Natural Resources Institute, University of Manitoba. Canada.

Thorneloe SA. 1993. Methane emissions originating from the anaerobic waste stabilization ponds case study: Izmir Wastewater Treatment System. Chemosphere. 26(1–4): 633–639.

## Annex 4 Comparison of Sectoral and Reference Approaches

This annex covers the energy and the CO<sub>2</sub> emission results from the reference approach (RA), a comparison of its results with those estimated by the sectoral approach (SA) and a summary of the national energy balance, which is the main energy data source for both the RA and SA.

### ***A4.1 Comparison of Reference Approach with Sectoral Approach***

Results from the RA were compared with the SA as a check of energy consumed and CO<sub>2</sub> emissions from the combustion of fossil fuels. The check was performed for all years from 1990 to 2006 and is an integral part of reporting to the UNFCCC.

When results from the RA are directly compared with those from the SA, the comparison produces a significant discrepancy, since the SA total for combustion does not include the energy and the fossil fuel-derived CO<sub>2</sub> from the non-energy use of fossil fuels and feedstocks, as presented in Table A4-1. When the RA and SA are directly compared, there is an 8.73% to 10.38% variation in energy and a 6.65% to 9.04% variation in emissions.

In Canada, a significant amount of fossil fuels are used as feedstocks in various industrial processes, such as aluminium production, ammonia production, ethylene production, and iron and steel production. The emissions resulting from these processes are reported under industrial processes, whereas CO<sub>2</sub> emissions resulting from flaring activities in the production and processing of oil and gas are reported in the Fugitive Oil and Natural Gas category. Because of these discrepancies, the predefined comparison of energy and emission are not appropriate for Canada, since the RA and the SA is not comparing similar sources. However, this can be rectified by excluding the non-combustion of energy consumed as feedstocks and its corresponding emissions into the comparison.

When the RA energy amount is corrected to exclude non-energy use of fossil fuels, the variation between the sectoral and adjusted RA varies between -3.64% to -1.72%, while the emission totals match within -0.78% to 1.91%. A comparison of the adjusted RA and SA is shown in Table A4-1.

**Table A4-1: Comparison of Adjusted Reference Approach and Sectoral Approach for Canada**

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
<b>Overall Energy Comparison</b>																	
Reference Approach (PJ)	7 153	7 017	7 228	7 265	7 485	7 668	7 919	8 090	8 137	8 431	8 757	8 704	8 819	9 129	9 136	8 979	8 843
Sectoral Approach (PJ)	6 508	6 368	6 605	6 614	6 834	6 996	7 192	7 326	7 441	7 699	8 054	7 919	8 085	8 369	8 281	8 191	8 011
Percentage Difference without Adjustment (%)	9.9	10.2	9.4	9.8	9.5	9.6	10.1	10.4	9.4	9.5	8.7	9.9	9.1	9.1	10.3	9.6	10.4
Reference Approach with Non-Energy Use of Fossil Fuels and Feedstock Adjustment (PJ)	6 396	6 241	6 436	6 467	6 689	6 851	7 032	7 172	7 239	7 515	7 882	7 763	7 849	8 151	8 031	7 923	7 719
Percentage Difference with Adjustment - 100% x (RA-SA)/SA	-1.72	-1.99	-2.55	-2.22	-2.12	-2.11	-2.23	-2.11	-2.71	-2.39	-2.13	-1.97	-2.92	-2.60	-3.02	-3.27	-3.64
<b>Non-Energy Use of Fossil Fuels and Feedstocks</b>																	
Non-Energy Use of Liquid Fuels (PJ)	427	403	416	415	418	433	494	525	500	510	504	540	571	576	680	665	706
Non-Energy Use of Solid Fuels (PJ)	125	139	140	138	134	138	137	132	135	142	148	141	139	142	146	152	156
Non-Energy Use of Gaseous Fuels (PJ)	207	233	235	244	244	246	256	261	263	263	222	260	260	259	279	299	262
<b>Overall Emission Comparison</b>																	
Reference Approach (Gg CO <sub>2</sub> )	449 657	440 528	451 014	449 888	462 114	474 046	487 992	501 100	505 120	521 837	544 990	539 843	541 618	564 399	560 527	550 564	535 763
Sectoral Approach (Gg CO <sub>2</sub> )	414 098	403 996	417 476	414 504	427 105	438 375	449 779	460 795	467 677	483 888	506 429	500 623	507 836	527 403	522 635	515 686	501 499
Percentage Difference without Adjustment (%)	8.59	9.04	8.03	8.54	8.20	8.14	8.50	8.75	8.01	7.84	7.61	7.83	6.65	7.01	7.25	6.76	6.83
Reference Approach with Non-Energy Use of Fossil Fuels and Feedstock Adjustment (Gg CO <sub>2</sub> )	422 012	410 973	421 387	419 036	431 143	442 123	454 864	467 427	470 479	488 111	511 322	507 087	508 465	530 053	523 708	514 038	497 564
Percentage Difference with Adjustment - 100% x (RA-SA)/SA	1.91	1.73	0.94	1.09	0.95	0.85	1.13	1.44	0.60	0.87	0.97	1.29	0.12	0.50	0.21	-0.32	-0.78
<b>Carbon dioxide emissions from non-energy use of fossil fuel and feedstocks</b>																	
Liquid (Gg CO <sub>2</sub> )	8 636	8 434	8 579	9 307	9 505	10 069	11 092	11 740	12 772	11 129	11 241	11 427	12 402	12 951	14 664	14 465	15 588
Solid (Gg CO <sub>2</sub> )	11 314	12 631	12 758	12 593	12 383	12 598	12 527	12 049	12 285	13 024	13 653	13 101	12 947	13 382	13 676	14 299	14 592
Gaseous (Gg CO <sub>2</sub> )	7 695	8 490	8 290	8 951	9 083	9 256	9 509	9 884	9 584	9 573	8 774	8 228	7 805	8 013	8 478	7 762	8 020
<b>Specific details on carbon dioxide emissions from non-energy use of fossil fuel and feedstocks</b>																	
<b>Liquid Fuels</b>																	
Reference Approach (Gg CO <sub>2</sub> )	191 831	179 292	177 097	179 409	183 464	184 855	191 357	199 855	200 340	203 528	207 036	210 334	203 760	219 492	228 889	219 801	210 945
Reference Approach with Non-Energy Use of Fossil Fuels and Feedstock Adjustment (Gg CO <sub>2</sub> )	183 195	170 857	168 518	170 102	173 959	174 786	180 265	188 115	187 568	192 399	195 795	198 908	191 359	206 541	214 225	205 336	195 357
<b>Carbon dioxide emissions from non-energy use of fossil fuel and feedstocks</b>																	
Non-Energy Consumption of Ethane	1 194	1 194	1 194	1 238	1 269	1 195	1 195	1 283	1 187	1 218	1 278	1 816	1 965	1 903	2 498	2 739	2 828
Non-Energy Consumption of Naphtha	165	174	159	125	97	72	78	95	74	72	130	82	65	66	60	44	41
Non-Energy Consumption of Bitumen	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Non-Energy Consumption of Lubricants	1 305	1 211	1 202	1 259	1 386	1 412	1 410	1 539	1 480	1 492	1 534	1 436	1 676	1 717	1 668	1 718	1 576
Non-Energy Consumption of Petrochemical Feedstock	1 879	1 751	1 914	1 896	1 809	2 164	2 278	2 252	2 270	2 412	2 255	2 100	2 287	2 196	2 549	1 910	2 303
Non-Energy Use of Other Products	507	623	560	931	1 040	1 136	1 745	1 995	1 573	1 346	1 472	1 697	1 556	2 089	2 937	3 169	3 450
Flaring for Oil Production and Processing (including Combined Oil & Gas)	3 585	3 481	3 550	3 857	3 905	4 089	4 385	4 576	6 189	4 590	4 572	4 295	4 852	4 980	4 953	4 886	5 389
Sectoral Approach (Gg CO <sub>2</sub> )	177 356	166 584	167 182	168 159	172 375	173 784	177 828	184 464	189 171	190 946	194 444	195 570	194 284	207 652	212 589	210 688	203 353
Percentage Difference with Adjustment - 100% x (RA-SA)/SA	3.29	2.57	0.80	1.16	0.92	0.58	1.37	1.98	-0.85	0.76	0.69	1.71	-1.51	-0.53	0.77	-2.54	-3.93
<b>Solid Fuels</b>																	
Reference Approach (Gg CO <sub>2</sub> )	103 168	106 866	110 453	103 279	107 148	109 880	111 220	116 894	122 862	124 006	133 147	132 642	131 052	134 352	130 029	127 793	124 066
Reference Approach with Non-Energy Use of Fossil Fuels and Feedstock Adjustment (Gg CO <sub>2</sub> )	91 854	94 235	97 695	90 686	94 764	97 282	98 693	104 844	110 577	110 982	119 494	119 541	118 105	120 970	116 352	113 494	109 474
<b>Carbon dioxide emissions from non-energy use of fossil fuel and feedstocks</b>																	
Non-Energy Use of Anthracite	173	132	172	198	197	232	278	278	274	257	273	187	149	163	158	153	141
Non-Energy Use of Canadian Bituminous	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	464	211
Non-Energy Use of Coke (iron and steel & other)	8 056	9 273	9 219	8 882	8 194	8 522	8 308	8 107	8 317	8 514	8 521	7 928	7 771	7 705	7 877	7 694	8 409
Non-Energy Use of Foreign Bituminous	467	418	372	399	438	486	472	487	503	458	521	419	504	572	612	513	580
Non-Energy Use of Lignite	123	127	123	196	151	167	166	189	154	119	197	204	200	215	238	267	267
Non-Energy Use of Petroleum coke	2 495	2 681	2 873	2 918	3 402	3 191	3 283	2 988	3 038	3 676	4 141	4 362	4 322	4 728	4 791	5 208	4 984
Sectoral Approach (Gg CO <sub>2</sub> )	91 779	94 143	97 617	90 620	94 725	97 231	98 654	104 798	110 596	111 012	119 551	119 633	118 194	121 044	116 446	113 631	109 589
Percentage Difference with Adjustment - 100% x (RA-SA)/SA	0.08	0.10	0.08	0.07	0.04	0.05	0.04	0.04	-0.02	-0.03	-0.05	-0.08	-0.07	-0.06	-0.08	-0.12	-0.10
<b>Gaseous Fuels</b>																	
Reference Approach (Gg CO <sub>2</sub> )	154 658	154 371	163 464	167 199	171 502	179 311	185 415	184 352	181 918	194 303	204 807	196 866	206 806	210 555	201 609	202 970	200 752
Reference Approach with Non-Energy Use of Fossil Fuels and Feedstock Adjustment (Gg CO <sub>2</sub> )	146 963	145 881	155 175	158 248	162 419	170 055	175 906	174 468	172 334	184 730	196 033	188 638	199 001	202 542	193 131	195 208	192 733
<b>Carbon dioxide emissions from non-energy use of fossil fuel and feedstocks</b>																	
Non-Energy Consumption of Natural Gas	6 339	7 062	6 713	7 498	7 668	7 714	7 889	8 334	8 035	8 202	7 616	6 381	5 947	6 199	6 569	6 282	6 260
Non-Energy Consumption of Butane	275	381	392	437	432	514	604	527	563	358	273	1 137	977	1 109	1 182	813	915
Non-Energy Consumption of Propane	314	314	426	249	165	129	104	108	181	343	116	79	373	141	200	169	349
Flaring from Natural Gas Production and Processing	767	733	760	768	817	899	911	915	805	670	769	631	507	563	528	498	496
Sectoral Approach (Gg CO <sub>2</sub> )	144 962	143 269	152 677	155 726	160 005	167 360	173 297	171 533	167 909	181 930	192 434	185 421	195 358	198 707	193 600	191 366	188 556
Percentage Difference with Adjustment - 100% x (RA-SA)/SA	1.38	1.82	1.64	1.62	1.51	1.61	1.51	1.71	2.64	1.54	1.87	1.74	1.87	1.93	-0.24	2.01	2.21

## A4.2 Reference-approach Methodology

The RA for the most part follows the IPCC designated method with the use of country-specific energy conversion factors (in higher heating value (HHV)/gross calorific value (GCV)) and emission factors. In Canada, like the United States, HHV is used to record the energy content of fuels. Fuel quantities from the RESD are entered in their physical units, with the exception of international bunkers. A discussion of the data for international bunkers is presented in the following sections; 3.4.1 International Bunker Fuels, A2.4.2.3 Civil Aviation and A2.4.2.4



Navigation. For primary fuels (crude oil, coal, and natural gas), the stock change data have been adjusted to account for inter-product transfers, stock variation, other adjustments and transformed to other fuels to determine the apparent consumption values. The stock change data for secondary fuels takes into consideration imports, exports, international bunkers, stock variations, and other adjustments.

Once the apparent consumption is determined, country-specific energy conversion factors and carbon emission factors are used to calculate the carbon content and emissions. These factors are taken from the following sources: Statistics Canada's annual Report on Energy Supply–Demand (RES-D #57-003); Canada's Greenhouse Gas Emissions: Estimates for 1990 (Jaques 1992); the 1998 Fossil Fuel and Derivative Factors (McCann 2000); and Measurement Canada, an Industry Canada agency. For the majority of fossil fuels, the applied emission factors and oxidation factors are from the McCann 2000, Jaques 1992 and default IPCC factors.

Table A4-2 presents the applied emission factor, energy conversion factor, oxidation value and allocation of fuels in the RA. The energy conversion factors are taken directly from the RES-D, with the exception of crude oil, natural gas, petroleum coke and still gas, where their overall factors have been developed to account for the quantity and variation of energy content at the point of consumption such as commercial usage or self-generated usage. For example, there are two emission factors for natural gas, marketable and non-marketable natural gas which are consumed directly by the producers of natural gas.

To adjust the RA for comparison with the SA, the energy associated with non-energy use of fossil fuels and feedstocks and the corresponding carbon dioxide emitted must be calculated following the storage factors and emission factors for industrial processes as presented in Annex 12 of the NIR.

**Table A4-2: Reference Approach Energy Conversion and Emission Factors for Canada**

Fuel Types			Energy Conversion Factor, GCV			Carbon Emission Factor, (t C/TJ GCV)		Oxidation Factors (IPCC Default)		
			2006 Value	Unit	Reference	2006 Value	Reference			
Liquid Fossil	Primary Fuels								1) Energy values associated with LPG (for butane and propane), with refinery still gas and with petroleum coke have been allocated to Gaseous and Solid Fossil fuel category. 2) Weighted energy conversion and emission factor are based on country specific	
		Crude Oil	38.52	TJ/ML	Refer to Comments	19.8	Refer to Comments	0.99		
		Orimulsion	NA	–	–	NA	–	0.99		
		Natural Gas Liquids	17.22	TJ/ML	4	15.61	2	0.99	1) Report use of ethane from natural gas liquid. 2) Use of butane and propane have been allocated to the Gaseous Fossil fuel category.	
	Secondary Fuels	Gasoline	35	TJ/ML	4	18.02	2	0.99		
		Jet Kerosene	37.4	TJ/ML	4	18.67	2	0.99	Use of aviation turbo fuel.	
		Other Kerosene	37.68	TJ/ML	4	18.53	2	0.99		
		Shale Oil	NA	–	–	NA	–	–		
		Gas/Diesel Oil	38.3	TJ/ML	4	19.06	2	0.99	Use of diesel fuel oil.	
		Residual Fuel Oil	42.5	TJ/ML	4	20.28	2	0.99	Use of heavy fuel oil.	
		LPG	IE	–	–	IE	–	–	Propane and butane from refineries have been allocated to Gaseous Fossil fuel category.	
		Ethane	17.22	TJ/ML	4	15.61	2	0.995	1)Use of ethane from NGL. 2) Total available ethane is consumed as a feedstock in industrial processes.	
		Naphtha	35.17	TJ/ML	4	19.33	3	0.99		
		Bitumen	44.46	TJ/ML	4	21.11	3	0.99	Use of asphalt.	
		Lubricants	39.16	TJ/ML	4	19.66	3	0.99		
		Petroleum Coke	IE	–	–	IE	–	–	Allocated to Solid Fossil fuel category.	
		Refinery Feedstocks	35.17	TJ/ML	4	19.33	3	0.99	Use of petrochemical feedstock in industrial processes	
		Other Oil	38.8	TJ/ML	4	19.35	2	0.99	Use of light fuel oil.	
	Other Liquid Fuels	Aviation Gasoline	33.52	TJ/ML	4	19.25	2	0.99		
		Other Product Feedstocks	39.82	TJ/ML	4	19.84	3	0.99		
Solid Fossil	Primary Fuels	Anthracite	27.7	TJ/kt	4	23.74	3	0.99		
		Coking Coal	28.83	TJ/kt	4	23.69	2	0.99		
		Other Bituminous Coal	26.5	TJ/kt	4	21.03	2	0.99	Use of Canadian bituminous coal	
		Sub-Bituminous Coal	19.15	TJ/kt	4	25.31	2	0.99		
		Lignite	15	TJ/kt	4	26.31	2	0.99		
		Oil Shale	NA	–	–	NA	–	–		
		Peat	NA	–	–	NA	–	–		
	Secondary Fuels	BKB & Patent Fuel	NA	–	–	NA	–	–		
		Coke Oven Gas	IE	–	–	IE	–	–	Allocated to Gaseous Fossil fuel category.	
	Other Solid Fuels	Petroleum Coke – Refinery and Upgrader	34.59	TJ/ML	4	29.74	6	0.99	Country specific weighted emission factors based on available emission factor for refinery and upgrading (of oil sands to synthetic crude oil).	
		Foreign Bituminous Coal	29.82	TJ/kt	4	22.05	2	0.99		
	Gaseous Fossil		Natural Gas	38.26	TJ/GL	4	14.12	2	0.995	Country specific weighted emission factor based on proportion of marketable and non-marketable natural gas.
		Other Gaseous Fuels	Propane	25.31	TJ/ML	4	16.35	2	0.995	Includes consumption of NGL-propane and LPG-propane.
Coke Oven Gas			19.14	TJ/ML	4	23.03	2	0.99		
Butane			28.44	TJ/ML	4	16.67	2	0.995	Includes consumption of NGL-butane and LPG-butane.	
Still Gas – Refinery and Upgrader Fuel Gas			38.97	TJ/ML	4	13.48	6	0.99	Country specific weighted emission factor based on factors from refinery and from upgrading (of crude from oil sands to synthetic crude oil) activities.	
Biomass		Solid Biomass	18	TJ/kt	4	28.41	7	0.99	1) Consist of industrial and residential biomass consumption. 2) Assumed 99% oxidation.	
		Liquid Biomass	14	TJ/kt	4	19	3	0.95	1) Consist of spent pulping liquor. 2) Assumed a 95% oxidation factor.	
		Gas Biomass	29.37	TJ/1000m <sup>3</sup>	1.5	16.36	1.5	0.99	1) Consists of ethanol and landfill gas. 2) Assumed a 99% oxidation factor.	

References: (1) IPCC/OECD/IEA (1997); (2) McCann (2000); (3) Jaques (1992); (4) Statistics Canada, #57-003 (2003 data); (5) Heat of Combustion of Fuels, retrieved April 12, 2006, from: [http://www.webmo.net/curriculum/heat\\_of\\_combustion/heat\\_of\\_combustion](http://www.webmo.net/curriculum/heat_of_combustion/heat_of_combustion)

NA = Not applicable; BKB = Charcoal briquettes; NGL = natural gas liquids; LPG = liquified petroleum gas

### A4.3 National Energy Balance

Statistics Canada provides Environment Canada with a large portion of the underlying activity data to estimate GHG emissions for the Energy and the Industrial Processes sectors. Statistics Canada's Manufacturing, Construction and Energy Division (MCED) is responsible for the collection, compilation, and dissemination of the energy balance in the RESD (#57-003). The objective of MCED is to ensure that the information as collected under the authority of the *Statistics Act* and used in the development of the energy balance meets the following quality criteria: completeness, consistency, coherency, and accuracy. The quality management system for the energy balance also includes an internal and external review process. MCED's quality assurance framework and methodological reports are documented and made available through Statistics Canada's Integrated Meta Database.

The energy balance is an accounting of all available energy forms in Canada from import and export activities through production and domestic consumption (refer to Figure A4-1 for a sample of an energy flow diagram). Energy and fossil fuel data are collected by various methods, such as a mix of annual or monthly surveys and some censuses from industry, federal agencies (such as the National Energy Board (NEB), the Energy Resources Conservation Board (ERCB) and the Alberta Utilities Commissions (AUC) previously the Alberta Energy Utilities Board (AEUB)), provincial energy departments, and from the Canadian Industrial Energy End Use Data and Analysis Centre (CIEEDAC). Refer to Figure A4-2 for a sample of the energy and fossil fuel data input to MCED and what information is provided by each of the data sources or respondents. Oil and gas information as provided by the ERCB is highly accurate, since it is tied to oil and gas exploitation permits and to federal and provincial royalty schemes.

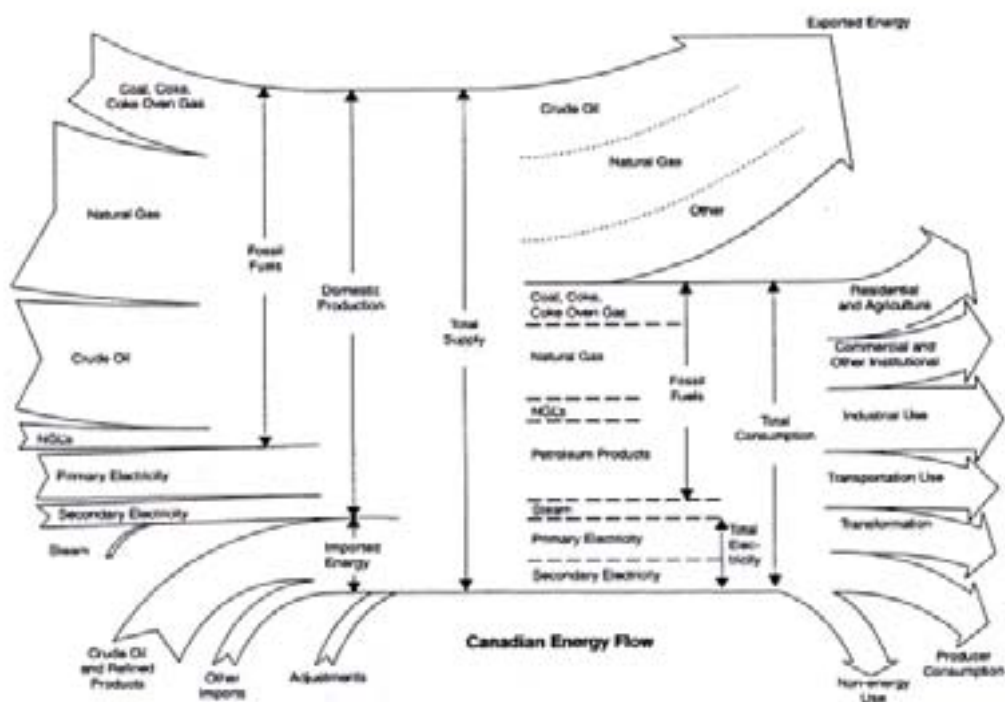


Figure A4-1: Sample of an Energy Balance Flow Diagram for Canada

There are also other internal data quality checks of the information collected through provincial energy departments and from various supply, disposition, and consumption surveys. For example, the quantity of crude oil shipped as reported by the producer is verified against report receipts from pipeline companies, and the information as reported by pipelines is verified against refinery receipts. MCED also applies both a top-down approach through the supply and disposition surveys and a bottom-up approach through the Industrial Consumption of Energy survey to verify the quality of the data for manufacturing industries, including the petroleum refining industry. In addition, technical information on energy characteristics is collected to verify reported fuels in physical and energy units.

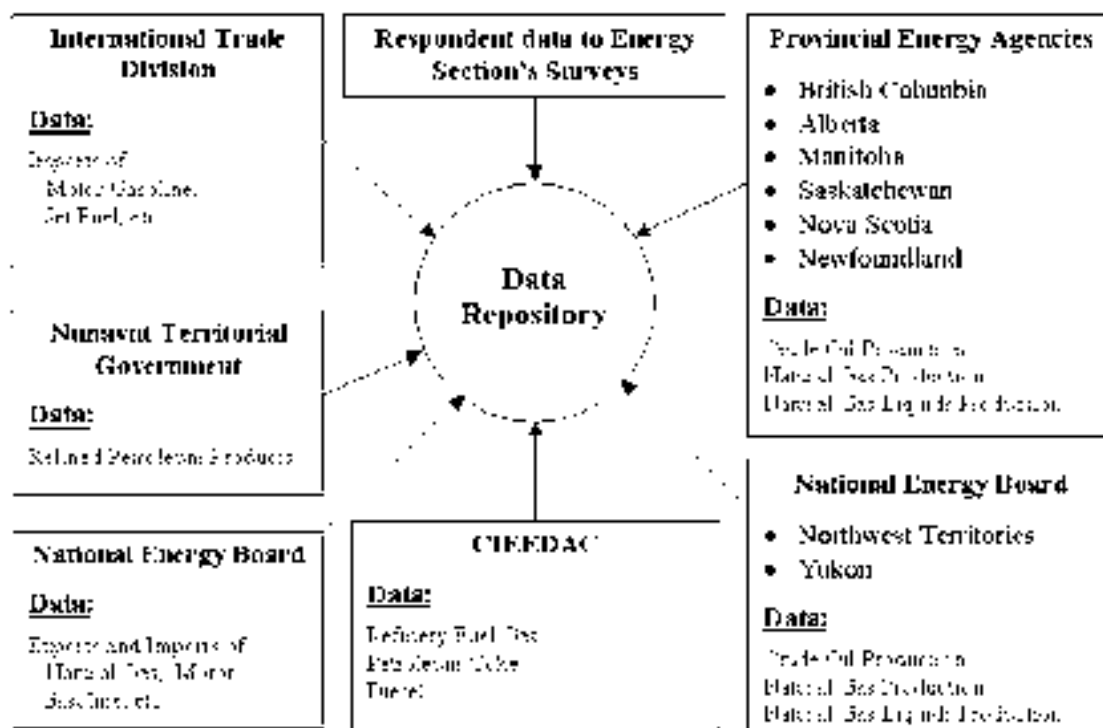


Figure A4-2: Fossil Fuel and Energy Data Input

The energy balance consists of information on crude oil, natural gas, coal, refined petroleum product (RPPs), electricity, steam, non-energy use of fossil fuels, feedstock, and other secondary energy forms for all Canadian industrial sectors and other energy use, such as the transportation, residential, and commercial sectors.

Both the industrial consumption of energy product and the energy balance are used by various federal departments for energy efficiency programs, policy development, reporting to the International Energy Agency, energy and emission forecasting, and reporting to the UNFCCC. As such, MCED has established partnerships with various federal government departments, provincial energy ministries, industrial associations, and centres of excellence to assist with their quality assurance process.

For example, a “work-in-progress” review has been established with Environment Canada and Natural Resources Canada (NRCan) to review the industrial consumption of energy estimates and the energy balance prior to their official release. Canadian industrial members also participate in the review of industrial data through the Canadian Industrial Program for Energy Conservation

group. The Canadian Industrial Energy End-Use Data and Analysis Centre (CIEEDAC) also participates in the review of refinery data and the industrial energy statistics.

Owing to the complexity of energy data, a Working Group on Energy Statistics was established to provide advice, direction, and recommendations. The working group consists of members from Statistics Canada, Environment Canada, and NRCan, and its mandate is to identify and address issues related to the collection of a comprehensive set of energy data for various sectors of the economy and to improve existing energy statistics.

## ***References***

[CIEEDAC] Canadian Industrial Energy End-Use Data and Analysis Centre. 2003. A Review of Energy Consumption in Canadian Oil Sands Operations, Heavy Oil Upgrading, 1990, 1994 to 2001. Canadian Industrial Energy End-Use Data and Analysis Centre, Simon Fraser University, Burnaby, British Columbia, Canada.

[CIEEDAC] Canadian Industrial Energy End-Use Data and Analysis Centre. 2006. A Review of Energy consumption in Canadian Oil Refineries, 1990, 1994 to 2004. Canadian Industrial Energy End-Use Data and Analysis Centre, Simon Fraser University, Burnaby, British Columbia, Canada.

[EPA] United States Environmental Protection Agency. 1996. Compilation of Air Pollutant Emission Factors - Vol.I: Stationary Point and Area Sources, AP 42. 5th Edition, Supplement B. U.S. Environmental Protection Agency. Washington DC, USA.

[IPCC/OECD/IEA] Intergovernmental Panel on Climate Change, Organisation for Economic Co-operation and Development, and International Energy Agency. 1997. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Available online at: <http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm>

Jaques A.P. 1992. Canada's Greenhouse Gas Emissions: Estimates for 1990, Environmental Protection, Conservation and Protection. Environment Canada. Report No. EPS 5/AP/4.

McCann T.J. 2000. 1998 Fossil Fuel and Derivative Factors. Report prepared by T.J. McCann and Associates for Environment Canada.

Statistics Canada. Report on Energy Supply–Demand in Canada (Annual). #57-003-XIB.

## Annex 5 Assessment of Completeness

Although this inventory report serves as a comprehensive assessment of anthropogenic GHG emissions and removals in Canada, some categories have not been included or have been included with other categories for reasons explained in the CRF tables and in this annex.

### **A5.1**     *Energy*

Overall, the Energy Sector of the national inventory provides a full estimate of all significant sources. The following list delineates those that are not currently estimated and that may represent a source in their particular subsector, but which do not affect the completeness of the inventory owing to their relatively small contributions.

#### **A5.1.1**     **Emissions from Combustion of Waste Fuels**

Emissions from the combustion of waste fuels for the production of energy at industrial facilities are not included. A review of data sources is pending and it is anticipated that waste fuels will be included in the future. See Chapter 9 for details on planned improvements.

#### **A5.1.2**     **Fuel Combustion—Transportation**

Owing to a lack of reliable data illustrating historic biodiesel consumption for transport purposes in Canada, emissions from biodiesel (1.A.3.E Other Transportation/Other Non-Specified/Biomass) are not estimated but are expected to be minimal. The Canadian government has recently regulated the average renewable content of gasoline and diesel fuels. Currently, there is no process in place to track the domestic consumption of biofuels for transport (although, as indicated in Section 3.4.2.3 of Chapter 3, emissions from ethanol fuel use are inventoried). Additionally, all emissions from multilateral operations (1.C2) are reported within their respective civilian source categories (Aviation & Navigation) because of security limitations that restrict the disaggregation of military fuel consumption.

### **A5.2**     *Industrial Processes*

Overall, the Industrial Processes Sector of the national inventory provides a comprehensive estimate of all significant sources. Discussed in the following subsections are sources that are not currently estimated and that may represent a source in their particular subsector. However, their magnitudes are assumed to be small and to not affect the overall completeness of the GHG inventory.

#### **A5.2.1**     **Mineral Products**

Emissions from asphalt roofing, road paving with asphalt, and glass production (other than those related to the use of limestone and soda ash in the process) are not estimated and are thought to be negligible. Soda ash was produced in Canada until 2001. The Solvay process in which soda ash was produced results in some CO<sub>2</sub> emissions; however, as CO<sub>2</sub> is also a necessary component in the process reactions, it is most commonly recovered for reuse. Hence, the quantity of recovered CO<sub>2</sub> is estimated in this year's inventory for the years 1990–2001, but the net amount of non-recovered (i.e. emitted) CO<sub>2</sub> coming from soda ash production is not estimated and is considered to be minimal.

### **A5.2.2 Chemical Production**

N<sub>2</sub>O emissions associated with the production of chemicals other than nitric and adipic acids are not estimated. Production of chemicals other than nitric acid and adipic acid may be a source of N<sub>2</sub>O; however, more research is required to determine its significance.

Similarly, there are insufficient data available to estimate CH<sub>4</sub> emissions from chemical manufacturing processes in Canada, although they are thought to be insignificant.

Process-related CO<sub>2</sub> emissions from adipic acid production are not inventoried (i.e. not estimated) and are considered negligible.

### **A5.2.3 Metal Production**

Process CH<sub>4</sub> emissions associated with the production of metals are not estimated and are thought to be insignificant.

### **A5.2.4 Production and Consumption of Halocarbons and SF<sub>6</sub>**

Since data on PFCs used in aerosols are currently unavailable, the associated emissions are not inventoried (i.e. not estimated). HFC emissions from electronic industries are reported under the category 2.F.5 Solvents, not 2.F.9 Other (Contained and Emissive Emissions from Electronic Industries), in the CRF reporter, since it is not possible for this submission to separate HFC consumption as solvent in electronic industries from other types of solvent use. There are also some PFCs emitted from the electronic industry, and these emissions are reported under 2.F.9 Other (Contained and Emissive Emissions from Electronic Industries). HFC and PFC emissions coming from electrical equipment are reported as “Not Estimated” because it is thought that there is no known use of these halocarbons for electrical insulation and arc quenching in equipment used in the electricity industry.

Potential emissions of SF<sub>6</sub>, which should be derived from the information on imports and exports of SF<sub>6</sub> (in bulk and in product), and SF<sub>6</sub> destruction are reported as “not estimated” owing to the fact that there is currently no information on SF<sub>6</sub> exports in bulk and in product, and destruction of SF<sub>6</sub>.

### **A5.2.5 Other and Undifferentiated Production**

CO<sub>2</sub> emissions from the non-energy use of hydrocarbons are estimated using two types of emission factors. The first type was developed by simply converting the national carbon contents for non-energy fuel types to GHG emission factors, while the second type was derived based on both national carbon contents and IPCC default fractions of carbon stored. The IPCC default fractions of carbon stored take into account the release of carbon from the use or destruction of the manufactured products over a short term only. CO<sub>2</sub> emissions from the combustion of waste fuels (made from non-energy use of hydrocarbons) need to be researched further. This, to understand to what extent the IPCC default fraction of carbon stored represents the release of carbon from use or destruction of the product in the short term (versus the long term). Please see comments in A5.1 on this as well.

### **A5.3 Solvent and Other Product Use**

In this sector, only N<sub>2</sub>O emissions associated with the use of anaesthetics and propellants are estimated. Emissions from use of solvents in dry cleaning, printing, metal degreasing, and a

variety of industrial applications as well as household use are not estimated because, according to the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997), GHGs are not emitted in significant amounts from these types of uses.

#### **A5.4 Agriculture**

Overall, the Agriculture Sector of the national inventory provides a complete estimate of the significant sources. The following list includes sources that are not currently estimated. These are considered to be minor sources.

##### **A5.4.1 Enteric Fermentation and Manure Management**

Some minor animal categories, such as ranched deer, wild boar, elk, rabbit, ostrich and ducks, have not yet been included. Complete IPCC default emission factors and parameters are unavailable for these categories, and they have relatively low populations. Mules and asses are not included in the inventory since no activity data are available.

##### **A5.4.2 Residue Burning**

Residue burning is practised to a small extent in Canada and concerns mostly flax residues. This category is considered to be a minor source of emissions. Agriculture and Agri-Food Canada and Statistics Canada conducted a Farm Environmental Management Survey in 2001 (Korol 2004), which found that, in that year, 2.2% of crop residues on an area basis were burned, the majority in Manitoba and Saskatchewan. Expert opinion suggests that, on a national basis, field burning of crop residues has declined since the early 1990s. Owing to the paucity of the data and the absence of data collection mechanisms, no time series of data is available.

##### **A5.4.3 Rice Production**

CH<sub>4</sub> emissions from rice production are not currently inventoried, as rice production is not occurring in Canada.

#### **A5.5 Land Use, Land-Use Change and Forestry**

With the major methodological improvements implemented in the 2006 submission, the completeness of the LULUCF inventory has considerably improved through increased coverage of carbon pools and improvement in the resolution of activity data.

##### **A5.5.1 Forest Land**

Forest land estimates are provided for both forest land remaining forest land and land converted to forest land. These estimates include carbon stock changes and emissions from all pools (biomass, DOM, and soil) in managed forests resulting from growth and mortality, fire and insect disturbances, and management activities. Emissions of CO<sub>2</sub>, CH<sub>4</sub>, CO, and N<sub>2</sub>O are estimated. Emissions of NO<sub>x</sub> are not estimated. CO emissions occur during biomass burning only; they are reported as CO<sub>2</sub> emissions in the CRF Biomass Burning tables. Carbon stock changes and emissions reported from forest soils are assumed to include both mineral and organic soils, as specific data on organic soils are not readily available. Emissions from the burning of harvest residues are currently not included due to lack of reliable data sources; these emissions are considered minor. Uncertainty estimates are under preparation.



### **A5.5.2 Cropland**

Estimates of cropland remaining cropland include soil and partial biomass estimates. Estimates for mineral soils capture the major LMCs (crop mixture, tillage practices, and summerfallow). Other practices, such as irrigation, manure application, and fertilization, which are also known to have positive but small impacts on SOC, are not represented. The current estimate in the land converted to cropland category includes CO<sub>2</sub> emissions from all pools due to forest and grassland conversion to cropland. Non-CO<sub>2</sub> emissions (CH<sub>4</sub>, CO, N<sub>2</sub>O) from biomass burning during land conversion are also reported; NO<sub>x</sub> estimates have not been estimated. GHG emissions and removals from the conversion of wetlands and settlements to cropland have not been estimated because of a lack of data.

### **A5.5.3 Grassland**

Emissions and removals from grassland remaining grassland are not estimated. In Canada's definitional framework of LULUCF land categories (refer to Chapter 7), grasslands exclude improved pastures, which are captured under the Cropland category. The challenge resides in that there are no detailed and comprehensive activity data on change in management practices on grasslands that would allow the implementation of the IPCC methodology. Moreover, there is no indication that these lands have been losing or gaining SOC as a result of human activity. Moreover, according to the definitions, the conversion of forest land and cropland to grassland is not occurring. Emissions from the conversion of wetlands to grassland have not been estimated.

### **A5.5.4 Wetlands**

GHG emissions in land converted to flooded land, land converted to (managed) peatland, and (managed) wetlands remaining wetlands have been prepared but cannot be reported separately in the CRF tables. CO<sub>2</sub> estimates were developed in all categories; non-CO<sub>2</sub> (CH<sub>4</sub>, CO, and N<sub>2</sub>O) estimates associated with biomass burning are reported in forest land converted to flooded land. Emissions of NO<sub>x</sub> have not been estimated. Cropland and grassland converted to wetlands were not estimated; however, emissions from land converted to flooded land would include those arising from the flooding of unmanaged wetlands and grassland (tundra), which are reported in the category "Other Land converted to Wetlands". Uncertainty estimates are under preparation.

### **A5.5.5 Settlements**

The current estimates in the land converted to settlements category include forest loss to settlements and the conversion of tundra to settlements in the Canadian north. Non-CO<sub>2</sub> emissions (CH<sub>4</sub>, CO, and N<sub>2</sub>O) are reported only when biomass burning has occurred in the course of conversion activities. Emissions of NO<sub>x</sub> have not been estimated. Emissions and removals from the conversion of cropland, agricultural grassland, wetlands, and other land to settlements have not been estimated. CO<sub>2</sub> estimates in settlements remaining settlements include only net carbon sequestration in the above-ground biomass of urban trees. Uncertainty estimates are under preparation.

## **A5.6 Waste**

This category is for the most part complete, with the exception of the following.

### **A5.6.1 Unmanaged Solid Waste Disposal**

In previous submissions, the notation “Not Applicable” was used to qualify the emissions from unmanaged landfills, since the majority of the larger landfills are managed engineered landfills. Typically, even small communities are served by a managed landfill as provincial regulations require some form of management. It is assumed that the unmanaged landfills are shallow, i.e. aerobic biodegradation prevails, with relatively insignificant waste placement quantities. Thus, the emission contribution would be negligible in comparison with the managed landfills. The present estimation method results in a conservative estimate, as it is assumed that all wastes landfilled are placed in managed landfills. However, for the purpose of complying with the completeness principle this source is given the “Not Estimated” notation. Current data on unmanaged landfills are not readily available nor are they reliable and in addition the needed historical data is non-existent.

### **A5.6.2 Domestic and Commercial Wastewater**

N<sub>2</sub>O emissions from domestic and commercial wastewater without human sewage/wastewater are given the notation IE (included elsewhere) in the CRF tables and are reported in the human sewage subsector. CH<sub>4</sub> recovery from the wastewater treatment operations entered under the Wastewater (without human sewage) subcategory of the CRF is reported as “Not Estimated.” Recovery of CH<sub>4</sub> from these operations has not been confirmed but is not expected to occur. CH<sub>4</sub> and N<sub>2</sub>O emissions from the Sludge subcategory are reported as “Not Estimated,” as the data required to evaluate the quantities captured from specific sites are not available at this time. CH<sub>4</sub> recovery from covered anaerobic digesters is expected but has not yet been quantified.

### **A5.6.3 Industrial Wastewater**

Confirmation of industrial wastewater treatment methods for the 2007 NIR submission was obtained through personal communications with industry associations and provincial government officers. A suitable data collection mechanism has not been identified for this source of emissions. The ministries of the environment for Ontario, Quebec, and British Columbia, provinces where the majority of the relevant industries are centered were contacted. It was confirmed that, with the possible exception of a slaughterhouse in Quebec, anaerobic industrial wastewater treatment was not employed for those industries that were identified as the largest water consumers based upon process water usage. These industries are pulp and paper, food and beverage, rubber products, chemical products, petroleum products, textiles, and plastic. Since the slaughterhouse mentioned above captures and combusts the CH<sub>4</sub> generated from the anaerobic digestion, it was assumed that the CH<sub>4</sub> emissions were negligible on a national scale; therefore, the notation “Not Occurring” was reported in the 2007 NIR submission. We are aware of a few recent anaerobic treatment installations that were in operation in 2006; however, these emissions have not been quantified due to the lack of activity data. Therefore, the notation has been changed to “Not Estimated.” This notation is also used for industrial wastewater sludge CH<sub>4</sub> and N<sub>2</sub>O. Various data collection vehicles are being considered to provide for a more complete collection of activity data and assist in developing an improved methodology to estimate emissions from this subsector in the future. However, due to confidentiality issues, it is expected that this information will not be readily obtainable.

### **A5.6.4 Waste Incineration**

CH<sub>4</sub> emissions from MSW incineration are considered to be negligible and have not been estimated. Approximately less than 5% of all MSW is incinerated in Canada. Therefore, CH<sub>4</sub>

emissions from this source are not expected to contribute significantly to the national inventory and are reported as “Not Estimated.” We expect, through future facility-level activity data improvement studies and the derivation of reliable emission factors that are currently lacking for this source, to be able to quantify the emissions or at least to confirm that the quantities are in the trace range.

### ***References***

[IPCC] Intergovernmental Panel on Climate Change. 2003. Good Practice Guidance for Land Use, Land-Use Change and Forestry. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at: <http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf.htm>

[IPCC/OECD/IEA] Intergovernmental Panel on Climate Change, Organisation for Economic Co-operation and Development and International Energy Agency. 1997. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Available online at: <http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm>

Korol M. 2004. Farm environmental management survey in Canada. Fertilizer and Pesticide Management in Canada. 1(3). Statistics Canada.

## Annex 6 Quality Assurance and Quality Control

QA/QC procedures are an integral part of the inventory development and submission processes. These procedures ensure that Canada is able to meet the UNFCCC requirements of transparency, consistency, comparability, completeness, and accuracy. The Government of Canada is committed to improving data and methods in collaboration with industry, provinces and territories, academia, and the international community to ensure that a credible and defensible inventory is developed, meeting its international obligations.

To enable the full development and implementation of Canada's Quality Management System, a QA/QC coordinator position was staffed in 2006. While the review and revision of the Quality Management System, including a revised QA/QC plan, was major project in 2006, a key focus for 2007 has been the implementation of the QA/QC plan. The implementation has had emphasis on the transition from an informal approach of QA/QC to an approach that is formally defined and consistent across sectors. In addition, a Prioritization and Planning Committee, also established in 2006, was also used in the current inventory year to centralize inventory decision making, particularly on approaches to QA and planned improvements.

### ***A6.1 Characteristics of the QA/QC Plan for the National Inventory***

The QA/QC plan is an integrated approach to managing the inventory quality, working towards continuously improved emission and removal estimates. It is designed so that QA/QC procedures are implemented throughout the entire inventory development process: from initial data collection through development of emission and removal estimates to publication. Minor updates were made to the plan in 2007, including revisions to ensure that the QA/QC plan was complementary to the new *IPCC 2006 Guidelines for National Greenhouse Gas Inventories* (IPCC 2006).

The plan incorporates a system of continuous improvement that includes, but is not limited to, procedures to capture lessons learned as part of the inventory cycle; using QA/QC and other tools as a means to identify and prioritize improvements; and, processes to ensure that improvements identified are incorporated into the operating procedures.

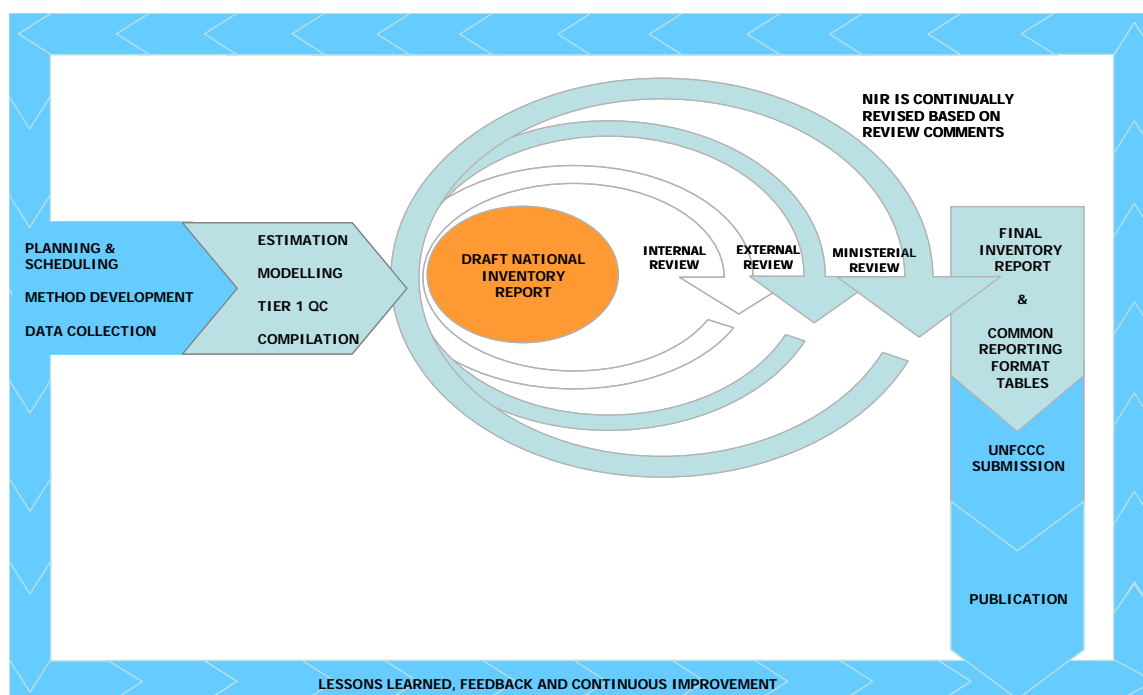
The plan also includes a schedule for multi-year implementation, such that in every submission year all key categories (and categories where a significant methodological change has occurred) will be subject to Tier 1 QC. Some Tier 2 QC, QA and verification activities will be performed every year based on a multi-year schedule with the objective to provide more comprehensive quality assessments of the entire inventory over a seven year timeframe. The implementation of the multi-year cycle is expected to ramp up over the next few years. Until this objective can be met, annual interim targets are set each year by a Prioritization and Planning Committee. In addition, the committee is responsible to approve all proposed significant methodological changes, ensuring adequate resources and application of due diligence.

Documentation of QA/QC procedures is at the core of the system. Standard checklists are used for the consistent, systematic documentation of all QA/QC activities in the annual inventory preparation and submission. QC checks are completed during each annual inventory preparation and archived along with other procedural and methodological documentation, by inventory category and by submission year.

The plan requires the coordination of QA/QC activities with outside agencies and organizations providing activity data and/or developing GHG emission and removal estimates for Environment Canada.

## **A6.2     *Annual Inventory Development Process***

The inventory development is built around a continuous process of methodological improvements, data collection, refinements, and review. Figure A6-1 illustrates a typical cycle in the preparation of the Canadian inventory.



**Figure A6-1: Typical Inventory Process Figure**

During the early portions of the project cycle (May to October), the required data starts to be collected while the new inventory schedule is prepared. By the end of October, methodologies are finalized and the data collection process is near completion.

Between November and January, estimates and the NIR text are prepared by sector experts. Emissions are calculated by inventory experts (dedicated to a specific sector), QC checks are conducted and signed-off by sectoral managers before the report and national totals are prepared. This process involves key category assessment, recalculations, uncertainty analysis, QC, and documentation preparation.

Over February and March, the compiled inventory is reviewed internally, and components externally reviewed by experts, government agencies and provincial/territorial governments. Comments received are documented and, where appropriate, incorporated into the final draft. Once the submission is approved by senior officials, the inventory is submitted to the UNFCCC by April 15. The inventory is then archived and the NIR is edited, translated and published.

The inventory cycle is completed by lesson-learned meetings held at the end of April each year. These meetings are held internally and with partners to review the procedures in order to continually improve the process.

### **A6.3 QC Procedures**

QC is designed to provide routine, technical checks to measure and control the quality of the inventory, to ensure data consistency, integrity, correctness, and completeness, and to identify and address errors and omissions. Its scope covers a wide range of inventory processes, from data acquisition and handling and application of approved procedures and methods to calculation of estimates and documentation.

#### **A6.3.1 Tier 1 QC**

A series of systematic Tier 1 QC checks are performed annually on at least the key categories and across sectors by staff in the inventory agency. Tier 1 QC follows the *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000), including (but not limited to)

- preventing easily avoidable data errors, e.g. during data flow, use of appropriate units, basic calculations;
- consistency checks among data used in multiple sectors;
- basic trend analysis, comparison with previous estimates;
- proper documentation of assumptions; selection criteria for emission factors, parameters, and methodologies; expert credentials; and
- completeness checks.

Checks on the documentation and archiving of all the information required to produce the national emission estimates are performed, focusing on the key categories. The QC checklists include a record of any corrective action taken and refer to supporting documentation. Formal cross-cutting QC checks on final products are performed and documented prior to submission.

#### **A6.3.2 Tier 2 QC**

A Tier 2 quality control assessment is an opportunity to review and investigate for the improvement of a specific category or categories. There is a need for a comprehensive assessment to ensure that the category will remain current and relevant for a number of years beyond the year of analysis. The investigation is broad and uses a variety of approaches, including:

- Making assessments of applicability of methods, EFs, activity data, uncertainty, etc;
- Understanding flow of information, secondary data and data inputs, and being able to trace inputs to their root sources;
- Cleaning and updating documentation (not covered by Tier I checks); and
- Laying the foundation for future activities, including making and prioritizing recommendations for improvement and making preparations for subsequent quality assurance.

Documentation of the Tier 2 QC checks may be done through a standard checklist or with an in-depth study to complete a comprehensive assessment.

#### **A6.4     *QA Procedures***

QA generally consists of review activities, by independent experts, to ensure that the inventory represents the best possible estimates of emissions and removals and to support the effectiveness of the QC program. Similar to QC, QA is undertaken every year on components of the inventory. Members of a formal provincial and territorial expert working group on emissions review pertinent sections of the draft inventory. Sections are also reviewed at the same time by experts and scientists in other government departments.

Selected underlying data and methods are independently assessed each year by various groups or individual experts in industry, academia, and government. QA is undertaken for the assessment of the activity data, methodology, and emission factor utilized for developing estimates; and prior to making a decision on implementing a methodological change.

#### **A6.5     *Verification***

Verification is the use of third-party information to confirm the veracity of the inventory. For example, where appropriate facility-level GHG data exist from the Greenhouse Gas Emissions Reporting Program, analysis is undertaken to perform bottom-up versus top-down comparisons.

#### **A6.6     *Key QA/QC Achievements in the 2008 Inventory Submission***

In the 2006 calendar year, a QA/QC coordinator role was staffed in line with the strategic priority of the Greenhouse Gas Division to review and redesign the quality framework. Implementation of the quality framework was a key focus for 2007.

QA/QC achievements for 2007 include:

- conducting a lessons learned review to identify potential improvements and risks for the inventory;
- hiring of a new project manager to manage inventory timeline and the development of an inventory schedule;
- conducting an internal audit for completeness and transparency of QC checklists;
- implementation of a new electronic archiving structure and creation of a hardcopy reference library;
- establishment of a Tier 1 QC working group, resulting in revised Tier 1 checklists and a new guidance manual,
- formalized Tier 2 and QA activities in Industrial Process and Energy Sectors and initiation of Tier 2 and QA guidance documents, and
- Development of a new process and documentation requirement prior to the implementation of methodological changes

For the 2008 submission, Tier 1 QC procedures were implemented and the results documented by the experts who prepared these category estimates. Cross-cutting checks on the NIR and CRF were also performed prior to submission.

### ***References***

[IPCC] Intergovernmental Panel on Climate Change. 2000. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at: <http://www.ipcc-nggip.iges.or.jp/public/gp/english/>

[IPCC] Intergovernmental Panel on Climate Change. 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at: <http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.htm>



## Annex 7 Uncertainty

### A7.1 Introduction

Identifying sources of uncertainty in the emission and removal estimates of the GHG inventory and quantifying the magnitudes of the uncertainty are of assistance in defining and prioritizing future improvements to the inventory. Quantitative estimates of the uncertainty can also be used to assess the relative importance of the input parameters (e.g. activity data and emission factors) according to their relative contribution to the uncertainty of the respective source category estimates. This information allows prioritized resource allocation to the reduction of uncertainty in inventory estimates.

The UNFCCC reporting guidelines on annual inventories state that Annex I Parties shall quantitatively estimate the uncertainties in the data used for all source and sink categories using the Tier 1 method, as provided in *the Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000). Annex I Parties may also choose to use the Tier 2 method in the *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000) to address technical limitations in the Tier 1 method.

Canada performed an uncertainty assessment of its 1990 estimates in 1994 (McCann 1994). In 2003–2004, Canada embarked on a comprehensive study to perform a Tier 2 uncertainty assessment associated with its source categories included in the 2001 GHG inventory (the latest inventory estimates available at the time of the study). The study report for this original phase of the study was published in September 2004 (ICF Consulting 2004). The LULUCF Sector was not included in the ICF Consulting (ICF) uncertainty assessment since, at the time, the estimation methodology was being entirely transformed.

Since the 2003 National Inventory Report (NIR) submission (Environment Canada 2003), which contained emission estimates for the year 2001, updates to the methods and the activity data have been made for certain source categories (for further discussion, see chapters 3 to 8 of this report and Section A7.4 of this annex). It is believed that these changes have led to a reduction in uncertainty for these categories; however, this still needs to be confirmed through an updated analysis. A target for Canada is to update the uncertainty assessment for the 2009 NIR.

Planned improvements for uncertainty include the development of a program that will ensure Canada's ability to provide an uncertainty assessment on an annual basis. While the details of the program will have not been finalized at the time of this publication, Canada will most likely build on previous methods and databases, including making use of the Monte Carlo simulation data and methods performed in 2004–2005.

### A7.2 Overall Inventory Uncertainty for 2001 (Reported in NIR 2003)

Table A7-1 shows the overall level and trend uncertainty picture for Canada's 2001 GHG inventory year (reported in NIR 2003) for each gas and for the overall inventory in Gg CO<sub>2</sub> eq. This assessment excluded the LULUCF Sector.

Canada's GHG inventory level uncertainty currently falls within a range of –3% to +6% for all GHGs combined. In regards to the particular gases, N<sub>2</sub>O exhibits the highest uncertainty range in the national inventory, with a range of –8% to +80%, followed by HFCs, with a range of –22% to +60%. CO<sub>2</sub> exhibits an uncertainty of –4% to 0%. The overall Canadian inventory uncertainty estimate falls within the range of the uncertainties reported by other Annex I countries. The results do not include uncertainty associated with Global Warming Potential because it is not a reporting requirement for the

UNFCCC. Further results of the study, on a sectoral and category basis, are detailed in Table A7-3 to Table A7-8 in Section A7.4 below.

**Table A7-1: Quantitative Tier 2 Uncertainty Assessment of Overall National Inventory GHG Emissions and Trends for 2001 by Gas<sup>1</sup>**

Gas	Base Year (1990) Emissions <sup>2</sup> (Gg CO <sub>2</sub> eq)	Year t (2001) Emissions <sup>2</sup> (Gg CO <sub>2</sub> eq)	Uncertainty in Year t Emissions as % of Emissions for the Gas		% Change in Emissions between 2001 and 1990	Range of Likely % Change between 2001 and 1990	
			% Below (2.5 <sup>th</sup> percentile)	% Above (97.5 <sup>th</sup> percentile)		Lower % (2.5 <sup>th</sup> percentile)	Upper % (97.5 <sup>th</sup> percentile)
CO <sub>2</sub>	472 000	566 000	-4	0	20	18	24
CH <sub>4</sub>	73 000	93 000	-5	35	27	0	75
N <sub>2</sub> O	50 000	50 000	-8	80	-3	-35	55
HFCs	0	900	-22	60	NA	NA	NA
PFCs	6 000	6 000	-70	-60	3	-70	-60
SF <sub>6</sub>	2 870	2 020	-1	1	-30	-30	-29
Total GHG Emissions	608 000	720 000	-3	6	19	12	27

Notes:

1. Excludes LULUCF Sector.

2. As reported in NIR 2003.

Sources: ICF Consulting (2004, 2005).

NA = Not applicable.

### **A7.3 Scope of 2004–2005 Uncertainty Study**

For the study conducted by ICF Consulting, a Tier 2 approach was adopted (IPCC 2000) since 1) the probability distributions underlying the estimates are non-Gaussian distributions, 2) the inventory estimation methodology is complex and includes several input variables, 3) the uncertainty surrounding the input variables is large, and 4) the variables are correlated between and/or within source categories. Tier 1 uncertainty analysis was not conducted owing to time and resource constraints, but it will be performed in the future.

Uncertainty ranges were developed for the 2.5<sup>th</sup> and 97.5<sup>th</sup> percentiles (95% confidence interval) for source categories. Where the methods for obtaining activity data and methodology to develop estimates have not changed, it is assumed that uncertainty ranges for many source categories included in the ICF Consulting (2004, 2005) study remain applicable to current GHG inventory estimates. For trend uncertainty estimates, the assumption is that the uncertainty ranges apply to the 2001 inventory estimates only. This is because estimates for the trend uncertainty are more sensitive to the inventory values for base and current years.

#### **A7.3.1 General Concepts**

Sources of uncertainty can include those arising from conceptualization, models and input data and assumptions and can be represented as random (lack of precision) or systematic (lack of accuracy or bias) error. Good practice requires that systematic error be prevented wherever possible, such as by using appropriate QA/QC procedures. Once biases are corrected to the extent possible, the uncertainty analysis can then focus on quantification of the random errors. The IPCC provides guidance in estimating and reporting uncertainties associated with both annual estimates of emissions and removals, and emission and removal trends over time (IPCC 2000). While the methods developed in the *Good Practice Guidance and Uncertainty Management in National*

*Greenhouse Gas Inventories* are intended to estimate uncertainties for the national inventory, it is important to recognize that some uncertainties that are not addressed by statistical means may exist, including those arising from omissions or double counting or other conceptual errors, or from incomplete understanding of the processes that may lead to inaccuracies in estimates developed from models. Therefore, an uncertainty analysis should be seen, first and foremost, as a means to help prioritize national efforts to reduce the uncertainty of inventories in the future and guide decisions on methodological choice.

### **A7.3.2 Input Data for the Uncertainty Model**

The Monte Carlo method of uncertainty estimation requires specifying the probability distributions underlying every input parameter used in the inventory estimation for each source category. Credibility of the uncertainty estimates developed using the Monte Carlo approach is essentially dependent on the accurate characterization of these probability distribution functions. Because the values of many of the input parameters used for GHG estimation were developed as point estimates, uncertainty ranges associated with the inventory estimates of the input variables were later obtained from various best available data sources, consistent with the guidelines provided in the *IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000). The two main sources of uncertainty data were

- published references, survey data, sample statistics, and other unpublished reports; and
- expert elicitations.

The important published references that were used in developing uncertainty for the input variables included McCann (2000), SGA Energy Ltd. (2000), *IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000), the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997), and the 2003 NIR (Environment Canada 2003).

For many other variables, uncertainty data to characterize the input variables were obtained through expert elicitations. Elicitations were administered using elicitation protocols and were structured similarly to the well-known Stanford/SRI International protocol (Morgan and Henrion 1990; IPCC 2000). During the expert elicitation, expert judgements on uncertainty estimates of input data were obtained from different experts coming from different areas, such as industry, industry associations, government, university, and consultants. A complete list of all the experts can be found in the ICF Consulting (2004) report.

In the case of other input variables for which uncertainty data were not available through expert elicitations, uncertainty estimates were developed based on the IPCC-recommended uncertainty ranges associated with the emission factors and/or activity data. When pertinent uncertainty data were not available from any of these sources, educated estimates were made by Environment Canada.

### **A7.3.3 Level of Aggregation Adopted for Uncertainty Analysis**

For each category, the level of disaggregation was determined in consultation between Environment Canada and ICF Consulting. It was generally conducted at the level at which it was believed that the uncertainty data associated with the inventory input variables could be reliably obtained. Table A7-2 reports the level of disaggregation adopted for performing the uncertainty analysis under this project.

**Table A7-2: Level of Aggregation Adopted for the Uncertainty Analysis, by Key Source Category (Canada's Greenhouse Gas Inventory, 1990–2001, Submitted by Environment Canada in 2003) <sup>1</sup>**

Source Category	IPCC Source Category	Direct GHG	Criteria for Identification <sup>2</sup>	Level of Aggregation
1.A.1.a	Fuel Combustion—Public Electricity and Heat Production	CO <sub>2</sub>	Level, Trend, and Quality	Provincial level for coal and national level for others
1.A.1.b	Fuel Combustion—Petroleum Refining	CO <sub>2</sub>	Level, Trend, and Quality	National
1.A.1.c	Fuel Combustion—Manufacture of Solid Fuels and Other Energy Industries	CO <sub>2</sub>	Level, Trend, and Quality	Provincial level for coal and national level for others
1.A.2	Fuel Combustion—Manufacturing Industries and Construction	CO <sub>2</sub>	Level and Trend	Provincial level for coal and national level for others
1.A.3.a	Fuel Combustion—Civil Aviation	CO <sub>2</sub>	Level	National, by fuel type
1.A.3.b	Fuel Combustion—Road Transportation	CO <sub>2</sub>	Level, Trend, and Quality	National, by vehicle category and fuel type
1.A.3.b	Fuel Combustion—Road Transportation	N <sub>2</sub> O	Level, Trend, and Quality	National, by vehicle category and fuel type
1.A.3.c	Fuel Combustion—Railways	CO <sub>2</sub>	Level and Trend	National, by fuel type
1.A.3.e	Fuel Combustion—Other Transport	CO <sub>2</sub>	Level	National, by fuel type
1.A.3.f	Fuel Combustion—Pipeline Transport	CO <sub>2</sub>	Level, Trend, and Quality	National, by fuel type
1.A.4	Fuel Combustion—Other Sectors	CO <sub>2</sub>	Level and Trend	Provincial level for coal and national level for others
1.B.1.a	Fugitive Emissions—Coal Mining	CH <sub>4</sub>	Level	National, by mine type
1.B.2.(a+b)	Fugitive Emissions—Oil and Natural Gas	CH <sub>4</sub>	Level, Trend, and Quality	National, by economic activity
1.B.2.c	Fugitive Emissions—Oil and Natural Gas—Venting and Flaring	CO <sub>2</sub>	Level, Trend, and Quality	National
1.B.2.c	Fugitive Emissions—Oil and Natural Gas—Venting and Flaring	CH <sub>4</sub>	Quality	National
2.A.1	Industrial Processes—Cement Production	CO <sub>2</sub>	Level and Quality	National
2.B.1	Industrial Processes—Ammonia Production	CO <sub>2</sub>	Level	National
2.B.3	Industrial Processes—Adipic Acid Production	N <sub>2</sub> O	Level, Trend, and Quality	National
2.C.1	Industrial Processes—Iron and Steel Production	CO <sub>2</sub>	Level	National
2.C.3	Industrial Processes—Aluminium Production	PFCs	Level and Quality	National, by technology type
2.C.4	Industrial Processes—Magnesium Production	SF <sub>6</sub>	Level and Quality	National
2.F	Industrial Processes—Other (Undifferentiated Production)	CO <sub>2</sub>	Level	National, by feedstock fuel type
4.A	Agriculture—Enteric Fermentation	CH <sub>4</sub>	Level	National, by cattle type
4.B	Agriculture—Manure Management	CH <sub>4</sub>	Level	National, by cattle type
4.D	Agriculture—Agricultural Soils	N <sub>2</sub> O	Level	National with subsector details
6.A	Waste—Solid Waste Disposal on Land	CH <sub>4</sub>	Level and Quality	National, by waste category

Notes:

<sup>1</sup> This table was adapted based on Table A1–1 of the 2003 National Inventory Report (Environment Canada, 2003)<sup>2</sup> Level, trend, and quality refer to the source category being a key source category based on level, trend, and quality.

### A7.3.4 Sensitivity Analysis

A sensitivity analysis was also performed to determine the relative contributions of source categories or key input variables to the overall uncertainty (ICF Consulting 2005). For this study, rank correlation coefficients ( $r$  values) were used as a measure to determine uncertainty importance: a value of  $r = 0.0$  indicates that there is no relationship between the input and the corresponding output variable and a value of  $r = 1.0$  indicates that the variation in the output variable is fully responsive to the variation in the input variable.

The sensitivity analysis of the overall uncertainty in the total inventory emissions indicates that the uncertainty associated with the  $N_2O$  emission source category from the mobile sources in the transport subsector has the most influence on the overall uncertainty in the inventory (with a correlation value, or  $r$ , of 0.47), although  $CO_2$  emissions from stationary source fossil fuel combustion accounted for over three quarters of Canada's total GHG emissions in 2001. The other significant input variables include the uncertainty associated with  $CH_4$  emissions from stationary source fossil fuel combustion ( $r = 0.37$ ),  $N_2O$  from agricultural soils ( $r = 0.36$ ),  $CH_4$  from the Waste Sector ( $r = 0.31$ ), and  $CO_2$  from stationary source fuel combustion ( $r = 0.30$ ).

In the case of uncertainty associated with the overall  $CO_2$  emissions, the key source categories include stationary fuel combustion, followed by mobile sources, industrial processes, and fugitive emissions.

In the case of uncertainty associated with the overall  $CH_4$  emissions, the key source categories include stationary fuel combustion, followed by the Waste Sector and fugitive emissions.

In the case of uncertainty associated with the overall  $N_2O$  emissions, the principal source categories include mobile sources, followed by agricultural soils and stationary fuel combustion.

In the case of PFC emissions, the  $CF_4$  from industrial sources is the primary source category, followed by  $C_2F_6$  from industrial processes.

In the case of HFC emissions, the halocarbons-use source category is the key source category, as it was the only source of HFC emissions in Canada in 2001.

Similarly,  $SF_6$  from industrial processes is the only source category that contributed to  $SF_6$  emissions in Canada in 2001.

### A7.4 Summary of Sector Uncertainties

Canada has adopted Table 6.2 of IPCC (2000) for presenting its 2001 GHG inventory uncertainty estimates, as shown in Table A7-3 to Table A7-8. Based on the results of the ICF Consulting study, the tables provide the source category, followed by the rounded inventory estimates for the 1990 baseline inventory year and for the 2001 inventory year as reported in the 2003 NIR submission, followed by the level uncertainty range in percentage of the inventory estimate for 2001. The level uncertainty sensitivity is then reported as a ranked correlation ( $r$  value). Finally, for the trend uncertainty, the values shown in the tables provide a picture of trend uncertainty in 2001. Highlights of the results obtained from analysis of uncertainty for various source sectors are presented at the end of this section, along with a summary of changes to the activity data and/or emission factors and uncertainty estimates that have occurred to some categories since the study of the 2001 inventory uncertainty. For details of findings, reference should be made to the uncertainty sections within chapters 3 to 8.

Table A7-3: Tier 2 Uncertainty Reporting—Energy (Stationary Combustion)<sup>1</sup>

IPCC Source Category	Gas	Base Year (1990) Emissions (Gg <sup>2</sup> CO <sub>2</sub> eq)	Year t (2001) Emissions (Gg CO <sub>2</sub> eq)	Uncertainty in Year t Emissions as % of Emissions in the Category		Uncertainty Rank Correlation Value National Total in Year t (2001)	% Change in Emissions between 2001 and 1990	Range of Likely % Change between 2001 and 1990	
				% Below (2.5 <sup>th</sup> percentile)	% Above (97.5 <sup>th</sup> percentile)			Lower % (2.5 <sup>th</sup> percentile)	Upper % (97.5 <sup>th</sup> percentile)
<b>1.A Stationary Combustion</b>	CO <sub>2</sub>	276 000	335 000	−4	1	0.30	21	20	23
	CH <sub>4</sub>	4 000	5 000	−24	700	0.37	25	−2	45
	N <sub>2</sub> O	2 000	2 000	−11	650	0.24	20	−45	190
<b>1.A.1 Energy Industries</b>	CO <sub>2</sub>	144 000	201 000	−6	2				
	CH <sub>4</sub>	2 000	3 000	1	230				
	N <sub>2</sub> O	900	1 000	−23	800				
<b>1.A.1.a Public Electricity and Heat Production</b>	CO <sub>2</sub>	94 700	136 000	−3	3		44	45	50
	CH <sub>4</sub>	38	100	−20	40		175	100	200
	N <sub>2</sub> O	500	800	−35	900		40	−75	950
<b>1.A.1.b Petroleum Refining</b>	CO <sub>2</sub>	26 000	29 000	−35	7		11	7	10
	CH <sub>4</sub>	8	9	−50	900		13	−26	50
	N <sub>2</sub> O	90	90	−28	1 000		5	−40	40
<b>1.A.1.c Manufacture of Solid Fuels and Other Energy Industries</b>	CO <sub>2</sub>	23 600	35 500	−8	8		50	45	60
	CH <sub>4</sub>	2 000	2 000	0	240		50	40	55
	N <sub>2</sub> O	200	300	−90	1 500		50	35	80
<b>1.A.2 Manufacturing Industries and Construction</b>	CO <sub>2</sub>	62 100	59 700	−3	2				
	CH <sub>4</sub>	40	40	−35	380				
	N <sub>2</sub> O	400	400	−55	850				

IPCC Source Category	Gas	Base Year (1990) Emissions (Gg <sup>2</sup> CO <sub>2</sub> eq)	Year t (2001) Emissions (Gg CO <sub>2</sub> eq)	Uncertainty in Year t Emissions as % of Emissions in the Category		Uncertainty Rank Correlation Value National Total in Year t (2001)	% Change in Emissions between 2001 and 1990	Range of Likely % Change between 2001 and 1990	
				% Below (2.5 <sup>th</sup> percentile)	% Above (97.5 <sup>th</sup> percentile)			Lower % (2.5 <sup>th</sup> percentile)	Upper % (97.5 <sup>th</sup> percentile)
<b>1.A.2.a Iron and Steel</b>	CO <sub>2</sub>	6 420	5 830	-5	5		-9	-15	-4
	CH <sub>4</sub>	5	5	-70	320		-6	-90	550
	N <sub>2</sub> O	60	50	-85	650		-6	-90	650
<b>1.A.2.b Non-Ferrous Metals</b>	CO <sub>2</sub>	3 210	3 480	-6	-1		8	18	22
	CH <sub>4</sub>	1	2	-19	95		19	10	27
	N <sub>2</sub> O	10	20	-55	850		21	-60	240
<b>1.A.2.c Chemicals</b>	CO <sub>2</sub>	7 060	6 440	-3	2		-9	-10	-8
	CH <sub>4</sub>	3	3	-35	40		-7	-9	-1
	N <sub>2</sub> O	40	40	-85	1 300		-7	-11	9
<b>1.A.2.d Pulp, Paper &amp; Print</b>	CO <sub>2</sub>	13 400	9 500	-4	4		-29	-29	-27
	CH <sub>4</sub>	20	20	-60	900		0	-28	35
	N <sub>2</sub> O	100	100	-60	900		-6	-29	30
<b>1.A.2.f Other</b>	CO <sub>2</sub>	32 000	34 400	-3	2				
	CH <sub>4</sub>	10	10	-28	120				
	N <sub>2</sub> O	200	200	-65	1 000				
<b>1.A.4 Other Sectors</b>	CO <sub>2</sub>	69 400	74 300	-3	2				
	CH <sub>4</sub>	2 000	2 000	-90	1 500				
	N <sub>2</sub> O	700	700	-65	1 000				

Note:

1. Refer to Chapter 3 of the 2003 NIR for a discussion of the uncertainty associated with CH<sub>4</sub> and N<sub>2</sub>O emission factors.

**Table A7-4: Tier 2 Uncertainty Reporting—Energy (Transport)<sup>1</sup>**

IPCC Source Category	Gas	Base Year (1990) Emissions (Gg <sup>2</sup> CO <sub>2</sub> eq)	Year t (2001) Emissions (Gg CO <sub>2</sub> eq)	Uncertainty in Year t Emissions as % of Emissions in the Category		Uncertainty Rank Correlation Value National Total in Year t (2001)	% Change in Emissions between 2001 and 1990	Range of Likely % Change between 2001 and 1990	
				% Below (2.5 <sup>th</sup> percentile)	% Above (97.5 <sup>th</sup> percentile)			Lower % (2.5 <sup>th</sup> percentile)	Upper % (97.5 <sup>th</sup> percentile)
1.A.3 Transport	CO <sub>2</sub>	146 000	178 000	–	–	0.12			
	CH <sub>4</sub>	600	700	–	–	0.05			
	N <sub>2</sub> O	6 000	9 000			0.47			
Total Mobile Sources (Total Transport excluding Pipelines)									
	CO <sub>2</sub>	139 000	168 000	–4	0				
	CH <sub>4</sub>	500	400	–24	700				
	N <sub>2</sub> O	6 000	9 000	–28	410				
Total Non-Rail Surface Transport Vehicles (On-Road & Off-Road)									
	CO <sub>2</sub>	118 000	145 200	–4	0				
	CH <sub>4</sub>	500	400	–29	700				
	N <sub>2</sub> O	5 000	7 000	–35	390				
1.A.3.a Civil Aviation	CO <sub>2</sub>	10 410	11 800	–1	1		13	12	15
	CH <sub>4</sub>	10	10	–75	900		–12	–35	13
	N <sub>2</sub> O	300	400	–90	1 500		13	–17	16
1.A.3.b Road Transportation	CO <sub>2</sub>	103 000	127 000	–8	–3		24	20	28
	CH <sub>4</sub>	350	290	–19	18		–17	–24	–8
	N <sub>2</sub> O	3 600	5 700	–35	35		57	40	75
On-Road Gasoline Vehicles	CO <sub>2</sub>	75 200	87 000	–7	–3		16	12	19
	CH <sub>4</sub>	280	210	–22	16		–25	–30	–18
	N <sub>2</sub> O	3 400	5 400	–35	30		58	40	80
On-Road Diesel Vehicles	CO <sub>2</sub>	25 500	39 400	–13	–1		55	45	70
	CH <sub>4</sub>	30	40	–65	55		55	45	70
	N <sub>2</sub> O	200	400	–70	260		53	35	65



IPCC Source Category	Gas	Base Year (1990) Emissions (Gg <sup>2</sup> CO <sub>2</sub> eq)	Year t (2001) Emissions (Gg CO <sub>2</sub> eq)	Uncertainty in Year t Emissions as % of Emissions in the Category		Uncertainty Rank Correlation Value National Total in Year t (2001)	% Change in Emissions between 2001 and 1990	Range of Likely % Change between 2001 and 1990	
				% Below (2.5 <sup>th</sup> percentile)	% Above (97.5 <sup>th</sup> percentile)			Lower % (2.5 <sup>th</sup> percentile)	Upper % (97.5 <sup>th</sup> percentile)
On-Road Natural Gas Vehicles	CO <sub>2</sub>	84	118	-4	4		40	35	45
	CH <sub>4</sub>	20	30	-50	120		40	35	45
	N <sub>2</sub> O	1	1	-95	1 400		40	35	45
On-Road Propane Vehicles	CO <sub>2</sub>	2 080	979	-2	2		-55	-55	-50
	CH <sub>4</sub>	20	10	-50	120		-53	-55	-50
	N <sub>2</sub> O	10	6	-95	1 500		-55	-55	-50
1.A.3.c Railways	CO <sub>2</sub>	6 320	5 820	-5	3		-8	-13	-5
	CH <sub>4</sub>	7	7	-60	60		-8	-12	-4
	N <sub>2</sub> O	800	700	-95	1 500		-8	-12	-4
1.A.3.d Navigation	CO <sub>2</sub>	4 730	5 180	-3	3		9	6	13
	CH <sub>4</sub>	7	8	-40	190		11	6	15
	N <sub>2</sub> O	300	300	-90	1 300		7	2	12
1.A.3.e.i Off-Road	CO <sub>2</sub>	15 100	17 700	4	45		17	-5	50
	CH <sub>4</sub>	100	100	-80	2 300		-3	-35	60
	N <sub>2</sub> O	1 000	2 000	-90	1 800		27	-1	60
1.A.3.e.ii Pipeline (Transport)	CO <sub>2</sub>	6 700	9 970	-3	3	0.02	50	45	50
	CH <sub>4</sub>	140	210	-15	-15		50	45	50
	N <sub>2</sub> O	50	80			0.01	50	3	50

Notes:

1. The uncertainty indicated in the ICF Consulting study may no longer be representative of that embodied in estimates due to some significant changes to Transport estimation methodology.

See Chapter 3 and Section A7.4.1.2 for more details.

2. Gg = gigagram.

**Table A7-5: Tier 2 Uncertainty Reporting—Energy (Fugitives) <sup>1</sup>**

IPCC Source Category	Gas	Base Year (1990) Emissions (Gg <sup>2</sup> CO <sub>2</sub> eq)	Year t (2001) Emissions (Gg CO <sub>2</sub> eq)	Uncertainty in Year t Emissions as % of Emissions in the Category		Uncertainty Rank Correlation Value National Total in Year t (2001)	% Change in Emissions between 2001 and 1990	Range of Likely % Change between 2001 and 1990	
				% Below (2.5 <sup>th</sup> percentile)	% Above (97.5 <sup>th</sup> percentile)			Lower % (2.5 <sup>th</sup> percentile)	Upper % (97.5 <sup>th</sup> percentile)
1.B Fugitive Emissions from Coal Mining/Handling and from Oil and Gas	CO <sub>2</sub>	9 800	15 000	−35	−13	0.06	55	−3	45
	CH <sub>4</sub>	28 000	39 000	−7	16	0.15	40	23	65
1.B.1.a Fugitive Emissions—Coal Mining	CO <sub>2</sub>	—	—	—	—				
	CH <sub>4</sub>	2 000	1 000	−30	130		−50	−70	22
1.B.2.(a+b) Fugitive Emissions—Oil and Natural Gas	CO <sub>2</sub> eq	36 000	53 000	−10	9				
	CO <sub>2</sub>	9 800	15 000	−35	−13		55	−3	45
	CH <sub>4</sub>	26 000	38 000	−7	15		45	28	75
1.B.2.a Oil	CO <sub>2</sub>	30	80	−60	−40		190	−11	90
	CH <sub>4</sub>	8 500	14 000	−29	13		65	29	150
1.B.2.b Natural Gas	CO <sub>2</sub>	20	30	25	55		55	35	85
	CH <sub>4</sub>	17 000	24 000	1	28		40	19	70
1.B.2.c Fugitive Emissions—Oil and Natural Gas—Venting and Flaring	CO <sub>2</sub>	9 800	15 000	−35	−13		55	−4	44
	CH <sub>4</sub>	500	700	−95	−90		35	−90	−85
Venting	CO <sub>2</sub>	4 500	7 800	−29	10				
	CH <sub>4</sub>	0	0	—	—				
Flaring	CO <sub>2</sub>	5 300	7 400	−50	−30				
	CH <sub>4</sub>	500	700	−95	−90				

Notes:

1. Uncertainty in year t emissions as % of the category's emissions has been taken from ICF Consulting (2005) study. New uncertainty data have been obtained from a more recent study; see Energy Sector chapter for more details.

2. Gg = gigagram.

**Table A7-6: Tier 2 Uncertainty Reporting—Industrial Processes, Solvent and Other Product Use<sup>1</sup>**

IPCC Source Category	Gas	Base Year (1990) Emissions (Gg <sup>3</sup> CO <sub>2</sub> eq)	Year t (2001) Emissions (Gg CO <sub>2</sub> eq)	Uncertainty in Year t Emissions as % of Emissions in the Category		Uncertainty Rank Correlation Value National Total in Year t (2001)	% Change in Emissions between 2001 and 1990	Range of Likely % Change between 2001 and 1990	
				% Below (2.5 <sup>th</sup> percentile)	% Above (97.5 <sup>th</sup> percentile)			Lower % (2.5 <sup>th</sup> percentile)	Upper % (97.5 <sup>th</sup> percentile)
2.A Mineral Products		8 200	8 700	–	–		6	–28	55
2.A.1 Cement Production	CO <sub>2</sub>	5 900	6 500	–35	35		11	–35	85
2.A.2 Lime Production	CO <sub>2</sub>	2 000	2 000	–2	110		–5	–45	65
2.A.3 Limestone and Dolomite Use	CO <sub>2</sub>	370	340	–16	16		–9	–15	–2
2.A.4 Soda Ash Use	CO <sub>2</sub>	68	64	–26	29		–6	–35	30
2.B Chemical Industry		16 500	7 520	–	–		–55	–65	–40
2.B.1 Ammonia Production	CO <sub>2</sub>	5 000	6 000	–23	55		18	–16	65
2.B.2 Nitric Acid Production	N <sub>2</sub> O	780	800	–15	–16		2	–18	28
2.B.3 Adipic Acid Production	N <sub>2</sub> O	10 700	802	–2	2		–95	–95	–90
2.C Metal Production		19 100	20 300	–	–		6	–19	–11
2.C.1 Iron and Steel Production	CO <sub>2</sub>	7 590	7 920	–5	5		4	3	6
2.C.3 Aluminium Production (Total GHGs)	–	8 600	10 000	–45	–30		20	–35	–19
2.C.4 SF <sub>6</sub> Used in Magnesium Foundries	SF <sub>6</sub>	2 870	2 020	–1	1		–30	–30	–29
2.G Other		9 200	11 700	–40	1		27	–30	50
Other and Undifferentiated Production	CO <sub>2</sub>	9 200	11 700	–40	1		27	–30	50
Total GHG Emissions from Industrial Processes	CO <sub>2</sub> eq	52 900	48 900	–7	5	0.10	–9	–27	–12
Total CO <sub>2</sub> Emissions—Industrial Processes	CO <sub>2</sub>	32 600	38 300	2	19		18	–3	27

IPCC Source Category	Gas	Base Year (1990) Emissions (Gg <sup>3</sup> CO <sub>2</sub> eq)	Year t (2001) Emissions (Gg CO <sub>2</sub> eq)	Uncertainty in Year t Emissions as % of Emissions in the Category		Uncertainty Rank Correlation Value National Total in Year t (2001)	% Change in Emissions between 2001 and 1990	Range of Likely % Change between 2001 and 1990	
				% Below (2.5 <sup>th</sup> percentile)	% Above (97.5 <sup>th</sup> percentile)			Lower % (2.5 <sup>th</sup> percentile)	Upper % (97.5 <sup>th</sup> percentile)
Total N <sub>2</sub> O Emissions—Industrial Processes	N <sub>2</sub> O	11 500	1 600	–8	8		–85	–85	–85
Total HFC Emissions from ODS Substitutes <sup>2</sup>	HFC	0	900	–21	55	0.01	–	–	–
Total PFC Emissions—Industrial Processes	PFC	6 000	6 000	–70	–60		–	–	–
Total SF <sub>6</sub> Emissions—Industrial Processes	SF <sub>6</sub>	2 870	1 910	–1	1		–30	–30	–29
3. Solvent and Other Product Use	N <sub>2</sub> O	420	470	–23	22		12	12	12

Notes:

1. For details on the applicability of the uncertainty ranges provided in the ICF Consulting study to the current emission estimates, please refer to Section A.7.4.2 and category-specific uncertainty sections in Chapter 4.

2. ODS = Ozone-depleting substance.

3. Gg = gigagram.

**Table A7-7: Tier 2 Uncertainty Reporting—Agriculture<sup>1</sup>**

IPCC Source Category	Gas	Base Year (1990) Emissions (Gg <sup>2</sup> CO <sub>2</sub> eq)	Year t (2001) Emissions (Gg CO <sub>2</sub> eq)	Uncertainty in Year t Emissions as % of Emissions in the Category		Uncertainty Rank Correlation Value National Total in Year t (2001)	% Change in Emissions between 2001 and 1990	Range of Likely % Change between 2001 and 1990	
				% Below (2.5 <sup>th</sup> percentile)	% Above (97.5 <sup>th</sup> percentile)			Lower % (2.5 <sup>th</sup> percentile)	Upper % (97.5 <sup>th</sup> percentile)
4.A Enteric Fermentation	CH <sub>4</sub>	16 000	18 800	−9	9	0.06	18	15	20
4.B Manure Management	CH <sub>4</sub>	4 600	5 500	−15	15	0.04	19	15	23
	N <sub>2</sub> O	3 700	4 600	−30	35	0.05	25	−10	60
	CO <sub>2</sub> eq	8 300	10 000	−16	18		22	6	40
4.D Agricultural Soils						0.36			
Direct Soil Emissions	N <sub>2</sub> O	22 000	24 000	−25	35		11	7	16
Indirect Soil Emissions	N <sub>2</sub> O	5 400	7 000	−60	120		28	24	35
Total (Direct and Indirect Soil Emissions)	N <sub>2</sub> O	27 000	31 000	−25	40		15	11	20

Notes:

1. Revised uncertainty estimates have been obtained from more recent studies. See Agriculture Sector, Chapter 6, for more details.

2. Gg – gigagram.

**Table A7-8: Tier 2 Uncertainty Reporting—Waste**

IPCC Source Category	Gas	Base Year (1990) Emissions (Gg <sup>5</sup> CO <sub>2</sub> eq)	Year t (2001) Emissions (Gg CO <sub>2</sub> eq)	Uncertainty in Year t Emissions as % of Emissions in the Category		Uncertainty Rank Correlation Value National Total in Year t (2001)	% Change in Emissions between 2001 and 1990	Range of Likely % Change between 2001 and 1990	
				% Below (2.5 <sup>th</sup> percentile)	% Above (97.5 <sup>th</sup> percentile)			Lower % (2.5 <sup>th</sup> percentile)	Upper % (97.5 <sup>th</sup> percentile)
6. Waste	CO <sub>2</sub> eq	20 000	25 000			0.31			
6.A Solid Waste Disposal on Land	CH <sub>4</sub>	19 000	23 000	−35	40		25	29	55
Emissions from MSW Landfills <sup>1</sup>	CH <sub>4</sub>	17 000	22 000	−40	35				
Emissions from Wood Waste <sup>2</sup>	CH <sub>4</sub>	2 000	2 000	−60	190				

IPCC Source Category	Gas	Base Year (1990) Emissions (Gg <sup>5</sup> CO <sub>2</sub> eq)	Year t (2001) Emissions (Gg CO <sub>2</sub> eq)	Uncertainty in Year t Emissions as % of Emissions in the Category		Uncertainty Rank Correlation Value National Total in Year t (2001)	% Change in Emissions between 2001 and 1990	Range of Likely % Change between 2001 and 1990	
				% Below (2.5 <sup>th</sup> percentile)	% Above (97.5 <sup>th</sup> percentile)			Lower % (2.5 <sup>th</sup> percentile)	Upper % (97.5 <sup>th</sup> percentile)
6.B Wastewater Handling/Treatment <sup>2</sup>	CO <sub>2</sub> eq	1 000	1 000	-40	55		12	12	13
Emissions from Wastewater Treatment	CH <sub>4</sub>	360	400	-40	45		13	12	13
	N <sub>2</sub> O	900	1 000	-60	65		12	12	12
6.C Waste Incineration	CO <sub>2</sub> eq	300	300	-12	65		10	10	11
Emissions from MSW Incineration <sup>3</sup>	CO <sub>2</sub>	300	300	-3	85		12	11	12
	N <sub>2</sub> O	50	60	-80	85		11	11	12
Emissions from Sewage Sludge Incineration <sup>4</sup>	CH <sub>4</sub>	10	7	-60	60		-25	-30	-19

## Notes:

1. The accuracy of these values is subject to the following limitations: 1) the uncertainty values from the ICF Consulting (2004) study were calculated from the Monte Carlo method employing a much simplified CH<sub>4</sub> generation model compared with that utilized in the NIR; 2) only one expert's opinion was used to provide the uncertainty lower and upper limits for each activity data input CH<sub>4</sub> volume capture, MSW landfilling rate per capita, Scholl Canyon constants (CH<sub>4</sub> generation potential, L<sub>0</sub>, and the CH<sub>4</sub> rate constant, k), and population statistics. A revision of the landfill gas collection inventory in 2004 has since found the 2001 inventory value of the quantity of CH<sub>4</sub> captured to be 10% overestimated. The uncertainty about the quantity of CH<sub>4</sub> captured was overestimated due to a transcription error.
2. The input values for this category were IPCC default values or assumed values.
3. Uncertainties for all inputs were assumed except for the N<sub>2</sub>O emissions, which were based on IPCC estimates.
4. The uncertainty range for the CH<sub>4</sub> emission factor for fluidized beds in the 2001 inventory year was assumed. For simplicity, the multi-hearth incinerators were not included. Uncertainty about the quantity of sewage sludge incinerated was assumed based upon IPCC values.
5. Gg = gigagrams.

### **A7.4.1 Energy**

Emissions evaluated for this sector include CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O from stationary combustion and from transport and CO<sub>2</sub> and CH<sub>4</sub> from fugitive emissions. Uncertainty values were obtained from the ICF Consulting (2004, 2005) study based upon data and models that were developed for the 2003 National Inventory Report submission year for the year 2001 inventory (Environment Canada 2003).

#### *A7.4.1.1 Energy—Stationary Combustion*

The overall uncertainty for CO<sub>2</sub> is found to have a range of -4% to +1%. The highest uncertainty range for CO<sub>2</sub> from major fuel types used in the stationary combustion sector relates to liquid fuels (-15% to +2%). Estimates for uncertainty ranges for CH<sub>4</sub> and N<sub>2</sub>O emissions are -24% to +700% and -11% to +650%, respectively.

High uncertainty with regards to liquid fuels was primarily due to the variability in emission factors for a few specific fuels. Revisions to emission factors in recent years and an update of the stationary combustion methodology are believed to have reduced the uncertainty, although this has not yet been quantified. In addition, landfill gas utilization has recently been added to the Energy Industries category. The specific uncertainty associated with the emissions attributed to the use of landfill gas has not yet been determined, although the contribution to the overall emissions is minimal. Additional analysis of uncertainty is provided in Chapter 3.

#### *A7.4.1.2 Energy—Transport*

The ICF Consulting uncertainty range for CO<sub>2</sub> estimates from transport, including road, aviation, and marine mobile sources, follows closely the values quoted for stationary combustion (-4% to 0% in this case). This is understandable, since the uncertainty for CO<sub>2</sub> estimates directly follows the uncertainty existing in the fuel quantities consumed. Uncertainties for CH<sub>4</sub> and N<sub>2</sub>O are in the ranges of -24% to +700% and -28% to +410%, respectively.

In the time since the ICF Consulting uncertainty study was completed, some significant changes to Transport estimation methodology have been employed. Specifically, the methodology to allocate aviation fuels to either domestic or international use has changed, along with the method to allocate Transport fuels between On- and Off-Road. Additionally, an internal technical review of all Transport emission factors was conducted to assess accuracy and applicability, while a -review performed across Canada in the fall of 2007 identified a more appropriate set of CO<sub>2</sub> emission factors for liquid fuels based on newer data and knowledge. While the reduction of uncertainty accompanying these improvements has not yet been quantified, Canada believes that the uncertainty indicated in the ICF Consulting study is not representative of that embodied in the new estimates. Please see Chapter 3 for more details regarding Energy Sector uncertainty.

Historic fuel ethanol consumption has been added to the Transport subsector. The specific uncertainty associated with the emissions attributed to the use of this fuel has not yet been determined. Nevertheless, only minor quantities are combusted, and emissions from ethanol are very small, in relative terms. Thus, any uncertainty associated with their estimation will have very little impact on Transport category uncertainties.

#### *A7.4.1.3 Energy—Fugitive Emissions*

This subsector includes CH<sub>4</sub> and CO<sub>2</sub> fugitive emissions occurring in the coal mining and oil and gas industry. It includes emissions associated with leaks, venting, and flaring in oil and gas operations, as well as in coal mining. The uncertainty ranges for fugitive emissions are -35% to -13% for CO<sub>2</sub> and -7% to +16% for CH<sub>4</sub>. The uncertainty discussion presented in Chapter 3 of this report for the

upstream oil and gas industry is based on results from a Tier 1 analysis conducted by Clearstone Engineering Ltd. for the Canadian Association of Petroleum Producers (CAPP) (CAPP 2005).

For the refining industry, the uncertainty analysis was conducted by Levelton Consultants Ltd. for the Canadian Petroleum Products Institute (CPPI) (CPPI 2004). The overall uncertainty estimate, based on a Tier 1 analysis, was found to be  $\pm 8.3\%$ . A Tier 2 analysis was also conducted; in this case, overall uncertainties were estimated to be  $\pm 14\%$ . Note that the uncertainty estimates presented in Table A7-5 for the overall fugitive category (1.B), the overall oil category (1.B.2.a), Oil Production (1.B.2.a.ii), and Venting and Flaring (1.B.2.c) do not incorporate this new information from the CPPI study on the oil refining industry.

## **A7.4.2 Industrial Processes**

According to the ICF Consulting analysis, the Tier 2 uncertainty for the 2001 GHG emission estimate of the Industrial Processes Sector, excluding halocarbon estimates, ranged from  $-7\%$  to  $+5\%$ . There have been additions of new sources, improvements in calculation methods, and acquisition of new activity data for a number of categories since the completion of the ICF Consulting study. It is therefore expected that the uncertainty associated with the Industrial Processes Sector will be slightly different from the value provided by ICF Consulting.

Major factors that have affected the results of the ICF Consulting uncertainty assessment are described in the following sections. The Tier 1 uncertainty analyses conducted for some categories are also described. Further details regarding the uncertainty assessment for each category are provided in Chapter 4.

### *A7.4.2.1 Industrial Processes—Mineral Products*

Improvements have been made to the calculation methods and to the uncertainty in activity data for the categories of cement and lime production since the completion of the ICF Consulting study. An assessment for their uncertainty, using a Tier 1 method, was undertaken and the results were  $\pm 33\%$  and  $\pm 21\%$  for cement and lime production respectively. Because of these improvements, results from the ICF Consulting study are no longer valid for these categories.

Inclusion of additional emissions coming from uses of limestone, which were not reported in the 1990–2001 inventory, is also expected to have an impact on uncertainty estimates provided by ICF Consulting. A 2006 AMEC Earth & Environmental (AMEC) study provided an uncertainty range of  $\pm 16\%$  to  $\pm 19\%$  by performing a Tier 1 assessment for the categories of limestone and dolomite use (for the time series). According to this study, the uncertainty should be mostly related to the activity data and the ratio of limestone to dolomite used in developing the emission estimates.

Improvements in the activity data used to estimate emissions from soda ash use renders the ICF Consulting study no longer valid for this category. Uncertainty associated with CO<sub>2</sub> emissions from soda ash use was assessed using a Tier 1 method. It varies from  $\pm 10\%$  to  $\pm 14\%$  (AMEC Earth & Environmental 2006). In addition, a Tier 1 uncertainty assessment was undertaken for emissions from magnesite use in the whole time series and the result varies from  $\pm 4.9\%$  to  $\pm 6.0\%$  (AMEC Earth & Environmental 2006).

### *A7.4.2.2 Industrial Processes—Chemical Industry*

Improvements have been made to estimating emissions from the category of ammonia production. For instance, the values of ammonia production not involving steam methane reformation have been updated for all years. The uncertainty (assessed using a Tier 2 approach) associated with this category would likely have lowered as a result of these updates. The Tier 2 uncertainty range, provided in the ICF Consulting study for the category of nitric acid production, is no longer applicable, since the



emission estimation methodology has been revised as a result of a recent study (Cheminfo Services 2006). Gathered from the study were plant-specific data on emissions, production, and emission factors for most companies and most years of the time-series. The collected data and information have helped reduce the uncertainty related to this category. The uncertainty estimates developed using a Tier 1 approach for nitric acid production are  $\pm 8\%$  for 1990–1998 and  $\pm 7\%$  for 1999–2006. Since there has not been any change in method or data source for adipic acid production, the uncertainty values presented in the ICF Consulting report are still applicable to the emission estimates presented in this report.

#### *A7.4.2.3 Industrial Processes—Metal Production*

Since the completion of the ICF Consulting study, the shift from a Tier 1 to a Tier 2 estimation methodology for estimating CO<sub>2</sub> emissions from iron and steel production would have decreased the uncertainty (of  $\pm 5\%$ ) for this category. The uncertainties in CO<sub>2</sub> and PFC emission estimates for aluminium production provided in the ICF Consulting report are no longer applicable due to an improvement in the calculation method. SF<sub>6</sub> from aluminium production is a category for which uncertainty was not assessed by ICF Consulting. Since there has not been any change in data source for magnesium production, the uncertainty value presented in the ICF Consulting report is still applicable to the emission estimates in this submission. SF<sub>6</sub> from magnesium casting was not a category considered in the ICF Consulting study. However, a Tier 1 assessment, which was performed as part of the Cheminfo Services (2005) study, showed an uncertainty of  $\pm 4\%$  for this category.

#### *A7.4.2.4 Industrial Processes—Consumption of Halocarbons and SF<sub>6</sub>*

Owing to the acquisition of more recent consumption data on both HFCs and PFCs, and method improvements, the uncertainty ranges for HFC and PFC emissions of  $-21\%$  to  $+55\%$  and  $-28\%$  to  $70\%$  (ICF Consulting 2004), respectively, would be considered as highly conservative. A Cheminfo Services study (Cheminfo 2005) provided a Tier 2 uncertainty assessment; it showed as result an uncertainty range of  $-50\%$  to  $+19\%$  for the category of SF<sub>6</sub> emissions from electrical equipment. Uncertainty has not been assessed for both categories of SF<sub>6</sub> emissions from semiconductor manufacturing and HFC-23 emissions from HCFC production.

#### *A7.4.2.5 Industrial Processes—Other and Undifferentiated Production*

The time series for this category has been revised since the completion of the ICF Consulting study. Revisions are due to changes in the CO<sub>2</sub> emission estimates for aluminium production, ammonia production, and iron and steel production. These revised estimates are subtracted from the total non-energy emissions to avoid double counting. In addition, there has been a reallocation of CO<sub>2</sub> emissions from natural gas used for hydrogen making to the Energy Sector categories. Although the uncertainty around the current emission estimate has not been reassessed, the ranges provided in the ICF Consulting study are considered acceptable.

### **A7.4.3 Solvent and Other Product Use**

The time-series estimates for Solvent and Other Product Use has been revised based on the N<sub>2</sub>O sales information gathered during the 2006 Cheminfo Services study. Although a complete uncertainty assessment has not been done, the study provided some ideas of the possible uncertainty range. For further details, see Chapter 5, Section 5.1.3.

#### **A7.4.4 Agriculture**

Since the ICF Consulting study was performed, significant changes in methodologies and updates to parameters were made in the Agriculture Sector, through, in particular, the adoption of Tier 2 methods for CH<sub>4</sub> sources and N<sub>2</sub>O from agricultural soils. A new analysis of uncertainty for these categories was undertaken by experts at AAFC in 2006 and was updated in 2007. Results are presented in the respective sections in Chapter 6.

#### **A7.4.5 Land Use, Land-Use Change and Forestry**

The LULUCF Sector was not included in top-down uncertainty analyses such as the ICF Consulting study, since at the time the estimation methodology was being entirely transformed. Quantitative uncertainty analyses have become possible due to the methodological improvements implemented since the 2006 submission.

All LULUCF categories do not contribute equally to the overall sectoral uncertainty. By virtue of their contribution to the overall fluxes, uncertainties about estimates in the Forest Land and Cropland categories and the cross-cutting Forest Land conversion category dominate the sector and are prioritized.

Work is under way to develop formal uncertainty estimates in the Forest Land category (White et al. in press). Uncertainty values in the Cropland category are reported in Chapter 7. Section A3.5 in Annex 3 presents preliminary assessments and expert-based, partial uncertainty estimates in, notably, wetlands and areas subject to forest conversion.

#### **A7.4.6 Waste**

Emissions evaluated for this sector include CH<sub>4</sub> emissions from solid waste disposal on land, CH<sub>4</sub> and N<sub>2</sub>O emissions from wastewater handling, and CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O emissions from waste incineration. Uncertainty values were obtained from the ICF Consulting study (2004, 2005) based upon data and models that were developed for the 2003 NIR submission year for the year 2001 inventory.

##### *A7.4.6.1 Waste—Solid Waste Disposal on Land*

The only GHG being considered for this subsector is CH<sub>4</sub>, since CO<sub>2</sub> emissions originate from the biodegradation of biomass and therefore are not included in the total emissions and since N<sub>2</sub>O emissions are assumed to be negligible. The uncertainty associated with CH<sub>4</sub> emissions from the combined municipal and wood waste landfills was estimated to be in the range of –35% to +40%.

The uncertainty is mainly due to a difference of opinion, presented during the expert elicitation process, on the values of the CH<sub>4</sub> generation potential and the CH<sub>4</sub> rate constant used in the Scholl Canyon model for the MSW landfill CH<sub>4</sub> generation estimates. As a result of the ICF Consulting report, a study was conducted by the University of Manitoba, with the direct support of Environment Canada, which focused on the development of more accurate estimates for these two key input parameters to the model (Thompson et al. 2005). In addition, the provincial/territorial CH<sub>4</sub> generation potentials were recently further revised. Therefore, in the absence of a quantitative statement based upon a follow-up Tier 2 uncertainty study, it is expected that the uncertainty of the CH<sub>4</sub> emissions from this source would be reduced by the introduction of these new values.

##### *A7.4.6.2 Waste—Wastewater Handling*

N<sub>2</sub>O emissions are responsible for approximately 80% of the total emissions from this subsector. The overall level uncertainty associated with the Wastewater Handling subsector is estimated to be in the range of –40% to +55%.

Uncertainties for CH<sub>4</sub> and N<sub>2</sub>O emissions are –40% to +45% and –60% to +65%, respectively. It is expected that the overall uncertainty range associated with the emissions from this subsector and uncertainties around the emission values related to the categories for this inventory would be reduced due to the introduction of new activity data. Specifically, the N<sub>2</sub>O emissions were recently revised based upon updated protein consumption per capita data.

#### *A7.4.6.3 Waste—Waste Incineration*

The overall uncertainty associated with the Waste Incineration source category is estimated to be in the range of –12% to +65%. CO<sub>2</sub> contributed roughly 79% of the total emissions from this subsector. The uncertainties associated with CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O emissions are –3% to +85%, –60% to +60%, and –80% to +85%, respectively. Since new activity data were obtained subsequent to the publication of the ICF Consulting report, it is expected that the uncertainties associated with these category emissions, for the present submission, would be less than those presented in the ICF Consulting study.

### ***References***

[AMEC] AMEC Earth & Environmental. 2006. Identifying and Updating Industrial Process Activity Data in the Minerals Sector for the Canadian Greenhouse Gas Inventory. AMEC Earth & Environmental, a division of AMEC Americas Ltd.

[CAPP] Canadian Association of Petroleum Producers. 2005. A National Inventory of Greenhouse Gas (GHG). Criteria Air Contaminant (CAC) and Hydrogen Sulphide (H<sub>2</sub>S) Emissions by the Upstream Oil and Gas Industry. Vols. 1–5. Calgary (AB): Clearstone Engineering Ltd.

Cheminfo Services. 2005. Improving and Updating Industrial Process-Related Activity Data and Methodologies Used in Canada's Greenhouse Gas Inventory. Markham (ON): Cheminfo Services for Environment Canada.

Cheminfo Services. 2006. Improvements and Updates to Certain Industrial Process and Solvent Use-Related Sections in Canada's Greenhouse Gas Inventory. Prepared by Cheminfo Services for Environment Canada. Markham, Ontario, Canada.

[CPPI] Canadian Petroleum Products Institute. 2004. Economic and Environmental Impacts of Removing Sulphur from Canadian Gasoline and Distillate Production. Markham (ON): Levelton Consultants Ltd. in association with Purvin & Gertz Inc.

Environment Canada. 2003. Canada's Greenhouse Gas Inventory, 1990–2001, Greenhouse Gas Division, Environment Canada.

ICF Consulting. 2004. Quantitative Assessment of Uncertainty in Canada's National GHG Inventory Estimates for 2001. Unpublished report. Contract # K-2362-3-0060, submitted to Environment Canada.

ICF Consulting. 2005. Quantitative Assessment of Uncertainty in Canada's National GHG Inventory Estimates for 2001—Supplementary Analysis, Unpublished report. Contract # K2362-04-0121, submitted to Environment Canada.

[IPCC] Intergovernmental Panel on Climate Change. 2000. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at: <http://www.ipcc-nggip.iges.or.jp/public/gp/english/>

[IPCC/OECD/IEA] Intergovernmental Panel on Climate Change, Organisation for Economic Co-operation and Development, and International Energy Agency. 1997. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Available online at <http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm>

McCann TJ. 2000. 1998 Fossil Fuel and Derivative Factors, Report prepared by T.J. McCann and Associates for Environment Canada.

McCann TJ. 1994. Uncertainties in Canada's 1990 Greenhouse Gas Emission Estimates: A Quantitative Assessment. Unpublished report prepared by T.J. McCann and Associates for the Greenhouse Gas Division, Environment Canada.

Morgan MG, Henrion M. 1990. Uncertainty: A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis. Cambridge (UK): Cambridge University Press.

[SGA] SGA Energy Ltd. 2000. Emission Factors and Uncertainties for CH<sub>4</sub> & N<sub>2</sub>O from Fuel Combustion. Unpublished report prepared by SGA Energy for the Greenhouse Gas Division, Environment Canada.

Thompson S, Sawyer J, Bonam RK, Smith S. 2005. Review of Existing Landfill Methane Generation Model: Interim Report. Winnipeg (MB): Natural Resources Institute, University of Manitoba.

White T, Luckai N, Larocque GR, Kurz WA, Smyth C. A practical approach for assessing the sensitivity of the Carbon Budget Model of the Canadian forest sector (CBM-CFS3). Ecological Modelling. (in press)

## Annex 8 Canada's Greenhouse Gas Emission Tables, 1990–2006

Annex 8 contains summary tables (Table A8-1 to Table A8-19) illustrating national GHG emissions by year, by gas, and by sector.

**Table A8-1: GHG Source/Sink Category Description**

### GHG Source/Sink Categories

#### ENERGY

##### a. Stationary Combustion Sources

Electricity and Heat Generation	Emissions from fuel consumed by:
Electricity Generation	Utility and industry electricity generation
Heat Generation	Steam generation (for sale)
Fossil Fuel Industries	Emissions from fuel consumed by:
Petroleum Refining and Upgrading	Petroleum production (upstream oil industry) refining industries
Fossil Fuel Production	Natural gas production and some conventional and unconventional oil production industries (some refining is included)
Mining & Oil and Gas Extraction	Emissions from commercial fuel sold to:
	Metal and non metal mines, stone quarries, and gravel pits
	Oil and gas extraction industries
	Mineral exploration and contract drilling operations
Manufacturing Industries	Emissions from fuel consumed by the following industries:
	Iron and Steel (steel foundries, casting and rolling mills)
	Non-ferrous metals (aluminium, magnesium, and other production)
	Chemical (fertilizer manufacturing, organic and inorganic chemical manufacturing)
	Pulp and Paper (primarily pulp, paper, and paper product manufacturers)
	Cement production
	Other manufacturing industries not listed (such as automobile manufacturing, textiles, food and beverage industries)
Construction	Emissions from fuels consumed by the construction industry - buildings, highways etc.
Commercial & Institutional	Emissions from fuel consumed by:
	Service industries related to mining, communication, wholesale and retail trade, finance and insurance, real estate, education, etc.)
	education etc.)
	Federal, provincial, and municipal establishment
	National Defence and Canadian Coast Guard
	Train stations, airports, and warehouses
Residential	Emissions from fuel consumed for personal residences (homes, apartment hotels, condominiums, and farm house)
Agriculture & Forestry	Emissions from fuel consumed by:
	Forestry and logging service industry
	Agricultural, hunting, and trapping industry (excluding food processing, farm machinery manufacturing, and repair)
b. Transportation	Emissions resulting from the:
Domestic Aviation	-consumption of fossil fuels by Canadian registered airlines flying domestically
Road Transportation	-consumption of fossil fuels (including non-CO <sub>2</sub> emissions from ethanol) by vehicles licensed to operate on roads
Railways	-consumption of fossil fuels by Canadian railways
Domestic Marine	-consumption of fossil fuels by Canadian registered marine vessels fuelled domestically
Others - Off Road	-consumption of fossil fuels (including non-CO <sub>2</sub> emissions from ethanol) by combustion devices not licensed to operate on roads
Others - Pipelines	-transportation and distribution of crude oil, natural gas, and other products
c. Fugitive Sources	Intentional and unintentional releases of greenhouse gases from the following activities:
Coal Mining	Underground and surface mining
Oil and Natural Gas	Conventional and unconventional oil and gas exploration, production, transportation, and distribution
INDUSTRIAL PROCESSES	Emissions resulting from the following process activities:
a. Mineral Products	Production of cement and lime; use of soda ash, limestone & dolomite, and magnesite
b. Chemical Industry	Production of ammonia, nitric acid, and adipic acid
c. Metal Production	Production of aluminum, iron and steel, magnesium production and casting
d. Consumption of Halocarbons and SF <sub>6</sub>	Use of HFCs and/or PFCs in ACunits, refrigeration units, fire extinguishers, aerosol cans, solvents, foam blowing, semiconductor manufacturing and electronics industry; use of SF <sub>6</sub> in electrical equipment and semiconductors
e. Other & Undifferentiated Production	Non-energy use of fossil fuels
SOLVENT & OTHER PRODUCT USE	Emissions resulting from the use of N <sub>2</sub> O as anaesthetic and propellant
AGRICULTURE	Emissions resulting from:
a. Enteric Fermentation	Livestock enteric fermentation
b. Manure Management	Livestock waste management
c. Agricultural Soils	
Direct sources	Direct N <sub>2</sub> O emissions from synthetic fertilizer, manure on cropland, crop residue, tillage, summerfallow, irrigation, and cultivation of organic soils
Manure on Pasture, Range, and Paddock	Direct N <sub>2</sub> O emissions from manure deposited on pasture, range, and paddock
Indirect Sources	Indirect N <sub>2</sub> O emissions from volatilization and leaching of animal manure nitrogen, synthetic fertilizer nitrogen, and crop residue nitrogen
WASTE	Emissions resulting from:
a. Solid Waste Disposal on Land	Municipal solid waste management sites (landfills) and dedicated wood waste landfills
b. Wastewater Handling	Domestic and industrial wastewater treatment
c. Waste Incineration	Municipal solid waste and sewage sludge incineration
Land Use, Land-Use Change and Forestry	Emissions and removals resulting from:
a. Forest Land	Managed forests and lands converted to forests; includes growth, natural and anthropogenic disturbances
b. Cropland	Mineral and organic cropland soils management, liming, woody biomass (CO <sub>2</sub> ) ; lands converted to cropland
c. Grassland	Managed grasslands, lands converted to grasslands (CO <sub>2</sub> )
d. Wetlands	Lands converted to wetlands (peatlands, flooded lands) and wetlands remaining wetlands (peatlands only)
e. Settlements	Urban trees and forest and grassland conversion to built-up lands (settlements, transport infrastructure, oil & gas infrastructure)

Table A8-2: Canada's 1990–2006 GHG Emissions by Sector

Greenhouse Gas Categories	1990	1995	2000	2001	2002	2003	2004	2005	2006
	<i>kt CO<sub>2</sub> equivalent</i>								
<b>TOTAL<sup>1</sup></b>	<b>592 000</b>	<b>642 000</b>	<b>718 000</b>	<b>710 000</b>	<b>717 000</b>	<b>741 000</b>	<b>743 000</b>	<b>734 000</b>	<b>721 000</b>
<b>ENERGY</b>	<b>470 000</b>	<b>510 000</b>	<b>587 000</b>	<b>582 000</b>	<b>588 000</b>	<b>609 000</b>	<b>604 000</b>	<b>596 000</b>	<b>583 000</b>
<b>a. Stationary Combustion Sources</b>	<b>282 000</b>	<b>294 000</b>	<b>344 000</b>	<b>340 000</b>	<b>345 000</b>	<b>360 000</b>	<b>350 000</b>	<b>338 000</b>	<b>324 000</b>
Electricity and Heat Generation	95 400	101 000	132 000	134 000	129 000	135 000	127 000	125 000	117 000
Fossil Fuel Industries	52 000	54 000	67 000	68 000	73 000	74 000	73 000	69 000	68 000
Petroleum Refining and Upgrading	16 000	14 000	14 000	16 000	19 000	19 000	18 000	17 000	16 000
Fossil Fuel Production	36 000	40 000	53 000	53 000	54 000	54 000	55 000	52 000	52 000
Mining & Oil and Gas Extraction	6 190	7 860	10 400	10 300	11 800	15 700	14 800	15 600	16 500
Manufacturing Industries	54 900	53 000	53 100	48 900	49 000	49 400	51 000	47 300	46 300
Iron and Steel	6 500	7 050	7 190	5 900	6 490	6 380	6 490	6 480	6 380
Non Ferrous Metals	3 190	3 090	3 190	3 460	3 220	3 200	3 230	3 270	3 050
Chemical	7 100	8 450	7 860	6 760	6 120	5 810	6 770	6 340	6 490
Pulp and Paper	13 700	11 700	11 000	9 840	9 250	9 060	9 400	7 180	5 950
Cement	3 690	3 670	3 890	3 860	4 090	4 080	4 210	4 590	4 850
Other Manufacturing	20 700	19 000	19 900	19 000	19 800	20 800	20 900	19 400	19 600
Construction	1 870	1 170	1 070	1 010	1 230	1 300	1 350	1 360	1 300
Commercial & Institutional	25 700	28 900	33 100	33 100	35 200	37 800	37 700	36 700	33 400
Residential	44 000	45 000	45 000	42 000	43 000	45 000	43 000	42 000	40 000
Agriculture & Forestry	2 390	2 760	2 540	2 200	2 100	2 200	2 090	1 980	1 920
<b>b. Transport<sup>2</sup></b>	<b>150 000</b>	<b>160 000</b>	<b>180 000</b>	<b>180 000</b>	<b>180 000</b>	<b>180 000</b>	<b>190 000</b>	<b>190 000</b>	<b>190 000</b>
Civil Aviation (Domestic Aviation)	6 400	5 900	6 500	6 100	6 700	7 200	7 800	8 600	8 400
Road Transportation	98 400	109 000	119 000	121 000	123 000	125 000	130 000	131 000	133 000
Light-Duty Gasoline Vehicles	45 800	44 400	42 100	41 800	41 900	41 400	41 100	39 900	38 900
Light-Duty Gasoline Trucks	20 700	27 900	36 800	37 500	39 100	40 500	42 000	43 100	44 800
Heavy-Duty Gasoline Vehicles	7 810	6 080	5 290	6 000	5 870	6 050	6 410	6 300	6 280
Motorcycles	146	121	158	182	206	226	245	251	259
Light-Duty Diesel Vehicles	355	327	353	368	389	398	431	432	433
Light-Duty Diesel Trucks	707	1 330	1 690	1 710	1 810	1 880	1 990	2 130	2 330
Heavy-Duty Diesel Vehicles	20 700	26 500	31 300	32 400	32 700	34 100	36 500	37 900	39 400
Propane & Natural Gas Vehicles	2 200	2 100	1 100	1 100	840	820	860	720	800
Railways	7 000	6 000	7 000	6 000	6 000	6 000	6 000	6 000	6 000
Navigation (Domestic Marine)	5 000	4 400	5 100	5 500	5 500	6 100	6 600	6 400	5 800
Other Transportation	30 000	30 000	40 000	40 000	40 000	40 000	40 000	40 000	40 000
Off-Road Gasoline	7 000	6 000	8 000	7 000	8 000	8 000	8 000	7 000	7 000
Off-Road Diesel	20 000	20 000	20 000	20 000	20 000	20 000	20 000	20 000	20 000
Pipelines	6 900	12 000	11 300	10 300	10 900	9 100	8 520	10 100	9 660
<b>c. Fugitive Sources</b>	<b>42 700</b>	<b>57 000</b>	<b>64 700</b>	<b>65 600</b>	<b>65 400</b>	<b>66 000</b>	<b>66 300</b>	<b>65 500</b>	<b>66 800</b>
Coal Mining <sup>4</sup>	2 000	2 000	900	1 000	1 000	900	700	700	600
Oil and Natural Gas	40 700	55 300	63 700	64 600	64 400	65 100	65 600	64 800	66 200
Oil	4 180	5 150	5 430	5 770	5 580	5 770	5 930	5 650	5 710
Natural Gas	12 900	16 500	19 400	19 600	19 700	20 100	20 400	20 800	21 300
Venting	19 300	28 600	33 500	34 200	33 600	33 700	33 700	32 800	33 100
Flaring	4 400	5 100	5 400	5 000	5 400	5 600	5 600	5 500	6 000
<b>INDUSTRIAL PROCESSES</b>	<b>54 800</b>	<b>56 600</b>	<b>51 100</b>	<b>49 800</b>	<b>49 700</b>	<b>51 200</b>	<b>55 300</b>	<b>54 800</b>	<b>54 400</b>
<b>a. Mineral Products</b>	<b>8 300</b>	<b>8 800</b>	<b>9 600</b>	<b>9 000</b>	<b>9 000</b>	<b>9 100</b>	<b>9 500</b>	<b>9 500</b>	<b>9 600</b>
Cement Production	5 400	6 100	6 700	6 500	6 700	6 800	7 100	7 200	7 300
Lime Production	1 700	1 800	1 900	1 600	1 700	1 600	1 800	1 700	1 600
Mineral Product Use <sup>3</sup>	1 090	878	1 020	844	636	612	585	589	600
<b>b. Chemical Industry</b>	<b>17 000</b>	<b>18 000</b>	<b>8 900</b>	<b>8 200</b>	<b>8 700</b>	<b>8 500</b>	<b>11 000</b>	<b>10 000</b>	<b>9 000</b>
Ammonia Production	5 000	6 500	6 800	6 100	6 200	6 100	6 800	6 300	6 600
Nitric Acid Production	1 010	1 000	1 230	1 280	1 260	1 260	1 230	1 250	1 230
Adipic Acid Production	11 000	11 000	900	800	1 300	1 100	3 100	2 600	1 200
<b>c. Metal Production</b>	<b>19 500</b>	<b>19 200</b>	<b>18 900</b>	<b>17 400</b>	<b>17 500</b>	<b>17 200</b>	<b>16 700</b>	<b>16 200</b>	<b>16 800</b>
Iron and Steel Production	7 060	7 880	7 900	7 280	7 120	7 040	7 200	7 020	7 760
Aluminum Production	9 300	9 200	8 200	7 700	7 500	7 700	7 300	7 900	7 600
SF <sub>6</sub> Used in Magnesium Smelters and Casters	3 110	2 110	2 780	2 360	2 940	2 480	2 190	1 290	1 390
<b>d. Consumption of Halocarbons and SF<sub>6</sub></b>	<b>2 300</b>	<b>2 000</b>	<b>4 500</b>	<b>5 500</b>	<b>5 000</b>	<b>6 000</b>	<b>5 500</b>	<b>6 400</b>	<b>6 600</b>
<b>e. Other &amp; Undifferentiated Production</b>	<b>8 000</b>	<b>8 400</b>	<b>9 200</b>	<b>9 600</b>	<b>9 500</b>	<b>10 000</b>	<b>13 000</b>	<b>12 000</b>	<b>12 000</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>	<b>170</b>	<b>210</b>	<b>240</b>	<b>210</b>	<b>170</b>	<b>220</b>	<b>210</b>	<b>180</b>	<b>320</b>
<b>AGRICULTURE</b>	<b>49 000</b>	<b>56 000</b>	<b>60 000</b>	<b>59 000</b>	<b>58 000</b>	<b>61 000</b>	<b>63 000</b>	<b>63 000</b>	<b>62 000</b>
<b>a. Enteric Fermentation</b>	<b>18 000</b>	<b>21 000</b>	<b>22 000</b>	<b>23 000</b>	<b>23 000</b>	<b>23 000</b>	<b>24 000</b>	<b>25 000</b>	<b>24 000</b>
<b>b. Manure Management</b>	<b>6 100</b>	<b>6 900</b>	<b>7 500</b>	<b>7 800</b>	<b>7 900</b>	<b>7 900</b>	<b>8 100</b>	<b>8 200</b>	<b>8 000</b>
<b>c. Agriculture Soils</b>	<b>25 000</b>	<b>28 000</b>	<b>30 000</b>	<b>28 000</b>	<b>27 000</b>	<b>29 000</b>	<b>30 000</b>	<b>29 000</b>	<b>30 000</b>
Direct Sources	14 000	15 000	15 000	14 000	13 000	15 000	15 000	15 000	15 000
Pasture, Range and Paddock Manure	2 600	3 200	3 500	3 700	3 700	3 700	3 800	3 900	3 800
Indirect Sources	9 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000
<b>WASTE</b>	<b>18 000</b>	<b>19 000</b>	<b>20 000</b>	<b>20 000</b>	<b>20 000</b>	<b>20 000</b>	<b>20 000</b>	<b>21 000</b>	<b>21 000</b>
<b>a. Solid Waste Disposal on Land</b>	<b>17 000</b>	<b>18 000</b>	<b>19 000</b>	<b>18 000</b>	<b>19 000</b>	<b>19 000</b>	<b>19 000</b>	<b>19 000</b>	<b>20 000</b>
<b>b. Wastewater Handling</b>	<b>780</b>	<b>820</b>	<b>880</b>	<b>910</b>	<b>910</b>	<b>910</b>	<b>930</b>	<b>940</b>	<b>930</b>
<b>c. Waste Incineration</b>	<b>400</b>	<b>350</b>	<b>250</b>	<b>250</b>	<b>220</b>	<b>230</b>	<b>230</b>	<b>240</b>	<b>240</b>
<b>Land Use, Land-use Change and Forestry</b>	<b>-110 000</b>	<b>160 000</b>	<b>-98 000</b>	<b>-88 000</b>	<b>51 000</b>	<b>12 000</b>	<b>41 000</b>	<b>-8 400</b>	<b>31 000</b>
<b>a. Forest Land</b>	<b>-130 000</b>	<b>150 000</b>	<b>-110 000</b>	<b>-100 000</b>	<b>39 000</b>	<b>500</b>	<b>31 000</b>	<b>-18 000</b>	<b>23 000</b>
<b>b. Cropland</b>	<b>14 000</b>	<b>6 800</b>	<b>2 600</b>	<b>1 700</b>	<b>1 500</b>	<b>640</b>	<b>76</b>	<b>-860</b>	<b>-1 400</b>
<b>c. Grassland</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>
<b>d. Wetlands</b>	<b>4 000</b>	<b>3 000</b>	<b>2 000</b>	<b>2 000</b>	<b>2 000</b>	<b>2 000</b>	<b>2 000</b>	<b>2 000</b>	<b>2 000</b>
<b>e. Settlements</b>	<b>9 000</b>	<b>9 000</b>	<b>8 000</b>	<b>8 000</b>	<b>8 000</b>	<b>8 000</b>	<b>8 000</b>	<b>8 000</b>	<b>8 000</b>

## Notes:

1. National totals exclude all GHGs from the Land Use, Land-use Change and Forestry sector.

2. Emissions from Fuel Ethanol are reported within the gasoline transportation sub-categories.

3. The category Mineral Product Use includes CO<sub>2</sub> emissions coming from the use of limestone & dolomite, soda ash, and magnesite.

4. Fugitive emissions from coal mining activities for 2002 and 2003 have been extrapolated based on publicly available coal production data.

– Indicates no emissions.

0.0 Indicates emissions truncated due to rounding.

Table A8-3: 2006 GHG Emission Summary for Canada

Greenhouse Gas Categories		Greenhouse Gases								
Global Warming Potential	Unit	CO <sub>2</sub>	CH <sub>4</sub>	CH <sub>4</sub>	N <sub>2</sub> O	N <sub>2</sub> O	HFCs	PFCs	SF <sub>6</sub>	TOTAL
		kt	kt	kt CO <sub>2</sub> eq	kt	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq
TOTAL <sup>1</sup>		560 000	4 900	100 000	150	48 000	5 300	2 600	2 700	721 000
ENERGY		519 000	2 600	54 000	30	10 000	—	—	—	583 000
a.	Stationary Combustion Sources	317 000	200	4 000	8	2 000	—	—	—	324 000
	Electricity and Heat Generation	116 000	4.6	96	2	700	—	—	—	117 000
	Fossil Fuel Industries	65 200	100	2 000	1	400	—	—	—	68 000
	Petroleum Refining and Upgrading	16 000	—	—	0.4	100	—	—	—	16 000
	Fossil Fuel Production	49 100	100	2 000	1	300	—	—	—	52 000
	Mining & Oil and Gas Extraction	16 400	0.3	7	0.4	100	—	—	—	16 500
	Manufacturing Industries	45 800	3	60	2	500	—	—	—	46 300
	Iron and Steel	6 310	0.2	5	0.2	60	—	—	—	6 380
	Non Ferrous Metals	3 030	0.07	1	0.04	10	—	—	—	3 050
	Chemical	6 450	0.14	2.9	0.1	40	—	—	—	6 490
	Pulp and Paper	5 650	2	40	0.8	300	—	—	—	5 950
	Cement	4 840	0.1	2	0.04	10	—	—	—	4 850
	Other Manufacturing	19 500	0.4	8	0.4	100	—	—	—	19 600
	Construction	1 290	0.02	0.5	0.03	10	—	—	—	1 300
	Commercial & Institutional	33 200	0.6	10	0.7	200	—	—	—	33 400
	Residential	37 300	100	2 000	2	500	—	—	—	40 000
	Agriculture & Forestry	1 900	0.03	0.7	0.06	20	—	—	—	1 920
b.	Transport <sup>2</sup>	184 000	30	600	20	7 000	—	—	—	190 000
	Civil Aviation (Domestic Aviation)	8 190	0.4	9	0.7	200	—	—	—	8 400
	Road Transportation	130 000	9.3	200	11	3 400	—	—	—	133 000
	Light-Duty Gasoline Vehicles	37 700	2.9	62	3.6	1 100	—	—	—	38 900
	Light-Duty Gasoline Trucks	43 100	3.2	68	5.3	1 600	—	—	—	44 800
	Heavy-Duty Gasoline Vehicles	6 130	0.35	7.4	0.44	140	—	—	—	6 280
	Motorcycles	254	0.17	3.5	0.01	1.6	—	—	—	259
	Light-Duty Diesel Vehicles	423	0.01	0.2	0.03	10	—	—	—	433
	Light-Duty Diesel Trucks	2 270	0.06	1	0.2	60	—	—	—	2 330
	Heavy-Duty Diesel Vehicles	39 000	2	40	1	400	—	—	—	39 400
	Propane & Natural Gas Vehicles	784	0.7	20	0.02	5	—	—	—	800
	Railways	5 660	0.3	7	2	700	—	—	—	6 000
	Navigation (Domestic Marine)	5 380	0.4	8	1	400	—	—	—	5 800
	Other Transportation	35 000	20	400	8	3 000	—	—	—	40 000
	Off-Road Gasoline	6 000	8	200	0.1	40	—	—	—	7 000
	Off-Road Diesel	19 000	1	20	8	2 000	—	—	—	20 000
	Pipelines	9 390	9.4	200	0.3	80	—	—	—	9 660
c.	Fugitive Sources	17 000	2 400	49 000	0.1	40	—	—	—	66 800
	Coal Mining	—	30	600	—	—	—	—	—	600
	Oil and Natural Gas	17 400	2 320	48 800	0.1	40	—	—	—	66 200
	Oil	190	262	5 490	0.1	30	—	—	—	5 710
	Natural Gas	65.6	1 010	21 300	—	—	—	—	—	21 300
	Venting	11 200	1 040	21 900	0.01	4.61	—	—	—	33 100
	Flaring	5 900	4.1	86	0.01	3	—	—	—	6 000
INDUSTRIAL PROCESSES		41 000	—	—	7.88	2 440	5 300	2 600	2 700	54 400
a.	Mineral Products	9 600	—	—	—	—	—	—	—	9 600
	Cement Production	7 300	—	—	—	—	—	—	—	7 300
	Lime Production	1 600	—	—	—	—	—	—	—	1 600
	Mineral Product Use <sup>3</sup>	600	—	—	—	—	—	—	—	600
b.	Chemical Industry	6 600	—	—	7.88	2 440	—	—	—	9 000
	Ammonia Production	6 600	—	—	—	—	—	—	—	6 600
	Nitric Acid Production	—	—	—	3.98	1 230	—	—	—	1 230
	Adipic Acid Production	—	—	—	3.9	1 200	—	—	—	1 200
c.	Metal Production	12 800	—	—	—	—	—	2 600	1 410	16 800
	Iron and Steel Production	7 760	—	—	—	—	—	—	—	7 760
	Aluminum Production	5 000	—	—	—	—	—	2 600	13.1	7 600
	SF <sub>6</sub> Used in Magnesium Smelters and Casters	—	—	—	—	—	—	—	1 390	1 390
d.	Consumption of Halocarbons and SF <sub>6</sub>	—	—	—	—	—	5 300	30	1 300	6 600
e.	Other & Undifferentiated Production	12 000	—	—	—	—	—	—	—	12 000
SOLVENT & OTHER PRODUCT USE		—	—	—	1.0	320	—	—	—	320
AGRICULTURE		—	1 300	27 000	110	34 000	—	—	—	62 000
a.	Enteric Fermentation	—	1 200	24 000	—	—	—	—	—	24 000
b.	Manure Management	—	160	3 300	15	4 800	—	—	—	8 000
c.	Agriculture Soils	—	—	—	96	30 000	—	—	—	30 000
	Direct Sources	—	—	—	49	15 000	—	—	—	15 000
	Pasture, Range and Paddock Manure	—	—	—	12	3 800	—	—	—	3 800
	Indirect Sources	—	—	—	30	10 000	—	—	—	10 000
WASTE		190	950	20 000	2	700	—	—	—	21 000
a.	Solid Waste Disposal on Land	—	940	20 000	—	—	—	—	—	20 000
b.	Wastewater Handling	—	12	260	2	700	—	—	—	930
c.	Waste Incineration	190	0.07	1	0.2	50	—	—	—	240
Land Use, Land-use Change and Forestry		19 000	360	7 500	15	4 700	—	—	—	31 000
a.	Forest Land	11 000	340	7 200	14	4 500	—	—	—	23 000
b.	Cropland	-1 700	7	200	0.4	100	—	—	—	-1 400
c.	Grassland	—	—	—	—	—	—	—	—	—
d.	Wetlands	2 000	0	—	0	—	—	—	—	2 000
e.	Settlements	8 000	5	100	0.2	50	—	—	—	8 000

Notes:

1. National totals exclude all GHGs from the Land Use, Land-use Change and Forestry sector.

2. Emissions from Fuel Ethanol are reported within the gasoline transportation sub-categories.

3. The category Mineral Product Use includes CO<sub>2</sub> emissions coming from the use of limestone & dolomite, soda ash, and magnesite.

— Indicates no emissions.

0.0 Indicates emissions truncated due to rounding.

Table A8-4: 2005 GHG Emission Summary for Canada

Greenhouse Gas Categories		Greenhouse Gases								
		CO <sub>2</sub>	CH <sub>4</sub>	CH <sub>4</sub>	N <sub>2</sub> O	N <sub>2</sub> O	HFCs	PFCs	SF <sub>6</sub>	TOTAL
		Global Warming Potential	21	310						
	Unit	kt	kt	kt CO <sub>2</sub> eq	kt	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq
TOTAL <sup>1</sup>		572 000	4 900	100 000	160	49 000	5 200	3 100	2 500	734 000
ENERGY		532 000	2 600	54 000	30	10 000	—	—	—	596 000
a.	Stationary Combustion Sources	331 000	200	4 000	8	3 000	—	—	—	338 000
	Electricity and Heat Generation	124 000	4.8	100	2	700	—	—	—	125 000
	Fossil Fuel Industries	66 200	100	2 000	1	400	—	—	—	69 000
	Petroleum Refining and Upgrading	17 000	—	—	0.4	100	—	—	—	17 000
	Fossil Fuel Production	49 000	100	2 000	1	300	—	—	—	52 000
	Mining & Oil and Gas Extraction	15 400	0.3	6	0.4	100	—	—	—	15 600
	Manufacturing Industries	46 700	3	60	2	500	—	—	—	47 300
	Iron and Steel	6 410	0.2	5	0.2	60	—	—	—	6 480
	Non Ferrous Metals	3 250	0.08	2	0.05	20	—	—	—	3 270
	Chemical	6 300	0.13	2.7	0.1	30	—	—	—	6 340
	Pulp and Paper	6 880	2	40	0.8	300	—	—	—	7 180
	Cement	4 580	0.1	2	0.04	10	—	—	—	4 590
	Other Manufacturing	19 300	0.4	8	0.4	100	—	—	—	19 400
	Construction	1 350	0.02	0.5	0.03	10	—	—	—	1 360
	Commercial & Institutional	36 500	0.6	10	0.7	200	—	—	—	36 700
	Residential	39 300	90	2 000	2	500	—	—	—	42 000
	Agriculture & Forestry	1 960	0.03	0.7	0.06	20	—	—	—	1 980
b.	Transport <sup>2</sup>	184 000	30	600	20	8 000	—	—	—	190 000
	Civil Aviation (Domestic Aviation)	8 330	0.4	9	0.8	200	—	—	—	8 600
	Road Transportation	127 000	9.3	200	11	3 500	—	—	—	131 000
	Light-Duty Gasoline Vehicles	38 600	3.2	66	4.1	1 300	—	—	—	39 900
	Light-Duty Gasoline Trucks	41 400	3.2	66	5.3	1 600	—	—	—	43 100
	Heavy-Duty Gasoline Vehicles	6 150	0.38	8.0	0.43	130	—	—	—	6 300
	Motorcycles	246	0.16	3.5	0.00	1.5	—	—	—	251
	Light-Duty Diesel Vehicles	421	0.01	0.2	0.03	10	—	—	—	432
	Light-Duty Diesel Trucks	2 080	0.05	1	0.2	50	—	—	—	2 130
	Heavy-Duty Diesel Vehicles	37 500	2	40	1	400	—	—	—	37 900
	Propane & Natural Gas Vehicles	706	0.7	10	0.01	4	—	—	—	720
	Railways	5 480	0.3	6	2	700	—	—	—	6 000
	Navigation (Domestic Marine)	6 050	0.4	9	1	400	—	—	—	6 400
	Other Transportation	37 000	20	400	9	3 000	—	—	—	40 000
	Off-Road Gasoline	7 000	8	200	0.2	50	—	—	—	7 000
	Off-Road Diesel	20 000	1	20	8	3 000	—	—	—	20 000
	Pipelines	9 840	9.8	210	0.3	80	—	—	—	10 100
c.	Fugitive Sources	16 000	2 300	49 000	0.1	40	—	—	—	65 500
	Coal Mining	—	30	700	—	—	—	—	—	700
	Oil and Natural Gas	16 300	2 310	48 400	0.1	40	—	—	—	64 800
	Oil	170	259	5 450	0.1	30	—	—	—	5 650
	Natural Gas	61.0	989	20 800	—	—	—	—	—	20 800
	Venting	10 700	1 050	22 100	0.01	4.56	—	—	—	32 800
	Flaring	5 400	3.7	78	0.01	2	—	—	—	5 500
INDUSTRIAL PROCESSES		40 000	—	—	12.6	3 900	5 200	3 100	2 500	54 800
a.	Mineral Products	9 500	—	—	—	—	—	—	—	9 500
	Cement Production	7 200	—	—	—	—	—	—	—	7 200
	Lime Production	1 700	—	—	—	—	—	—	—	1 700
	Mineral Product Use <sup>3</sup>	589	—	—	—	—	—	—	—	589
b.	Chemical Industry	6 300	—	—	12.6	3 900	—	—	—	10 000
	Ammonia Production	6 300	—	—	—	—	—	—	—	6 300
	Nitric Acid Production	—	—	—	4.04	1 250	—	—	—	1 250
	Adipic Acid Production	—	—	—	8.5	2 600	—	—	—	2 600
c.	Metal Production	11 900	—	—	—	—	—	3 100	1 310	16 200
	Iron and Steel Production	7 020	—	—	—	—	—	—	—	7 020
	Aluminum Production	4 800	—	—	—	—	—	3 100	17.6	7 900
	SF <sub>6</sub> Used in Magnesium Smelters and Casters	—	—	—	—	—	—	—	1 290	1 290
d.	Consumption of Halocarbons and SF <sub>6</sub>	—	—	—	—	—	5 200	30	1 200	6 400
e.	Other & Undifferentiated Production	12 000	—	—	—	—	—	—	—	12 000
SOLVENT & OTHER PRODUCT USE		—	—	—	0.58	180	—	—	—	180
AGRICULTURE		—	1 300	28 000	110	34 000	—	—	—	63 000
a.	Enteric Fermentation	—	1 200	25 000	—	—	—	—	—	25 000
b.	Manure Management	—	160	3 300	16	4 900	—	—	—	8 200
c.	Agriculture Soils	—	—	—	95	29 000	—	—	—	29 000
	Direct Sources	—	—	—	48	15 000	—	—	—	15 000
	Pasture, Range and Paddock Manure	—	—	—	13	3 900	—	—	—	3 900
	Indirect Sources	—	—	—	30	10 000	—	—	—	10 000
WASTE		190	940	20 000	2	700	—	—	—	21 000
a.	Solid Waste Disposal on Land	—	930	19 000	—	—	—	—	—	19 000
b.	Wastewater Handling	—	12	250	2	700	—	—	—	940
c.	Waste Incineration	190	0.06	1	0.2	50	—	—	—	240
Land Use, Land-use Change and Forestry		-17 000	260	5 400	11	3 400	—	—	—	-8 400
a.	Forest Land	-26 000	240	5 100	10	3 200	—	—	—	-18 000
b.	Cropland	-1 100	7	200	0.4	100	—	—	—	-860
c.	Grassland	—	—	—	—	—	—	—	—	—
d.	Wetlands	2 000	2	30	0.07	20	—	—	—	2 000
e.	Settlements	8 000	5	100	0.2	50	—	—	—	8 000

Notes:

1. National totals exclude all GHGs from the Land Use, Land-use Change and Forestry sector.

2. Emissions from Fuel Ethanol are reported within the gasoline transportation sub-categories.

3. The category Mineral Product Use includes CO<sub>2</sub> emissions coming from the use of limestone & dolomite, soda ash, and magnesite.

— Indicates no emissions.

0.0 Indicates emissions truncated due to rounding.



Table A8-5: 2004 GHG Emission Summary for Canada

Greenhouse Gas Categories		Greenhouse Gases								
Global Warming Potential	Unit	CO <sub>2</sub>	CH <sub>4</sub>	CH <sub>4</sub>	N <sub>2</sub> O	N <sub>2</sub> O	HFCs	PFCs	SF <sub>6</sub>	TOTAL
		kt	kt	kt CO <sub>2</sub> eq	kt	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq
TOTAL <sup>1</sup>		580 000	4 900	100 000	160	50 000	4 700	3 100	3 000	743 000
ENERGY		539 000	2 600	55 000	30	10 000	—	—	—	604 000
a.	Stationary Combustion Sources	342 000	200	5 000	8	3 000	—	—	—	350 000
	Electricity and Heat Generation	126 000	4.8	100	2	700	—	—	—	127 000
	Fossil Fuel Industries	70 100	100	2 000	1	500	—	—	—	73 000
	Petroleum Refining and Upgrading	18 000	—	—	0.4	100	—	—	—	18 000
	Fossil Fuel Production	51 900	100	2 000	1	300	—	—	—	55 000
	Mining & Oil and Gas Extraction	14 700	0.3	6	0.3	100	—	—	—	14 800
	Manufacturing Industries	50 400	3	70	2	500	—	—	—	51 000
	Iron and Steel	6 420	0.2	5	0.2	60	—	—	—	6 490
	Non Ferrous Metals	3 220	0.07	2	0.05	10	—	—	—	3 230
	Chemical	6 730	0.14	2.9	0.1	40	—	—	—	6 770
	Pulp and Paper	9 060	2	50	0.9	300	—	—	—	9 400
	Cement	4 190	0.09	2	0.04	10	—	—	—	4 210
	Other Manufacturing	20 800	0.4	9	0.4	100	—	—	—	20 900
	Construction	1 340	0.02	0.5	0.03	10	—	—	—	1 350
	Commercial & Institutional	37 500	0.7	10	0.8	200	—	—	—	37 700
	Residential	40 400	90	2 000	2	500	—	—	—	43 000
	Agriculture & Forestry	2 080	0.04	0.7	0.06	20	—	—	—	2 090
b.	Transport <sup>2</sup>	180 000	30	600	20	8 000	—	—	—	190 000
	Civil Aviation (Domestic Aviation)	7 610	0.4	9	0.7	200	—	—	—	7 800
	Road Transportation	126 000	9.6	200	12	3 700	—	—	—	130 000
	Light-Duty Gasoline Vehicles	39 600	3.5	72	4.6	1 400	—	—	—	41 100
	Light-Duty Gasoline Trucks	40 300	3.2	66	5.4	1 700	—	—	—	42 000
	Heavy-Duty Gasoline Vehicles	6 270	0.41	8.7	0.42	130	—	—	—	6 410
	Motorcycles	240	0.16	3.4	0.00	1.5	—	—	—	245
	Light-Duty Diesel Vehicles	420	0.01	0.2	0.03	10	—	—	—	431
	Light-Duty Diesel Trucks	1 940	0.05	1	0.2	50	—	—	—	1 990
	Heavy-Duty Diesel Vehicles	36 100	2	40	1	300	—	—	—	36 500
	Propane & Natural Gas Vehicles	842	0.7	20	0.02	5	—	—	—	860
	Railways	5 220	0.3	6	2	700	—	—	—	6 000
	Navigation (Domestic Marine)	6 230	0.5	10	1	400	—	—	—	6 600
	Other Transportation	35 000	20	400	9	3 000	—	—	—	40 000
	Off-Road Gasoline	7 000	9	200	0.2	50	—	—	—	8 000
	Off-Road Diesel	20 000	1	20	8	3 000	—	—	—	20 000
	Pipelines	8 280	8.3	170	0.2	70	—	—	—	8 520
c.	Fugitive Sources	17 000	2 400	50 000	0.1	40	—	—	—	66 300
	Coal Mining	—	30	700	—	—	—	—	—	700
	Oil and Natural Gas	16 600	2 330	49 000	0.1	40	—	—	—	65 600
	Oil	180	272	5 720	0.1	30	—	—	—	5 930
	Natural Gas	57.2	968	20 300	—	—	—	—	—	20 400
	Venting	10 900	1 090	22 900	0.02	4.66	—	—	—	33 700
	Flaring	5 500	3.8	80	0.01	2	—	—	—	5 600
INDUSTRIAL PROCESSES		40 000	—	—	13.9	4 320	4 700	3 100	3 000	55 300
a.	Mineral Products	9 500	—	—	—	—	—	—	—	9 500
	Cement Production	7 100	—	—	—	—	—	—	—	7 100
	Lime Production	1 800	—	—	—	—	—	—	—	1 800
	Mineral Product Use <sup>3</sup>	585	—	—	—	—	—	—	—	585
b.	Chemical Industry	6 800	—	—	13.9	4 320	—	—	—	11 000
	Ammonia Production	6 800	—	—	—	—	—	—	—	6 800
	Nitric Acid Production	—	—	—	3.96	1 230	—	—	—	1 230
	Adipic Acid Production	—	—	—	10	3 100	—	—	—	3 100
c.	Metal Production	11 400	—	—	—	—	—	3 000	2 220	16 700
	Iron and Steel Production	7 200	—	—	—	—	—	—	—	7 200
	Aluminum Production	4 200	—	—	—	—	—	3 000	31.9	7 300
	SF <sub>6</sub> Used in Magnesium Smelters and Casters	—	—	—	—	—	—	—	2 190	2 190
d.	Consumption of Halocarbons and SF <sub>6</sub>	—	—	—	—	—	4 700	30	820	5 500
e.	Other & Undifferentiated Production	13 000	—	—	—	—	—	—	—	13 000
SOLVENT & OTHER PRODUCT USE		—	—	—	0.68	210	—	—	—	210
AGRICULTURE		—	1 300	28 000	110	35 000	—	—	—	63 000
a.	Enteric Fermentation	—	1 200	24 000	—	—	—	—	—	24 000
b.	Manure Management	—	160	3 300	15	4 800	—	—	—	8 100
c.	Agriculture Soils	—	—	—	97	30 000	—	—	—	30 000
	Direct Sources	—	—	—	49	15 000	—	—	—	15 000
	Pasture, Range and Paddock Manure	—	—	—	12	3 800	—	—	—	3 800
	Indirect Sources	—	—	—	40	10 000	—	—	—	10 000
WASTE		180	930	19 000	2	700	—	—	—	20 000
a.	Solid Waste Disposal on Land	—	920	19 000	—	—	—	—	—	19 000
b.	Wastewater Handling	—	12	250	2	700	—	—	—	930
c.	Waste Incineration	180	0.06	1	0.2	50	—	—	—	230
Land Use, Land-use Change and Forestry		24 000	510	11 000	22	6 700	—	—	—	41 000
a.	Forest Land	14 000	500	10 000	21	6 500	—	—	—	31 000
b.	Cropland	-210	8	200	0.4	100	—	—	—	76
c.	Grassland	—	—	—	—	—	—	—	—	—
d.	Wetlands	2 000	0.9	20	0.04	10	—	—	—	2 000
e.	Settlements	8 000	5	100	0.2	50	—	—	—	8 000

Notes:

1. National totals exclude all GHGs from the Land Use, Land-use Change and Forestry sector.

2. Emissions from Fuel Ethanol are reported within the gasoline transportation sub-categories.

3. The category Mineral Product Use includes CO<sub>2</sub> emissions coming from the use of limestone & dolomite, soda ash, and magnesite.

— Indicates no emissions.

0.0 Indicates emissions truncated due to rounding.

Table A8-6: 2003 GHG Emission Summary for Canada

Greenhouse Gas Categories		Greenhouse Gases								
Global Warming Potential		CO <sub>2</sub>	CH <sub>4</sub>	CH <sub>4</sub>	N <sub>2</sub> O	N <sub>2</sub> O	HFCs	PFCs	SF <sub>6</sub>	TOTAL
Unit		kt	kt	kt CO <sub>2</sub> eq	kt	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq
<b>TOTAL<sup>1</sup></b>		<b>582 000</b>	<b>4 800</b>	<b>100 000</b>	<b>150</b>	<b>47 000</b>	<b>4 400</b>	<b>3 000</b>	<b>4 200</b>	<b>741 000</b>
<b>ENERGY</b>		<b>544 000</b>	<b>2 600</b>	<b>54 000</b>	<b>30</b>	<b>10 000</b>	—	—	—	<b>609 000</b>
<b>a. Stationary Combustion Sources</b>		<b>353 000</b>	<b>200</b>	<b>5 000</b>	<b>8</b>	<b>3 000</b>	—	—	—	<b>360 000</b>
Electricity and Heat Generation		134 000	5.1	110	2	800	—	—	—	135 000
Fossil Fuel Industries		70 600	100	2 000	1	500	—	—	—	74 000
Petroleum Refining and Upgrading		19 000	—	—	0.3	100	—	—	—	19 000
Fossil Fuel Production		51 300	100	2 000	1	400	—	—	—	54 000
Mining & Oil and Gas Extraction		15 600	0.3	7	0.3	100	—	—	—	15 700
Manufacturing Industries		48 800	3	60	2	500	—	—	—	49 400
Iron and Steel		6 320	0.2	5	0.2	60	—	—	—	6 380
Non Ferrous Metals		3 190	0.07	1	0.05	10	—	—	—	3 200
Chemical		5 780	0.12	2.5	0.1	30	—	—	—	5 810
Pulp and Paper		8 740	2	40	0.9	300	—	—	—	9 060
Cement		4 070	0.08	2	0.04	10	—	—	—	4 080
Other Manufacturing		20 700	0.4	9	0.4	100	—	—	—	20 800
Construction		1 290	0.02	0.5	0.03	9	—	—	—	1 300
Commercial & Institutional		37 500	0.7	10	0.8	200	—	—	—	37 800
Residential		42 600	90	2 000	2	500	—	—	—	45 000
Agriculture & Forestry		2 180	0.04	0.8	0.06	20	—	—	—	2 200
<b>b. Transport<sup>2</sup></b>		<b>175 000</b>	<b>30</b>	<b>600</b>	<b>20</b>	<b>8 000</b>	—	—	—	<b>180 000</b>
Civil Aviation (Domestic Aviation)		7 020	0.4	9	0.6	200	—	—	—	7 200
Road Transportation		121 000	9.7	200	12	3 800	—	—	—	125 000
Light-Duty Gasoline Vehicles		39 700	3.7	77	5.1	1 600	—	—	—	41 400
Light-Duty Gasoline Trucks		38 700	3.1	66	5.5	1 700	—	—	—	40 500
Heavy-Duty Gasoline Vehicles		5 920	0.42	8.8	0.38	120	—	—	—	6 050
Motorcycles		222	0.15	3.2	0.00	1.4	—	—	—	226
Light-Duty Diesel Vehicles		388	0.01	0.2	0.03	10	—	—	—	398
Light-Duty Diesel Trucks		1 840	0.05	1	0.1	50	—	—	—	1 880
Heavy-Duty Diesel Vehicles		33 800	2	30	1	300	—	—	—	34 100
Propane & Natural Gas Vehicles		795	0.7	10	0.02	5	—	—	—	820
Railways		5 130	0.3	6	2	700	—	—	—	6 000
Navigation (Domestic Marine)		5 820	0.4	9	1	300	—	—	—	6 100
Other Transportation		35 000	20	400	8	3 000	—	—	—	40 000
Off-Road Gasoline		8 000	9	200	0.2	50	—	—	—	8 000
Off-Road Diesel		19 000	1	20	8	2 000	—	—	—	20 000
Pipelines		8 840	8.8	190	0.2	70	—	—	—	9 100
<b>c. Fugitive Sources</b>		<b>17 000</b>	<b>2 300</b>	<b>49 000</b>	<b>0.1</b>	<b>40</b>	—	—	—	<b>66 000</b>
Coal Mining <sup>4</sup>		—	40	900	—	—	—	—	—	900
Oil and Natural Gas		16 700	2 300	48 300	0.1	40	—	—	—	65 100
Oil		170	265	5 570	0.1	40	—	—	—	5 770
Natural Gas		55.3	953	20 000	—	—	—	—	—	20 100
Venting		11 000	1 080	22 700	0.02	4.96	—	—	—	33 700
Flaring		5 500	3.7	77	0.00	1	—	—	—	5 600
<b>INDUSTRIAL PROCESSES</b>		<b>37 000</b>	—	—	<b>7.58</b>	<b>2 350</b>	<b>4 400</b>	<b>3 000</b>	<b>4 200</b>	<b>51 200</b>
<b>a. Mineral Products</b>		<b>9 100</b>	—	—	—	—	—	—	—	<b>9 100</b>
Cement Production		6 800	—	—	—	—	—	—	—	6 800
Lime Production		1 600	—	—	—	—	—	—	—	1 600
Mineral Product Use <sup>3</sup>		612	—	—	—	—	—	—	—	612
<b>b. Chemical Industry</b>		<b>6 100</b>	—	—	<b>7.58</b>	<b>2 350</b>	—	—	—	<b>8 500</b>
Ammonia Production		6 100	—	—	—	—	—	—	—	6 100
Nitric Acid Production		—	—	—	4.08	1 260	—	—	—	1 260
Adipic Acid Production		—	—	—	3.5	1 100	—	—	—	1 100
<b>c. Metal Production</b>		<b>11 600</b>	—	—	—	—	—	<b>3 000</b>	<b>2 550</b>	<b>17 200</b>
Iron and Steel Production		7 040	—	—	—	—	—	—	—	7 040
Aluminum Production		4 600	—	—	—	—	—	3 000	70.4	7 700
SF <sub>6</sub> Used in Magnesium Smelters and Casters		—	—	—	—	—	—	—	2 480	2 480
<b>d. Consumption of Halocarbons and SF<sub>6</sub></b>		—	—	—	—	—	<b>4 400</b>	<b>30</b>	<b>1 600</b>	<b>6 000</b>
<b>e. Other &amp; Undifferentiated Production</b>		<b>10 000</b>	—	—	—	—	—	—	—	<b>10 000</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>		—	—	—	<b>0.71</b>	<b>220</b>	—	—	—	<b>220</b>
<b>AGRICULTURE</b>		—	<b>1 300</b>	<b>27 000</b>	<b>110</b>	<b>34 000</b>	—	—	—	<b>61 000</b>
<b>a. Enteric Fermentation</b>		—	1 100	23 000	—	—	—	—	—	23 000
<b>b. Manure Management</b>		—	150	3 200	15	4 700	—	—	—	7 900
<b>c. Agriculture Soils</b>		—	—	—	94	29 000	—	—	—	29 000
Direct Sources		—	—	—	48	15 000	—	—	—	15 000
Pasture, Range and Paddock Manure		—	—	—	12	3 700	—	—	—	3 700
Indirect Sources		—	—	—	30	10 000	—	—	—	10 000
<b>WASTE</b>		<b>180</b>	<b>920</b>	<b>19 000</b>	<b>2</b>	<b>700</b>	—	—	—	<b>20 000</b>
<b>a. Solid Waste Disposal on Land</b>		—	900	19 000	—	—	—	—	—	19 000
<b>b. Wastewater Handling</b>		—	12	240	2	700	—	—	—	910
<b>c. Waste Incineration</b>		180	0.05	1	0.1	50	—	—	—	230
<b>Land Use, Land-use Change and Forestry</b>		<b>-4 100</b>	<b>460</b>	<b>9 600</b>	<b>19</b>	<b>6 000</b>	—	—	—	<b>12 000</b>
<b>a. Forest Land</b>		-15 000	440	9 300	19	5 800	—	—	—	500
<b>b. Cropland</b>		350	8	200	0.4	100	—	—	—	640
<b>c. Grassland</b>		—	—	—	—	—	—	—	—	—
<b>d. Wetlands</b>		2 000	0.7	20	0.03	10	—	—	—	2 000
<b>e. Settlements</b>		8 000	5	100	0.2	50	—	—	—	8 000

Notes:

1. National totals exclude all GHGs from the Land Use, Land-use Change and Forestry sector.

2. Emissions from Fuel Ethanol are reported within the gasoline transportation sub-categories.

3. The category Mineral Product Use includes CO<sub>2</sub> emissions coming from the use of limestone & dolomite, soda ash, and magnesite.

4. Fugitive emissions from coal mining activities for 2002 and 2003 have been extrapolated based on publicly available coal production data.

— Indicates no emissions.

0.0 Indicates emissions truncated due to rounding.

Table A8-7: 2002 GHG Emission Summary for Canada

Greenhouse Gas Categories		Greenhouse Gases								
Global Warming Potential		CO <sub>2</sub>	CH <sub>4</sub>	CH <sub>4</sub>	N <sub>2</sub> O	N <sub>2</sub> O	HFCs	PFCs	SF <sub>6</sub>	TOTAL
Unit		kt	kt	21 kt CO <sub>2</sub> eq	kt	310 kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq
<b>TOTAL<sup>1</sup></b>		<b>561 000</b>	<b>4 700</b>	<b>99 000</b>	<b>150</b>	<b>45 000</b>	<b>3 900</b>	<b>3 000</b>	<b>4 000</b>	<b>717 000</b>
<b>ENERGY</b>		<b>524 000</b>	<b>2 600</b>	<b>54 000</b>	<b>30</b>	<b>10 000</b>	—	—	—	<b>588 000</b>
<b>a. Stationary Combustion Sources</b>		<b>338 000</b>	<b>200</b>	<b>5 000</b>	<b>8</b>	<b>3 000</b>	—	—	—	<b>345 000</b>
Electricity and Heat Generation		128 000	4.7	99	2	700	—	—	—	129 000
Fossil Fuel Industries		70 100	100	2 000	1	400	—	—	—	73 000
Petroleum Refining and Upgrading		19 000	—	—	0.3	100	—	—	—	19 000
Fossil Fuel Production		51 600	100	2 000	1	300	—	—	—	54 000
Mining & Oil and Gas Extraction		11 700	0.2	5	0.3	90	—	—	—	11 800
Manufacturing Industries		48 400	3	60	2	500	—	—	—	49 000
Iron and Steel		6 430	0.2	5	0.2	60	—	—	—	6 490
Non Ferrous Metals		3 200	0.07	1	0.05	10	—	—	—	3 220
Chemical		6 090	0.12	2.6	0.1	30	—	—	—	6 120
Pulp and Paper		8 940	2	40	0.9	300	—	—	—	9 250
Cement		4 080	0.08	2	0.04	10	—	—	—	4 090
Other Manufacturing		19 700	0.4	8	0.4	100	—	—	—	19 800
Construction		1 220	0.02	0.5	0.03	9	—	—	—	1 230
Commercial & Institutional		35 000	0.6	10	0.7	200	—	—	—	35 200
Residential		40 700	90	2 000	2	500	—	—	—	43 000
Agriculture & Forestry		2 080	0.03	0.7	0.06	20	—	—	—	2 100
<b>b. Transport<sup>2</sup></b>		<b>170 000</b>	<b>30</b>	<b>700</b>	<b>20</b>	<b>7 000</b>	—	—	—	<b>180 000</b>
Civil Aviation (Domestic Aviation)		6 540	0.4	9	0.6	200	—	—	—	6 700
Road Transportation		119 000	10	210	13	4 000	—	—	—	123 000
Light-Duty Gasoline Vehicles		40 000	4.0	83	5.7	1 800	—	—	—	41 900
Light-Duty Gasoline Trucks		37 300	3.1	66	5.6	1 700	—	—	—	39 100
Heavy-Duty Gasoline Vehicles		5 760	0.44	9.3	0.35	110	—	—	—	5 870
Motorcycles		202	0.14	3.0	0.00	1.3	—	—	—	206
Light-Duty Diesel Vehicles		379	0.01	0.2	0.03	9	—	—	—	389
Light-Duty Diesel Trucks		1 760	0.05	1	0.1	40	—	—	—	1 810
Heavy-Duty Diesel Vehicles		32 300	2	30	1	300	—	—	—	32 700
Propane & Natural Gas Vehicles		824	0.7	20	0.02	5	—	—	—	840
Railways		5 150	0.3	6	2	700	—	—	—	6 000
Navigation (Domestic Marine)		5 110	0.4	8	1	400	—	—	—	5 500
Other Transportation		35 000	20	400	7	2 000	—	—	—	40 000
Off-Road Gasoline		7 000	9	200	0.2	50	—	—	—	8 000
Off-Road Diesel		17 000	0.9	20	7	2 000	—	—	—	20 000
Pipelines		10 600	11	220	0.3	90	—	—	—	10 900
<b>c. Fugitive Sources</b>		<b>17 000</b>	<b>2 300</b>	<b>49 000</b>	<b>0.1</b>	<b>40</b>	—	—	—	<b>65 400</b>
Coal Mining <sup>4</sup>		—	50	1 000	—	—	—	—	—	1 000
Oil and Natural Gas		16 600	2 270	47 700	0.1	40	—	—	—	64 400
Oil		180	256	5 370	0.1	30	—	—	—	5 580
Natural Gas		51.7	937	19 700	—	—	—	—	—	19 700
Venting		11 000	1 080	22 600	0.01	4.34	—	—	—	33 600
Flaring		5 400	3.6	75	0.01	2	—	—	—	5 400
<b>INDUSTRIAL PROCESSES</b>		<b>36 000</b>	—	—	<b>8.09</b>	<b>2 510</b>	<b>3 900</b>	<b>3 000</b>	<b>4 000</b>	<b>49 700</b>
<b>a. Mineral Products</b>		<b>9 000</b>	—	—	—	—	—	—	—	<b>9 000</b>
Cement Production		6 700	—	—	—	—	—	—	—	6 700
Lime Production		1 700	—	—	—	—	—	—	—	1 700
Mineral Product Use <sup>3</sup>		636	—	—	—	—	—	—	—	636
<b>b. Chemical Industry</b>		<b>6 200</b>	—	—	<b>8.09</b>	<b>2 510</b>	—	—	—	<b>8 700</b>
Ammonia Production		6 200	—	—	—	—	—	—	—	6 200
Nitric Acid Production		—	—	—	4.05	1 260	—	—	—	1 260
Adipic Acid Production		—	—	—	4.0	1 300	—	—	—	1 300
<b>c. Metal Production</b>		<b>11 500</b>	—	—	—	—	—	<b>3 000</b>	<b>3 020</b>	<b>17 500</b>
Iron and Steel Production		7 120	—	—	—	—	—	—	—	7 120
Aluminum Production		4 400	—	—	—	—	—	3 000	80.1	7 500
SF <sub>6</sub> Used in Magnesium Smelters and Casters		—	—	—	—	—	—	—	2 940	2 940
<b>d. Consumption of Halocarbons and SF<sub>6</sub></b>		—	—	—	—	—	<b>3 900</b>	<b>30</b>	<b>1 000</b>	<b>5 000</b>
<b>e. Other &amp; Undifferentiated Production</b>		<b>9 500</b>	—	—	—	—	—	—	—	<b>9 500</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>		—	—	—	<b>0.54</b>	<b>170</b>	—	—	—	<b>170</b>
<b>AGRICULTURE</b>		—	<b>1 300</b>	<b>27 000</b>	<b>100</b>	<b>32 000</b>	—	—	—	<b>58 000</b>
<b>a. Enteric Fermentation</b>		—	1 100	23 000	—	—	—	—	—	23 000
<b>b. Manure Management</b>		—	150	3 200	15	4 700	—	—	—	7 900
<b>c. Agriculture Soils</b>		—	—	—	87	27 000	—	—	—	27 000
Direct Sources		—	—	—	43	13 000	—	—	—	13 000
Pasture, Range and Paddock Manure		—	—	—	12	3 700	—	—	—	3 700
Indirect Sources		—	—	—	30	10 000	—	—	—	10 000
<b>WASTE</b>		<b>180</b>	<b>900</b>	<b>19 000</b>	<b>2</b>	<b>700</b>	—	—	—	<b>20 000</b>
<b>a. Solid Waste Disposal on Land</b>		—	890	19 000	—	—	—	—	—	19 000
<b>b. Wastewater Handling</b>		—	11	240	2	700	—	—	—	910
<b>c. Waste Incineration</b>		180	0.05	1	0.1	40	—	—	—	220
<b>Land Use, Land-use Change and Forestry</b>		<b>32 000</b>	<b>560</b>	<b>12 000</b>	<b>24</b>	<b>7 300</b>	—	—	—	<b>51 000</b>
<b>a. Forest Land</b>		21 000	550	11 000	23	7 100	—	—	—	39 000
<b>b. Cropland</b>		1 200	8	200	0.4	100	—	—	—	1 500
<b>c. Grassland</b>		—	—	—	—	—	—	—	—	—
<b>d. Wetlands</b>		2 000	0	—	0	—	—	—	—	2 000
<b>e. Settlements</b>		8 000	5	100	0.2	50	—	—	—	8 000

Notes:

1. National totals exclude all GHGs from the Land Use, Land-use Change and Forestry sector.

2. Emissions from Fuel Ethanol are reported within the gasoline transportation sub-categories.

3. The category Mineral Product Use includes CO<sub>2</sub> emissions coming from the use of limestone & dolomite, soda ash, and magnesite.

4. Fugitive emissions from coal mining activities for 2002 and 2003 have been extrapolated based on publicly available coal production data.

— Indicates no emissions.

0.0 Indicates emissions truncated due to rounding.

Table A8-8: 2001 GHG Emission Summary for Canada

Greenhouse Gas Categories		Greenhouse Gases								
Global Warming Potential	Unit	CO <sub>2</sub>	CH <sub>4</sub>	CH <sub>4</sub>	N <sub>2</sub> O	N <sub>2</sub> O	HFCs	PFCs	SF <sub>6</sub>	TOTAL
		kt	kt	21 kt CO <sub>2</sub> eq	kt	310 kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq
<b>TOTAL<sup>1</sup></b>		<b>553 000</b>	<b>4 700</b>	<b>100 000</b>	<b>150</b>	<b>46 000</b>	<b>3 500</b>	<b>3 500</b>	<b>4 400</b>	<b>710 000</b>
<b>ENERGY</b>		<b>517 000</b>	<b>2 600</b>	<b>55 000</b>	<b>30</b>	<b>10 000</b>	—	—	—	<b>582 000</b>
<b>a. Stationary Combustion Sources</b>		<b>333 000</b>	<b>200</b>	<b>5 000</b>	<b>8</b>	<b>3 000</b>	—	—	—	<b>340 000</b>
Electricity and Heat Generation		133 000	5.0	110	3	800	—	—	—	134 000
Fossil Fuel Industries		65 600	100	2 000	1	400	—	—	—	68 000
Petroleum Refining and Upgrading		16 000	—	—	0.3	90	—	—	—	16 000
Fossil Fuel Production		50 000	100	2 000	1	300	—	—	—	53 000
Mining & Oil and Gas Extraction		10 200	0.2	4	0.3	80	—	—	—	10 300
Manufacturing Industries		48 300	3	60	2	500	—	—	—	48 900
Iron and Steel		5 840	0.2	5	0.2	50	—	—	—	5 900
Non Ferrous Metals		3 450	0.08	2	0.05	20	—	—	—	3 460
Chemical		6 720	0.14	2.9	0.1	40	—	—	—	6 760
Pulp and Paper		9 540	2	40	0.8	300	—	—	—	9 840
Cement		3 840	0.07	2	0.04	10	—	—	—	3 860
Other Manufacturing		18 900	0.4	8	0.4	100	—	—	—	19 000
Construction		1 000	0.02	0.4	0.03	8	—	—	—	1 010
Commercial & Institutional		32 900	0.6	10	0.7	200	—	—	—	33 100
Residential		39 100	90	2 000	2	500	—	—	—	42 000
Agriculture & Forestry		2 180	0.04	0.8	0.06	20	—	—	—	2 200
<b>b. Transport<sup>2</sup></b>		<b>168 000</b>	<b>30</b>	<b>600</b>	<b>20</b>	<b>8 000</b>	—	—	—	<b>180 000</b>
Civil Aviation (Domestic Aviation)		5 960	0.4	9	0.5	200	—	—	—	6 100
Road Transportation		117 000	10	220	13	4 100	—	—	—	121 000
Light-Duty Gasoline Vehicles		39 800	4.2	88	6.1	1 900	—	—	—	41 800
Light-Duty Gasoline Trucks		35 700	3.1	65	5.6	1 700	—	—	—	37 500
Heavy-Duty Gasoline Vehicles		5 890	0.48	10	0.34	100	—	—	—	6 000
Motorcycles		178	0.13	2.7	0.00	1.1	—	—	—	182
Light-Duty Diesel Vehicles		359	0.01	0.2	0.03	9	—	—	—	368
Light-Duty Diesel Trucks		1 660	0.04	0.9	0.1	40	—	—	—	1 710
Heavy-Duty Diesel Vehicles		32 000	2	30	1	300	—	—	—	32 400
Propane & Natural Gas Vehicles		1 110	0.9	20	0.02	7	—	—	—	1 100
Railways		5 680	0.3	7	2	700	—	—	—	6 000
Navigation (Domestic Marine)		5 140	0.4	8	1	400	—	—	—	5 500
Other Transportation		34 000	20	400	8	2 000	—	—	—	40 000
Off-Road Gasoline		7 000	9	200	0.2	50	—	—	—	7 000
Off-Road Diesel		17 000	0.9	20	7	2 000	—	—	—	20 000
Pipelines		9 960	10	210	0.3	80	—	—	—	10 300
<b>c. Fugitive Sources</b>		<b>16 000</b>	<b>2 400</b>	<b>49 000</b>	<b>0.1</b>	<b>40</b>	—	—	—	<b>65 600</b>
Coal Mining		—	50	1 000	—	—	—	—	—	1 000
Oil and Natural Gas		16 100	2 310	48 500	0.1	40	—	—	—	64 600
Oil		170	265	5 570	0.1	30	—	—	—	5 770
Natural Gas		50.8	933	19 600	—	—	—	—	—	19 600
Venting		11 000	1 110	23 200	0.01	4.34	—	—	—	34 200
Flaring		4 900	3.4	71	0.01	2	—	—	—	5 000
<b>INDUSTRIAL PROCESSES</b>		<b>36 000</b>	—	—	<b>6.74</b>	<b>2 090</b>	<b>3 500</b>	<b>3 500</b>	<b>4 400</b>	<b>49 800</b>
<b>a. Mineral Products</b>		<b>9 000</b>	—	—	—	—	—	—	—	<b>9 000</b>
Cement Production		6 500	—	—	—	—	—	—	—	6 500
Lime Production		1 600	—	—	—	—	—	—	—	1 600
Mineral Product Use <sup>3</sup>		844	—	—	—	—	—	—	—	844
<b>b. Chemical Industry</b>		<b>6 100</b>	—	—	<b>6.74</b>	<b>2 090</b>	—	—	—	<b>8 200</b>
Ammonia Production		6 100	—	—	—	—	—	—	—	6 100
Nitric Acid Production		—	—	—	4.14	1 280	—	—	—	1 280
Adipic Acid Production		—	—	—	2.6	800	—	—	—	800
<b>c. Metal Production</b>		<b>11 500</b>	—	—	—	—	—	<b>3 500</b>	<b>2 400</b>	<b>17 400</b>
Iron and Steel Production		7 280	—	—	—	—	—	—	—	7 280
Aluminum Production		4 200	—	—	—	—	—	3 500	43.9	7 700
SF <sub>6</sub> Used in Magnesium Smelters and Casters		—	—	—	—	—	—	—	2 360	2 360
<b>d. Consumption of Halocarbons and SF<sub>6</sub></b>		—	—	—	—	—	<b>3 500</b>	<b>30</b>	<b>2 000</b>	<b>5 500</b>
<b>e. Other &amp; Undifferentiated Production</b>		<b>9 600</b>	—	—	—	—	—	—	—	<b>9 600</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>		—	—	—	<b>0.69</b>	<b>210</b>	—	—	—	<b>210</b>
<b>AGRICULTURE</b>		—	<b>1 300</b>	<b>26 000</b>	<b>110</b>	<b>33 000</b>	—	—	—	<b>59 000</b>
<b>a. Enteric Fermentation</b>		—	1 100	23 000	—	—	—	—	—	23 000
<b>b. Manure Management</b>		—	150	3 100	15	4 600	—	—	—	7 800
<b>c. Agriculture Soils</b>		—	—	—	90	28 000	—	—	—	28 000
Direct Sources		—	—	—	46	14 000	—	—	—	14 000
Pasture, Range and Paddock Manure		—	—	—	12	3 700	—	—	—	3 700
Indirect Sources		—	—	—	30	10 000	—	—	—	10 000
<b>WASTE</b>		<b>200</b>	<b>890</b>	<b>19 000</b>	<b>2</b>	<b>700</b>	—	—	—	<b>20 000</b>
<b>a. Solid Waste Disposal on Land</b>		—	880	18 000	—	—	—	—	—	18 000
<b>b. Wastewater Handling</b>		—	11	240	2	700	—	—	—	910
<b>c. Waste Incineration</b>		200	0.04	0.9	0.2	50	—	—	—	250
<b>Land Use, Land-use Change and Forestry</b>		<b>-93 000</b>	<b>130</b>	<b>2 700</b>	<b>5.5</b>	<b>1 700</b>	—	—	—	<b>-88 000</b>
<b>a. Forest Land</b>		-100 000	120	2 500	5.0	1 500	—	—	—	-100 000
<b>b. Cropland</b>		1 400	7	100	0.4	100	—	—	—	1 700
<b>c. Grassland</b>		—	—	—	—	—	—	—	—	—
<b>d. Wetlands</b>		2 000	0	—	0	—	—	—	—	2 000
<b>e. Settlements</b>		8 000	5	100	0.2	50	—	—	—	8 000

Notes:

1. National totals exclude all GHGs from the Land Use, Land-use Change and Forestry sector.

2. Emissions from Fuel Ethanol are reported within the gasoline transportation sub-categories.

3. The category Mineral Product Use includes CO<sub>2</sub> emissions coming from the use of limestone & dolomite, soda ash, and magnesite.

— Indicates no emissions.

0.0 Indicates emissions truncated due to rounding.

Table A8-9: 2000 GHG Emission Summary for Canada

Greenhouse Gas Categories		Greenhouse Gases								
Global Warming Potential	Unit	CO <sub>2</sub>	CH <sub>4</sub>	CH <sub>4</sub>	N <sub>2</sub> O	N <sub>2</sub> O	HFCs	PFCs	SF <sub>6</sub>	TOTAL
		kt	kt	21	kt	310	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	
		kt	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	
<b>TOTAL<sup>1</sup></b>		<b>560 000</b>	<b>4 700</b>	<b>98 000</b>	<b>150</b>	<b>48 000</b>	<b>3 000</b>	<b>4 300</b>	<b>4 300</b>	<b>718 000</b>
<b>ENERGY</b>		<b>522 000</b>	<b>2 600</b>	<b>54 000</b>	<b>30</b>	<b>10 000</b>	—	—	—	<b>587 000</b>
<b>a. Stationary Combustion Sources</b>		<b>337 000</b>	<b>200</b>	<b>5 000</b>	<b>8</b>	<b>3 000</b>	—	—	—	<b>344 000</b>
Electricity and Heat Generation		132 000	4.8	100	2	800	—	—	—	132 000
Fossil Fuel Industries		64 000	100	2 000	1	400	—	—	—	67 000
Petroleum Refining and Upgrading		14 000	—	—	0.3	80	—	—	—	14 000
Fossil Fuel Production		50 200	100	2 000	1	300	—	—	—	53 000
Mining & Oil and Gas Extraction		10 300	0.2	4	0.2	80	—	—	—	10 400
Manufacturing Industries		52 500	3	60	2	500	—	—	—	53 100
Iron and Steel		7 120	0.3	5	0.2	60	—	—	—	7 190
Non Ferrous Metals		3 180	0.07	1	0.05	10	—	—	—	3 190
Chemical		7 810	0.16	3.3	0.1	40	—	—	—	7 860
Pulp and Paper		10 700	2	40	0.9	300	—	—	—	11 000
Cement		3 880	0.07	1	0.04	10	—	—	—	3 890
Other Manufacturing		19 800	0.4	8	0.4	100	—	—	—	19 900
Construction		1 060	0.02	0.4	0.03	8	—	—	—	1 070
Commercial & Institutional		32 900	0.6	10	0.7	200	—	—	—	33 100
Residential		42 200	90	2 000	2	500	—	—	—	45 000
Agriculture & Forestry		2 520	0.04	0.9	0.06	20	—	—	—	2 540
<b>b. Transport<sup>2</sup></b>		<b>169 000</b>	<b>30</b>	<b>700</b>	<b>30</b>	<b>8 000</b>	—	—	—	<b>180 000</b>
Civil Aviation (Domestic Aviation)		6 350	0.4	9	0.6	200	—	—	—	6 500
Road Transportation		114 000	11	230	13	4 200	—	—	—	119 000
Light-Duty Gasoline Vehicles		40 000	4.5	95	6.4	2 000	—	—	—	42 100
Light-Duty Gasoline Trucks		35 000	3.3	69	5.6	1 700	—	—	—	36 800
Heavy-Duty Gasoline Vehicles		5 200	0.50	11	0.26	79	—	—	—	5 290
Motorcycles		155	0.12	2.5	0.00	0.97	—	—	—	158
Light-Duty Diesel Vehicles		345	0.01	0.2	0.03	8	—	—	—	353
Light-Duty Diesel Trucks		1 650	0.04	0.9	0.1	40	—	—	—	1 690
Heavy-Duty Diesel Vehicles		31 000	1	30	1	300	—	—	—	31 300
Propane & Natural Gas Vehicles		1 070	1	20	0.02	7	—	—	—	1 100
Railways		5 780	0.3	7	2	700	—	—	—	7 000
Navigation (Domestic Marine)		4 730	0.3	7	1	400	—	—	—	5 100
Other Transportation		38 000	20	400	9	3 000	—	—	—	40 000
Off-Road Gasoline		7 000	9	200	0.2	50	—	—	—	8 000
Off-Road Diesel		20 000	1	20	8	3 000	—	—	—	20 000
Pipelines		11 000	11	230	0.3	90	—	—	—	11 300
<b>c. Fugitive Sources</b>		<b>16 000</b>	<b>2 300</b>	<b>49 000</b>	<b>0.1</b>	<b>40</b>	—	—	—	<b>64 700</b>
Coal Mining		—	50	900	—	—	—	—	—	900
Oil and Natural Gas		16 000	2 270	47 700	0.1	40	—	—	—	63 700
Oil		130	251	5 270	0.1	30	—	—	—	5 430
Natural Gas		50.7	923	19 400	—	—	—	—	—	19 400
Venting		10 500	1 090	23 000	0.02	4.65	—	—	—	33 500
Flaring		5 300	3.8	80	0.00	0.7	—	—	—	5 400
<b>INDUSTRIAL PROCESSES</b>		<b>37 000</b>	—	—	<b>6.87</b>	<b>2 130</b>	<b>3 000</b>	<b>4 300</b>	<b>4 300</b>	<b>51 100</b>
<b>a. Mineral Products</b>		<b>9 600</b>	—	—	—	—	—	—	—	<b>9 600</b>
Cement Production		6 700	—	—	—	—	—	—	—	6 700
Lime Production		1 900	—	—	—	—	—	—	—	1 900
Mineral Product Use <sup>3</sup>		1 020	—	—	—	—	—	—	—	1 020
<b>b. Chemical Industry</b>		<b>6 800</b>	—	—	<b>6.87</b>	<b>2 130</b>	—	—	—	<b>8 900</b>
Ammonia Production		6 800	—	—	—	—	—	—	—	6 800
Nitric Acid Production		—	—	—	3.97	1 230	—	—	—	1 230
Adipic Acid Production		—	—	—	2.9	900	—	—	—	900
<b>c. Metal Production</b>		<b>11 800</b>	—	—	—	—	—	<b>4 300</b>	<b>2 830</b>	<b>18 900</b>
Iron and Steel Production		7 900	—	—	—	—	—	—	—	7 900
Aluminum Production		3 900	—	—	—	—	—	4 300	47.3	8 200
SF <sub>6</sub> Used in Magnesium Smelters and Casters		—	—	—	—	—	—	—	2 780	2 780
<b>d. Consumption of Halocarbons and SF<sub>6</sub></b>		—	—	—	—	—	<b>3 000</b>	<b>30</b>	<b>1 500</b>	<b>4 500</b>
<b>e. Other &amp; Undifferentiated Production</b>		<b>9 200</b>	—	—	—	—	—	—	—	<b>9 200</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>		—	—	—	<b>0.78</b>	<b>240</b>	—	—	—	<b>240</b>
<b>AGRICULTURE</b>		—	<b>1 200</b>	<b>25 000</b>	<b>110</b>	<b>34 000</b>	—	—	—	<b>60 000</b>
<b>a. Enteric Fermentation</b>		—	1 100	22 000	—	—	—	—	—	22 000
<b>b. Manure Management</b>		—	140	3 000	14	4 500	—	—	—	7 500
<b>c. Agriculture Soils</b>		—	—	—	96	30 000	—	—	—	30 000
Direct Sources		—	—	—	50	15 000	—	—	—	15 000
Pasture, Range and Paddock Manure		—	—	—	11	3 500	—	—	—	3 500
Indirect Sources		—	—	—	30	10 000	—	—	—	10 000
<b>WASTE</b>		<b>200</b>	<b>890</b>	<b>19 000</b>	<b>2</b>	<b>700</b>	—	—	—	<b>20 000</b>
<b>a. Solid Waste Disposal on Land</b>		—	880	19 000	—	—	—	—	—	19 000
<b>b. Wastewater Handling</b>		—	11	240	2	600	—	—	—	880
<b>c. Waste Incineration</b>		200	0.04	0.8	0.2	50	—	—	—	250
<b>Land Use, Land-use Change and Forestry</b>		<b>-99 000</b>	<b>48</b>	<b>1 000</b>	<b>2.1</b>	<b>640</b>	—	—	—	<b>-98 000</b>
<b>a. Forest Land</b>		-110 000	36	750	1.5	470	—	—	—	-110 000
<b>b. Cropland</b>		2 400	7	200	0.4	100	—	—	—	2 600
<b>c. Grassland</b>		—	—	—	—	—	—	—	—	—
<b>d. Wetlands</b>		2 000	0	—	0	—	—	—	—	2 000
<b>e. Settlements</b>		8 000	5	100	0.2	50	—	—	—	8 000

Notes:

1. National totals exclude all GHGs from the Land Use, Land-use Change and Forestry sector.

2. Emissions from Fuel Ethanol are reported within the gasoline transportation sub-categories.

3. The category Mineral Product Use includes CO<sub>2</sub> emissions coming from the use of limestone & dolomite, soda ash, and magnesite.

— Indicates no emissions.

0.0 Indicates emissions truncated due to rounding.

Table A8-10: 1999 GHG Emission Summary for Canada

Greenhouse Gas Categories		Greenhouse Gases								
Global Warming Potential		CO <sub>2</sub>	CH <sub>4</sub>	CH <sub>4</sub>	N <sub>2</sub> O	N <sub>2</sub> O	HFCs	PFCs	SF <sub>6</sub>	TOTAL
Unit		kt	kt	21 kt CO <sub>2</sub> eq	kt	310 kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq
<b>TOTAL<sup>1</sup></b>		<b>537 000</b>	<b>4 500</b>	<b>95 000</b>	<b>160</b>	<b>48 000</b>	<b>2 500</b>	<b>4 600</b>	<b>3 800</b>	<b>692 000</b>
<b>ENERGY</b>		<b>500 000</b>	<b>2 500</b>	<b>52 000</b>	<b>30</b>	<b>10 000</b>	—	—	—	<b>562 000</b>
<b>a. Stationary Combustion Sources</b>		<b>316 000</b>	<b>200</b>	<b>4 000</b>	<b>8</b>	<b>2 000</b>	—	—	—	<b>323 000</b>
Electricity and Heat Generation		121 000	3.9	82	2	700	—	—	—	121 000
Fossil Fuel Industries		62 900	100	2 000	1	400	—	—	—	66 000
Petroleum Refining and Upgrading		13 000	—	—	0.2	70	—	—	—	13 000
Fossil Fuel Production		49 700	100	2 000	1	300	—	—	—	52 000
Mining & Oil and Gas Extraction		7 400	0.1	3	0.2	50	—	—	—	7 460
Manufacturing Industries		52 300	3	60	2	500	—	—	—	52 800
Iron and Steel		7 220	0.3	6	0.2	60	—	—	—	7 280
Non Ferrous Metals		3 240	0.06	1	0.05	10	—	—	—	3 250
Chemical		8 410	0.18	3.7	0.1	50	—	—	—	8 460
Pulp and Paper		10 900	2	40	0.9	300	—	—	—	11 200
Cement		3 910	0.07	2	0.04	10	—	—	—	3 920
Other Manufacturing		18 600	0.4	8	0.3	100	—	—	—	18 700
Construction		1 160	0.02	0.4	0.03	10	—	—	—	1 170
Commercial & Institutional		28 600	0.5	10	0.6	200	—	—	—	28 800
Residential		40 200	90	2 000	2	500	—	—	—	43 000
Agriculture & Forestry		2 640	0.04	0.8	0.06	20	—	—	—	2 660
<b>b. Transport<sup>2</sup></b>		<b>168 000</b>	<b>30</b>	<b>700</b>	<b>30</b>	<b>8 000</b>	—	—	—	<b>180 000</b>
Civil Aviation (Domestic Aviation)		6 360	0.4	9	0.6	200	—	—	—	6 600
Road Transportation		113 000	11	240	14	4 400	—	—	—	118 000
Light-Duty Gasoline Vehicles		40 400	4.9	100	7.0	2 200	—	—	—	42 700
Light-Duty Gasoline Trucks		34 200	3.3	69	5.8	1 800	—	—	—	36 100
Heavy-Duty Gasoline Vehicles		5 180	0.53	11	0.23	72	—	—	—	5 260
Motorcycles		139	0.11	2.3	0.00	0.88	—	—	—	142
Light-Duty Diesel Vehicles		330	0.01	0.2	0.03	8	—	—	—	338
Light-Duty Diesel Trucks		1 530	0.04	0.8	0.1	40	—	—	—	1 570
Heavy-Duty Diesel Vehicles		30 100	1	30	0.9	300	—	—	—	30 400
Propane & Natural Gas Vehicles		1 460	1	20	0.03	9	—	—	—	1 500
Railways		5 640	0.3	7	2	700	—	—	—	6 000
Navigation (Domestic Marine)		4 600	0.3	7	1	400	—	—	—	5 000
Other Transportation		38 000	20	500	8	2 000	—	—	—	40 000
Off-Road Gasoline		8 000	9	200	0.2	50	—	—	—	8 000
Off-Road Diesel		18 000	1	20	8	2 000	—	—	—	20 000
Pipelines		12 200	12	260	0.3	100	—	—	—	12 600
<b>c. Fugitive Sources</b>		<b>16 000</b>	<b>2 200</b>	<b>46 000</b>	<b>0.1</b>	<b>40</b>	—	—	—	<b>62 200</b>
Coal Mining		—	50	1 000	—	—	—	—	—	1 000
Oil and Natural Gas		15 700	2 160	45 400	0.1	40	—	—	—	61 100
Oil		130	249	5 230	0.1	30	—	—	—	5 390
Natural Gas		46.9	887	18 600	—	—	—	—	—	18 700
Venting		10 200	1 020	21 400	0.01	4.34	—	—	—	31 700
Flaring		5 300	3.5	74	0.00	0.7	—	—	—	5 300
<b>INDUSTRIAL PROCESSES</b>		<b>37 000</b>	—	—	<b>9.41</b>	<b>2 920</b>	<b>2 500</b>	<b>4 600</b>	<b>3 800</b>	<b>51 100</b>
<b>a. Mineral Products</b>		<b>9 400</b>	—	—	—	—	—	—	—	<b>9 400</b>
Cement Production		6 600	—	—	—	—	—	—	—	6 600
Lime Production		1 900	—	—	—	—	—	—	—	1 900
Mineral Product Use <sup>3</sup>		883	—	—	—	—	—	—	—	883
<b>b. Chemical Industry</b>		<b>6 800</b>	—	—	<b>9.41</b>	<b>2 920</b>	—	—	—	<b>9 700</b>
Ammonia Production		6 800	—	—	—	—	—	—	—	6 800
Nitric Acid Production		—	—	—	3.76	1 170	—	—	—	1 170
Adipic Acid Production		—	—	—	5.6	1 700	—	—	—	1 700
<b>c. Metal Production</b>		<b>11 800</b>	—	—	—	—	—	<b>4 600</b>	<b>2 320</b>	<b>18 800</b>
Iron and Steel Production		7 890	—	—	—	—	—	—	—	7 890
Aluminum Production		3 900	—	—	—	—	—	4 600	53.5	8 600
SF <sub>6</sub> Used in Magnesium Smelters and Casters		—	—	—	—	—	—	—	2 270	2 270
<b>d. Consumption of Halocarbons and SF<sub>6</sub></b>		—	—	—	—	—	<b>2 500</b>	<b>20</b>	<b>1 500</b>	<b>3 900</b>
<b>e. Other &amp; Undifferentiated Production</b>		<b>9 300</b>	—	—	—	—	—	—	—	<b>9 300</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>		—	—	—	<b>0.70</b>	<b>220</b>	—	—	—	<b>220</b>
<b>AGRICULTURE</b>		—	<b>1 200</b>	<b>25 000</b>	<b>110</b>	<b>34 000</b>	—	—	—	<b>59 000</b>
<b>a. Enteric Fermentation</b>		—	1 000	22 000	—	—	—	—	—	22 000
<b>b. Manure Management</b>		—	140	2 900	14	4 300	—	—	—	7 300
<b>c. Agriculture Soils</b>		—	—	—	96	30 000	—	—	—	30 000
Direct Sources		—	—	—	50	16 000	—	—	—	16 000
Pasture, Range and Paddock Manure		—	—	—	11	3 400	—	—	—	3 400
Indirect Sources		—	—	—	30	10 000	—	—	—	10 000
<b>WASTE</b>		<b>200</b>	<b>900</b>	<b>19 000</b>	<b>2</b>	<b>700</b>	—	—	—	<b>20 000</b>
<b>a. Solid Waste Disposal on Land</b>		—	890	19 000	—	—	—	—	—	19 000
<b>b. Wastewater Handling</b>		—	13	270	2	600	—	—	—	910
<b>c. Waste Incineration</b>		200	0.04	0.7	0.1	50	—	—	—	240
<b>Land Use, Land-use Change and Forestry</b>		<b>-25 000</b>	<b>310</b>	<b>6 400</b>	<b>13</b>	<b>4 000</b>	—	—	—	<b>-14 000</b>
<b>a. Forest Land</b>		-39 000	290	6 100	12	3 800	—	—	—	-29 000
<b>b. Cropland</b>		3 100	7	200	0.4	100	—	—	—	3 300
<b>c. Grassland</b>		—	—	—	—	—	—	—	—	—
<b>d. Wetlands</b>		3 000	2	40	0.07	20	—	—	—	3 000
<b>e. Settlements</b>		8 000	5	100	0.2	50	—	—	—	8 000

Notes:

1. National totals exclude all GHGs from the Land Use, Land-use Change and Forestry sector.

2. Emissions from Fuel Ethanol are reported within the gasoline transportation sub-categories.

3. The category Mineral Product Use includes CO<sub>2</sub> emissions coming from the use of limestone & dolomite, soda ash, and magnesite.

— Indicates no emissions.

0.0 Indicates emissions truncated due to rounding.

Table A8-11: 1998 GHG Emission Summary for Canada

Greenhouse Gas Categories		Greenhouse Gases								
Global Warming Potential	Unit	CO <sub>2</sub>	CH <sub>4</sub>	CH <sub>4</sub>	N <sub>2</sub> O	N <sub>2</sub> O	HFCs	PFCs	SF <sub>6</sub>	TOTAL
		kt	kt	21 kt CO <sub>2</sub> eq	kt	310 kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq
<b>TOTAL<sup>1</sup></b>		<b>521 000</b>	<b>4 600</b>	<b>96 000</b>	<b>160</b>	<b>51 000</b>	<b>1 900</b>	<b>5 600</b>	<b>3 700</b>	<b>679 000</b>
<b>ENERGY</b>		<b>485 000</b>	<b>2 500</b>	<b>52 000</b>	<b>30</b>	<b>10 000</b>	—	—	—	<b>548 000</b>
<b>a. Stationary Combustion Sources</b>		<b>304 000</b>	<b>200</b>	<b>4 000</b>	<b>8</b>	<b>2 000</b>	—	—	—	<b>310 000</b>
Electricity and Heat Generation		123 000	3.9	81	2	700	—	—	—	123 000
Fossil Fuel Industries		52 700	90	2 000	1	300	—	—	—	55 000
Petroleum Refining and Upgrading		12 000	—	—	0.2	80	—	—	—	12 000
Fossil Fuel Production		40 400	90	2 000	0.9	300	—	—	—	42 000
Mining & Oil and Gas Extraction		7 890	0.2	3	0.2	60	—	—	—	7 950
Manufacturing Industries		51 600	3	60	2	500	—	—	—	52 200
Iron and Steel		7 100	0.3	5	0.2	60	—	—	—	7 170
Non Ferrous Metals		3 480	0.07	2	0.05	20	—	—	—	3 500
Chemical		8 520	0.18	3.7	0.1	50	—	—	—	8 570
Pulp and Paper		10 800	2	40	0.8	300	—	—	—	11 100
Cement		3 620	0.07	1	0.04	10	—	—	—	3 630
Other Manufacturing		18 200	0.4	8	0.3	100	—	—	—	18 300
Construction		1 110	0.02	0.4	0.03	10	—	—	—	1 120
Commercial & Institutional		27 100	0.5	10	0.6	200	—	—	—	27 200
Residential		38 300	90	2 000	2	500	—	—	—	41 000
Agriculture & Forestry		2 560	0.04	0.8	0.06	20	—	—	—	2 580
<b>b. Transport<sup>2</sup></b>		<b>164 000</b>	<b>40</b>	<b>700</b>	<b>30</b>	<b>8 000</b>	—	—	—	<b>170 000</b>
Civil Aviation (Domestic Aviation)		6 260	0.4	9	0.6	200	—	—	—	6 400
Road Transportation		111 000	12	250	14	4 500	—	—	—	115 000
Light-Duty Gasoline Vehicles		39 500	5.0	110	7.3	2 300	—	—	—	41 800
Light-Duty Gasoline Trucks		32 100	3.2	67	5.8	1 800	—	—	—	34 000
Heavy-Duty Gasoline Vehicles		5 700	0.66	14	0.22	69	—	—	—	5 780
Motorcycles		142	0.12	2.5	0.00	0.91	—	—	—	146
Light-Duty Diesel Vehicles		317	0.01	0.2	0.02	8	—	—	—	325
Light-Duty Diesel Trucks		1 540	0.04	0.8	0.1	40	—	—	—	1 570
Heavy-Duty Diesel Vehicles		29 500	1	30	0.9	300	—	—	—	29 800
Propane & Natural Gas Vehicles		1 740	1	30	0.03	10	—	—	—	1 800
Railways		5 320	0.3	6	2	700	—	—	—	6 000
Navigation (Domestic Marine)		4 790	0.3	7	1	300	—	—	—	5 100
Other Transportation		37 000	20	500	7	2 000	—	—	—	40 000
Off-Road Gasoline		8 000	10	200	0.2	50	—	—	—	8 000
Off-Road Diesel		17 000	0.9	20	7	2 000	—	—	—	20 000
Pipelines		12 100	12	260	0.3	100	—	—	—	12 500
<b>c. Fugitive Sources</b>		<b>17 000</b>	<b>2 300</b>	<b>47 000</b>	<b>0.1</b>	<b>40</b>	—	—	—	<b>64 800</b>
Coal Mining		—	60	1 000	—	—	—	—	—	1 000
Oil and Natural Gas		17 400	2 190	46 000	0.1	40	—	—	—	63 500
Oil		120	251	5 270	0.1	30	—	—	—	5 430
Natural Gas		52.5	905	19 000	—	—	—	—	—	19 100
Venting		10 300	1 030	21 700	0.02	4.65	—	—	—	31 900
Flaring		7 000	4.6	96	0.00	1	—	—	—	7 100
<b>INDUSTRIAL PROCESSES</b>		<b>36 000</b>	—	—	<b>19.7</b>	<b>6 100</b>	<b>1 900</b>	<b>5 600</b>	<b>3 700</b>	<b>53 500</b>
<b>a. Mineral Products</b>		<b>9 100</b>	—	—	—	—	—	—	—	<b>9 100</b>
Cement Production		6 400	—	—	—	—	—	—	—	6 400
Lime Production		1 800	—	—	—	—	—	—	—	1 800
Mineral Product Use <sup>3</sup>		902	—	—	—	—	—	—	—	902
<b>b. Chemical Industry</b>		<b>6 600</b>	—	—	<b>19.7</b>	<b>6 100</b>	—	—	—	<b>13 000</b>
Ammonia Production		6 600	—	—	—	—	—	—	—	6 600
Nitric Acid Production		—	—	—	3.34	1 040	—	—	—	1 040
Adipic Acid Production		—	—	—	16	5 100	—	—	—	5 100
<b>c. Metal Production</b>		<b>11 700</b>	—	—	—	—	—	<b>5 600</b>	<b>2 260</b>	<b>19 500</b>
Iron and Steel Production		7 690	—	—	—	—	—	—	—	7 690
Aluminum Production		4 000	—	—	—	—	—	5 600	59.1	9 600
SF <sub>6</sub> Used in Magnesium Smelters and Casters		—	—	—	—	—	—	—	2 210	2 210
<b>d. Consumption of Halocarbons and SF<sub>6</sub></b>		—	—	—	—	—	<b>1 900</b>	<b>20</b>	<b>1 500</b>	<b>3 400</b>
<b>e. Other &amp; Undifferentiated Production</b>		<b>8 800</b>	—	—	—	—	—	—	—	<b>8 800</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>		—	—	—	<b>0.67</b>	<b>210</b>	—	—	—	<b>210</b>
<b>AGRICULTURE</b>		—	<b>1 200</b>	<b>25 000</b>	<b>110</b>	<b>33 000</b>	—	—	—	<b>58 000</b>
<b>a. Enteric Fermentation</b>		—	1 000	22 000	—	—	—	—	—	22 000
<b>b. Manure Management</b>		—	140	2 900	14	4 300	—	—	—	7 200
<b>c. Agriculture Soils</b>		—	—	—	94	29 000	—	—	—	29 000
Direct Sources		—	—	—	49	15 000	—	—	—	15 000
Pasture, Range and Paddock Manure		—	—	—	11	3 300	—	—	—	3 300
Indirect Sources		—	—	—	30	10 000	—	—	—	10 000
<b>WASTE</b>		<b>220</b>	<b>890</b>	<b>19 000</b>	<b>2</b>	<b>700</b>	—	—	—	<b>20 000</b>
<b>a. Solid Waste Disposal on Land</b>		—	880	18 000	—	—	—	—	—	18 000
<b>b. Wastewater Handling</b>		—	11	220	2	600	—	—	—	850
<b>c. Waste Incineration</b>		220	0.04	0.8	0.2	50	—	—	—	270
<b>Land Use, Land-use Change and Forestry</b>		<b>84 000</b>	<b>750</b>	<b>16 000</b>	<b>32</b>	<b>9 800</b>	—	—	—	<b>110 000</b>
<b>a. Forest Land</b>		70 000	740	15 000	31	9 600	—	—	—	95 000
<b>b. Cropland</b>		4 000	7	200	0.4	100	—	—	—	4 300
<b>c. Grassland</b>		—	—	—	—	—	—	—	—	—
<b>d. Wetlands</b>		3 000	1	20	0.04	10	—	—	—	3 000
<b>e. Settlements</b>		8 000	5	100	0.2	50	—	—	—	8 000

Notes:

1. National totals exclude all GHGs from the Land Use, Land-use Change and Forestry sector.

2. Emissions from Fuel Ethanol are reported within the gasoline transportation sub-categories.

3. The category Mineral Product Use includes CO<sub>2</sub> emissions coming from the use of limestone & dolomite, soda ash, and magnesite.

— Indicates no emissions.

0.0 Indicates emissions truncated due to rounding.



Table A8-12: 1997 GHG Emission Summary for Canada

Greenhouse Gas Categories				Greenhouse Gases							
	Global Warming Potential	CO <sub>2</sub>	CH <sub>4</sub>	CH <sub>4</sub>	N <sub>2</sub> O	N <sub>2</sub> O	HFCs	PFCs	SF <sub>6</sub>	TOTAL	
			21	310							
	Unit	kt	kt	kt CO <sub>2</sub> eq	kt	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	
TOTAL <sup>1</sup>		513 000	4 500	94 000	180	55 000	1 400	5 500	3 000	673 000	
ENERGY		477 000	2 400	51 000	30	10 000	—	—	—	538 000	
a.	Stationary Combustion Sources	300 000	200	4 000	7	2 000	—	—	—	306 000	
	Electricity and Heat Generation	111 000	3.2	68	2	600	—	—	—	111 000	
	Fossil Fuel Industries	49 200	70	2 000	1	300	—	—	—	51 000	
	Petroleum Refining and Upgrading	14 000	—	—	0.2	70	—	—	—	14 000	
	Fossil Fuel Production	35 500	70	2 000	0.7	200	—	—	—	37 000	
	Mining & Oil and Gas Extraction	8 900	0.2	4	0.2	60	—	900	—	8 970	
	Manufacturing Industries	54 100	3	60	2	500	—	—	—	54 700	
	Iron and Steel	7 240	0.3	5	0.2	60	—	—	—	7 310	
	Non Ferrous Metals	3 150	0.06	1	0.05	10	—	—	—	3 170	
	Chemical	8 830	0.18	3.9	0.2	50	—	—	—	8 880	
	Pulp and Paper	11 800	2	40	0.8	300	—	—	—	12 100	
	Cement	3 550	0.06	1	0.04	10	—	—	—	3 560	
	Other Manufacturing	19 600	0.4	8	0.3	100	—	—	—	19 700	
	Construction	1 240	0.02	0.4	0.03	10	—	—	—	1 250	
	Commercial & Institutional	29 700	0.5	10	0.6	200	—	—	—	29 900	
	Residential	43 500	90	2 000	2	500	—	—	—	46 000	
	Agriculture & Forestry	2 890	0.04	0.9	0.07	20	—	—	—	2 910	
b.	Transport <sup>2</sup>	160 000	30	700	30	8 000	—	—	—	170 000	
	Civil Aviation (Domestic Aviation)	6 130	0.4	9	0.6	200	—	—	—	6 300	
	Road Transportation	107 000	12	260	15	4 600	—	—	—	112 000	
	Light-Duty Gasoline Vehicles	40 600	5.5	120	7.9	2 400	—	—	—	43 200	
	Light-Duty Gasoline Trucks	29 700	3.2	66	5.7	1 800	—	—	—	31 500	
	Heavy-Duty Gasoline Vehicles	5 580	0.71	15	0.18	56	—	—	—	5 650	
	Motorcycles	121	0.11	2.3	0.00	0.77	—	—	—	124	
	Light-Duty Diesel Vehicles	306	0.01	0.2	0.02	7	—	—	—	314	
	Light-Duty Diesel Trucks	1 400	0.04	0.8	0.1	30	—	—	—	1 430	
	Heavy-Duty Diesel Vehicles	27 700	1	30	0.8	300	—	—	—	28 000	
	Propane & Natural Gas Vehicles	1 800	1	30	0.04	10	—	—	—	1 800	
	Railways	5 520	0.3	6	2	700	—	—	—	6 000	
	Navigation (Domestic Marine)	4 170	0.3	6	1	300	—	—	—	4 500	
	Other Transportation	37 000	20	500	8	2 000	—	—	—	40 000	
	Off-Road Gasoline	7 000	8	200	0.2	50	—	—	—	7 000	
	Off-Road Diesel	18 000	1	20	8	2 000	—	—	—	20 000	
	Pipelines	12 200	12	260	0.3	100	—	—	—	12 600	
c.	Fugitive Sources	16 000	2 200	47 000	0.1	40	—	—	—	62 600	
	Coal Mining	—	80	2 000	—	—	—	—	—	2 000	
	Oil and Natural Gas	15 800	2 150	45 200	0.1	40	—	—	—	61 000	
	Oil	120	257	5 400	0.1	30	—	—	—	5 560	
	Natural Gas	41.3	835	17 500	—	—	—	—	—	17 600	
	Venting	10 100	1 050	22 100	0.01	4.03	—	—	—	32 300	
	Flaring	5 500	3.6	75	0.00	0.7	—	—	—	5 600	
INDUSTRIAL PROCESSES		37 000	—	—	35.3	10 900	1 400	5 500	3 000	57 500	
a.	Mineral Products	9 000	—	—	—	—	—	—	—	9 000	
	Cement Production	6 200	—	—	—	—	—	—	—	6 200	
	Lime Production	1 800	—	—	—	—	—	—	—	1 800	
	Mineral Product Use <sup>3</sup>	929	—	—	—	—	—	—	—	929	
b.	Chemical Industry	6 600	—	—	35.3	10 900	—	—	—	18 000	
	Ammonia Production	6 600	—	—	—	—	—	—	—	6 600	
	Nitric Acid Production	—	—	—	3.41	1 060	—	—	—	1 060	
	Adipic Acid Production	—	—	—	32	9 900	—	—	—	9 900	
c.	Metal Production	11 500	—	—	—	—	—	5 400	1 730	18 700	
	Iron and Steel Production	7 550	—	—	—	—	—	—	—	7 550	
	Aluminum Production	3 900	—	—	—	—	—	5 400	59.1	9 400	
	SF <sub>6</sub> Used in Magnesium Smelters and Casters	—	—	—	—	—	—	—	1 670	1 670	
d.	Consumption of Halocarbons and SF <sub>6</sub>	—	—	—	—	—	1 400	20	1 300	2 700	
e.	Other & Undifferentiated Production	9 600	—	—	—	—	—	—	—	9 600	
SOLVENT & OTHER PRODUCT USE		—	—	—	0.73	230	—	—	—	230	
AGRICULTURE		—	1 200	25 000	110	33 000	—	—	—	58 000	
a.	Enteric Fermentation	—	1 000	22 000	—	—	—	—	—	22 000	
b.	Manure Management	—	140	2 900	14	4 200	—	—	—	7 100	
c.	Agriculture Soils	—	—	—	92	29 000	—	—	—	29 000	
	Direct Sources	—	—	—	49	15 000	—	—	—	15 000	
	Pasture, Range and Paddock Manure	—	—	—	11	3 300	—	—	—	3 300	
	Indirect Sources	—	—	—	30	10 000	—	—	—	10 000	
WASTE		220	880	18 000	2	700	—	—	—	19 000	
a.	Solid Waste Disposal on Land	—	870	18 000	—	—	—	—	—	18 000	
b.	Wastewater Handling	—	11	220	2	600	—	—	—	850	
c.	Waste Incineration	220	0.03	0.7	0.2	50	—	—	—	280	
Land Use, Land-use Change and Forestry		-110 000	67	1 400	2.9	900	—	—	—	-110 000	
a.	Forest Land	-120 000	55	1 200	2.3	720	—	—	—	-120 000	
b.	Cropland	5 100	8	200	0.4	100	—	—	—	5 400	
c.	Grassland	—	—	—	—	—	—	—	—	—	
d.	Wetlands	2 000	0.1	3	0.01	2	—	—	—	2 000	
e.	Settlements	8 000	5	100	0.2	50	—	—	—	8 000	

Notes:

1. National totals exclude all GHGs from the Land Use, Land-use Change and Forestry sector.

2. Emissions from Fuel Ethanol are reported within the gasoline transportation sub-categories.

3. The category Mineral Product Use includes CO<sub>2</sub> emissions coming from the use of limestone & dolomite, soda ash, and magnesite.

— Indicates no emissions.

0.0 Indicates emissions truncated due to rounding.



Table A8-13: 1996 GHG Emission Summary for Canada

Greenhouse Gas Categories		Greenhouse Gases								
Global Warming Potential		CO <sub>2</sub>	CH <sub>4</sub>	CH <sub>4</sub>	N <sub>2</sub> O	N <sub>2</sub> O	HFCs	PFCs	SF <sub>6</sub>	TOTAL
Unit		kt	kt	kt CO <sub>2</sub> eq	kt	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq
<b>TOTAL<sup>1</sup></b>		<b>501 000</b>	<b>4 400</b>	<b>93 000</b>	<b>180</b>	<b>57 000</b>	<b>850</b>	<b>5 500</b>	<b>2 800</b>	<b>660 000</b>
<b>ENERGY</b>		<b>465 000</b>	<b>2 400</b>	<b>50 000</b>	<b>30</b>	<b>10 000</b>	—	—	—	<b>526 000</b>
<b>a. Stationary Combustion Sources</b>		<b>295 000</b>	<b>200</b>	<b>4 000</b>	<b>7</b>	<b>2 000</b>	—	—	—	<b>301 000</b>
Electricity and Heat Generation		99 000	2.6	55	2	600	—	—	—	99 600
Fossil Fuel Industries		53 200	80	2 000	1	400	—	—	—	55 000
Petroleum Refining and Upgrading		15 000	—	—	0.4	100	—	—	—	15 000
Fossil Fuel Production		38 000	80	2 000	0.8	200	—	—	—	40 000
Mining & Oil and Gas Extraction		8 680	0.2	4	0.2	60	—	—	—	8 740
Manufacturing Industries		54 200	3	60	2	500	—	—	—	54 700
Iron and Steel		7 270	0.3	5	0.2	60	—	—	—	7 340
Non Ferrous Metals		3 470	0.07	1	0.05	20	—	—	—	3 480
Chemical		8 740	0.18	3.8	0.2	50	—	—	—	8 790
Pulp and Paper		11 900	2	40	0.8	300	—	—	—	12 200
Cement		3 490	0.07	1	0.03	10	—	—	—	3 500
Other Manufacturing		19 200	0.4	8	0.3	100	—	—	—	19 400
Construction		1 250	0.02	0.4	0.03	10	—	—	—	1 260
Commercial & Institutional		29 300	0.5	10	0.6	200	—	—	—	29 500
Residential		46 700	90	2 000	2	500	—	—	—	49 000
Agriculture & Forestry		2 900	0.04	0.9	0.07	20	—	—	—	2 920
<b>b. Transport<sup>2</sup></b>		<b>155 000</b>	<b>40</b>	<b>700</b>	<b>30</b>	<b>8 000</b>	—	—	—	<b>160 000</b>
Civil Aviation (Domestic Aviation)		5 980	0.4	9	0.5	200	—	—	—	6 200
Road Transportation		103 000	12	260	15	4 600	—	—	—	108 000
Light-Duty Gasoline Vehicles		40 600	5.8	120	8.1	2 500	—	—	—	43 300
Light-Duty Gasoline Trucks		27 100	3.1	65	5.5	1 700	—	—	—	28 900
Heavy-Duty Gasoline Vehicles		5 620	0.77	16	0.16	48	—	—	—	5 680
Motorcycles		114	0.11	2.3	0.00	0.74	—	—	—	117
Light-Duty Diesel Vehicles		306	0.01	0.2	0.02	7	—	—	—	313
Light-Duty Diesel Trucks		1 270	0.03	0.7	0.1	30	—	—	—	1 300
Heavy-Duty Diesel Vehicles		25 700	1	30	0.8	200	—	—	—	26 000
Propane & Natural Gas Vehicles		1 940	1	30	0.04	10	—	—	—	2 000
Railways		5 450	0.3	6	2	700	—	—	—	6 000
Navigation (Domestic Marine)		4 110	0.3	6	1	300	—	—	—	4 500
Other Transportation		36 000	20	500	7	2 000	—	—	—	40 000
Off-Road Gasoline		8 000	9	200	0.2	50	—	—	—	8 000
Off-Road Diesel		16 000	0.9	20	7	2 000	—	—	—	20 000
Pipelines		12 200	12	250	0.3	100	—	—	—	12 500
<b>c. Fugitive Sources</b>		<b>15 000</b>	<b>2 200</b>	<b>45 000</b>	<b>0.1</b>	<b>40</b>	—	—	—	<b>60 900</b>
Coal Mining		—	80	2 000	—	—	—	—	—	2 000
Oil and Natural Gas		15 500	2 080	43 600	0.1	40	—	—	—	59 200
Oil		120	247	5 180	0.1	30	—	—	—	5 330
Natural Gas		46.3	857	18 000	—	—	—	—	—	18 100
Venting		10 000	971	20 400	0.01	4.03	—	—	—	30 400
Flaring		5 300	3.5	73	0.00	0.7	—	—	—	5 400
<b>INDUSTRIAL PROCESSES</b>		<b>36 000</b>	—	—	<b>40.6</b>	<b>12 600</b>	<b>850</b>	<b>5 500</b>	<b>2 800</b>	<b>57 500</b>
<b>a. Mineral Products</b>		<b>8 400</b>	—	—	—	—	—	—	—	<b>8 400</b>
Cement Production		5 800	—	—	—	—	—	—	—	5 800
Lime Production		1 800	—	—	—	—	—	—	—	1 800
Mineral Product Use <sup>3</sup>		883	—	—	—	—	—	—	—	883
<b>b. Chemical Industry</b>		<b>6 500</b>	—	—	<b>40.6</b>	<b>12 600</b>	—	—	—	<b>19 000</b>
Ammonia Production		6 500	—	—	—	—	—	—	—	6 500
Nitric Acid Production		—	—	—	3.57	1 110	—	—	—	1 110
Adipic Acid Production		—	—	—	37	11 000	—	—	—	11 000
<b>c. Metal Production</b>		<b>11 600</b>	—	—	—	—	—	<b>5 500</b>	<b>1 700</b>	<b>18 800</b>
Iron and Steel Production		7 750	—	—	—	—	—	—	—	7 750
Aluminum Production		3 900	—	—	—	—	—	5 500	59.1	9 400
SF <sub>6</sub> Used in Magnesium Smelters and Casters		—	—	—	—	—	—	—	1 640	1 640
<b>d. Consumption of Halocarbons and SF<sub>6</sub></b>		—	—	—	—	—	<b>850</b>	<b>20</b>	<b>1 100</b>	<b>2 000</b>
<b>e. Other &amp; Undifferentiated Production</b>		<b>9 200</b>	—	—	—	—	—	—	—	<b>9 200</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>		—	—	—	<b>0.68</b>	<b>210</b>	—	—	—	<b>210</b>
<b>AGRICULTURE</b>		—	<b>1 200</b>	<b>25 000</b>	<b>110</b>	<b>33 000</b>	—	—	—	<b>58 000</b>
<b>a. Enteric Fermentation</b>		—	1 000	22 000	—	—	—	—	—	22 000
<b>b. Manure Management</b>		—	140	2 900	13	4 200	—	—	—	7 000
<b>c. Agriculture Soils</b>		—	—	—	93	29 000	—	—	—	29 000
Direct Sources		—	—	—	49	15 000	—	—	—	15 000
Pasture, Range and Paddock Manure		—	—	—	10	3 200	—	—	—	3 200
Indirect Sources		—	—	—	30	10 000	—	—	—	10 000
<b>WASTE</b>		<b>230</b>	<b>870</b>	<b>18 000</b>	<b>2</b>	<b>700</b>	—	—	—	<b>19 000</b>
<b>a. Solid Waste Disposal on Land</b>		—	850	18 000	—	—	—	—	—	18 000
<b>b. Wastewater Handling</b>		—	12	240	2	600	—	—	—	840
<b>c. Waste Incineration</b>		230	0.3	7	0.3	100	—	—	—	340
<b>Land Use, Land-use Change and Forestry</b>		<b>-69 000</b>	<b>200</b>	<b>4 300</b>	<b>8.6</b>	<b>2 700</b>	—	—	—	<b>-62 000</b>
<b>a. Forest Land</b>		-86 000	190	4 000	8.0	2 500	—	—	—	-79 000
<b>b. Cropland</b>		5 800	7	200	0.4	100	—	—	—	6 100
<b>c. Grassland</b>		—	—	—	—	—	—	—	—	—
<b>d. Wetlands</b>		2 000	0	—	0	—	—	—	—	2 000
<b>e. Settlements</b>		8 000	5	100	0.2	50	—	—	—	8 000

Notes:

1. National totals exclude all GHGs from the Land Use, Land-use Change and Forestry sector.

2. Emissions from Fuel Ethanol are reported within the gasoline transportation sub-categories.

3. The category Mineral Product Use includes CO<sub>2</sub> emissions coming from the use of limestone & dolomite, soda ash, and magnesite.

— Indicates no emissions.

0.0 Indicates emissions truncated due to rounding.

Table A8-14: 1995 GHG Emission Summary for Canada

Greenhouse Gas Categories		Greenhouse Gases								
Global Warming Potential	Unit	CO <sub>2</sub>	CH <sub>4</sub>	CH <sub>4</sub>	N <sub>2</sub> O	N <sub>2</sub> O	HFCs	PFCs	SF <sub>6</sub>	TOTAL
		kt	kt	21 kt CO <sub>2</sub> eq	kt	310 kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq
<b>TOTAL<sup>1</sup></b>		<b>488 000</b>	<b>4 200</b>	<b>89 000</b>	<b>180</b>	<b>54 000</b>	<b>480</b>	<b>5 500</b>	<b>3 700</b>	<b>642 000</b>
<b>ENERGY</b>		<b>453 000</b>	<b>2 200</b>	<b>47 000</b>	<b>30</b>	<b>10 000</b>	—	—	—	<b>510 000</b>
<b>a. Stationary Combustion Sources</b>		<b>287 000</b>	<b>200</b>	<b>4 000</b>	<b>7</b>	<b>2 000</b>	—	—	—	<b>294 000</b>
Electricity and Heat Generation		100 000	3.0	63	2	600	—	—	—	101 000
Fossil Fuel Industries		52 300	80	2 000	1	400	—	—	—	54 000
Petroleum Refining and Upgrading		14 000	—	—	0.3	100	—	—	—	14 000
Fossil Fuel Production		38 100	80	2 000	0.8	200	—	—	—	40 000
Mining & Oil and Gas Extraction		7 800	0.2	3	0.2	60	—	—	—	7 860
Manufacturing Industries		52 400	3	60	2	500	—	—	—	53 000
Iron and Steel		6 980	0.3	5	0.2	60	—	—	—	7 050
Non Ferrous Metals		3 070	0.06	1	0.04	10	—	—	—	3 090
Chemical		8 400	0.17	3.6	0.1	50	—	—	—	8 450
Pulp and Paper		11 400	2	40	0.8	300	—	—	—	11 700
Cement		3 660	0.07	1	0.04	10	—	—	—	3 670
Other Manufacturing		18 900	0.4	8	0.3	100	—	—	—	19 000
Construction		1 160	0.02	0.4	0.03	10	—	—	—	1 170
Commercial & Institutional		28 700	0.5	10	0.6	200	—	—	—	28 900
Residential		42 100	100	2 000	2	500	—	—	—	45 000
Agriculture & Forestry		2 730	0.04	0.9	0.07	20	—	—	—	2 760
<b>b. Transport<sup>2</sup></b>		<b>151 000</b>	<b>30</b>	<b>700</b>	<b>30</b>	<b>8 000</b>	—	—	—	<b>160 000</b>
Civil Aviation (Domestic Aviation)		5 710	0.4	9	0.5	200	—	—	—	5 900
Road Transportation		104 000	13	280	15	4 600	—	—	—	109 000
Light-Duty Gasoline Vehicles		41 700	6.3	130	8.4	2 600	—	—	—	44 400
Light-Duty Gasoline Trucks		26 200	3.2	67	5.5	1 700	—	—	—	27 900
Heavy-Duty Gasoline Vehicles		6 020	0.86	18	0.14	44	—	—	—	6 080
Motorcycles		118	0.12	2.5	0.00	0.77	—	—	—	121
Light-Duty Diesel Vehicles		319	0.01	0.2	0.02	8	—	—	—	327
Light-Duty Diesel Trucks		1 290	0.03	0.7	0.1	30	—	—	—	1 330
Heavy-Duty Diesel Vehicles		26 200	1	30	0.8	200	—	—	—	26 500
Propane & Natural Gas Vehicles		2 060	1	30	0.04	10	—	—	—	2 100
Railways		5 570	0.3	6	2	700	—	—	—	6 000
Navigation (Domestic Marine)		4 020	0.3	6	1	300	—	—	—	4 400
Other Transportation		32 000	20	400	6	2 000	—	—	—	30 000
Off-Road Gasoline		6 000	7	200	0.1	40	—	—	—	6 000
Off-Road Diesel		14 000	0.8	20	6	2 000	—	—	—	20 000
Pipelines		11 700	12	240	0.3	100	—	—	—	12 000
<b>c. Fugitive Sources</b>		<b>15 000</b>	<b>2 000</b>	<b>42 000</b>	<b>0.1</b>	<b>40</b>	—	—	—	<b>57 000</b>
Coal Mining		—	80	2 000	—	—	—	—	—	2 000
Oil and Natural Gas		14 600	1 940	40 700	0.1	40	—	—	—	55 300
Oil		120	238	5 000	0.1	30	—	—	—	5 150
Natural Gas		33.6	783	16 400	—	—	—	—	—	16 500
Venting		9 420	914	19 200	0.01	4.03	—	—	—	28 600
Flaring		5 000	3.3	69	0.00	0.3	—	—	—	5 100
<b>INDUSTRIAL PROCESSES</b>		<b>35 000</b>	—	—	<b>37.8</b>	<b>11 700</b>	<b>480</b>	<b>5 500</b>	<b>3 700</b>	<b>56 600</b>
<b>a. Mineral Products</b>		<b>8 800</b>	—	—	—	—	—	—	—	<b>8 800</b>
Cement Production		6 100	—	—	—	—	—	—	—	6 100
Lime Production		1 800	—	—	—	—	—	—	—	1 800
Mineral Product Use <sup>3</sup>		878	—	—	—	—	—	—	—	878
<b>b. Chemical Industry</b>		<b>6 500</b>	—	—	<b>37.8</b>	<b>11 700</b>	—	—	—	<b>18 000</b>
Ammonia Production		6 500	—	—	—	—	—	—	—	6 500
Nitric Acid Production		—	—	—	3.24	1 000	—	—	—	1 000
Adipic Acid Production		—	—	—	35	11 000	—	—	—	11 000
<b>c. Metal Production</b>		<b>11 500</b>	—	—	—	—	—	<b>5 500</b>	<b>2 170</b>	<b>19 200</b>
Iron and Steel Production		7 880	—	—	—	—	—	—	—	7 880
Aluminum Production		3 600	—	—	—	—	—	5 500	59.1	9 200
SF <sub>6</sub> Used in Magnesium Smelters and Casters		—	—	—	—	—	—	—	2 110	2 110
<b>d. Consumption of Halocarbons and SF<sub>6</sub></b>		—	—	—	—	—	<b>480</b>	<b>30</b>	<b>1 500</b>	<b>2 000</b>
<b>e. Other &amp; Undifferentiated Production</b>		<b>8 400</b>	—	—	—	—	—	—	—	<b>8 400</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>		—	—	—	<b>0.67</b>	<b>210</b>	—	—	—	<b>210</b>
<b>AGRICULTURE</b>		—	<b>1 100</b>	<b>24 000</b>	<b>100</b>	<b>32 000</b>	—	—	—	<b>56 000</b>
<b>a. Enteric Fermentation</b>		—	1 000	21 000	—	—	—	—	—	21 000
<b>b. Manure Management</b>		—	140	2 800	13	4 100	—	—	—	6 900
<b>c. Agriculture Soils</b>		—	—	—	89	28 000	—	—	—	28 000
Direct Sources		—	—	—	47	15 000	—	—	—	15 000
Pasture, Range and Paddock Manure		—	—	—	10	3 200	—	—	—	3 200
Indirect Sources		—	—	—	30	10 000	—	—	—	10 000
<b>WASTE</b>		<b>240</b>	<b>870</b>	<b>18 000</b>	<b>2</b>	<b>700</b>	—	—	—	<b>19 000</b>
<b>a. Solid Waste Disposal on Land</b>		—	860	18 000	—	—	—	—	—	18 000
<b>b. Wastewater Handling</b>		—	10	220	2	600	—	—	—	820
<b>c. Waste Incineration</b>		<b>240</b>	<b>0.3</b>	<b>7</b>	<b>0.3</b>	<b>100</b>	—	—	—	<b>350</b>
<b>Land Use, Land-use Change and Forestry</b>		<b>130 000</b>	<b>960</b>	<b>20 000</b>	<b>40</b>	<b>13 000</b>	—	—	—	<b>160 000</b>
<b>a. Forest Land</b>		110 000	950	20 000	40	12 000	—	—	—	150 000
<b>b. Cropland</b>		6 600	7	200	0.4	100	—	—	—	6 800
<b>c. Grassland</b>		—	—	—	—	—	—	—	—	—
<b>d. Wetlands</b>		3 000	0.02	0.3	0.00	0.2	—	—	—	3 000
<b>e. Settlements</b>		8 000	5	100	0.2	50	—	—	—	9 000

Notes:

1. National totals exclude all GHGs from the Land Use, Land-use Change and Forestry sector.

2. Emissions from Fuel Ethanol are reported within the gasoline transportation sub-categories.

3. The category Mineral Product Use includes CO<sub>2</sub> emissions coming from the use of limestone & dolomite, soda ash, and magnesite.

— Indicates no emissions.

0.0 Indicates emissions truncated due to rounding.

Table A8-15: 1994 GHG Emission Summary for Canada

Greenhouse Gas Categories		Greenhouse Gases								
		CO <sub>2</sub>	CH <sub>4</sub>	CH <sub>4</sub>	N <sub>2</sub> O	N <sub>2</sub> O	HFCs	PFCs	SF <sub>6</sub>	TOTAL
		Global Warming Potential Unit	21	310						
		kt	kt	kt CO <sub>2</sub> eq	kt	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq
TOTAL <sup>1</sup>		475 000	4 100	86 000	170	54 000	—	6 000	3 900	624 000
ENERGY		441 000	2 100	44 000	30	10 000	—	—	—	495 000
a.	Stationary Combustion Sources	280 000	200	4 000	7	2 000	—	—	—	286 000
	Electricity and Heat Generation	95 800	2.6	54	2	600	—	—	—	96 400
	Fossil Fuel Industries	50 700	80	2 000	1	300	—	—	—	53 000
	Petroleum Refining and Upgrading	14 000	—	—	0.3	100	—	—	—	14 000
	Fossil Fuel Production	36 800	80	2 000	0.8	200	—	—	—	39 000
	Mining & Oil and Gas Extraction	7 430	0.2	3	0.2	50	—	—	—	7 490
	Manufacturing Industries	51 800	3	60	2	500	—	—	—	52 300
	Iron and Steel	7 390	0.3	6	0.2	60	—	—	—	7 460
	Non Ferrous Metals	3 270	0.07	2	0.05	20	—	—	—	3 290
	Chemical	8 480	0.18	3.7	0.1	50	—	—	—	8 530
	Pulp and Paper	11 700	2	40	0.8	300	—	—	—	12 000
	Cement	3 520	0.07	1	0.03	10	—	—	—	3 530
	Other Manufacturing	17 300	0.4	7	0.3	90	—	—	—	17 400
	Construction	1 380	0.02	0.5	0.03	10	—	—	—	1 390
	Commercial & Institutional	27 100	0.5	10	0.6	200	—	—	—	27 300
	Residential	43 300	100	2 000	2	500	—	—	—	46 000
	Agriculture & Forestry	2 510	0.04	0.8	0.06	20	—	—	—	2 530
b.	Transport <sup>2</sup>	147 000	30	700	20	8 000	—	—	—	160 000
	Civil Aviation (Domestic Aviation)	5 260	0.4	8	0.5	100	—	—	—	5 400
	Road Transportation	102 000	14	290	15	4 600	—	—	—	107 000
	Light-Duty Gasoline Vehicles	42 300	6.7	140	8.4	2 600	—	—	—	45 100
	Light-Duty Gasoline Trucks	25 400	3.3	70	5.3	1 700	—	—	—	27 100
	Heavy-Duty Gasoline Vehicles	6 480	0.96	20	0.16	50	—	—	—	6 550
	Motorcycles	122	0.12	2.6	0.00	0.79	—	—	—	125
	Light-Duty Diesel Vehicles	331	0.01	0.2	0.03	8	—	—	—	339
	Light-Duty Diesel Trucks	1 120	0.03	0.6	0.09	30	—	—	—	1 150
	Heavy-Duty Diesel Vehicles	24 800	1	30	0.8	200	—	—	—	25 100
	Propane & Natural Gas Vehicles	1 880	1	30	0.04	10	—	—	—	1 900
	Railways	6 150	0.3	7	3	800	—	—	—	7 000
	Navigation (Domestic Marine)	4 310	0.3	6	1	300	—	—	—	4 700
	Other Transportation	29 000	20	400	6	2 000	—	—	—	30 000
	Off-Road Gasoline	6 000	7	100	0.1	40	—	—	—	6 000
	Off-Road Diesel	13 000	0.7	10	5	2 000	—	—	—	10 000
	Pipelines	10 500	10	220	0.3	90	—	—	—	10 800
c.	Fugitive Sources	14 000	1 900	40 000	0.1	40	—	—	—	53 700
	Coal Mining	—	80	2 000	—	—	—	—	—	2 000
	Oil and Natural Gas	13 800	1 820	38 200	0.1	40	—	—	—	52 000
	Oil	110	220	4 620	0.1	30	—	—	—	4 770
	Natural Gas	30.9	753	15 800	—	—	—	—	—	15 800
	Venting	8 900	841	17 700	0.01	3.72	—	—	—	26 600
	Flaring	4 700	3.1	66	0.00	1	—	—	—	4 800
INDUSTRIAL PROCESSES		34 000	—	—	38.5	11 900	—	6 000	3 900	55 600
a.	Mineral Products	8 100	—	—	—	—	—	—	—	8 100
	Cement Production	5 400	—	—	—	—	—	—	—	5 400
	Lime Production	1 800	—	—	—	—	—	—	—	1 800
	Mineral Product Use <sup>3</sup>	842	—	—	—	—	—	—	—	842
b.	Chemical Industry	5 800	—	—	38.5	11 900	—	—	—	18 000
	Ammonia Production	5 800	—	—	—	—	—	—	—	5 800
	Nitric Acid Production	—	—	—	3.08	956	—	—	—	956
	Adipic Acid Production	—	—	—	35	11 000	—	—	—	11 000
c.	Metal Production	11 300	—	—	—	—	—	6 000	2 340	19 600
	Iron and Steel Production	7 540	—	—	—	—	—	—	—	7 540
	Aluminum Production	3 800	—	—	—	—	—	6 000	59.1	9 800
	SF <sub>6</sub> Used in Magnesium Smelters and Casters	—	—	—	—	—	—	—	2 280	2 280
d.	Consumption of Halocarbons and SF <sub>6</sub>	—	—	—	—	—	—	—	1 500	1 500
e.	Other & Undifferentiated Production	8 600	—	—	—	—	—	—	—	8 600
SOLVENT & OTHER PRODUCT USE		—	—	—	0.55	170	—	—	—	170
AGRICULTURE		—	1 100	23 000	100	31 000	—	—	—	54 000
a.	Enteric Fermentation	—	960	20 000	—	—	—	—	—	20 000
b.	Manure Management	—	130	2 700	13	3 900	—	—	—	6 600
c.	Agriculture Soils	—	—	—	87	27 000	—	—	—	27 000
	Direct Sources	—	—	—	47	14 000	—	—	—	14 000
	Pasture, Range and Paddock Manure	—	—	—	9.7	3 000	—	—	—	3 000
	Indirect Sources	—	—	—	30	10 000	—	—	—	10 000
WASTE		240	870	18 000	2	700	—	—	—	19 000
a.	Solid Waste Disposal on Land	—	860	18 000	—	—	—	—	—	18 000
b.	Wastewater Handling	—	11	220	2	600	—	—	—	820
c.	Waste Incineration	240	0.3	6	0.3	100	—	—	—	350
Land Use, Land-use Change and Forestry		-75 000	290	6 200	12	3 900	—	—	—	-65 000
a.	Forest Land	-93 000	280	5 900	12	3 600	—	—	—	-83 000
b.	Cropland	8 000	9	200	0.5	200	—	—	—	8 400
c.	Grassland	—	—	—	—	—	—	—	—	—
d.	Wetlands	2 000	0	—	0	—	—	—	—	2 000
e.	Settlements	8 000	5	100	0.2	50	—	—	—	8 000

Notes:

1. National totals exclude all GHGs from the Land Use, Land-use Change and Forestry sector.

2. Emissions from Fuel Ethanol are reported within the gasoline transportation sub-categories.

3. The category Mineral Product Use includes CO<sub>2</sub> emissions coming from the use of limestone & dolomite, soda ash, and magnesite.

— Indicates no emissions.

0.0 Indicates emissions truncated due to rounding.

Table A8-16: 1993 GHG Emission Summary for Canada

Greenhouse Gas Categories		Greenhouse Gases								
Global Warming Potential		CO <sub>2</sub>	CH <sub>4</sub>	CH <sub>4</sub>	N <sub>2</sub> O	N <sub>2</sub> O	HFCs	PFCs	SF <sub>6</sub>	TOTAL
Unit		kt	kt	21 kt CO <sub>2</sub> eq	kt	310 kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq
<b>TOTAL<sup>1</sup></b>		<b>461 000</b>	<b>3 900</b>	<b>83 000</b>	<b>160</b>	<b>50 000</b>	—	<b>6 500</b>	<b>3 800</b>	<b>604 000</b>
<b>ENERGY</b>		<b>428 000</b>	<b>2 000</b>	<b>42 000</b>	<b>30</b>	<b>9 000</b>	—	—	—	<b>480 000</b>
<b>a. Stationary Combustion Sources</b>		<b>274 000</b>	<b>200</b>	<b>4 000</b>	<b>7</b>	<b>2 000</b>	—	—	—	<b>280 000</b>
Electricity and Heat Generation		93 400	2.5	53	2	600	—	—	—	94 000
Fossil Fuel Industries		50 100	70	2 000	1	300	—	—	—	52 000
Petroleum Refining and Upgrading		15 000	—	—	0.3	100	—	—	—	15 000
Fossil Fuel Production		35 000	70	2 000	0.7	200	—	—	—	37 000
Mining & Oil and Gas Extraction		7 360	0.2	3	0.2	50	—	—	—	7 420
Manufacturing Industries		48 700	2	50	1	500	—	—	—	49 200
Iron and Steel		6 610	0.3	5	0.2	60	—	—	—	6 670
Non Ferrous Metals		2 690	0.06	1	0.04	10	—	—	—	2 710
Chemical		7 260	0.15	3.2	0.1	40	—	—	—	7 310
Pulp and Paper		11 900	2	30	0.7	200	—	—	—	12 200
Cement		3 110	0.06	1	0.03	9	—	—	—	3 120
Other Manufacturing		17 100	0.4	7	0.3	100	—	—	—	17 200
Construction		1 370	0.02	0.5	0.03	10	—	—	—	1 380
Commercial & Institutional		27 800	0.5	10	0.6	200	—	—	—	28 000
Residential		42 500	100	2 000	2	500	—	—	—	45 000
Agriculture & Forestry		3 010	0.05	1	0.07	20	—	—	—	3 030
<b>b. Transport<sup>2</sup></b>		<b>140 000</b>	<b>30</b>	<b>700</b>	<b>20</b>	<b>7 000</b>	—	—	—	<b>150 000</b>
Civil Aviation (Domestic Aviation)		5 080	0.4	8	0.5	100	—	—	—	5 200
Road Transportation		96 900	14	290	14	4 300	—	—	—	101 000
Light-Duty Gasoline Vehicles		42 500	7.0	150	8.1	2 500	—	—	—	45 200
Light-Duty Gasoline Trucks		23 400	3.2	68	4.8	1 500	—	—	—	24 900
Heavy-Duty Gasoline Vehicles		6 390	1.0	21	0.17	52	—	—	—	6 460
Motorcycles		128	0.13	2.7	0.00	0.83	—	—	—	131
Light-Duty Diesel Vehicles		337	0.01	0.2	0.03	8	—	—	—	346
Light-Duty Diesel Trucks		937	0.03	0.5	0.07	20	—	—	—	959
Heavy-Duty Diesel Vehicles		21 200	1	20	0.6	200	—	—	—	21 500
Propane & Natural Gas Vehicles		1 990	1	30	0.04	10	—	—	—	2 000
Railways		5 950	0.3	7	2	800	—	—	—	7 000
Navigation (Domestic Marine)		4 150	0.3	6	1	300	—	—	—	4 500
Other Transportation		28 000	20	400	6	2 000	—	—	—	30 000
Off-Road Gasoline		5 000	6	100	0.1	40	—	—	—	6 000
Off-Road Diesel		13 000	0.7	10	5	2 000	—	—	—	10 000
Pipelines		10 100	10	210	0.3	80	—	—	—	10 400
<b>c. Fugitive Sources</b>		<b>13 000</b>	<b>1 800</b>	<b>38 000</b>	<b>0.1</b>	<b>30</b>	—	—	—	<b>51 300</b>
Coal Mining		—	90	2 000	—	—	—	—	—	2 000
Oil and Natural Gas		13 200	1 720	36 200	0.1	30	—	—	—	49 500
Oil		110	217	4 560	0.1	30	—	—	—	4 700
Natural Gas		28.6	711	14 900	—	—	—	—	—	15 000
Venting		8 460	794	16 700	—	—	—	—	—	25 100
Flaring		4 600	3.0	64	0.00	0.7	—	—	—	4 700
<b>INDUSTRIAL PROCESSES</b>		<b>33 000</b>	—	—	<b>32.7</b>	<b>10 100</b>	—	<b>6 500</b>	<b>3 800</b>	<b>53 300</b>
<b>a. Mineral Products</b>		<b>7 200</b>	—	—	—	—	—	—	—	<b>7 200</b>
Cement Production		4 600	—	—	—	—	—	—	—	4 600
Lime Production		1 800	—	—	—	—	—	—	—	1 800
Mineral Product Use <sup>3</sup>		855	—	—	—	—	—	—	—	855
<b>b. Chemical Industry</b>		<b>5 700</b>	—	—	<b>32.7</b>	<b>10 100</b>	—	—	—	<b>16 000</b>
Ammonia Production		5 700	—	—	—	—	—	—	—	5 700
Nitric Acid Production		—	—	—	3.40	1 050	—	—	—	1 050
Adipic Acid Production		—	—	—	29	9 100	—	—	—	9 100
<b>c. Metal Production</b>		<b>12 100</b>	—	—	—	—	—	<b>6 500</b>	<b>2 270</b>	<b>20 800</b>
Iron and Steel Production		8 180	—	—	—	—	—	—	—	8 180
Aluminum Production		3 900	—	—	—	—	6 500	—	59.1	10 000
SF <sub>6</sub> Used in Magnesium Smelters and Casters		—	—	—	—	—	—	—	2 210	2 210
<b>d. Consumption of Halocarbons and SF<sub>6</sub></b>		—	—	—	—	—	—	—	<b>1 500</b>	<b>1 500</b>
<b>e. Other &amp; Undifferentiated Production</b>		<b>7 900</b>	—	—	—	—	—	—	—	<b>7 900</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>		—	—	—	<b>0.50</b>	<b>160</b>	—	—	—	<b>160</b>
<b>AGRICULTURE</b>		—	<b>1 100</b>	<b>22 000</b>	<b>96</b>	<b>30 000</b>	—	—	—	<b>52 000</b>
<b>a. Enteric Fermentation</b>		—	920	19 000	—	—	—	—	—	19 000
<b>b. Manure Management</b>		—	130	2 700	12	3 800	—	—	—	6 400
<b>c. Agriculture Soils</b>		—	—	—	84	26 000	—	—	—	26 000
Direct Sources		—	—	—	45	14 000	—	—	—	14 000
Pasture, Range and Paddock Manure		—	—	—	9.3	2 900	—	—	—	2 900
Indirect Sources		—	—	—	30	9 000	—	—	—	9 000
<b>WASTE</b>		<b>250</b>	<b>860</b>	<b>18 000</b>	<b>2</b>	<b>700</b>	—	—	—	<b>19 000</b>
<b>a. Solid Waste Disposal on Land</b>		—	850	18 000	—	—	—	—	—	18 000
<b>b. Wastewater Handling</b>		—	10	220	2	600	—	—	—	800
<b>c. Waste Incineration</b>		250	0.3	7	0.3	100	—	—	—	360
<b>Land Use, Land-use Change and Forestry</b>		<b>-60 000</b>	<b>310</b>	<b>6 400</b>	<b>13</b>	<b>4 000</b>	—	—	—	<b>-50 000</b>
<b>a. Forest Land</b>		-82 000	290	6 100	12	3 800	—	—	—	-72 000
<b>b. Cropland</b>		9 300	10	200	0.5	200	—	—	—	9 600
<b>c. Grassland</b>		—	—	—	—	—	—	—	—	—
<b>d. Wetlands</b>		3 000	0.2	5	0.01	3	—	—	—	3 000
<b>e. Settlements</b>		9 000	5	100	0.2	50	—	—	—	9 000

Notes:

1. National totals exclude all GHGs from the Land Use, Land-use Change and Forestry sector.

2. Emissions from Fuel Ethanol are reported within the gasoline transportation sub-categories.

3. The category Mineral Product Use includes CO<sub>2</sub> emissions coming from the use of limestone & dolomite, soda ash, and magnesite.

— Indicates no emissions.

0.0 Indicates emissions truncated due to rounding.

Table A8-17: 1992 GHG Emission Summary for Canada

Greenhouse Gas Categories		Greenhouse Gases								
Global Warming Potential	Unit	CO <sub>2</sub>	CH <sub>4</sub>	CH <sub>4</sub>	N <sub>2</sub> O	N <sub>2</sub> O	HFCs	PFCs	SF <sub>6</sub>	TOTAL
		kt	kt	21 kt CO <sub>2</sub> eq	kt	310 kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq
<b>TOTAL<sup>1</sup></b>		<b>462 000</b>	<b>3 800</b>	<b>80 000</b>	<b>160</b>	<b>49 000</b>	<b>660</b>	<b>6 600</b>	<b>4 000</b>	<b>603 000</b>
<b>ENERGY</b>		<b>430 000</b>	<b>1 900</b>	<b>41 000</b>	<b>30</b>	<b>9 000</b>	—	—	—	<b>479 000</b>
<b>a. Stationary Combustion Sources</b>		<b>280 000</b>	<b>200</b>	<b>4 000</b>	<b>7</b>	<b>2 000</b>	—	—	—	<b>286 000</b>
Electricity and Heat Generation		102 000	2.3	49	2	600	—	—	—	103 000
Fossil Fuel Industries		49 700	70	2 000	1	300	—	—	—	52 000
Petroleum Refining and Upgrading		15 000	—	—	0.3	100	—	—	—	15 000
Fossil Fuel Production		34 800	70	2 000	0.7	200	—	—	—	37 000
Mining & Oil and Gas Extraction		4 860	0.1	2	0.1	30	—	—	—	4 900
Manufacturing Industries		51 200	3	50	2	500	—	—	—	51 700
Iron and Steel		6 660	0.3	5	0.2	60	—	—	—	6 730
Non Ferrous Metals		2 790	0.06	1	0.04	10	—	—	—	2 800
Chemical		7 410	0.15	3.2	0.1	40	—	—	—	7 450
Pulp and Paper		12 000	2	30	0.7	200	—	—	—	12 300
Cement		3 130	0.06	1	0.03	10	—	—	—	3 140
Other Manufacturing		19 200	0.4	8	0.4	100	—	—	—	19 300
Construction		1 730	0.03	0.6	0.06	20	—	—	—	1 750
Commercial & Institutional		26 700	0.5	10	0.5	200	—	—	—	26 900
Residential		40 600	90	2 000	2	500	—	—	—	43 000
Agriculture & Forestry		3 200	0.05	1	0.08	20	—	—	—	3 230
<b>b. Transport<sup>2</sup></b>		<b>137 000</b>	<b>30</b>	<b>700</b>	<b>20</b>	<b>7 000</b>	—	—	—	<b>140 000</b>
Civil Aviation (Domestic Aviation)		5 330	0.4	9	0.5	200	—	—	—	5 500
Road Transportation		94 500	14	300	12	3 700	—	—	—	98 500
Light-Duty Gasoline Vehicles		42 700	7.3	150	7.0	2 200	—	—	—	45 000
Light-Duty Gasoline Trucks		21 600	3.2	67	4.0	1 200	—	—	—	22 900
Heavy-Duty Gasoline Vehicles		6 570	1.0	22	0.18	55	—	—	—	6 640
Motorcycles		131	0.13	2.8	0.00	0.85	—	—	—	134
Light-Duty Diesel Vehicles		336	0.01	0.2	0.03	8	—	—	—	344
Light-Duty Diesel Trucks		793	0.02	0.5	0.06	20	—	—	—	811
Heavy-Duty Diesel Vehicles		19 800	1	20	0.6	200	—	—	—	20 000
Propane & Natural Gas Vehicles		2 630	2	30	0.05	20	—	—	—	2 700
Railways		5 970	0.3	7	2	800	—	—	—	7 000
Navigation (Domestic Marine)		4 750	0.3	7	1	300	—	—	—	5 100
Other Transportation		27 000	20	300	5	2 000	—	—	—	30 000
Off-Road Gasoline		5 000	6	100	0.1	40	—	—	—	5 000
Off-Road Diesel		12 000	0.7	10	5	2 000	—	—	—	10 000
Pipelines		9 610	9.6	200	0.3	80	—	—	—	9 890
<b>c. Fugitive Sources</b>		<b>12 000</b>	<b>1 700</b>	<b>36 000</b>	<b>0.1</b>	<b>30</b>	—	—	—	<b>48 600</b>
Coal Mining		—	90	2 000	—	—	—	—	—	2 000
Oil and Natural Gas		12 200	1 640	34 500	0.1	30	—	—	—	46 700
Oil		110	216	4 530	0.1	30	—	—	—	4 670
Natural Gas		25.6	678	14 200	—	—	—	—	—	14 300
Venting		7 780	745	15 700	—	—	—	—	—	23 400
Flaring		4 300	2.7	58	0.00	0.7	—	—	—	4 400
<b>INDUSTRIAL PROCESSES</b>		<b>32 000</b>	—	—	<b>35.5</b>	<b>11 000</b>	<b>660</b>	<b>6 600</b>	<b>4 000</b>	<b>54 400</b>
<b>a. Mineral Products</b>		<b>7 400</b>	—	—	—	—	—	—	—	<b>7 400</b>
Cement Production		4 500	—	—	—	—	—	—	—	4 500
Lime Production		1 800	—	—	—	—	—	—	—	1 800
Mineral Product Use <sup>3</sup>		1 100	—	—	—	—	—	—	—	1 100
<b>b. Chemical Industry</b>		<b>5 100</b>	—	—	<b>35.5</b>	<b>11 000</b>	—	—	—	<b>16 000</b>
Ammonia Production		5 100	—	—	—	—	—	—	—	5 100
Nitric Acid Production		—	—	—	3.41	1 060	—	—	—	1 060
Adipic Acid Production		—	—	—	32	10 000	—	—	—	10 000
<b>c. Metal Production</b>		<b>11 800</b>	—	—	—	—	—	<b>6 600</b>	<b>2 460</b>	<b>20 800</b>
Iron and Steel Production		8 500	—	—	—	—	—	—	—	8 500
Aluminum Production		3 300	—	—	—	—	—	6 600	59.1	9 900
SF <sub>6</sub> Used in Magnesium Smelters and Casters		—	—	—	—	—	—	—	2 400	2 400
<b>d. Consumption of Halocarbons and SF<sub>6</sub></b>		—	—	—	—	—	<b>660</b>	—	<b>1 500</b>	<b>2 200</b>
<b>e. Other &amp; Undifferentiated Production</b>		<b>7 900</b>	—	—	—	—	—	—	—	<b>7 900</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>		—	—	—	<b>0.45</b>	<b>140</b>	—	—	—	<b>140</b>
<b>AGRICULTURE</b>		—	<b>1 000</b>	<b>22 000</b>	<b>93</b>	<b>29 000</b>	—	—	—	<b>51 000</b>
<b>a. Enteric Fermentation</b>		—	910	19 000	—	—	—	—	—	19 000
<b>b. Manure Management</b>		—	130	2 700	12	3 700	—	—	—	6 400
<b>c. Agriculture Soils</b>		—	—	—	81	25 000	—	—	—	25 000
Direct Sources		—	—	—	43	13 000	—	—	—	13 000
Pasture, Range and Paddock Manure		—	—	—	9.1	2 800	—	—	—	2 800
Indirect Sources		—	—	—	30	9 000	—	—	—	9 000
<b>WASTE</b>		<b>260</b>	<b>850</b>	<b>18 000</b>	<b>2</b>	<b>700</b>	—	—	—	<b>19 000</b>
<b>a. Solid Waste Disposal on Land</b>		—	840	18 000	—	—	—	—	—	18 000
<b>b. Wastewater Handling</b>		—	10	220	2	600	—	—	—	790
<b>c. Waste Incineration</b>		260	0.5	10	0.4	100	—	—	—	400
<b>Land Use, Land-use Change and Forestry</b>		<b>-130 000</b>	<b>63</b>	<b>1 300</b>	<b>2.7</b>	<b>850</b>	—	—	—	<b>-130 000</b>
<b>a. Forest Land</b>		-160 000	46	970	1.9	600	—	—	—	-160 000
<b>b. Cropland</b>		11 000	10	200	0.6	200	—	—	—	11 000
<b>c. Grassland</b>		—	—	—	—	—	—	—	—	—
<b>d. Wetlands</b>		4 000	0.8	20	0.03	10	—	—	—	4 000
<b>e. Settlements</b>		9 000	5	100	0.2	50	—	—	—	9 000

Notes:

1. National totals exclude all GHGs from the Land Use, Land-use Change and Forestry sector.

2. Emissions from Fuel Ethanol are reported within the gasoline transportation sub-categories.

3. The category Mineral Product Use includes CO<sub>2</sub> emissions coming from the use of limestone & dolomite, soda ash, and magnesite.

— Indicates no emissions.

0.0 Indicates emissions truncated due to rounding.

Table A8-18: 1991 GHG Emission Summary for Canada

Greenhouse Gas Categories		Greenhouse Gases								
Global Warming Potential		CO <sub>2</sub>	CH <sub>4</sub>	CH <sub>4</sub>	N <sub>2</sub> O	N <sub>2</sub> O	HFCs	PFCs	SF <sub>6</sub>	TOTAL
Unit		kt	kt	kt CO <sub>2</sub> eq	kt	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq
<b>TOTAL<sup>1</sup></b>		<b>447 000</b>	<b>3 600</b>	<b>76 000</b>	<b>160</b>	<b>49 000</b>	<b>840</b>	<b>6 900</b>	<b>5 200</b>	<b>585 000</b>
<b>ENERGY</b>		<b>415 000</b>	<b>1 800</b>	<b>38 000</b>	<b>30</b>	<b>8 000</b>	—	—	—	<b>461 000</b>
<b>a. Stationary Combustion Sources</b>		<b>270 000</b>	<b>200</b>	<b>4 000</b>	<b>7</b>	<b>2 000</b>	—	—	—	<b>276 000</b>
Electricity and Heat Generation		96 100	1.7	36	2	500	—	—	—	96 700
Fossil Fuel Industries		47 300	70	1 000	1	300	—	—	—	49 000
Petroleum Refining and Upgrading		15 000	—	—	0.3	100	—	—	—	15 000
Fossil Fuel Production		32 600	70	1 000	0.7	200	—	—	—	34 000
Mining & Oil and Gas Extraction		5 040	0.1	2	0.1	30	—	—	—	5 070
Manufacturing Industries		51 900	3	50	2	500	—	—	—	52 400
Iron and Steel		6 390	0.3	5	0.2	60	—	—	—	6 460
Non Ferrous Metals		2 570	0.06	1	0.04	10	—	—	—	2 580
Chemical		7 440	0.15	3.2	0.1	40	—	—	—	7 480
Pulp and Paper		12 800	2	30	0.7	200	—	—	—	13 000
Cement		3 170	0.06	1	0.03	10	—	—	—	3 180
Other Manufacturing		19 500	0.4	8	0.4	100	—	—	—	19 700
Construction		1 610	0.03	0.6	0.05	20	—	—	—	1 620
Commercial & Institutional		26 200	0.5	10	0.5	200	—	—	—	26 300
Residential		39 400	90	2 000	2	500	—	—	—	42 000
Agriculture & Forestry		2 700	0.04	0.8	0.06	20	—	—	—	2 720
<b>b. Transport<sup>2</sup></b>		<b>134 000</b>	<b>30</b>	<b>600</b>	<b>20</b>	<b>6 000</b>	—	—	—	<b>140 000</b>
Civil Aviation (Domestic Aviation)		5 480	0.4	9	0.5	200	—	—	—	5 600
Road Transportation		92 600	14	300	11	3 500	—	—	—	96 400
Light-Duty Gasoline Vehicles		42 400	7.3	150	6.7	2 100	—	—	—	44 700
Light-Duty Gasoline Trucks		20 200	3.0	64	3.7	1 100	—	—	—	21 400
Heavy-Duty Gasoline Vehicles		6 840	1.1	24	0.19	59	—	—	—	6 920
Motorcycles		135	0.14	2.9	0.00	0.88	—	—	—	138
Light-Duty Diesel Vehicles		337	0.01	0.2	0.02	8	—	—	—	345
Light-Duty Diesel Trucks		722	0.02	0.4	0.05	20	—	—	—	739
Heavy-Duty Diesel Vehicles		19 700	1	20	0.6	200	—	—	—	19 900
Propane & Natural Gas Vehicles		2 280	1	30	0.04	10	—	—	—	2 300
Railways		5 710	0.3	7	2	700	—	—	—	6 000
Navigation (Domestic Marine)		4 900	0.4	7	1	300	—	—	—	5 200
Other Transportation		25 000	10	300	5	2 000	—	—	—	30 000
Off-Road Gasoline		6 000	6	100	0.1	40	—	—	—	6 000
Off-Road Diesel		12 000	0.7	10	5	2 000	—	—	—	10 000
Pipelines		7 430	7.4	160	0.2	60	—	—	—	7 640
<b>c. Fugitive Sources</b>		<b>11 000</b>	<b>1 600</b>	<b>33 000</b>	<b>0.1</b>	<b>30</b>	—	—	—	<b>44 500</b>
Coal Mining		—	100	2 000	—	—	—	—	—	2 000
Oil and Natural Gas		11 000	1 490	31 300	0.1	30	—	—	—	42 400
Oil		100	200	4 210	0.1	30	—	—	—	4 340
Natural Gas		23.6	636	13 400	—	—	—	—	—	13 400
Venting		6 670	654	13 700	—	—	—	—	—	20 400
Flaring		4 200	2.5	53	0.00	0.4	—	—	—	4 300
<b>INDUSTRIAL PROCESSES</b>		<b>32 000</b>	—	—	<b>35.7</b>	<b>11 100</b>	<b>840</b>	<b>6 900</b>	<b>5 200</b>	<b>56 100</b>
<b>a. Mineral Products</b>		<b>7 300</b>	—	—	—	—	—	—	—	<b>7 300</b>
Cement Production		4 400	—	—	—	—	—	—	—	4 400
Lime Production		1 800	—	—	—	—	—	—	—	1 800
Mineral Product Use <sup>3</sup>		1 090	—	—	—	—	—	—	—	1 090
<b>b. Chemical Industry</b>		<b>4 900</b>	—	—	<b>35.7</b>	<b>11 100</b>	—	—	—	<b>16 000</b>
Ammonia Production		4 900	—	—	—	—	—	—	—	4 900
Nitric Acid Production		—	—	—	3.41	1 060	—	—	—	1 060
Adipic Acid Production		—	—	—	32	10 000	—	—	—	10 000
<b>c. Metal Production</b>		<b>11 500</b>	—	—	—	—	—	<b>6 900</b>	<b>3 650</b>	<b>22 100</b>
Iron and Steel Production		8 320	—	—	—	—	—	—	—	8 320
Aluminum Production		3 100	—	—	—	—	—	6 900	59.1	10 000
SF <sub>6</sub> Used in Magnesium Smelters and Casters		—	—	—	—	—	—	—	3 590	3 590
<b>d. Consumption of Halocarbons and SF<sub>6</sub></b>		—	—	—	—	—	<b>840</b>	—	<b>1 500</b>	<b>2 400</b>
<b>e. Other &amp; Undifferentiated Production</b>		<b>8 400</b>	—	—	—	—	—	—	—	<b>8 400</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>		—	—	—	<b>0.54</b>	<b>170</b>	—	—	—	<b>170</b>
<b>AGRICULTURE</b>		—	<b>1 000</b>	<b>21 000</b>	<b>91</b>	<b>28 000</b>	—	—	—	<b>49 000</b>
<b>a. Enteric Fermentation</b>		—	870	18 000	—	—	—	—	—	18 000
<b>b. Manure Management</b>		—	120	2 600	—	—	—	—	—	6 100
<b>c. Agriculture Soils</b>		—	—	—	80	25 000	—	—	—	25 000
Direct Sources		—	—	—	43	13 000	—	—	—	13 000
Pasture, Range and Paddock Manure		—	—	—	8.4	2 600	—	—	—	2 600
Indirect Sources		—	—	—	30	9 000	—	—	—	9 000
<b>WASTE</b>		<b>250</b>	<b>840</b>	<b>18 000</b>	<b>2</b>	<b>700</b>	—	—	—	<b>18 000</b>
<b>a. Solid Waste Disposal on Land</b>		—	830	17 000	—	—	—	—	—	17 000
<b>b. Wastewater Handling</b>		—	9.8	210	2	500	—	—	—	750
<b>c. Waste Incineration</b>		250	0.5	10	0.4	100	—	—	—	390
<b>Land Use, Land-use Change and Forestry</b>		<b>-90 000</b>	<b>220</b>	<b>4 700</b>	<b>9.4</b>	<b>2 900</b>	—	—	—	<b>-83 000</b>
<b>a. Forest Land</b>		-120 000	200	4 300	8.6	2 700	—	—	—	-110 000
<b>b. Cropland</b>		12 000	10	300	0.7	200	—	—	—	13 000
<b>c. Grassland</b>		—	—	—	—	—	—	—	—	—
<b>d. Wetlands</b>		4 000	0.5	10	0.02	7	—	—	—	4 000
<b>e. Settlements</b>		9 000	5	100	0.2	50	—	—	—	9 000

Notes:

1. National totals exclude all GHGs from the Land Use, Land-use Change and Forestry sector.

2. Emissions from Fuel Ethanol are reported within the gasoline transportation sub-categories.

3. The category Mineral Product Use includes CO<sub>2</sub> emissions coming from the use of limestone & dolomite, soda ash, and magnesite.

— Indicates no emissions.

0.0 Indicates emissions truncated due to rounding.

Table A8-19: 1990 GHG Emission Summary for Canada

Greenhouse Gas Categories			Greenhouse Gases							
	Global Warming Potential	CO <sub>2</sub>	CH <sub>4</sub>	CH <sub>4</sub>	N <sub>2</sub> O	N <sub>2</sub> O	HFCs	PFCs	SF <sub>6</sub>	TOTAL
		21	310							
	Unit	kt	kt	kt CO <sub>2</sub> eq	kt	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq
TOTAL <sup>1</sup>		456 000	3 500	74 000	160	50 000	770	6 500	4 700	592 000
ENERGY		425 000	1 700	37 000	30	8 000	—	—	—	470 000
a.	Stationary Combustion Sources	276 000	200	4 000	7	2 000	—	—	—	282 000
	Electricity and Heat Generation	94 800	1.8	39	2	500	—	—	—	95 400
	Fossil Fuel Industries	49 700	80	2 000	1	300	—	—	—	52 000
	Petroleum Refining and Upgrading	16 000	—	—	0.3	100	—	—	—	16 000
	Fossil Fuel Production	34 100	80	2 000	0.7	200	—	—	—	36 000
	Mining & Oil and Gas Extraction	6 150	0.1	3	0.1	40	—	—	—	6 190
	Manufacturing Industries	54 300	3	60	2	500	—	—	—	54 900
	Iron and Steel	6 430	0.2	5	0.2	60	—	—	—	6 500
	Non Ferrous Metals	3 170	0.07	1	0.05	10	—	—	—	3 190
	Chemical	7 060	0.15	3.0	0.1	40	—	—	—	7 100
	Pulp and Paper	13 500	2	40	0.8	200	—	—	—	13 700
	Cement	3 680	0.07	1	0.04	10	—	—	—	3 690
	Other Manufacturing	20 500	0.4	9	0.4	100	—	—	—	20 700
	Construction	1 850	0.03	0.7	0.05	20	—	—	—	1 870
	Commercial & Institutional	25 500	0.5	10	0.5	200	—	—	—	25 700
	Residential	40 900	100	2 000	2	500	—	—	—	44 000
	Agriculture & Forestry	2 370	0.04	0.8	0.05	20	—	—	—	2 390
b.	Transport <sup>2</sup>	138 000	30	700	20	6 000	—	—	—	150 000
	Civil Aviation (Domestic Aviation)	6 180	0.5	10	0.6	200	—	—	—	6 400
	Road Transportation	94 900	15	310	10	3 200	—	—	—	98 400
	Light-Duty Gasoline Vehicles	43 800	7.8	160	6.2	1 900	—	—	—	45 800
	Light-Duty Gasoline Trucks	19 600	3.1	66	3.2	1 000	—	—	—	20 700
	Heavy-Duty Gasoline Vehicles	7 720	1.3	27	0.22	69	—	—	—	7 810
	Motorcycles	143	0.14	3.0	0.00	0.93	—	—	—	146
	Light-Duty Diesel Vehicles	347	0.01	0.2	0.03	8	—	—	—	355
	Light-Duty Diesel Trucks	691	0.02	0.4	0.05	20	—	—	—	707
	Heavy-Duty Diesel Vehicles	20 500	1	20	0.6	200	—	—	—	20 700
	Propane & Natural Gas Vehicles	2 170	1	30	0.04	10	—	—	—	2 200
	Railways	6 160	0.3	7	3	800	—	—	—	7 000
	Navigation (Domestic Marine)	4 690	0.3	7	1	300	—	—	—	5 000
	Other Transportation	26 000	20	300	6	2 000	—	—	—	30 000
	Off-Road Gasoline	6 000	8	200	0.1	40	—	—	—	7 000
	Off-Road Diesel	13 000	0.7	20	6	2 000	—	—	—	20 000
	Pipelines	6 700	6.7	140	0.2	60	—	—	—	6 900
c.	Fugitive Sources	11 000	1 500	32 000	0.1	30	—	—	—	42 700
	Coal Mining	—	90	2 000	—	—	—	—	—	2 000
	Oil and Natural Gas	10 600	1 440	30 100	0.1	30	—	—	—	40 700
	Oil	95	193	4 060	0.1	30	—	—	—	4 180
	Natural Gas	22.6	613	12 900	—	—	—	—	—	12 900
	Venting	6 090	627	13 200	—	—	—	—	—	19 300
	Flaring	4 400	2.6	54	0.00	0.4	—	—	—	4 400
INDUSTRIAL PROCESSES		31 000	—	—	37.8	11 700	770	6 500	4 700	54 800
a.	Mineral Products	8 300	—	—	—	—	—	—	—	8 300
	Cement Production	5 400	—	—	—	—	—	—	—	5 400
	Lime Production	1 700	—	—	—	—	—	—	—	1 700
	Mineral Product Use <sup>3</sup>	1 090	—	—	—	—	—	—	—	1 090
b.	Chemical Industry	5 000	—	—	37.8	11 700	—	—	—	17 000
	Ammonia Production	5 000	—	—	—	—	—	—	—	5 000
	Nitric Acid Production	—	—	—	3.27	1 010	—	—	—	1 010
	Adipic Acid Production	—	—	—	35	11 000	—	—	—	11 000
c.	Metal Production	9 770	—	—	—	—	—	6 500	3 170	19 500
	Iron and Steel Production	7 060	—	—	—	—	—	—	—	7 060
	Aluminum Production	2 700	—	—	—	—	—	6 500	59.1	9 300
	SF <sub>6</sub> Used in Magnesium Smelters and Casters	—	—	—	—	—	—	—	3 110	3 110
d.	Consumption of Halocarbons and SF <sub>6</sub>	—	—	—	—	—	770	—	1 500	2 300
e.	Other & Undifferentiated Production	8 000	—	—	—	—	—	—	—	8 000
SOLVENT & OTHER PRODUCT USE		—	—	—	0.56	170	—	—	—	170
AGRICULTURE		—	980	21 000	93	29 000	—	—	—	49 000
a.	Enteric Fermentation	—	860	18 000	—	—	—	—	—	18 000
b.	Manure Management	—	120	2 600	11	3 500	—	—	—	6 100
c.	Agriculture Soils	—	—	—	82	25 000	—	—	—	25 000
	Direct Sources	—	—	—	45	14 000	—	—	—	14 000
	Pasture, Range and Paddock Manure	—	—	—	8.2	2 600	—	—	—	2 600
	Indirect Sources	—	—	—	30	9 000	—	—	—	9 000
WASTE		270	820	17 000	2	700	—	—	—	18 000
a.	Solid Waste Disposal on Land	—	810	17 000	—	—	—	—	—	17 000
b.	Wastewater Handling	—	11	220	2	600	—	—	—	780
c.	Waste Incineration	270	0.4	9	0.4	100	—	—	—	400
Land Use, Land-use Change and Forestry		-110 000	150	3 200	6.5	2 000	—	—	—	-110 000
a.	Forest Land	-140 000	130	2 800	5.6	1 700	—	—	—	-130 000
b.	Cropland	13 000	10	300	0.7	200	—	—	—	14 000
c.	Grassland	—	—	—	—	—	—	—	—	—
d.	Wetlands	4 000	0.3	6	0.01	4	—	—	—	4 000
e.	Settlements	9 000	5	100	0.2	50	—	—	—	9 000

Notes:

<sup>1</sup> National totals exclude all GHGs from the Land Use, Land-use Change and Forestry sector.<sup>2</sup> Emissions from Fuel Ethanol are reported within the gasoline transportation sub-categories.<sup>3</sup> The category Mineral Product Use includes CO<sub>2</sub> emissions coming from the use of limestone & dolomite, soda ash, and magnesite.

- Indicates no emissions.

0.0 Indicates emissions truncated due to rounding.

## Annex 9 Electricity Intensity Tables

This annex presents detailed GHG information related to the generation of electricity by public utilities on a national and provincial level. The GHG emissions presented in this annex include stationary combustion sources only and are a subcategory of the Public Electricity and Heat Production category (CRF Category 1.A.1.a).

The Canadian electricity generation industry is composed of utility, non-utility, and industrial generators that transform energy from water, coal, natural gas, refined petroleum products (RPPs), miscellaneous other fuels, biomass, nuclear, wind, and solar resources into electricity. The process of supplying electricity to the public involves not only power generation at the plant, but also distribution through the electricity grid. Although the efficiency of the transmission system has an impact on the amount of electricity available to the consumers, data is not currently available at that level of refinement to discuss the impacts of the distribution infrastructure. GHG emission estimates and electricity generation values are therefore based on activities that occur at the plant only and do not include SF<sub>6</sub> emissions associated with transformer stations.

The analysis in this section relies on a variety of data sources. Fuel consumption and electricity production data is published by Statistics Canada in the RESD (Statistics Canada #57-003-XIB) and the *Electric Power Generation, Transmission and Distribution* (EPGTD) publication (Statistics Canada #57-202-XIB). The EPGTD is generally published after the RESD, and the data within the reports may differ slightly due to revisions. The EPGTD is assumed to contain the most up-to-date data; the data presented in this section, unless otherwise stated, are from the EPGTD. Both publications collect data from major electricity suppliers with station capacities of 500 kW or more and account for more than 95% of electricity generation in Canada. Data for 2006 was obtained from Statistics Canada via CANSIM (Tables v222128 to v222133) as the EPGTD was not available at the time of publication. The regional analysis and discussion is further supported by reviewing and incorporating data published in annual reports prepared by the major power producers in each province or territory.

### ***A9.1 Methodology and Limitations***

GHG emissions resulting from the combustion of fuel for electricity generation by public utilities are presented in this annex. Detailed data on industrial contributions to the electricity grid are available; however, fuel consumption data associated with this specific area of electricity production is not currently available in the EPGTD. Nevertheless, the contribution of industry-generated electricity to the Canadian total is on average less than 9% and is not considered to be a major factor in the trends discussion.

The information presented in this annex also excludes the emissions associated with heat and steam generation. Emissions and trends for the entire Electricity and Heat Generation Sector are covered briefly in Greenhouse Gas Emission Trends, 1990–2006 (Chapter 2), and the Energy Sector (Chapter 3). GHG emissions by gas for the entire sector are presented in Canada's Greenhouse Gas Emission Tables, 1990–2006 (Annex 8) and the Provincial/Territorial Greenhouse Gas Emission Tables, 1990–2006 (Annex 11).

Electricity intensity values were derived for each fuel type using GHG emission estimates and electricity generation data. The methodology used to develop the GHG emissions is discussed in Chapter 3 and Annex 2 of this report. GHG emissions are based on total fuel consumed by the utility, as provided in the RESD, while the net electricity generation presented herein is from the



EPGTD. For the period of 1990–1997, net electricity generation was calculated from gross electricity generation values provided in the EPGTD.

In some cases, GHG intensities for natural gas–fuelled generators are calculated as being close to those of coal-based generation. This is a limitation of the method, as it relies on electricity data and fuel efficiencies published in the EPGTD. This may be related to peaking stations, which are used to meet public demand at peak times, the usage of co-generation units, or data limitations.

## A9.2 National Trends

Public utility-generated electricity has increased by 26% since 1990, while GHG emissions associated with this sector have increased by 19% over the same period. GHG intensity is down from 217 g CO<sub>2</sub> eq/kWh in 1990 to 205 g CO<sub>2</sub> eq/kWh in 2006. GHG intensity is at its lowest level since 1995, largely due to increasing hydro and nuclear generation and fuel switching from RPPs to natural gas.

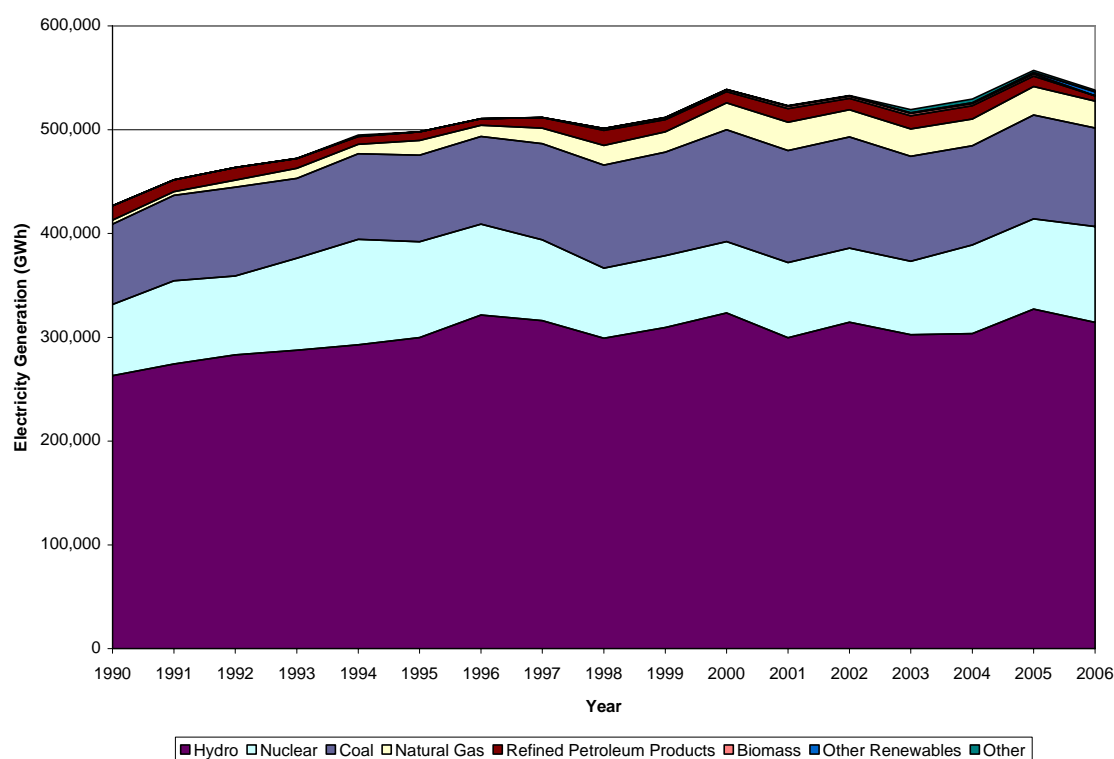


Figure A9-1: Utility-Generated Electricity by Source

As shown in Figure A9-1, hydroelectric resources still supply the majority of Canada's electricity, contributing 58% of total generation in 2006, down from 61% in 1990. Hydroelectric generation is essentially free of direct GHG emissions except for CH<sub>4</sub> emissions that result from the flooding of lands to build reservoirs. Hydro resources are primarily concentrated in Labrador, Quebec, British Columbia, and Manitoba. Since 1990, the contribution of hydro generation to the total supply mix has been relatively stable, with yearly fluctuations directly related to hydraulic conditions.

Nuclear power is Canada's second largest source of emission-free electricity<sup>78</sup>, contributing approximately 17% of total generation in 2006, up slightly from 16% in 1990. Nuclear generation peaked in 1996, with 102 000 GWh, then declined in subsequent years due to reactor maintenance and shutdowns (due to safety concerns). In 2006, nuclear power stations generated a total of 92 400 GWh, the vast majority (90%) in the province of Ontario. Nuclear power plants also operate in Quebec and New Brunswick and significant efforts have been made to recover nuclear generation capacity in the country since 2003.

Coal provided approximately 17% of the electricity generated in Canada in 2006, totalling 95 000 GWh, an increase of 23% (or 17 700 GWh) from 1990. Coal-fired generation is responsible for about 83% of the country's electricity-related GHG emissions and is the primary fuel in the provinces of Alberta and Saskatchewan. Coal use is also significant in Ontario and Nova Scotia (see Figure A9-3 below for generation sources by region). The gradual increase in coal generation is primarily due to increasing demand, while annual variations usually depend on fluctuations in hydro generation; that is, in years with lower water levels, coal use increases to compensate. In Ontario, coal use also increased in those years when there was less nuclear generation. Coal-based electricity in Canada was responsible for 92 Mt of GHG emissions, a 13 Mt increase over 1990 and a decrease of 4 Mt from 2005. In 2006, the amount of electricity generated from coal and associated GHG emissions were at their lowest levels since 1997.

The use of natural gas for electricity generation has increased significantly since 1990, and it now surpasses RPPs in its contribution to total supply. In 2006, its share was 5%—more than five times that in 1990. Natural gas-fired generators are part of the generation mix in most regions of the country, with Ontario and Alberta leading in natural gas-fired generation, followed by British Columbia and Saskatchewan. In Quebec and the Atlantic provinces, gas has been available only since 2000, but it is already used in several new plants and in several retrofitted oil plants. Because of the relative ease of firing up natural gas generators and the cost of fuel, they are generally used to top up the base load supply (hydro, coal, or nuclear) at peak times to meet fluctuations in demand and supplement the base load. Since the GHG emissions from natural gas generation per kilowatt-hour are about half those from coal, any displacement of coal by natural gas results in fewer GHG emissions. The use and installation of co-generation units has also been increasing and has had a positive impact on the amount of usable power being captured per unit of fuel combusted. Total GHG emissions from natural gas in 2006 were 13 Mt, an increase of 10 Mt from 1990.

RPPs such as heavy fuel oil, diesel and Orimulsion® were used to generate 5 100 GWh of electricity in 2006, a significant 62% decrease from 1990. RPP-fired generation made up 1% of Canada's total electricity production for 2006. RPPs are used for electricity generation primarily in Nova Scotia and New Brunswick, where they made up 3% and 38% of their respective supply mixes in 2006. These percentages vary from year to year, depending on the price of RPPs relative to the price of coal and overall demand. The remainder of RPP generation is located in Alberta and Quebec. In Canada, oil prices reached a record level in 2006, making RPP-fired generation a more expensive option than natural gas to meet demand. GHG emissions from RPP generation in 2006 were 4 Mt, more than 63% lower than their level in 1990. The majority of this decrease was in the Atlantic provinces and the factors behind it are discussed in greater detail in the regional discussion.

---

78. The inventory analysis does not consider emissions related to uranium mining, processing, or disposal of waste fuel.

The contribution of biomass sources, in particular wood and wood wastes, to electrical generation was not available for 2006 at the time of publication. Based on data for 2005, these sources contribute less than 1% to the Canadian total with generation mainly located in the provinces of British Columbia, Alberta, and New Brunswick. GHG emissions from biomass are considered carbon-neutral and are not included in the totals.

The positive news story for 2006 surrounds the increase in electricity generated from other renewable energy sources like wind and tidal power installations. New large-scale (> 100 MW) wind farm installations in Ontario, Manitoba and Saskatchewan helped increase power generation by 139% from 2005. Provincial programs for increased renewable content (from wind and other sources) in the electrical supply grid will play a role in 2007 and beyond as more projects come on line. Data for 2007 indicate that installed wind capacity increased by at least another 25% nationwide while current estimates indicate that, across Canada, provincial governments are seeking to put in place a minimum of 12 000 MW of installed wind capacity by 2016. For comparison purposes, Canada's 18 nuclear reactors (operating in 2006) have a gross total capacity of 13 400 MW ([http://www.cna.ca/english/pdf/NuclearFacts/2007/Reactors\\_Canada\\_2007.pdf](http://www.cna.ca/english/pdf/NuclearFacts/2007/Reactors_Canada_2007.pdf)).

### **A9.3      *Sectoral Discussion***

Overall electricity generation decreased by 3% from a peak observed in 2005 while electricity exports decreased by 26% over the same period. Fluctuations in electricity generation over time (Figure A9-1) primarily depend on changes in demand since electricity is generated to meet an instantaneous need and, once generated, cannot be stored effectively. Generation can also be affected by demand in the United States via exports.

Decreasing electrical demand can occur via action by the final consumer (through conservation and outreach programs), new technology (higher-efficiency appliances), weather, or through market and/or economic restructuring, plant shutdowns or strike actions. The major consumers of electricity in Canada for 2006 are grouped (in order of decreasing consumption) as follows: Manufacturing Industries (including Mining and Oil & Gas extraction<sup>79</sup>) (44%), Residential (28%), and Commercial/Institutional & Public Administration (26%). Since 1990, the overall consumption of each sector has increased while their consumption as a percentage of the whole has remained virtually unchanged.

---

79. By itself, the Mining and Oil & Gas extraction Sector consumed 7% of the electricity in Canada in 2006.

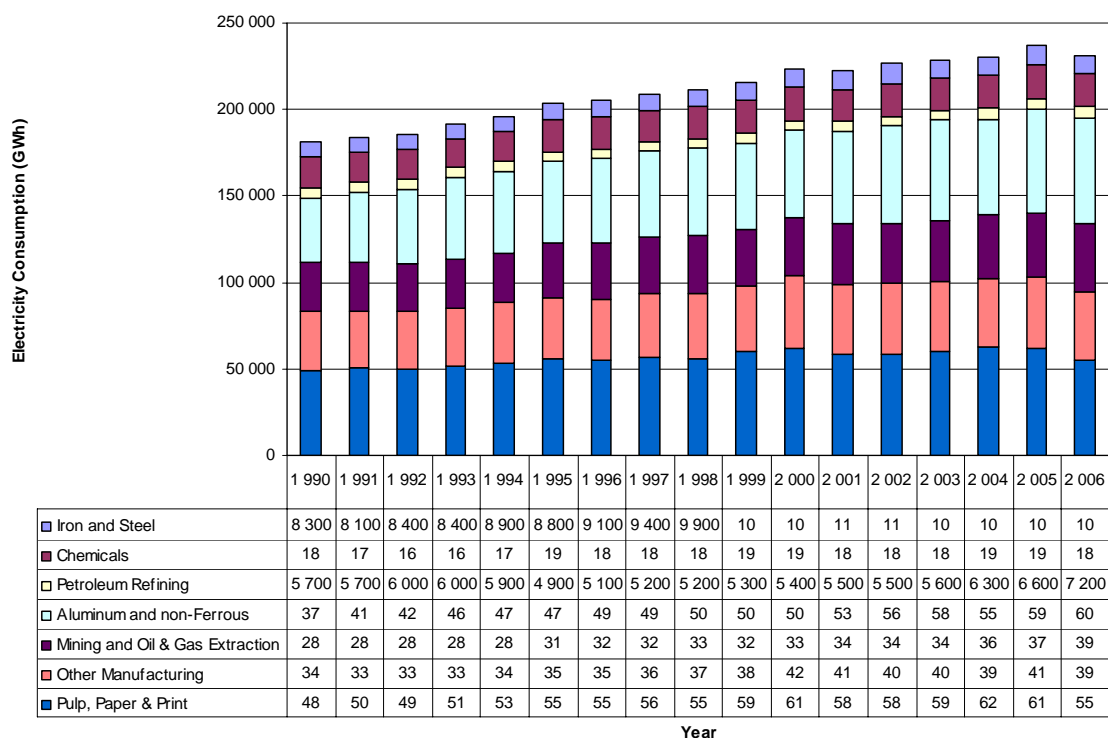


Figure A9-2: Electricity Consumption by Manufacturing Industry

### *Manufacturing Industries*

Electricity consumption for selected manufacturing sectors is presented in Figure A9-2. Over the long term, consumption increased in all subsectors, although the increases are not equally distributed as the Canadian economy has changed over time. A shift from a resource-based economy, the rise of the automotive and electronics sector, and the growth of the service/IT industry have all had impacts on electricity consumption. Over the short term, 4 of the 7 sectors showed a decrease in electrical consumption. The short-term changes can be directly attributed to economic factors.

The iron and steel subsector has increased electrical energy consumption mainly due to changes in technology and economic factors. A protracted strike in 1990 reduced production (and subsequently consumption and GHG emissions) and has the impact of skewing the long-term trend. Regardless, the use of electric arc furnaces (EAFs) has increased electrical consumption while reducing plant level fossil fuel consumption and GHGs. Economic issues in the early part of the decade moderated the growth in electrical consumption, although the subsector has begun to rebound due to stronger export demand.

Electricity consumption in the chemical industry has remained fairly constant over time. Plant closures, higher efficiency, operational issues and strikes are generally responsible for the interannual changes in consumption.

The petroleum refining subsector has seen electrical consumption remain fairly constant over time with an increasing trend noted in the last 3 years. Higher prices and demand for refined petroleum products has meant increased profits for refining operations and an upsurge in

production. Increases in production efficiency have helped reduce power costs, although advanced technologies to create cleaner fuels and increased capacity at existing facilities have meant a small increase in electrical consumption. Record demand for gasoline and the effects of Hurricane Katrina on refinery operations in the United States in 2005 were behind the growth in electrical demand experienced in the last 2 years.

The Aluminium and Non-ferrous metals Production subsector has shown significant growth since 1990. Increased global demand for these products has been the main reason for the increased consumption. The Aluminium subsector uses significant amounts of electricity in their processes and demand is directly related to production.

The Mining and Oil & Gas Extraction Sector has grown steadily since 1990. This sector also includes oil sands mining as well as primary metals (i.e., zinc, bauxite, nickel, copper). The growth of the oil sands plus surging global demand for primarily metals in the last 5 years on the global market are the key drivers behind the growth in electrical consumption. The growth in this sector is similar to that shown in the Petroleum Refining and Aluminium sectors.

The Other Manufacturing subsector includes many industries, and of particular interest are the automotive and electronics manufacturing subsectors. Electricity consumption reached a peak in 2000 and has been on a slow decrease as the subsector deals with difficult economic conditions brought about by the effects of the dot-com bust, 9/11 terrorist attacks, and a slowdown in the United States housing market. The subsector has shown tremendous resiliency and the ability to adapt with increases in energy efficiency (particularly in the automotive subsector), and a shift from relying solely on United States markets to taking advantage of other Canadian and global markets for exports. Strong demand for manufactured products in Alberta helped to temper decreased demand from the United States due to increases in the Canadian dollar compared to the American dollar.

In recent years, the Pulp, Paper & Print subsector has faced the greatest economic difficulties. Compared to 2005, the Pulp, Paper & Print subsector showed the greatest decrease in electricity demand in 2006. Strikes and plant closures in the Atlantic provinces reduced electricity demand in 2006, and had the effect of reducing GHG emissions from power generation since significantly fewer RPP fuels were combusted to meet peak power requirements. Softening demand for newsprint, as people come to rely more on electronic media, and lower prices and demand for softwood lumber from the United States housing market have both been key factors in the economic downturn faced by this industry.

### ***Residential Sector***

The Residential Sector is a major consumer of electricity, increasing 14% between 1990 and 2006 and 6% since 2001. At the same time, the number of homes in Canada increased by 26% between 1990 and 2005 (the last year data is available) and 5% between 2001 and 2005. Electricity consumption by this sector can be affected by weather but also by economic prosperity. Growth in demand was low to moderate during the recession exhibited in the early 1990s and increased significantly after 1999. The rise in home computer usage and the number of electronic gadgets that have been purchased thanks to increases in disposable income has helped to push consumption higher, while energy efficiency gains have been realized in new appliances (via programs like EnergyStar). Larger homes have also played a role requiring more heating, cooling and lighting, with the average size of a housing unit has increasing by about 4 m<sup>2</sup> from 1990.

Electricity consumption by the Residential Sector decreased by 2% between 2005 and 2006. 2004 and 2005 marked the full-scale implementation of significant and successful efforts in GHG reductions and electricity conservation through campaigns such as the One Tonne Challenge, the Project Porchlight and utility-organized conservation programs. The Coalition of Large Distributors (CLD), six of the largest electricity distribution companies in Ontario (Canada's most populous province) reported that their conservation and public outreach efforts helped reduce residential electrical demand by 111 GWh in 2005, and 303 GWh in 2006, even though an all-time record of 27 005 MW for electricity demand was set in Ontario on August 1, 2006. Lower demand was also the result of a warmer winter and had the greatest impact in the populous provinces of Quebec and Ontario, although the effects were felt across the country.

### ***Commercial/Institutional and Public Administration Sector***

The same temperature effects can be seen in the Commercial/Institutional and Public Administration subsectors in 2006. Consumption decreased by 2% from 2005 but increased by 24% from 1990. These sectors have exhibited significant growth in long-term electrical consumption as the service and I/T sectors have grown as a result of structural changes in Canada's economy. These subsectors have also meant an increase in the number of commercial buildings and floor space, which has meant larger areas to heat and cool, while computers, printers and other electrical appliances have become commonplace. Commercial floor space increased 28% between 1990 and 2005 (the last year for which data is available) and 7% between 2001 and 2005.

Electricity conservation and outreach programs in 2005 and 2006 have also targeted these sectors. The Clean Air Foundation in Ontario reports that their Cool Shops program has helped reduce electricity consumption in the retailing sector by 5 000 MWh since starting the program in 2005.

## ***A9.4 Regional Discussion***

Figure A9-3 provides a breakdown of electricity generation by region and by source for the years 1990 and 2006.<sup>80</sup> Coal-fired sources predominate in Alberta and Saskatchewan, due in no small part to easy and reliable access to abundant coal resources. Hydro provides the majority of electricity generation in the provinces of Quebec, British Columbia, Manitoba, and Newfoundland and Labrador. In Ontario and the Atlantic region, the electricity generation mix is fairly diverse, with nuclear power providing the greatest percentage of supply in Ontario. In terms of total generation, Quebec and Ontario have by far the highest generation totals—combined, they produced 312 400 GWh (or 58%) of Canada's electricity supply in 2006. They are followed by Alberta and British Columbia, with about 54 200 GWh and 48 800 GWh, respectively, then by Newfoundland and Labrador, with 41 800 GWh.

---

80. Owing to their relatively small contribution to Canadian supply, the Atlantic provinces have been grouped together, as have the territories.

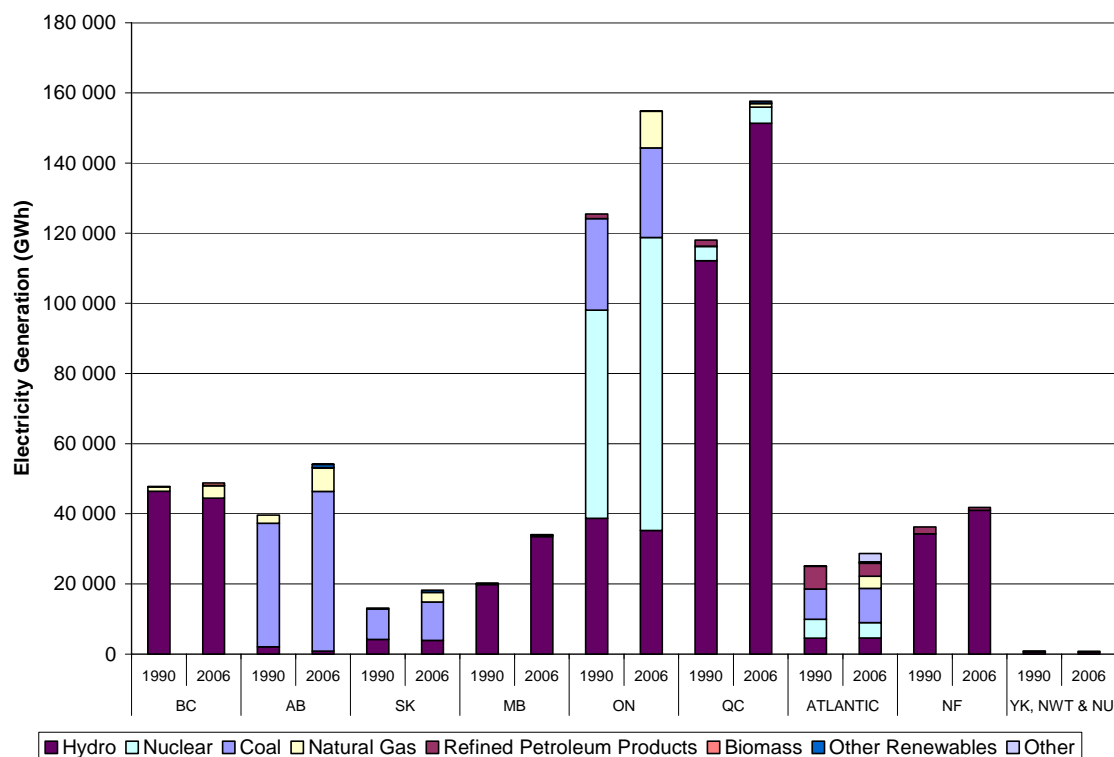


Figure A9-3: Electricity Generation by Region and Source, 1990 and 2006

Generation has increased in all provinces, although the increase was minimal in British Columbia. Since 1990, generation in Alberta, Saskatchewan, and Manitoba has grown by over 35%. In Manitoba, this growth was based on the new hydro development at Churchill Falls, while in Alberta and Saskatchewan, the increase was due to expanded use of coal and natural gas to meet demand in the oil patch. The Atlantic region's 27% growth was also primarily brought about through increased use of fossil fuels—a combination of coal, RPPs, and natural gas. In Ontario, a 20% increase in generation was met with increased nuclear over the period, plus a tenfold increase in the use of natural gas.

Overall, zero-GHG-emitting electricity sources (nuclear, hydro, biomass, wind, and tidal) continue to provide at least three quarters of the electricity in Canada. The contribution of Other Renewables (mostly new wind installations) has increased almost 500% in the last five years and will likely increase further in 2007 and 2008 due to federal and provincial incentive programs and increased public acceptance.

Since public utilities are limited in their ability to increase electricity rates for consumers, economic factors can play a major role in fuel consumption. For example, natural gas-fuelled generation increased by about 550% between 1990 and 2000 and remained constant between 2000 and 2005. Natural gas-based generation was lower between 2002 and 2004, due in part to higher natural gas prices, while generation in 2006 was lower because of warmer winter temperatures. The rapid valuation of the Canadian currency in 2004, however, had the effect of lowering natural gas costs, as these prices are based on international markets and foreign currency. Similar impacts can be inferred for coal, RPPs, and Other fuel generation. With increasing oil costs, the usage of lower-priced and subsequently lower-grade fuels like coal and

those included in the Other category have increased while RPP usage has decreased due to the limited ability of public utilities to pass on rising fuel costs.

There are three main factors for the 8.3 Mt decrease in GHG emissions from this sector. The first involves a warmer winter felt across the country that reduced the typical winter peak in electricity consumption. The number of heating degree days for Canada as a whole decreased by 8.1% between 2005 and 2006, with the biggest decreases observed in Ontario and points east. The second involved increases in non-GHG emitting generation, like nuclear in Ontario, wind across most of the country, and higher hydraulic output in the Atlantic provinces. The third factor however, had the greatest impact. GHG emissions decreased the most in the Atlantic provinces due to an extended strike action at a major industrial consumer of electricity. This resulted in a significant decrease in electricity demand in the region, which further reduced peak power requirements. Lower overall demand reduced the amount of RPP-fired generation that would typically be used to meet peak requirements. RPP fuels were also more expensive compared to natural gas due to high oil prices and lower natural gas prices. Thus the economic decision to reduce the amount of RPPs combusted, combined with the lower power demands and increased hydro availability, significantly decreased GHG emissions.

### **A9.5      *GHG Emission Intensities***

The quantity of GHG emissions per megawatt-hour for a specific fuel (or for a specific fuel and generation type) is known as emission intensity and can be measured in tonnes of CO<sub>2</sub>-equivalent emissions per gigawatt-hour (t CO<sub>2</sub> eq/GWh). Emission intensities vary according to the specific type of fuel used, the quality of that fuel, the conversion technology used, and the efficiency of the combustion unit. Coal-fired electricity generally has the highest emission intensity; its emission intensity varies with the type of coal, although it is usually in the range of 1000 t CO<sub>2</sub> eq/GWh. The intensity of RPPs also varies with fuel type and technology, ranging from 600 to 800 t CO<sub>2</sub> eq/GWh, and reflects the variability of this category. Natural gas generators tend to generate at around 500 t CO<sub>2</sub> eq/GWh, although the value could be substantially lower for cogeneration plants.

On a regional basis, GHG intensities give a quick glimpse into the wide variation of supply mixes in each province and region. Alberta, with a generation system that is predominantly coal-based, has the highest GHG intensity in Canada, although its GHG intensity has been decreasing as a result of increased use of natural gas, biomass, and other renewable sources of energy. The Atlantic region, with a mix of RPPs, coal, and nuclear, has a GHG intensity that is lower than that of Alberta, whereas Quebec, Manitoba, and British Columbia, where generation is dominated by hydro, have the lowest GHG intensities. With its mix of hydro, nuclear, and fossil fuels, Ontario lies between the two and is very close to the Canadian average.

Electricity generation and GHG emissions details for Canada and the provinces and territories are provided in tables A9-1 to A9-12.



**Table A9-1: Electricity Generation and GHG Emission Details for Canada<sup>1</sup>**

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006 <sup>c</sup>
<b>Greenhouse Gas Emissions<sup>a</sup></b> <i>kt CO<sub>2</sub> equivalent</i>																	
Coal	78 790	82 440	85 450	78 180	81 680	82 990	84 750	91 300	97 040	96 680	104 770	103 370	101 950	101 260	92 860	95 620	91 810
Refined Petroleum Products <sup>2</sup>	11 070	9 030	10 260	7 500	5 850	6 590	5 170	7 810	11 630	9 230	8 450	10 290	8 230	10 000	9 830	7 860	4 040
Natural Gas	2 630	2 140	4 410	5 470	5 540	7 000	5 570	7 440	9 640	9 740	12 910	13 860	12 700	13 580	12 580	13 240	12 570
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro <sup>3</sup>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass <sup>4</sup>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	40	20	20	0	30	10	10	110	40	40	120	370	420	3 840	3 980	2 120	2 120
<b>Overall Total</b>	<b>92 530</b>	<b>93 630</b>	<b>100 140</b>	<b>91 150</b>	<b>93 100</b>	<b>96 590</b>	<b>95 500</b>	<b>106 660</b>	<b>118 350</b>	<b>115 690</b>	<b>126 250</b>	<b>127 890</b>	<b>123 300</b>	<b>128 680</b>	<b>119 250</b>	<b>118 840</b>	<b>110 540</b>
<b>Electricity Generation<sup>b</sup></b> <i>GWh</i>																	
Coal	77 350	82 490	85 510	77 060	82 310	83 360	84 550	92 580	99 250	99 600	107 710	107 860	107 010	101 200	95 740	100 160	95 050
Refined Petroleum Products	13 630	11 470	12 190	9 380	7 380	8 420	6 280	10 110	14 540	11 750	10 810	13 260	10 800	12 660	12 920	10 090	5 140
Natural Gas	3 890	3 410	6 820	9 550	9 190	14 190	10 780	15 100	18 910	19 690	25 890	27 300	26 410	26 450	25 570	27 410	25 780
Nuclear	68 760	80 120	76 020	88 640	101 710	92 310	87 510	77 860	67 470	69 330	68 680	72 350	71 250	70 650	85 240	86 830	92 420
Hydro	262 920	274 180	283 040	287 450	292 660	299 740	321 410	315 960	299 120	309 330	323 470	299 600	314 550	302 440	303 590	327 170	314 230
Biomass <sup>4</sup>	10	20	0	130	340	IE	IE	IE	1 700	1 740	1 910	2 120	2 180	2 150	2 010	1 870	N/A
Other Renewables <sup>5</sup>	30	30	60	30	30	30	30	80	80	280	260	370	430	700	970	1 580	3,770 <sup>7</sup>
Other <sup>6</sup>	80	10	0	0	1 200	20	10	100	40	40	120	310	350	3 060	3 330	1 890	1 870
<b>Overall Total</b>	<b>426 670</b>	<b>451 750</b>	<b>463 640</b>	<b>472 230</b>	<b>494 820</b>	<b>498 060</b>	<b>510 580</b>	<b>511 790</b>	<b>501 110</b>	<b>511 770</b>	<b>538 850</b>	<b>523 180</b>	<b>533 010</b>	<b>519 320</b>	<b>529 360</b>	<b>557 000</b>	<b>538 250</b>
<b>Greenhouse Gas Intensity</b> <i>g CO<sub>2</sub> eq / kWh</i>																	
Coal	1 020	1 000	1 000	1 010	990	1 000	1 000	990	980	970	970	960	950	1 000	970	950	970
Refined Petroleum Products	810	790	840	800	790	780	820	770	800	790	780	780	760	790	760	780	790
Natural Gas	680	630	650	570	600	490	520	490	510	490	500	510	480	510	490	480	490
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	490	1 680	N/A	N/A	20	770	1 380	1 110	990	1 070	990	1 220	1 200	1 260	1 200	1 120	1 130
<b>Overall Total</b>	<b>217</b>	<b>207</b>	<b>216</b>	<b>193</b>	<b>188</b>	<b>194</b>	<b>187</b>	<b>208</b>	<b>236</b>	<b>226</b>	<b>234</b>	<b>244</b>	<b>231</b>	<b>248</b>	<b>225</b>	<b>213</b>	<b>205</b>

Sources:

a. Report on Energy Supply-Demand in Canada, Catalogue No. 57-003-XIB, Statistics Canada.

b. Electric Power Generation, Transmission and Distribution, Catalogue No. 57-202-XIB, Statistics Canada.

c. Electricity data from CANSIM, tables v222128, v222129, v222130, v222131, v222132, v222133 - downloaded February 5, 2008.

Notes:

1. Data presented includes emissions, generation and intensity for public utilities.

2. Includes emissions from the use of light fuel oil, heavy fuel oil and diesel fuel oil.

3. Emissions from the flooding of land for hydro dams are not included.

4. Emissions related to the use of biomass for electric power generation are not included.

5. Other Renewables - includes electricity generation by wind and tidal.

6. Others - includes electricity generation by fuels not easily categorized (i.e. waste).

7. Other renewables are estimated to provide 0.7% of total generation for Canada.

IE - Generation data is Included Elsewhere.

N/A - Not Available.

**Table A9-2: Electricity Generation and GHG Emission Details for Newfoundland and Labrador<sup>1</sup>**

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006 <sup>c</sup>
	<b>Greenhouse Gas Emissions<sup>a</sup></b> <i>kt CO<sub>2</sub> equivalent</i>																
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Refined Petroleum Products <sup>2</sup>	1 630	1 290	1 490	1 350	720	1 260	1 170	1 220	1 030	810	810	1 670	1 850	1 540	1 290	1 070	630
Natural Gas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro <sup>3</sup>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass <sup>4</sup>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>Overall Total</b>	<b>1 630</b>	<b>1 290</b>	<b>1 490</b>	<b>1 350</b>	<b>720</b>	<b>1 260</b>	<b>1 170</b>	<b>1 220</b>	<b>1 030</b>	<b>810</b>	<b>810</b>	<b>1 670</b>	<b>1 850</b>	<b>1 540</b>	<b>1 290</b>	<b>1 070</b>	<b>630</b>
<b>Electricity Generation<sup>b</sup></b> <i>GWh</i>																	
Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Refined Petroleum Products	1 960	1 510	1 780	1 630	850	1 600	1 470	1 570	1 310	960	1 020	2 150	2 430	2 000	1 700	1 360	790
Natural Gas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydro	34 320	34 920	34 370	38 680	37 090	35 780	34 830	39 650	43 140	39 920	41 760	37 430	40 110	38 350	38 100	38 950	41 020
Biomass	10	20	0	20	30	20	10	0	0	0	0	0	0	0	0	0	0
Other Renewables <sup>5</sup>	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other <sup>6</sup>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<b>Overall Total</b>	<b>36 290</b>	<b>36 450</b>	<b>36 170</b>	<b>40 330</b>	<b>37 970</b>	<b>37 400</b>	<b>36 310</b>	<b>41 220</b>	<b>44 450</b>	<b>40 880</b>	<b>42 780</b>	<b>39 580</b>	<b>42 540</b>	<b>40 350</b>	<b>39 800</b>	<b>40 310</b>	<b>41 810</b>
<b>Greenhouse Gas Intensity</b> <i>g CO<sub>2</sub> eq/kWh</i>																	
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Refined Petroleum Products	830	860	840	830	850	790	800	780	790	850	790	780	760	770	760	780	800
Natural Gas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>Overall Total</b>	<b>45</b>	<b>35</b>	<b>41</b>	<b>33</b>	<b>19</b>	<b>34</b>	<b>32</b>	<b>30</b>	<b>23</b>	<b>20</b>	<b>19</b>	<b>42</b>	<b>43</b>	<b>38</b>	<b>32</b>	<b>27</b>	<b>15</b>

Sources:

a. Report on Energy Supply-Demand in Canada, Catalogue No. 57-003-XIB, Statistics Canada.

b. Electric Power Generation, Transmission and Distribution, Catalogue No. 57-202-XIB, Statistics Canada.

c. Electricity data from CANSIM, tables v222128, v222129, v222130, v222131, v222132, v222133 - downloaded February 5, 2008.

Notes:

1. Data presented includes emissions, generation and intensity for public utilities.

2. Includes emissions from the use of light fuel oil, heavy fuel oil and diesel fuel oil.

3. Emissions from the flooding of land for hydro dams are not included.

4. Emissions related to the use of biomass for electric power generation are not included.

5. Other Renewables - includes electricity generation by wind and tidal.

6. Others - includes electricity generation by fuels not easily categorized (i.e. waste).

**Table A9-3: Electricity Generation and GHG Emission Details for Prince Edward Island<sup>1</sup>**

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006 <sup>c</sup>
<b>Greenhouse Gas Emissions<sup>a</sup></b> <i>kt CO<sub>2</sub> equivalent</i>																	
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Refined Petroleum Products <sup>2</sup>	100	90	50	70	60	40	20	30	10	20	60	50	30	40	20	10	10
Natural Gas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro <sup>3</sup>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass <sup>4</sup>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>Overall Total</b>	<b>100</b>	<b>90</b>	<b>50</b>	<b>70</b>	<b>60</b>	<b>40</b>	<b>20</b>	<b>30</b>	<b>10</b>	<b>20</b>	<b>60</b>	<b>50</b>	<b>30</b>	<b>40</b>	<b>20</b>	<b>10</b>	<b>10</b>
<b>Electricity Generation<sup>b</sup></b> <i>GWh</i>																	
Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Refined Petroleum Products	81	71	34	59	40	22	9	21	3	8	48	43	19	43	10	4	1
Natural Gas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydro	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass	0	0	0	0	0	0	0	0	0	0	0	1	1	0	2	2	1
Other Renewables <sup>5</sup>	0	0	0	0	0	0	0	0	0	0	0	5	19	20	35	40	50 <sup>7</sup>
Other <sup>6</sup>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
<b>Overall Total</b>	<b>81</b>	<b>71</b>	<b>34</b>	<b>59</b>	<b>40</b>	<b>22</b>	<b>9</b>	<b>21</b>	<b>3</b>	<b>8</b>	<b>48</b>	<b>49</b>	<b>39</b>	<b>63</b>	<b>48</b>	<b>46</b>	<b>52</b>
<b>Greenhouse Gas Intensity</b> <i>g CO<sub>2</sub> eq/kWh</i>																	
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Refined Petroleum Products	1 260	1 280	1 500	1 250	1 450	1 730	2 780	1 470	3 940	2 260	1 150	1 160	1 550	990	1 860	2 810	7 630 <sup>8</sup>
Natural Gas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>Overall Total</b>	<b>1 235</b>	<b>1 268</b>	<b>1 471</b>	<b>1 186</b>	<b>1 500</b>	<b>1 818</b>	<b>2 222</b>	<b>1 429</b>	<b>3 333</b>	<b>2 500</b>	<b>1 250</b>	<b>1 020</b>	<b>769</b>	<b>635</b>	<b>417</b>	<b>217</b>	<b>192</b>

Sources:

a. Report on Energy Supply-Demand in Canada, Catalogue No. 57-003-XIB, Statistics Canada.

b. Electric Power Generation, Transmission and Distribution, Catalogue No. 57-202-XIB, Statistics Canada.

c. Electricity data from CANSIM, tables v222128, v222129, v222130, v222131, v222132, v222133 - downloaded February 5, 2008.

Notes:

1 Data presented includes emissions, generation and intensity for public utilities

2. Includes emissions from the use of light fuel oil, heavy fuel oil and diesel fuel oil.

3. Emissions from the flooding of land for hydro dams are not included.

4. Emissions related to the use of biomass for electric power generation are not included.

5. Other Renewables - includes electricity generation by wind and tidal.

6. Others - includes electricity generation by fuels not easily categorized (i.e. waste).

7. Estimated via linear regression and continued growth in wind energy sector in PEI.

8. Intensity value for RPPs well outside the normal range and is the result of two separate datasets required for the 2006 reporting year.

**Table A9-4: Electricity Generation and GHG Emission Details for Nova Scotia<sup>1</sup>**

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006 <sup>c</sup>
<b>Greenhouse Gas Emissions<sup>a</sup></b>																	
<i>kt CO<sub>2</sub> equivalent</i>																	
Coal	5 030	5 270	5 380	5 530	6 100	5 840	6 510	6 860	5 890	6 530	7 590	7 660	6 110	4 820	5 240	5 200	4 780
Refined Petroleum Products <sup>2</sup>	1 780	1 700	1 980	1 740	990	1 030	550	650	1 910	1 520	1 210	830	270	1 330	1 400	1 300	410
Natural Gas	0	0	0	0	0	0	0	0	0	0	0	0	880	60	50	110	160
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro <sup>3</sup>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass <sup>4</sup>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	0	0	0	0	0	0	0	0	0	0	0	0	0	640	600	700	790
<b>Overall Total</b>	<b>6 810</b>	<b>6 970</b>	<b>7 360</b>	<b>7 270</b>	<b>7 090</b>	<b>6 870</b>	<b>7 060</b>	<b>7 510</b>	<b>7 800</b>	<b>8 050</b>	<b>8 800</b>	<b>8 490</b>	<b>7 260</b>	<b>6 850</b>	<b>7 290</b>	<b>7 310</b>	<b>6 140</b>
<b>Electricity Generation<sup>b</sup></b>																	
<i>GWh</i>																	
Coal	7 640	5 870	6 010	6 310	7 160	7 020	7 840	8 250	7 270	7 810	8 790	9 620	7 940	7 100	6 710	7 070	7 010
Refined Petroleum Products	300	2 120	2 460	2 150	1 190	1 270	620	780	2 120	1 880	1 470	1 040	450	2 060	2 010	1 800	600
Natural Gas	0	0	0	0	0	0	0	0	0	0	0	0	2 250	150	110	220	360
Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydro	1 120	1 000	840	850	980	870	1 080	920	870	960	890	680	1 000	1 050	860	1 040	950
Biomass	0	0	30	30	20	0	190	180	150	170	200	220	260	230	200	190	210
Other Renewables <sup>5</sup>	30	30	30	30	30	30	30	20	30	80	0	30	30	30	30	110	130 <sup>7</sup>
Other <sup>6</sup>	0	0	0	0	20	0	0	0	0	0	0	0	0	1 520	2 430	1 780	1 930
<b>Overall Total</b>	<b>9 090</b>	<b>9 020</b>	<b>9 370</b>	<b>9 370</b>	<b>9 400</b>	<b>9 190</b>	<b>9 760</b>	<b>10 150</b>	<b>10 440</b>	<b>10 900</b>	<b>11 350</b>	<b>11 590</b>	<b>11 930</b>	<b>12 140</b>	<b>12 350</b>	<b>12 210</b>	<b>11 190</b>
<b>Greenhouse Gas Intensity</b>																	
<i>g CO<sub>2</sub> eq/kWh</i>																	
Coal	660	900	900	880	850	830	830	830	810	840	860	800	770	680	780	740	680
Refined Petroleum Products	5 920	800	800	810	830	810	880	840	900	810	820	790	590	640	700	720	680
Natural Gas	-	-	-	-	-	-	-	-	-	-	-	-	390	420	470	480	450
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	0	-	-	-	-	-	-	-	-	420	250	390	410
<b>Overall Total</b>	<b>749</b>	<b>773</b>	<b>785</b>	<b>776</b>	<b>754</b>	<b>748</b>	<b>723</b>	<b>740</b>	<b>747</b>	<b>739</b>	<b>775</b>	<b>733</b>	<b>609</b>	<b>564</b>	<b>590</b>	<b>599</b>	<b>549</b>

Sources:

a. Report on Energy Supply-Demand in Canada, Catalogue No. 57-003-XIB, Statistics Canada.

b. Electric Power Generation, Transmission and Distribution, Catalogue No. 57-202-XIB, Statistics Canada.

c. Electricity data from CANSIM, tables v222128, v222129, v222130, v222131, v222132, v222133 - downloaded February 5, 2008.

Notes:

1. Data presented includes emissions, generation and intensity for public utilities.

2. Includes emissions from the use of light fuel oil, heavy fuel oil and diesel fuel oil.

3. Emissions from the flooding of land for hydro dams are not included.

4. Emissions related to the use of biomass for electric power generation are not included.

5. Other Renewables - includes electricity generation by wind and tidal.

6. Others - includes electricity generation by fuels not easily categorized (i.e. waste and petroleum coke).

7. Other renewables estimated based on growth statistics and compared with financial reporting by the provincial utility.

**Table A9-5: Electricity Generation and GHG Emission Details for New Brunswick<sup>1</sup>**

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006 <sup>c</sup>
<b>Greenhouse Gas Emissions<sup>a</sup></b> <i>kt CO<sub>2</sub> equivalent</i>																	
Coal	1 180	980	1 060	1 210	2 700	3 050	3 160	3 030	3 240	3 130	2 820	3 180	2 740	3 100	2 770	2 590	2 530
Refined Petroleum Products <sup>2</sup>	4 660	4 270	4 930	3 800	3 260	3 520	2 630	5 080	5 960	4 780	5 530	6 630	5 290	4 330	4 980	4 980	2 650
Natural Gas	0	0	0	0	0	0	0	0	0	0	0	0	310	620	680	780	950
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro <sup>3</sup>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass <sup>4</sup>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	0	0	0	0	0	0	0	0	0	N/A	110	40	150	150	960	1 260	260
<b>Overall Total</b>	<b>5 840</b>	<b>5 250</b>	<b>5 990</b>	<b>5 010</b>	<b>5 960</b>	<b>6 570</b>	<b>5 790</b>	<b>8 110</b>	<b>9 200</b>	<b>7 910</b>	<b>8 460</b>	<b>9 850</b>	<b>8 490</b>	<b>8 200</b>	<b>9 390</b>	<b>9 610</b>	<b>6 390</b>
<b>Electricity Generation<sup>b</sup></b> <i>GWh</i>																	
Coal	1 000	1 060	1 170	1 380	3 030	3 490	3 560	3 560	3 790	3 680	3 890	3 960	3 660	3 890	3 300	3 230	2 770
Refined Petroleum Products	6 100	5 550	6 380	4 780	4 190	4 300	3 160	6 500	7 640	6 020	7 020	8 160	6 370	5 110	6 430	6 720	3 130
Natural Gas	0	0	0	0	0	0	0	0	0	0	0	0	590	1 130	1 740	930	3 060
Nuclear	5 340	5 440	4 830	5 320	5 240	1 580	4 590	3 440	3 770	4 080	3 960	4 520	3 760	4 740	4 300	4 380	4 370
Hydro	3 460	2 930	2 940	2 990	2 720	2 640	3 440	2 300	2 780	3 300	3 220	2 070	2 190	3 160	2 950	3 820	3 660
Biomass	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Renewables <sup>5</sup>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other <sup>6</sup>	80	10	N/A	0	20	0	0	0	0	390	130	40	160	150	900	1 220	450
<b>Overall Total</b>	<b>15 980</b>	<b>14 990</b>	<b>15 320</b>	<b>14 470</b>	<b>15 200</b>	<b>12 010</b>	<b>14 750</b>	<b>15 800</b>	<b>17 980</b>	<b>17 470</b>	<b>18 220</b>	<b>18 750</b>	<b>16 730</b>	<b>18 180</b>	<b>19 620</b>	<b>20 300</b>	<b>17 440</b>
<b>Greenhouse Gas Intensity</b> <i>g CO<sub>2</sub> eq/kWh</i>																	
Coal	1 180	930	910	880	890	870	890	850	850	850	720	800	750	800	840	800	910
Refined Petroleum Products	760	770	770	790	780	820	830	780	780	790	790	810	830	850	780	740	840
Natural Gas	0	0	0	0	0	0	0	0	0	0	0	0	530	550	390	840	310
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	0	0	N/A	0	0	0	0	0	0	0	900	1 020	940	1 010	1 070	1 030	580
<b>Overall Total</b>	<b>365</b>	<b>350</b>	<b>391</b>	<b>346</b>	<b>392</b>	<b>547</b>	<b>393</b>	<b>513</b>	<b>512</b>	<b>453</b>	<b>464</b>	<b>525</b>	<b>507</b>	<b>451</b>	<b>479</b>	<b>473</b>	<b>366</b>

## Sources:

a. Report on Energy Supply-Demand in Canada, Catalogue No. 57-003-XIB, Statistics Canada.

b. Electric Power Generation, Transmission and Distribution, Catalogue No. 57-202-XIB, Statistics Canada.

c. Electricity data from CANSIM, tables v222128, v222129, v222130, v222131, v222132, v222133 - downloaded February 5, 2008.

## Notes:

1. Data presented includes emissions, generation and intensity for public utilities.

2. Includes emissions from the use of light fuel oil, heavy fuel oil, diesel fuel oil and Orimulsion®.

3. Emissions from the flooding of land for hydro dams are not included.

4. Emissions related to the use of biomass for electric power generation are not included.

5. Other Renewables - includes electricity generation by wind and tidal.

6. Others - includes electricity generation by fuels not easily categorized (i.e. waste, petroleum coke).

N/A - Not Available.

**Table A9-6: Electricity Generation and GHG Emission Details for Quebec<sup>1</sup>**

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006 <sup>c</sup>
<b>Greenhouse Gas Emissions<sup>a</sup></b> <i>kt CO<sub>2</sub> equivalent</i>																	
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Refined Petroleum Products <sup>2</sup>	1 370	370	800	140	310	190	180	200	1 320	900	290	320	190	1 500	1 270	310	170
Natural Gas	70	70	70	70	80	80	80	80	70	60	70	60	60	60	60	210	770
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro <sup>3</sup>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass <sup>4</sup>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>Overall Total</b>	<b>1 440</b>	<b>440</b>	<b>870</b>	<b>210</b>	<b>390</b>	<b>270</b>	<b>260</b>	<b>280</b>	<b>1 390</b>	<b>960</b>	<b>360</b>	<b>380</b>	<b>250</b>	<b>1 560</b>	<b>1 330</b>	<b>520</b>	<b>940</b>
<b>Electricity Generation<sup>b</sup></b> <i>GWh</i>																	
Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Refined Petroleum Products	1 730	400	1 010	160	230	370	190	220	1 700	1 160	340	390	280	2 070	1 840	850	160
Natural Gas	100	100	110	110	80	260	200	220	190	190	200	180	120	230	110	260	990
Nuclear	4 070	3 910	4 600	4 810	5 410	4 510	5 240	4 200	3 810	3 780	4 890	4 700	4 530	3 550	4 880	4 480	4 600
Hydro	112 160	120 900	124 360	130 140	136 900	148 300	146 710	141 750	130 300	143 120	153 380	144 840	150 630	152 190	146 160	154 680	151 360
Biomass	0	0	0	0	0	0	420	610	640	590	620	770	810	820	660	270	N/A
Other Renewables <sup>5</sup>	0	0	0	0	0	0	0	0	0	120	170	190	170	170	190	420	500 <sup>7</sup>
Other <sup>6</sup>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<b>Overall Total</b>	<b>118 060</b>	<b>125 310</b>	<b>130 080</b>	<b>135 220</b>	<b>142 620</b>	<b>153 440</b>	<b>152 760</b>	<b>147 000</b>	<b>136 640</b>	<b>148 960</b>	<b>159 600</b>	<b>151 070</b>	<b>156 540</b>	<b>159 030</b>	<b>153 840</b>	<b>160 960</b>	<b>157 610</b>
<b>Greenhouse Gas Intensity</b> <i>g CO<sub>2</sub> eq/kWh</i>																	
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Refined Petroleum Products	790	930	790	890	1,330	510	920	930	780	780	870	820	690	720	690	360	1,010
Natural Gas	660	670	620	630	920	300	380	350	370	310	340	340	510	280	590	800	770
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>Overall Total</b>	<b>12</b>	<b>4</b>	<b>7</b>	<b>2</b>	<b>3</b>	<b>2</b>	<b>2</b>	<b>2</b>	<b>10</b>	<b>6</b>	<b>2</b>	<b>3</b>	<b>2</b>	<b>10</b>	<b>9</b>	<b>3</b>	<b>6</b>

Sources:

a. Report on Energy Supply-Demand in Canada, Catalogue No. 57-003-XIB, Statistics Canada.

b. Electric Power Generation, Transmission and Distribution, Catalogue No. 57-202-XIB, Statistics Canada.

c. Electricity data from CANSIM , tables v222128, v222129, v222130, v222131, v222132, v222133 - downloaded February 5, 2008.

Notes:

1. Data presented includes emissions, generation and intensity for public utilities.

2. Includes emissions from the use of light fuel oil, heavy fuel oil and diesel fuel oil.

3. Emissions from the flooding of land for hydro dams are not included.

4. Emissions related to the use of biomass for electric power generation are not included.

5. Other Renewables - includes electricity generation by wind and tidal.

6. Others - includes electricity generation by fuels not easily categorized (i.e. waste).

7. Other renewables are estimated based on forecasted growth in wind based generation in Quebec.

N/A - Not Available.

**Table A9-7: Electricity Generation and GHG Emission Details for Ontario<sup>1</sup>**

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006 <sup>c</sup>
<b>Greenhouse Gas Emissions<sup>a</sup></b>																	
<i>kt CO<sub>2</sub> equivalent</i>																	
Coal	24 740	26 170	25 390	16 500	13 530	14 250	16 360	20 520	27 150	28 230	36 160	33 300	33 110	32 870	24 460	27 290	24 000
Refined Petroleum Products <sup>2</sup>	1 130	910	680	110	220	250	220	320	1 100	1 000	350	610	440	1 080	690	40	30
Natural Gas	0	0	740	1 160	1 610	2 940	2 730	3 460	3 690	4 850	4 610	5 300	5 380	5 630	4 810	5 660	4 430
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro <sup>3</sup>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass <sup>4</sup>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	0	0	0	0	0	10	10	110	40	40	20	0	50	10	0	0	0
<b>Overall Total</b>	<b>25 870</b>	<b>27 090</b>	<b>26 810</b>	<b>17 770</b>	<b>15 350</b>	<b>17 450</b>	<b>19 330</b>	<b>24 400</b>	<b>31 990</b>	<b>34 130</b>	<b>41 140</b>	<b>39 210</b>	<b>38 980</b>	<b>39 590</b>	<b>29 950</b>	<b>32 980</b>	<b>28 460</b>
<b>Electricity Generation<sup>b</sup></b>																	
<i>GWh</i>																	
Coal	26 140	30 350	28 540	20 470	16 740	16 150	17 660	26 510	33 080	33 380	40 470	36 250	35 970	30 310	25 720	30 300	25 600
Refined Petroleum Products	1 320	1 130	750	570	190	240	220	250	800	1 280	420	700	550	1 620	740	30	30
Natural Gas	0	0	1 170	800	2 980	6 620	6 340	6 330	8 680	10 930	10 580	11 570	11 980	15 000	10 520	11 480	10 400
Nuclear	59 350	70 770	66 590	78 510	91 070	86 220	77 680	70 210	59 880	61 470	59 830	63 130	62 960	62 360	76 060	77 970	83 460
Hydro	38 670	35 960	38 790	39 270	37 570	37 460	40 300	38 690	34 410	36 020	36 570	35 810	37 090	34 740	38 080	34 550	35 270
Biomass	0	0	0	110	300	N/A	N/A	N/A	310	310	320	500	570	660	540	630	N/A
Other Renewables <sup>5</sup>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25	26	44 <sup>7</sup>
Other <sup>6</sup>	0	0	0	0	0	390	1 100	610	690	550	520	500	520	490	340	320	N/A
<b>Overall Total</b>	<b>125 490</b>	<b>138 210</b>	<b>135 830</b>	<b>139 730</b>	<b>148 850</b>	<b>147 080</b>	<b>143 310</b>	<b>142 600</b>	<b>137 830</b>	<b>143 950</b>	<b>148 700</b>	<b>148 450</b>	<b>149 660</b>	<b>145 200</b>	<b>152 030</b>	<b>155 310</b>	<b>154 800</b>
<b>Greenhouse Gas Intensity</b>																	
<i>g CO<sub>2</sub> eq/kWh</i>																	
Coal	950	860	890	810	810	880	930	770	820	850	890	920	920	1 080	950	900	940
Refined Petroleum Products	850	810	910	190	1 110	1 060	980	1 270	1 390	780	840	870	800	670	930	1 130	1 260
Natural Gas	560	550	630	1 450	540	440	430	550	420	440	440	460	450	380	460	490	430
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	0	0	0	0	0	30	10	170	60	80	40	0	90	30	0	0	N/A
<b>Overall Total</b>	<b>210</b>	<b>200</b>	<b>200</b>	<b>130</b>	<b>100</b>	<b>120</b>	<b>130</b>	<b>170</b>	<b>230</b>	<b>240</b>	<b>280</b>	<b>260</b>	<b>260</b>	<b>270</b>	<b>200</b>	<b>210</b>	<b>180</b>

Sources:

a. Report on Energy Supply-Demand in Canada, Catalogue No. 57-003-XIB, Statistics Canada.

b. Electric Power Generation, Transmission and Distribution, Catalogue No. 57-202-XIB, Statistics Canada.

c. Electricity data from CANSIM , tables v222128, v222129, v222130, v222131, v222132, v222133 - downloaded February 5, 2008.

Notes:

1. Data presented includes emissions, generation and intensity for public utilities.

2. Includes emissions from the use of light fuel oil, heavy fuel oil and diesel fuel oil.

3. Emissions from the flooding of land for hydro dams are not included.

4. Emissions related to the use of biomass for electric power generation are not included.

5. Other Renewables - includes electricity generation by wind and tidal.

6. Others - includes electricity generation by fuels not easily categorized (i.e. waste).

7. Wind generation data provided by Independent Electricity System Operator, news release dated January 10, 2008.

N/A - Not Available.

**Table A9-8: Electricity Generation and GHG Emission Details for Manitoba<sup>1</sup>**

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006 <sup>c</sup>
<b>Greenhouse Gas Emissions<sup>a</sup></b> <i>kt CO<sub>2</sub> equivalent</i>																	
Coal	460	350	350	280	280	180	270	210	940	520	970	460	380	600	310	480	340
Refined Petroleum Products <sup>2</sup>	50	50	50	30	30	20	40	20	10	10	10	20	10	20	10	10	10
Natural Gas	0	0	0	0	0	0	0	0	0	0	0	0	80	150	60	10	30
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro <sup>3</sup>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass <sup>4</sup>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>Overall Total</b>	<b>510</b>	<b>400</b>	<b>400</b>	<b>300</b>	<b>310</b>	<b>200</b>	<b>310</b>	<b>230</b>	<b>960</b>	<b>540</b>	<b>980</b>	<b>480</b>	<b>470</b>	<b>770</b>	<b>380</b>	<b>510</b>	<b>380</b>
<b>Electricity Generation<sup>b</sup></b> <i>GWh</i>																	
Coal	300	230	230	190	180	120	190	180	850	460	870	440	380	570	280	410	360
Refined Petroleum Products	40	40	40	20	40	20	40	10	10	10	10	20	20	20	10	20	10
Natural Gas	0	0	0	0	0	0	0	0	0	0	0	0	120	220	80	20	40
Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydro	19 830	22 550	26 430	26 890	28 150	29 010	30 870	33 390	30 780	28 140	31 540	32 900	28 820	20 250	27 220	36 440	33 500
Biomass	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Renewables <sup>5</sup>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50	150 <sup>7</sup>
Other <sup>6</sup>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<b>Overall Total</b>	<b>20 170</b>	<b>22 820</b>	<b>26 700</b>	<b>27 100</b>	<b>28 360</b>	<b>29 160</b>	<b>31 100</b>	<b>33 590</b>	<b>31 640</b>	<b>28 610</b>	<b>32 420</b>	<b>33 360</b>	<b>29 340</b>	<b>21 050</b>	<b>27 590</b>	<b>36 940</b>	<b>34 060</b>
<b>Greenhouse Gas Intensity</b> <i>g CO<sub>2</sub> eq/kWh</i>																	
Coal	1 510	1 550	1 540	1 470	1 530	1 480	1 460	1 170	1 120	1 130	1 120	1 050	990	1 050	1 120	1 180	950
Refined Petroleum Products	1 190	1 210	1 160	1 160	880	830	920	1 180	980	1 040	940	800	830	790	950	600	690
Natural Gas	830	870	860	870	0	790	890	0	0	0	0	0	680	710	760	580	670
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>Overall Total</b>	<b>30</b>	<b>20</b>	<b>10</b>	<b>10</b>	<b>10</b>	<b>10</b>	<b>10</b>	<b>10</b>	<b>30</b>	<b>20</b>	<b>30</b>	<b>10</b>	<b>20</b>	<b>40</b>	<b>10</b>	<b>10</b>	<b>10</b>

Sources:

a. Report on Energy Supply-Demand in Canada, Catalogue No. 57-003-XIB, Statistics Canada.

b. Electric Power Generation, Transmission and Distribution, Catalogue No. 57-202-XIB, Statistics Canada.

c. Electricity data from CANSIM, tables v222128, v222129, v222130, v222131, v222132, v222133 - downloaded February 5, 2008.

Notes:

1. Data presented includes emissions, generation and intensity for public utilities.

2. Includes emissions from the use of light fuel oil, heavy fuel oil and diesel fuel oil.

3. Emissions from the flooding of land for hydro dams are not included.

4. Emissions related to the use of biomass for electric power generation are not included.

5. Other Renewables - includes electricity generation by wind and tidal.

6. Others - includes electricity generation by fuels not easily categorized (i.e. waste).

7. Estimated based on production statistics from Algonquin Power Income Fund.



**Table A9-9: Electricity Generation and GHG Emission Details for Saskatchewan<sup>1</sup>**

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006 <sup>c</sup>
<b>Greenhouse Gas Emissions<sup>a</sup></b> <i>kt CO<sub>2</sub> equivalent</i>																	
Coal	10 090	10 290	11 560	12 110	13 120	13 410	13 540	14 010	14 080	13 980	13 200	13 570	13 570	13 590	14 300	13 430	12 960
Refined Petroleum Products <sup>2</sup>	10	10	10	10	10	20	20	30	20	20	20	20	20	20	20	30	30
Natural Gas	180	220	490	190	50	330	340	680	910	800	1 300	1 470	1 520	2 540	2 360	1 980	1 810
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro <sup>3</sup>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass <sup>4</sup>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>Overall Total</b>	<b>10 280</b>	<b>10 520</b>	<b>12 060</b>	<b>12 310</b>	<b>13 180</b>	<b>13 750</b>	<b>13 900</b>	<b>14 720</b>	<b>15 010</b>	<b>14 800</b>	<b>14 520</b>	<b>15 060</b>	<b>15 110</b>	<b>16 150</b>	<b>16 680</b>	<b>15 440</b>	<b>14 800</b>
<b>Electricity Generation<sup>b</sup></b> <i>GWh</i>																	
Coal	8 670	8 650	9 990	10 500	11 550	11 290	11 210	11 420	11 800	11 530	11 610	11 520	11 650	11 580	12 120	11 440	10 940
Refined Petroleum Products	10	10	0	0	10	10	10	30	10	20	20	20	20	30	20	40	40
Natural Gas	240	300	660	250	70	490	500	910	1 270	1 340	2 440	2 670	2 720	4 120	3 870	3 320	2 720
Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydro	4 210	4 210	3 060	4 050	3 390	4 120	4 380	3 990	3 440	3 690	3 050	2 390	2 840	3 420	2 750	4 570	3 950
Biomass	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Renewables <sup>5</sup>	0	0	0	0	0	0	0	0	0	0	0	0	40	60	70	90	590 <sup>7</sup>
Other <sup>6</sup>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<b>Overall Total</b>	<b>13 130</b>	<b>13 180</b>	<b>13 720</b>	<b>14 800</b>	<b>15 030</b>	<b>15 900</b>	<b>16 090</b>	<b>16 340</b>	<b>16 520</b>	<b>16 580</b>	<b>17 110</b>	<b>16 600</b>	<b>17 280</b>	<b>19 210</b>	<b>18 830</b>	<b>19 460</b>	<b>18 230</b>
<b>Greenhouse Gas Intensity</b> <i>g CO<sub>2</sub> eq/kWh</i>																	
Coal	1 160	1 190	1 160	1 150	1 140	1 190	1 210	1 230	1 190	1 210	1 140	1 180	1 160	1 170	1 180	1 170	1 180
Refined Petroleum Products	1 160	960	2 480	2 380	750	1 260	1 930	1 010	1 940	910	860	700	690	760	890	650	730
Natural Gas	750	740	740	760	680	670	680	750	720	600	530	550	560	620	610	600	670
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>Overall Total</b>	<b>780</b>	<b>800</b>	<b>880</b>	<b>830</b>	<b>880</b>	<b>860</b>	<b>860</b>	<b>900</b>	<b>910</b>	<b>890</b>	<b>850</b>	<b>910</b>	<b>870</b>	<b>840</b>	<b>890</b>	<b>790</b>	<b>810</b>

Sources:

a. Report on Energy Supply-Demand in Canada, Catalogue No. 57-003-XIB, Statistics Canada.

b. Electric Power Generation, Transmission and Distribution, Catalogue No. 57-202-XIB, Statistics Canada.

c. Electricity data from CANSIM, tables v222128, v222129, v222130, v222131, v222132, v222133 - downloaded February 5, 2008.

Notes:

1. Data presented includes emissions, generation and intensity for public utilities.

2. Includes emissions from the use of light fuel oil, heavy fuel oil and diesel fuel oil.

3. Emissions from the flooding of land for hydro dams are not included.

4. Emissions related to the use of biomass for electric power generation are not included.

5. Other Renewables - includes electricity generation by wind and tidal.

6. Others - includes electricity generation by fuels not easily categorized (i.e. waste).

7. Other renewables estimated from 2006 SaskPower Annual Report.

**Table A9-10: Electricity Generation and GHG Emission Details for Alberta<sup>1</sup>**

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006 <sup>c</sup>
<b>Greenhouse Gas Emissions<sup>a</sup></b>																	
<i>kt CO<sub>2</sub> equivalent</i>																	
Coal	37 290	39 370	41 710	42 550	45 960	46 270	44 910	46 660	45 740	44 280	44 030	45 200	46 040	45 640	45 170	45 920	46 420
Refined Petroleum Products <sup>2</sup>	10	10	10	20	20	20	40	10	30	20	30	30	20	40	40	30	40
Natural Gas	1 670	1 460	2 260	2 180	2 110	1 490	2 170	2 580	3 600	3 350	5 170	4 720	3 780	3 810	3 770	3 620	3 610
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro <sup>3</sup>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass <sup>4</sup>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	0	0	0	0	0	0	0	0	0	0	100	370	380	2 330	1 320	90	70
<b>Overall Total</b>	<b>38 970</b>	<b>40 850</b>	<b>43 980</b>	<b>44 750</b>	<b>48 080</b>	<b>47 770</b>	<b>47 120</b>	<b>49 250</b>	<b>49 370</b>	<b>47 650</b>	<b>49 330</b>	<b>50 320</b>	<b>50 230</b>	<b>51 820</b>	<b>50 300</b>	<b>49 670</b>	<b>50 130</b>
<b>Electricity Generation<sup>b</sup></b>																	
<i>GWh</i>																	
Coal	35 250	36 610	38 940	39 360	42 730	43 750	41 760	43 200	42 350	41 490	41 570	44 560	45 960	42 430	45 470	46 250	45 500
Refined Petroleum Products	10	20	10	20	20	10	40	10	30	30	30	30	30	30	50	40	40
Natural Gas	2 320	2 320	3 330	3 470	3 510	2 390	3 210	4 170	6 080	5 790	9 350	9 090	7 620	6 770	6 910	6 950	6 750
Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydro	2 060	2 030	1 560	1 810	1 810	2 190	2 260	1 840	2 050	2 170	1 760	1 430	1 720	1 740	1 880	2 240	880
Biomass	0	0	0	0	0	0	0	0	280	280	290	410	490	460	300	870	N/A
Other Renewables <sup>5</sup>	0	0	0	0	0	0	0	60	50	70	90	130	160	420	620	840	920 <sup>7</sup>
Other <sup>6</sup>	0	0	0	0	1 160	1 060	250	320	50	40	90	300	310	1 980	1 180	100	70
<b>Overall Total</b>	<b>39 640</b>	<b>40 970</b>	<b>43 850</b>	<b>44 660</b>	<b>49 220</b>	<b>49 400</b>	<b>47 520</b>	<b>49 590</b>	<b>50 890</b>	<b>49 870</b>	<b>53 170</b>	<b>55 960</b>	<b>56 280</b>	<b>53 840</b>	<b>56 400</b>	<b>57 290</b>	<b>54 170</b>
<b>Greenhouse Gas Intensity</b>																	
<i>g CO<sub>2</sub> eq/kWh</i>																	
Coal	1 060	1 080	1 070	1 080	1 080	1 060	1 080	1 080	1 080	1 070	1 060	1 010	1 000	1 080	990	990	1 020
Refined Petroleum Products	810	900	980	960	1 120	1 290	1 180	960	880	750	1 150	870	900	1 090	890	780	800
Natural Gas	720	630	680	630	600	620	680	620	590	580	550	520	500	560	550	520	530
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	0	0	0	0	0	0	0	0	0	0	1 150	1 220	1 230	1 180	1 120	940	960
<b>Overall Total</b>	<b>980</b>	<b>1 000</b>	<b>1 000</b>	<b>1 000</b>	<b>980</b>	<b>970</b>	<b>990</b>	<b>990</b>	<b>970</b>	<b>960</b>	<b>930</b>	<b>900</b>	<b>890</b>	<b>960</b>	<b>890</b>	<b>870</b>	<b>930</b>

Sources:

a. Report on Energy Supply-Demand in Canada, Catalogue No. 57-003-XIB, Statistics Canada.

b. Electric Power Generation, Transmission and Distribution, Catalogue No. 57-202-XIB, Statistics Canada.

c. Electricity data from CANSIM, tables v222128, v222129, v222130, v222131, v222132, v222133 - downloaded February 5, 2008.

Notes:

1. Data presented includes emissions, generation and intensity for public utilities.

2. Includes emissions from the use of light fuel oil, heavy fuel oil and diesel fuel oil.

3. Emissions from the flooding of land for hydro dams are not included.

4. Emissions related to the use of biomass for electric power generation are not included.

5. Other Renewables - includes electricity generation by wind and tidal.

6. Others - includes electricity generation by fuels not easily categorized (i.e. waste, petroleum coke).

7. Other renewables estimated based on historical growth.

N/A - Not Available.

**Table A9-11: Electricity Generation and GHG Emission Details for British Columbia<sup>1</sup>**

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006 <sup>c</sup>
<b>Greenhouse Gas Emissions<sup>a</sup></b> <i>kt CO<sub>2</sub> equivalent</i>																	
Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Refined Petroleum Products <sup>2</sup>	90	80	80	60	70	30	70	30	30	30	30	40	30	30	20	10	10
Natural Gas	710	380	850	1 870	1 700	2 170	260	650	1 380	670	1 760	2 300	670	690	790	870	810
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro <sup>3</sup>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass <sup>4</sup>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>Overall Total</b>	<b>790</b>	<b>470</b>	<b>920</b>	<b>1 930</b>	<b>1 770</b>	<b>2 210</b>	<b>330</b>	<b>680</b>	<b>1 410</b>	<b>710</b>	<b>1 790</b>	<b>2 330</b>	<b>700</b>	<b>720</b>	<b>810</b>	<b>880</b>	<b>830</b>
<b>Electricity Generation<sup>b</sup></b> <i>GWh</i>																	
Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Refined Petroleum Products	100	90	80	60	100	30	80	40	40	50	40	50	50	50	40	30	50
Natural Gas	1 260	660	1 510	3 410	3 020	4 160	450	1 210	2 640	1 580	3 350	4 800	1 660	1 800	2 230	2 370	3 570
Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydro	46 440	49 050	50 030	42 240	43 620	38 880	56 960	52 920	50 860	51 520	50 800	41 550	49 650	47 040	45 020	50 310	44 450
Biomass	0	0	0	0	600	510	460	450	410	650	550	590	560	600	720	650	700 <sup>7</sup>
Other Renewables <sup>5</sup>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other <sup>6</sup>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<b>Overall Total</b>	<b>47 790</b>	<b>49 810</b>	<b>51 620</b>	<b>45 720</b>	<b>47 350</b>	<b>43 580</b>	<b>57 950</b>	<b>54 630</b>	<b>53 960</b>	<b>53 790</b>	<b>54 730</b>	<b>46 990</b>	<b>51 920</b>	<b>49 480</b>	<b>48 020</b>	<b>53 350</b>	<b>48 780</b>
<b>Greenhouse Gas Intensity</b> <i>g CO<sub>2</sub> eq/kWh</i>																	
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Refined Petroleum Products	880	900	900	950	710	1 090	910	770	830	750	870	700	620	510	440	480	300
Natural Gas	560	580	560	550	560	520	580	530	520	430	520	480	400	390	350	370	230
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>Overall Total</b>	<b>20</b>	<b>10</b>	<b>20</b>	<b>40</b>	<b>40</b>	<b>50</b>	<b>10</b>	<b>10</b>	<b>30</b>	<b>10</b>	<b>30</b>	<b>50</b>	<b>10</b>	<b>10</b>	<b>20</b>	<b>20</b>	<b>20</b>

Sources:

a. Report on Energy Supply-Demand in Canada, Catalogue No. 57-003-XIB, Statistics Canada.

b. Electric Power Generation, Transmission and Distribution, Catalogue No. 57-202-XIB, Statistics Canada.

c. Electricity data from CANSIM, tables v222128, v222129, v222130, v222131, v222132, v222133 - downloaded February 5, 2008.

Notes:

1. Data presented includes emissions, generation and intensity for public utilities.

2. Includes emissions from the use of light fuel oil, heavy fuel oil and diesel fuel oil.

3. Emissions from the flooding of land for hydro dams are not included.

4. Emissions related to the use of biomass for electric power generation are not included.

5. Other Renewables - includes electricity generation by wind and tidal.

6. Others - includes electricity generation by fuels not easily categorized (i.e. waste).

7. Biomass generation estimated based on historical data.

**Table A9-12: Electricity Generation and GHG Emission Details for Yukon, Northwest Territories, and Nunavut<sup>1</sup>**

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006 <sup>c</sup>
<b>Greenhouse Gas Emissions<sup>a</sup></b> <i>kt CO<sub>2</sub> equivalent</i>																	
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Refined Petroleum Products <sup>2</sup>	260	220	180	170	170	210	220	220	210	110	110	130	80	80	90	70	70
Natural Gas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro <sup>3</sup>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass <sup>4</sup>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>Overall Total</b>	<b>260</b>	<b>220</b>	<b>180</b>	<b>170</b>	<b>170</b>	<b>210</b>	<b>220</b>	<b>220</b>	<b>210</b>	<b>110</b>	<b>110</b>	<b>130</b>	<b>80</b>	<b>80</b>	<b>90</b>	<b>70</b>	<b>70</b>
<b>Electricity Generation<sup>b</sup></b> <i>GWh</i>																	
Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Refined Petroleum Products	290	290	290	290	330	390	430	340	260	230	230	260	240	280	270	240	240
Natural Gas	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0
Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydro	650	620	660	530	430	490	580	500	490	500	510	510	510	500	560	580	590
Biomass	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Renewables <sup>5</sup>	0	0	0	0	0	0	0.2	0.2	0.3	0.3	0.4	1.1	1.0	0.9	0.5	0.9	0.9 <sup>7</sup>
Other <sup>6</sup>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<b>Overall Total</b>	<b>940</b>	<b>920</b>	<b>950</b>	<b>810</b>	<b>760</b>	<b>880</b>	<b>1 010</b>	<b>850</b>	<b>750</b>	<b>740</b>	<b>740</b>	<b>770</b>	<b>750</b>	<b>780</b>	<b>830</b>	<b>820</b>	<b>830</b>
<b>Greenhouse Gas Intensity</b> <i>g CO<sub>2</sub> eq/kWh</i>																	
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Refined Petroleum Products	880	750	630	600	520	540	520	640	810	470	480	480	340	300	340	290	270
Natural Gas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>Overall Total</b>	<b>270</b>	<b>240</b>	<b>190</b>	<b>210</b>	<b>230</b>	<b>240</b>	<b>220</b>	<b>260</b>	<b>280</b>	<b>140</b>	<b>150</b>	<b>160</b>	<b>110</b>	<b>110</b>	<b>110</b>	<b>80</b>	<b>80</b>

Sources:

a. Report on Energy Supply-Demand in Canada, Catalogue No. 57-003-XIB, Statistics Canada.

b. Electric Power Generation, Transmission and Distribution, Catalogue No. 57-202-XIB, Statistics Canada.

c. Electricity data from CANSIM, tables v222128, v222129, v222130, v222131, v222132, v222133 - downloaded February 5, 2008.

Notes:

1. Data presented includes emissions, generation and intensity for public utilities.

2. Includes emissions from the use of light fuel oil, heavy fuel oil and diesel fuel oil.

3. Emissions from the flooding of land for hydro dams are not included.

4. Emissions related to the use of biomass for electric power generation are not included.

5. Other Renewables - includes electricity generation by wind and tidal.

6. Others - includes electricity generation by fuels not easily categorized (i.e. waste).

7. Data from Yukon Energy Annual Report (2006).

***References***

Statistics Canada. Electric Power Generation, Transmission and Distribution (Annual). #57-202-XIB.

Statistics Canada. Electric Power Statistics, monthly. CANSIM Table no. 127-0001.

Statistics Canada. Report on Energy Supply–Demand in Canada (Annual). #57-003-XIB

Yukon Energy Corporation. 2007. 2006 Annual Report. Whitehorse (YK). Available online at: [http://www.transcanada.com/investor/annual\\_reports/2006/downloads/index.html](http://www.transcanada.com/investor/annual_reports/2006/downloads/index.html)

## Annex 10 Provincial/Territorial Analysis

The following discussion describes long-term (1990–2006) and short-term (2005–2006) changes in GHG emissions for each of the provinces and territories in Canada. Owing to data limitations—specifically confidentiality—there are a number of caveats associated with the data and analysis. While the national inventory of GHG emissions is developed utilizing national, provincial, and territorial information and data, the information used to develop the national estimates relies on survey and sampling data<sup>81</sup> that, while statistically valid and nationally representative, may not represent every discrete and small source within a province or territory. Therefore the following analysis, while reflecting an accurate national picture, may differ slightly from a more bottom-up, precise regional inventory. Nevertheless, the trends in emissions from each region are considered representative of the actual emission trends in each region.

The discussion for each province and territory includes a general overview of its economy and emission trends, with emphasis on population, GDP, energy supply and general economic structure, which all affect trends in GHG emissions. Long-term and recent changes in GHG emissions are identified on the basis of the 10 sectors that have shown the greatest absolute increase and decrease in emissions for that province or territory over the period in question. As such, the figures are not meant to explicitly show the greatest contributors to provincial and territorial GHG emissions although in some cases the categories with largest absolute changes may also contribute most to the total. The reader will also note that that provincial or territorial emission estimates in a particular sector or subsector are often kept confidential, due to the small number of facilities.

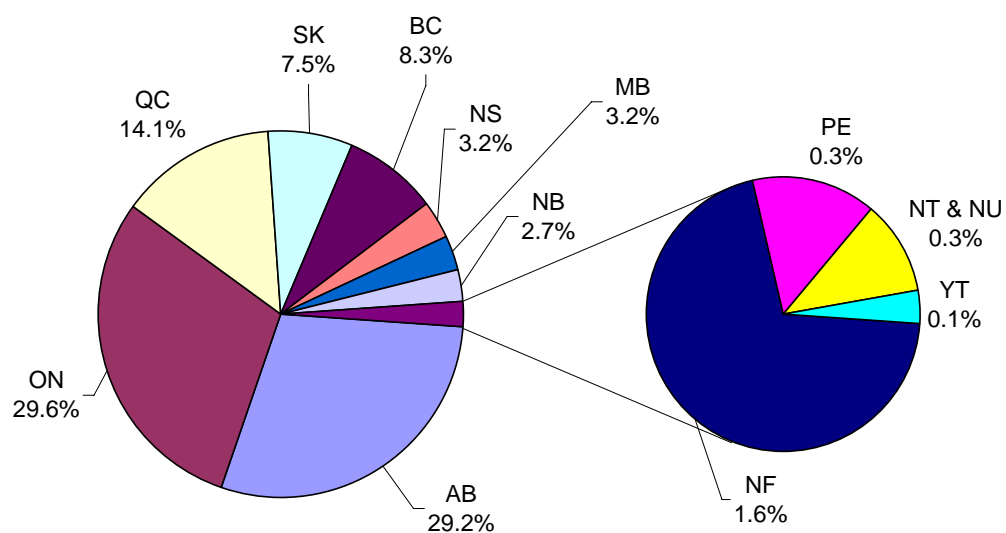
All emission references are from the 1990–2006 national GHG inventory and are given in units of CO<sub>2</sub> equivalent unless otherwise stated. All energy quantities, GDP, heating degree day (HDD), and cooling degree day (CDD) values originate from Statistics Canada (2008)<sup>82</sup>. All values provided within these graphs are presented in kilotonnes CO<sub>2</sub> equivalent.

Figure A10-1 and Figure A10-2 present provincial and territorial contributions to total Canadian GHG emissions in 1990 and 2006, respectively. On a per capita basis, the average GHG emissions for Canada increased by 3.2% from 21.4 t/person in 1990 to 22.1 t/person in 2006.

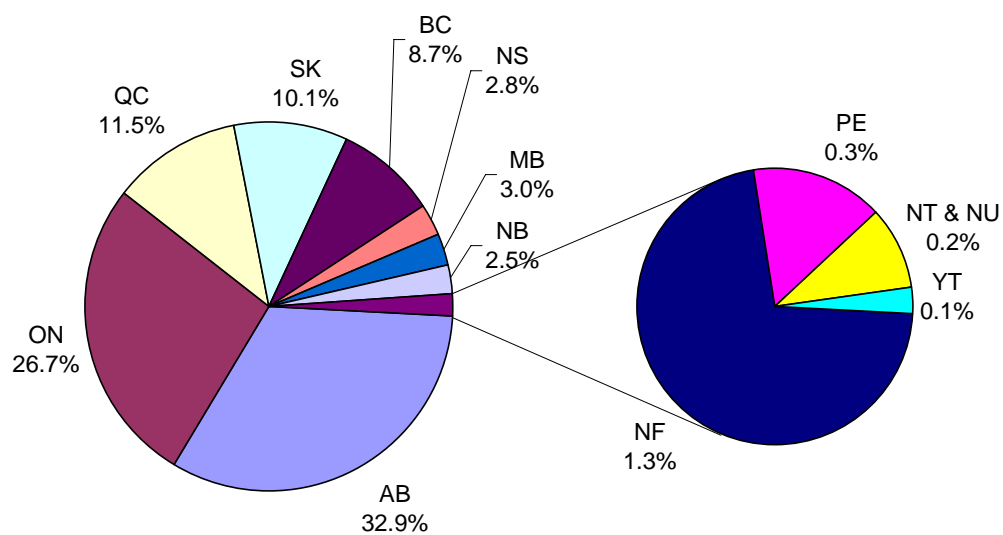
---

81. Another potential source of discrepancy is also the application at the provincial level of parameter values, which, while again representative as a whole of national circumstances, do not always accurately reflect regional conditions.

82. The meteorological data required to develop the HDD and CDD indicators are provided by Environment Canada. Annual HDDs and CDDs are common indicators used to determine the necessity for space heating or cooling in a region. Annual HDDs are the annual sum of the days when the average daily temperature is below 18° C multiplied by the number of degrees that the temperature is below 18° C on each of those days. Annual CDDs is the annual sum of days when the average daily temperature is above multiplied by the number of degrees above 18° C on each of those days.



-----  
**Figure A10-1: Provincial GHG Contributions – 1990 (592 Mt)**  
 -----



-----  
**Figure A10-2: Provincial GHG Contributions – 2006 (721 Mt)**  
 -----

**A10.1 Newfoundland and Labrador****Table A10-1: Trends in GHG Emissions and GHG Intensity, Newfoundland and Labrador**

	1990	1995	2000	2005	2006
<b>Total GHG (Mt)</b>	<b>9.387</b>	<b>8.193</b>	<b>8.653</b>	<b>9.991</b>	<b>9.385</b>
Growth Since 1990	NA	-12.7%	-7.8%	6.4%	0.0%
Annual Change	NA	14.5%	-2.8%	-0.5%	-6.1%
<b>GDP (millions)</b>	<b>9 510</b>	<b>9530</b>	<b>11 162</b>	<b>13 669</b>	<b>14 089</b>
Growth Since 1990	NA	0.2%	17.4%	43.7%	48.1%
<b>GHG Intensity (Mt/\$B GDP)</b>	<b>0.99</b>	<b>0.86</b>	<b>0.78</b>	<b>0.73</b>	<b>0.67</b>
<b>GHG Efficiency (\$GDP/Kt GHG)</b>	<b>1.01</b>	<b>1.16</b>	<b>1.29</b>	<b>1.37</b>	<b>1.50</b>
<b>Population (000s)</b>	<b>578</b>	<b>567</b>	<b>528</b>	<b>514</b>	<b>510</b>
Growth Since 1990	NA	-1.8%	-8.6%	-11.1%	-11.8%
<b>GHG Per Capita (tonnes/person)</b>	<b>16.2</b>	<b>14.4</b>	<b>16.4</b>	<b>19.4</b>	<b>18.4</b>
<b>Energy Production (Primary only) (PJ)</b>	<b>124 875</b>	<b>130 633</b>	<b>489 559</b>	<b>849 698</b>	<b>855 274</b>
Growth Since 1990	NA	4.6%	292.0%	580.4%	584.9%
<b>Net Supply (Primary &amp; Secondary)(PJ)</b>	<b>143 564</b>	<b>132 307</b>	<b>147 599</b>	<b>165 068</b>	<b>157 594</b>
Growth Since 1990	NA	-7.8%	2.8%	15.0%	9.8%
<b>Energy Use - Final Demand (Primary &amp; Secondary)(PJ)</b>	<b>123 162</b>	<b>112 845</b>	<b>119 060</b>	<b>124 673</b>	<b>113 408</b>
Growth Since 1990	NA	-8.4%	-3.3%	1.2%	-7.9%
<b>Heating Degree Days</b>	<b>4 904</b>	<b>4 970</b>	<b>4 462</b>	<b>4 531</b>	<b>4 276</b>
Growth Since 1990	NA	1.3%	-9.0%	-7.6%	-12.8%

Notes:

GDP at basic prices, by North American Industry Classification System (NAICS), 1990–1996: constant 1997 dollars; 1997–2006: chained 1997 dollars.

NA = Not applicable.

Newfoundland and Labrador is home to 1.6% of the population and generated approximately 1.3% (\$14.1 billion) of Canada's total GDP. The provincial economy is primarily resource-based, with major operations in the Mining, Oil & Gas, Forestry & Fisheries sectors. Over time, the economy has shifted from a Forestry & Fisheries to an Oil & Gas basis. The Oil & Gas Sector has been an important part of the provincial economy since 1997, when the Hibernia oil field first became operational. Since that time, additional offshore oil projects have been developed in the White Rose and Terra Nova fields.

Mining has always been an integral part of the economy with extraction focused on iron ore, and most recently nickel from the Voisey's Bay project which began production of concentrate in 2005. High raw metal prices have meant a significant increase in mineral exploration in the province, with expenditures reaching almost \$98 million in 2006, the highest level ever recorded (NL Dept. of Finance, 2007). Offshore oil and gas projects and mining operations have also resulted in the growth in manufacturing, construction and labour markets that respond to the demand created by these sectors.

In recent years, however, the combined Forestry & Fisheries industries have been negatively affected by higher fuel costs, lower commodity prices and a strengthening Canadian dollar. The continued decrease in North American newsprint demand in 2006, in combination with other economic factors, resulted in the closure of the Stephenville mill in 2005, leaving only two mills in operation in the province (Newfoundland and Labrador Dept. of Finance 2007).

Newfoundland and Labrador have significant hydroelectric resources. Newfoundland and Labrador Hydro has an installed generating capacity of 7289 MW, which is the fourth largest installed capacity of all utility companies in Canada (NL Hydro 2007). A small amount of



electricity (66 MW) is purchased from non-utility generating sources. The majority of the electricity generated (79% in 2006) is exported.

In 2006, provincial GHG emissions were approximately 9.4 Mt CO<sub>2</sub> eq, or 18.4 t per person. Newfoundland and Labrador ranks fifth among per-capita GHG emitters in Canada, slightly lower than the Canadian average, reflecting its resource-based economy and vast hydroelectric capacity. Fossil Fuel Production, Oil & Natural Gas Fugitives, Mining, Electricity & Heat Generation, and Light Duty Gasoline Trucks (LDGTs) were the major GHG contributors in 2006, accounting for 53% of provincial emissions.

### **A10.1.1 Long-Term Trends (1990–2006)**

Over the long term (1990–2006), Newfoundland and Labrador's GHG emissions are virtually unchanged. Energy Sector sources were responsible for both the greatest growth and the greatest decline in emissions. Increases in emissions from sectors related to oil and gas production, namely fugitive emissions (1.1 Mt), fossil fuel production (0.5 Mt), LDGTs (0.3 Mt), off-road diesel use (0.2 Mt), and Heavy Duty Diesel Vehicles (HDDVs) (0.2 Mt) were offset by reductions in electricity and heat generation (confidential), residential heating (0.4 Mt), manufacturing industries (0.3 Mt), mining industries (confidential), and Light Duty Gasoline Vehicles (LDGV)s (0.2 Mt).

The 585% increase in energy production (primary) since 1990 is a major driver behind the emissions increase, evidenced by a 132% growth at the start of the offshore operation during the 1997–1998 period and a further 72% spike between 2001 and 2002 following the ramping up of production from the Hibernia oil field. The offshore boom has also been an important contributor to provincial GDP. Over the long term, GHG intensity as a function of GDP has decreased from 0.99 Mt/\$B GDP<sup>83</sup> to 0.67 Mt/\$B GDP.

Decreases in long-term emissions in the Electricity and Heat Generation Sector are mainly due to fuel switching and increased hydro capacity. HDDs have decreased by almost 13% since 1990, leading to lower demand for heating fuels in the Residential Sector. The biggest reason for the decrease in emissions from the manufacturing industries is the economic difficulties being felt by the Pulp, Paper & Print Sector, including closures in recent years (Statistics Canada 2007a).

Long-term emission trends in Newfoundland and Labrador are illustrated in Figure A10-3.

### **A10.1.2 Short-Term Changes (2005–2006)**

Over the short term, provincial GHG emissions decreased by 0.6 Mt (or 6.1%), primarily as a result of a decline in emissions from the electricity and heat generation industries (confidential), off-road diesel use (0.2 Mt), and domestic aviation (0.1 Mt). These decreases helped to offset a 0.4 Mt increase in oil and natural gas fugitive emissions, which exhibited the greatest short-term increase.

The short-term decrease results from a combination of lower offshore production (due to lower production at Hibernia and Terra Nova) and lower demand for energy (National Energy Board 2007). The net supply of energy (both primary and secondary production) decreased by 4.5% between 2005 and 2006, while overall final energy demand decreased by 9% over the same

---

83. Megatonnes of CO<sub>2</sub> eq per billion dollars of provincial GDP.

period. These decreases in demand may be partially explained by the completion of the construction of the White Rose offshore oil project and Voisey’s Bay mineral project, and also the closure of the Stephenville newsprint mill in late 2005.

Short-term emission changes in Newfoundland and Labrador are illustrated in Figure A10-4.

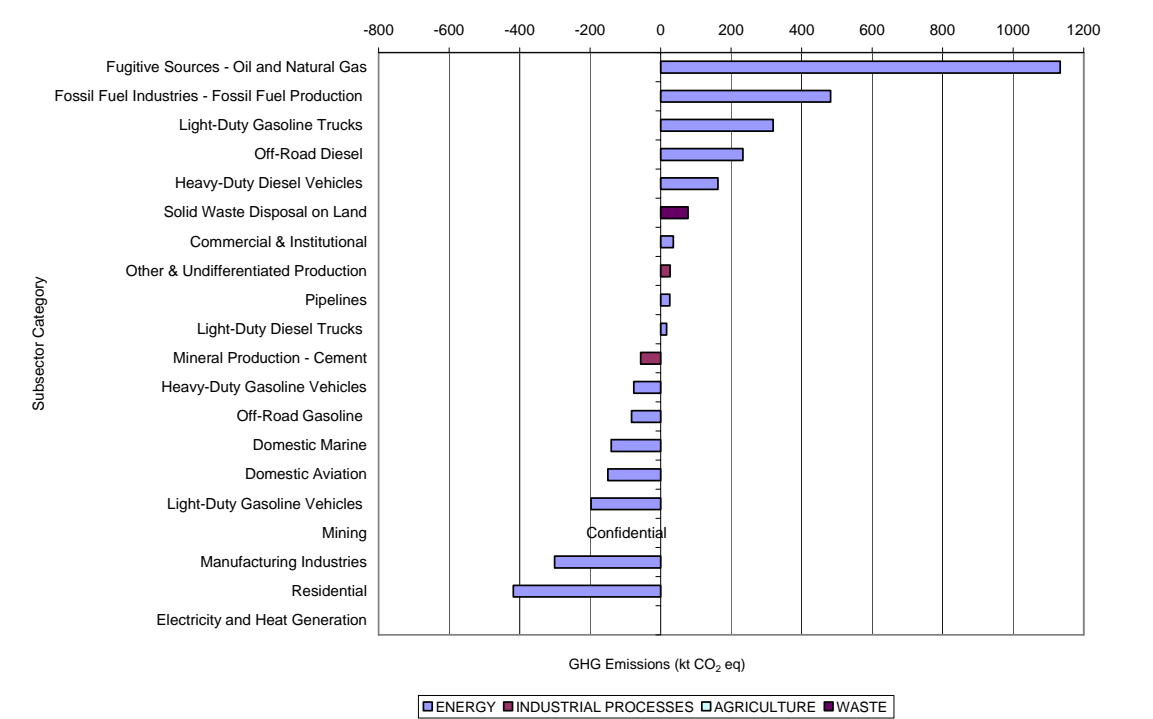


Figure A10-3: Newfoundland and Labrador Long-Term Emission Trends, 1990–2006

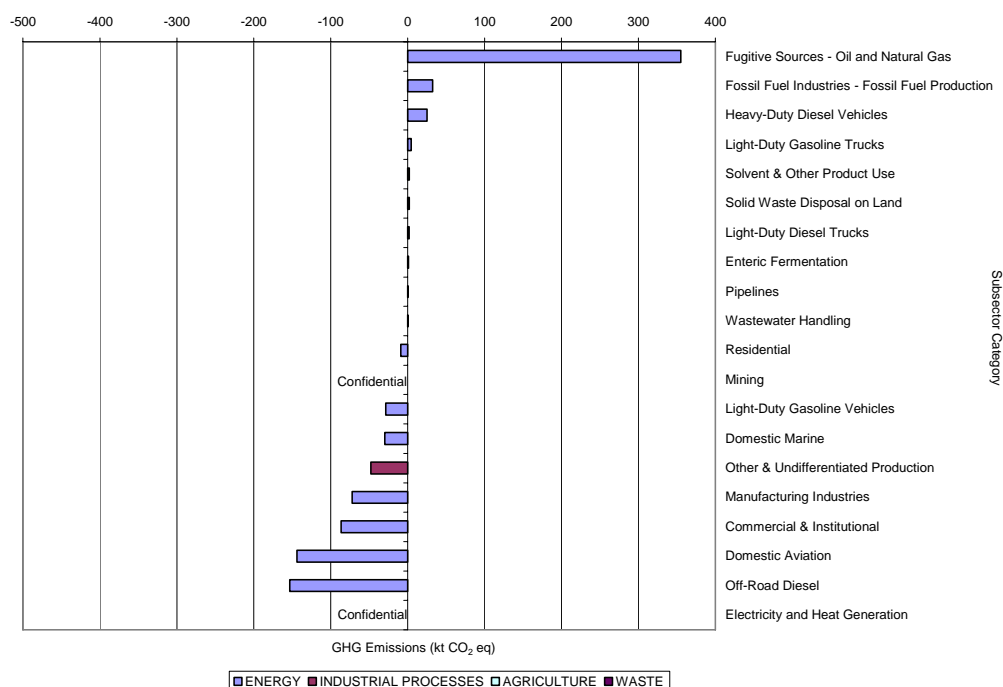


Figure A10-4: Newfoundland and Labrador Short-Term Emission Changes, 2005–2006

## A10.2 Prince Edward Island

Table A10-2: Trends in GHG Emissions and GHG Intensity, Prince Edward Island

		1990	1995	2000	2005	2006
<b>Total GHG (Mt)</b>		1.961	1.892	2.176	2.159	2.052
	Growth Since 1990	NA	-3.5%	11.0%	10.1%	4.7%
	Annual Change	NA	-1.5%	7.5%	-3.0%	-4.9%
<b>GDP (millions)</b>		2 167	2 453	2 808	3 135	3 206
	Growth Since 1990	NA	13.2%	29.6%	44.7%	47.9%
<b>GHG Intensity (Mt/\$B GDP)</b>		0.90	0.77	0.77	0.69	0.64
<b>GHG Efficiency (\$GDP/Kt GHG)</b>		1.11	1.30	1.29	1.45	1.56
<b>Population (000s)</b>		131	134	136	138	138
	Growth Since 1990	NA	3.0%	4.6%	5.9%	5.7%
<b>GHG Per Capita (tonnes/person)</b>		15.0	14.1	15.9	15.6	14.9
	Not	Not	Not	Not	Not	Not
<b>Energy Production (Primary only) (PJ)</b>	Available	Available	Available	Available	144	130
	Not	Not	Not	Not	Not	Not
	Growth Since 1990	Available	Available	Available	NA	NA
<b>Net Supply (Primary &amp; Secondary)(PJ)</b>		21 623	21 188	25 567	25 829	25 001
	Growth Since 1990	NA	-2.0%	18.2%	19.5%	15.6%
<b>Energy Use - Final Demand (Primary &amp; Secondary)(PJ)</b>		20 599	20 317	24 340	25 061	24 491
	Growth Since 1990	NA	-1.4%	18.2%	21.7%	18.9%
<b>Heating Degree Days</b>		4 559	4 738	4 480	4 440	3 996
	Growth Since 1990	NA	3.9%	-1.7%	-2.6%	-12.4%

Notes:

GDP at basic prices, by North American Industry Classification System (NAICS), 1990–1996: constant 1997 dollars; 1997–2006: chained 1997 dollars.

NA = Not applicable.

Geographically, Prince Edward Island (P.E.I.) is Canada's smallest province. In 2006, P.E.I. was home to 0.4% of the population while contributing 0.3% (\$3.3 billion) to Canada's total GDP. The provincial economy has important service and manufacturing sectors that support and contribute to the province's agriculture, forestry, and aquaculture sectors. Processed food products (mainly fish, seafood and potato products) make up almost two thirds of all manufacturing shipments and have the greatest impact on provincial GDP.

About 46% of the total land area of the province is classified as farmland, with agricultural activity generally dominated by potato crops and livestock. For example, the importance of the Agriculture Sector can be illustrated by reviewing GDP data over time. The combination of very dry conditions and U.S. trade restrictions in 2001 (due to potato wart) contributed to a drop of 0.2% in provincial GDP in 2001 and an almost 6% drop in GDP from the goods-producing industries (P.E.I. Dept. of the Provincial Treasury 2007). The impacts were also observed in provincial GHG emissions, which dropped by over 5% between 2000 and 2001, mainly in agricultural and off-road vehicle emissions.

The majority of the electricity consumed in P.E.I. is provided by New Brunswick via underwater transmission cables. There are two generating stations on the island; however, these are kept in standby mode in case of transmission problems from the mainland (Maritime Electric). The Atlantic Wind Test Site was established on the island in the 1980s, and a 13.56-MW wind farm was established by the PEI Energy Corporation (PEIEC) between 2001 and 2004. The wind farm supplies approximately 0.5% of the electricity demand in the province and the government plans to meet at least 15% of its electricity needs from renewable energy by 2010 (P.E.I. Dept. of the Provincial Treasury 2007). In 2007, the province quintupled its installed wind capacity with an additional 58.8 MW of projects (CanWEA 2008a).

In 2006, provincial GHG emissions were estimated at 2.1 Mt CO<sub>2</sub> eq, or 14.9 t per person. The province ranks ninth in terms of per capita emissions for 2006, reflecting its service-based economy and external electricity sources. The key contributors in 2006 to provincial emissions were Road Transportation (0.6 Mt), Agricultural Soils (0.3 Mt), Residential (0.2 Mt) and the Commercial & Institutional Sector (0.2 Mt).

### **A10.2.1 Long-Term Trends (1990–2006)**

Provincial emissions increased by 91 kt (4.7%) between 1990 and 2006. The increase was due to an overall increase in road transport-related emissions, specifically a 115% increase (131 kt) in LDGT emissions (including sport utility vehicles (SUVs), vans and pickups) and a 103% increase (62 kt) from off-road sources (gasoline, diesel and pipelines). Emissions from manufacturing industries also increased by over 150% (82 kt). Most of these increases were offset by decreases from the Residential Sector (150 kt), and Electricity and Heat Generation Sector (confidential).

Long-term road transportation emission increases can be attributed to the general shift from gasoline automobiles to SUVs, vans and pickups. Increases in manufacturing industry emissions are the result of the growth of fish processing, fabricated metal manufacturing and the aerospace industries, with provincial GDP growing by 51.5% since 1990.

The 39% decrease in residential emissions is mainly due to lower heating demands with HDDs having decreased by 12.4% since 1990. Increase efficiency and a shift in home heating fuels has also helped to reduce GHGs from this sector.

The net supply of energy has grown by 15.6%, while energy demand has increased by 18.9%. The installation and operation of wind farms on the island, combined with enhanced interconnections with the New Brunswick power grid, has helped to reduce GHGs from the Electricity and Heat Generation Sector (NB Power Group, 2007). Lower usage of the generating stations on the island has been the main reason for lower GHG emissions over the long term, and these emissions would be expected to decrease further assuming the provincial government's plan to increase renewable energy generation comes true.

Long-term emission trends in Prince Edward Island are illustrated in Figure A10-5.

### A10.2.2 Short-Term Changes (2005–2006)

Overall, GHG emissions in P.E.I. decreased by 4.9% between 2005 and 2006. This slight decrease was primarily due to decreases in the Residential, Commercial & Institutional sectors, and agricultural soil emissions. There were small increases in emissions from LDGTs and HDDVs, although their contribution to the total was very small.

Decreased fuel consumption for heating purposes is the biggest reason for lower GHG emissions from the Residential and Commercial & Institutional sectors. Over the short term, HDDs decreased by 10%, indicating a much warmer winter and less fuel consumption. Lower emissions from agricultural soils resulted from a lower consumption of synthetic nitrogen fertilizers that may be related to low market prices for potatoes.

Short-term emission changes in Prince Edward Island are illustrated in Figure A10-6.

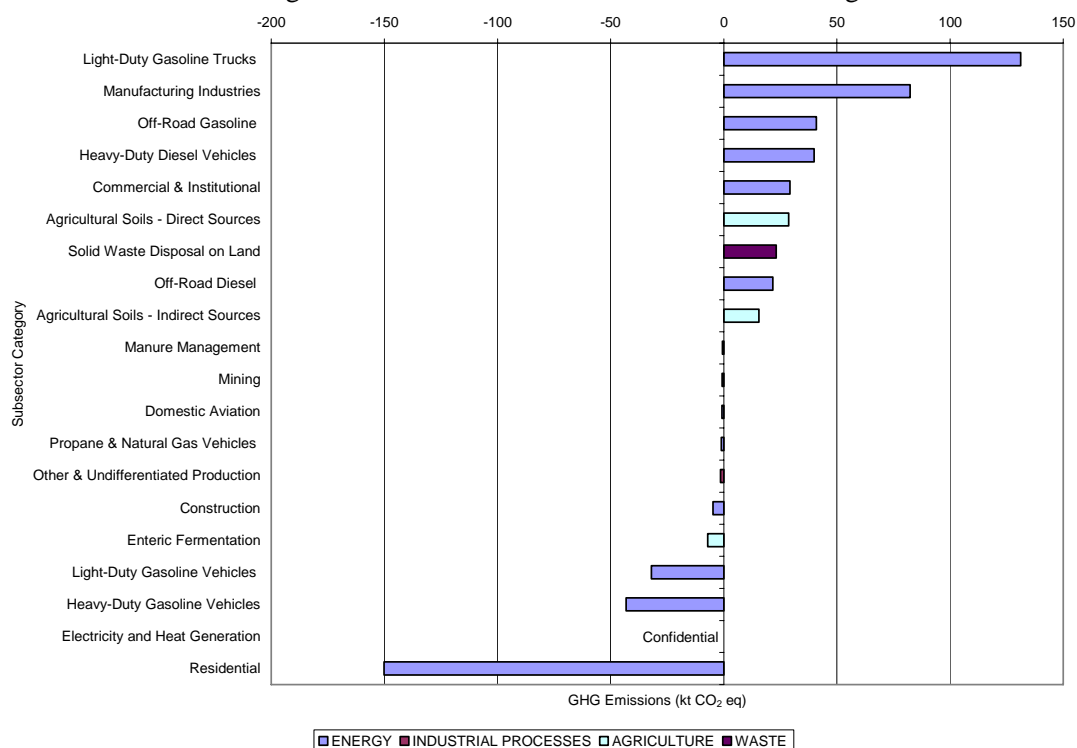


Figure A10-5: Prince Edward Island Long-Term Emission Trends, 1990–2006

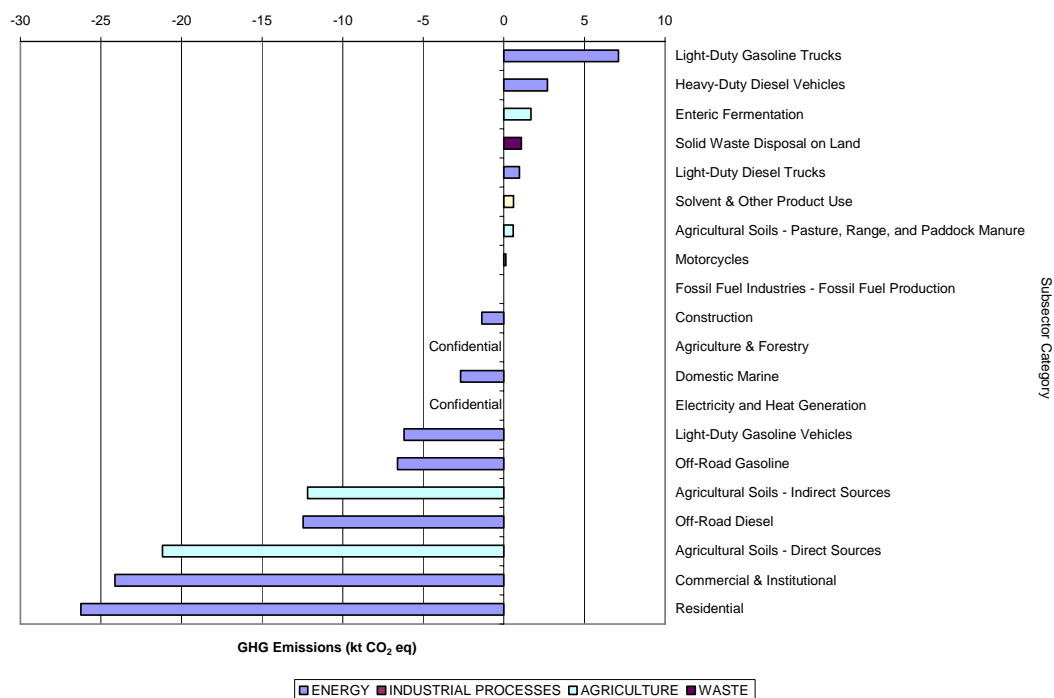


Figure A10-6: Prince Edward Island Short-Term Emission Changes, 2005–2006

### A10.3 Nova Scotia

Table A10-3: Trends in GHG Emissions and GHG Intensity, Nova Scotia

	1990	1995	2000	2005	2006
<b>Total GHG (Mt)</b>	18.978	18.567	20.871	21.719	19.603
Growth Since 1990	NA	-2.2%	10.0%	14.4%	3.3%
Annual Change	NA	-0.7%	5.5%	-4.5%	-9.7%
<b>GDP (millions)</b>	17 217	17 866	20 860	23 385	23 689
Growth Since 1990	NA	3.8%	21.2%	35.8%	37.6%
<b>GHG Intensity (Mt/\$B GDP)</b>	1.10	1.04	1.00	0.93	0.83
<b>GHG Efficiency (\$GDP/Kt GHG)</b>	0.91	0.96	1.00	1.08	1.21
<b>Population (000s)</b>	910	928	934	936	935
Growth Since 1990	NA	2.0%	2.7%	2.9%	2.8%
<b>GHG Per Capita (tonnes/person)</b>	20.9	20.0	22.3	23.2	21.0
<b>Energy Production (Primary only) (PJ)</b>	124 033	122 511	189 077	200 963	180 814
Growth Since 1990	NA	-1.2%	52.4%	62.0%	45.8%
<b>Net Supply (Primary &amp; Secondary)(PJ)</b>	187 033	181 040	203 250	210 329	193 117
Growth Since 1990	NA	-3.2%	8.7%	12.5%	3.3%
<b>Energy Use - Final Demand (Primary &amp; Secondary)(PJ)</b>	161 654	160 166	176 247	186 303	168 848
Growth Since 1990	NA	-0.9%	9.0%	15.2%	4.5%
<b>Heating Degree Days</b>	4 161	4 322	4 030	4 158	3 800
Growth Since 1990	NA	3.9%	-3.1%	-0.1%	-8.7%

Notes:

GDP at basic prices, by North American Industry Classification System (NAICS), 1990–1996: constant 1997 dollars; 1997–2006: chained 1997 dollars.

NA = Not applicable.

In 2006, Nova Scotia generated 19.6 Mt (3.0%) of Canada's total GHG emissions (Table A11-3). Nova Scotians represent 2.9% of the population and contributed 2.2% to the national GDP in 2006. The provincial economy has slowly been moving away from resource-based industries such as fishing, mining and industry to the services sector. This shift reinforces Nova Scotia's long-established position as the principal private-sector service centre for Atlantic Canada and the centre for regional public administration and defence.

The Manufacturing and Construction sectors have been the main contributors to the Goods-producing Sector, while Mining and Offshore Oil & Gas Exploration is also growing in importance. Coal mining has a long history in Nova Scotia, although the majority of the province's coal mines were shut down by 2001 (Nova Scotia Dept. of Finance 2006, 2007). Offshore oil and gas extraction has been a part of the provincial economy since the early 1990s with the Cohasset-Panuke Project, Canada's first offshore production project in 1992. Production from this project ceased in 1999 but was followed by the Sable Offshore Energy Project (SOEP), which first began producing gas in 1999. The scope and scale of the SOEP had a significant impact on the province's economy as complementary industries supported the project through goods and services. Expansion of the SOEP is currently underway as is the development of the Deep Panuke project (CNSOPB 2007).

Electricity for the province is supplied by wind, hydro, coal, natural gas, oil and tidal power. In fact, Nova Scotia is the site of the Western Hemisphere's only tidal power plant. The Annapolis power plant has been operational since 1984 and continues to provide power due to the tidal action of the Bay of Fundy (Nova Scotia Power, undated).

In 2006, provincial GHG emissions were estimated at 19.6 Mt CO<sub>2</sub> eq, or 21.0 t per person. Nova Scotia ranks fourth in terms of per capita emissions for 2006, and is very close to the Canadian average of 22.1 t per person. Electricity & Heat Generation is the largest contributor to provincial emissions, with Road Transportation, Commercial & Institutional, Residential, and Fossil Fuel Production sectors also contributing significantly to the total. These sectors combined accounted for 81% of provincial emissions.

### **A10.3.1 Long-Term Trends (1990–2006)**

Overall, GHG emissions increased by 0.6 Mt (3.3%) between 1990 and 2006. The greatest contributors to this increase were the Electricity and Heat Generation Sector (confidential), Commercial & Institutional Sector (1.0 Mt), LDGTs (0.7 Mt), and HDDVs (0.4 Mt). Decreases over the long term were led by fugitive emissions from coal mining (1.2 Mt), residential (1.1 Mt), LDGVs (0.3 Mt), and manufacturing industries (0.3 Mt).

Long-term emissions growth in the Road Transportation Sector is led by a switch to SUVs, vans and pickups from gasoline vehicles, and an increase in HDDVs. Growth in HDDV emissions can be linked to the expansion of the fossil fuel and manufacturing industries, as these vehicles are generally used in operations, and to move both finished goods and raw materials.

Fugitive emissions from coal mining have not all been eliminated, but are slowly being replaced with those from the oil and gas industry, as the primary energy production source in this province shifts from coal to petroleum. Primary energy production has increased over the long term by 45.8%, due to the development of the SOEP (CNSOPB 2007).

A decrease in long-term residential emissions can be attributed to an 8.7% decrease in HDDs, and fuel switching for home heating purposes. The decrease in emissions from the manufacturing

industries, on the other hand, has more to do with economic difficulties in the Pulp, Paper & Print Sector than fuel switching (Nova Scotia Dept. of Finance 2007).

Long-term emission trends in Nova Scotia are illustrated in Figure A10-7.

### **A10.3.2 Short-Term Changes (2005–2006)**

Between 2005 and 2006, total GHG emissions in Nova Scotia decreased by 2.1 Mt (or 9.7%), primarily as a result of decreased emissions from Electricity & Heat Generation (confidential), Off-road Diesel Transportation (0.3 Mt), and Domestic Marine (0.3 Mt). Over the same period, road transportation emissions, led by HDDVs and LDGTs increased by 0.1 Mt.

The short-term decrease in electricity and heat generation emissions are the result of a combination of factors. Petroleum coke supply issues in 2005 meant that Nova Scotia Power (NSP) had to switch to a higher CO<sub>2</sub> intensity fuel until supplies were re-established. This had the effect of increasing GHG emissions while generation stayed fairly close to 2003 and 2004 levels. In 2006, however, a long labour dispute at a pulp and paper mill in the province reduced demand significantly and thus peak generation needs. Between 2005 and 2006, generation decreased by almost 8%, while hydraulic conditions were excellent (Emera 2007). As a result, a major consumer of base load power was essentially removed from the power equation and, when combined with excellent hydroelectric conditions and a lower demand for peak power generated by oil-fired stations, resulted in a significant reduction in GHGs from this sector over the short term.

Decreased domestic marine and off-road transportation may be the result of a decrease in activity. The final decommissioning of the Cohasset Offshore Oil Project was completed in 2005, which may have played a role in higher consumption in 2005 compared to 2006.

Short-term emission changes in Nova Scotia are illustrated in Figure A10-8.



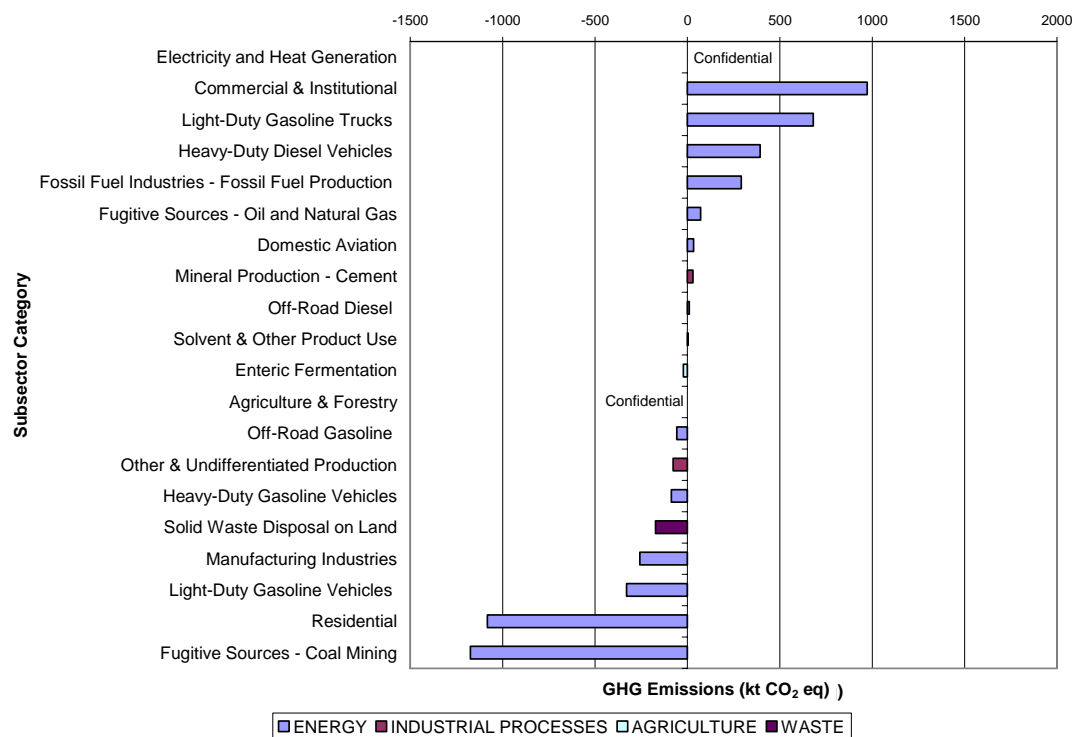


Figure A10-7: Nova Scotia Long-Term Emission Trends, 1990–2006

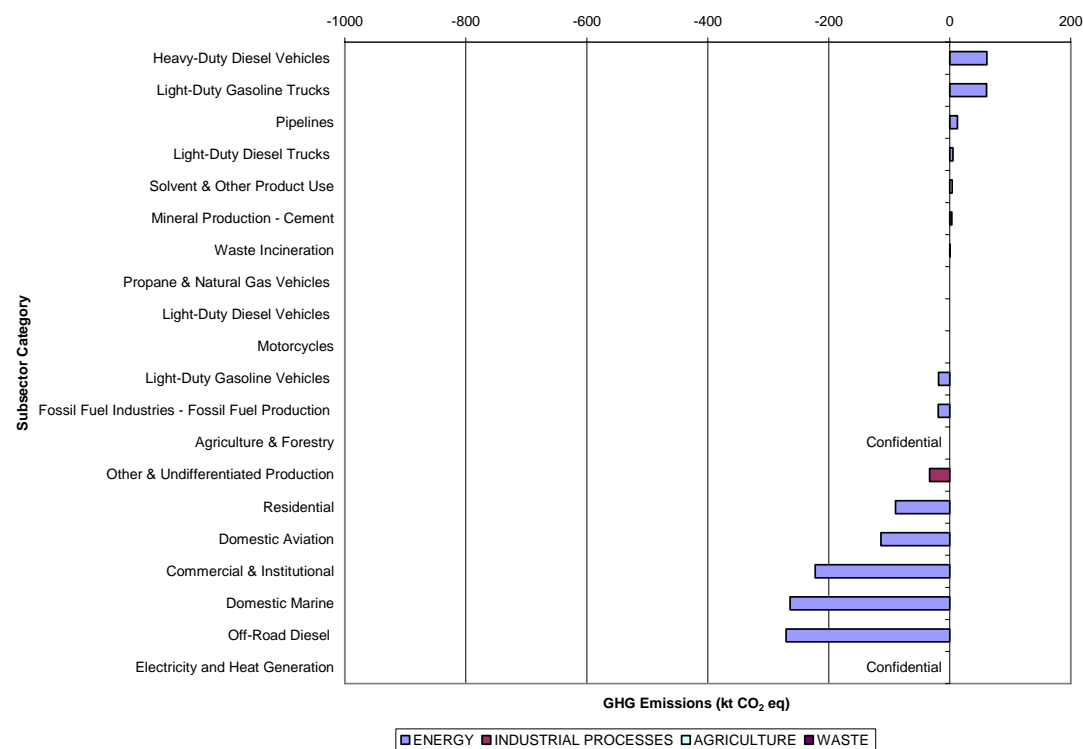


Figure A10-8: Nova Scotia Short-Term Emission Changes, 2005–2006

**A10.4 New Brunswick****Table A10-4: Trends in GHG Emissions and GHG Intensity, New Brunswick**

	1990	1995	2000	2005	2006
<b>Total GHG (Mt)</b>	15.870	16.769	19.932	20.879	17.919
Growth Since 1990	NA	5.7%	25.6%	31.6%	12.9%
<b>Annual Change</b>	NA	2.9%	6.3%	-1.3%	-14.2%
<b>GDP (millions)</b>	13 903	14 843	17 317	19 197	19 749
Growth Since 1990	NA	6.8%	24.6%	38.1%	42.1%
<b>GHG Intensity (Mt/\$B GDP)</b>	1.14	1.13	1.15	1.09	0.91
<b>GHG Efficiency (\$GDP/Kt GHG)</b>	0.88	0.89	0.87	0.92	1.10
<b>Population (000s)</b>	740	751	751	751	749
Growth Since 1990	NA	1.5%	1.4%	1.5%	1.2%
<b>GHG Per Capita (tonnes/person)</b>	21.4	22.3	26.6	27.8	23.9
<b>Energy Production (Primary only) (PJ)</b>	46 721	22 530	32 254	34 573	32 030
Growth Since 1990	NA	-51.8%	-31.0%	-26.0%	-31.4%
<b>Net Supply (Primary &amp; Secondary)(PJ)</b>	180 871	199 898	228 453	234 257	221 112
Growth Since 1990	NA	10.5%	26.3%	29.5%	22.2%
<b>Energy Use - Final Demand (Primary &amp; Secondary)(PJ)</b>	149 042	156 958	177 096	177 115	166 219
Growth Since 1990	NA	5.3%	18.8%	18.8%	11.5%
<b>Heating Degree Days</b>	4 470	4 786	4 682	4 596	4 155
Growth Since 1990	NA	7.1%	4.7%	2.8%	-7.1%

Notes:

GDP at basic prices, by North American Industry Classification System (NAICS), 1990–1996: constant 1997 dollars; 1997–2006: chained 1997 dollars.

NA = Not applicable.

In 2006, New Brunswick contributed 17.9 Mt (2.9%) to Canada's total GHG emissions (Table A10-4), which represents an increase of 12.9% since 1990. New Brunswick's GDP contribution increased 43% between 1990 and 2006, representing 1.8% of the national total in 2006. New Brunswick is the largest of Canada's three maritime provinces, with about 85% of the land categorized as productive forest (New Brunswick Dept. of Finance 2007). As such, the forestry industry is a major part of the provincial economy and is one of the key components of the province's resource-based economy. The Mining and Oil & Gas sectors have also seen significant growth in recent years. Manufacturing industries, particularly those complementary to resource industries, are also important contributors to the provincial economy.

Natural gas exploration in 2000 resulted in the discovery of the McCully field near Sussex. Two wells were installed to produce natural gas for a local market in 2003, with a larger plan to supply natural gas markets in New Brunswick and New England via pipeline in later years. The impact of this development was felt throughout the local economy with supporting Manufacturing Industries and the Professional Services sectors benefiting the most. Increased interest in mineral and oil and gas exploration helped to offset the economic impact of rising energy costs and decreased demand in the Forestry and Pulp, Paper & Print subsectors. The softwood lumber dispute that flared between Canada and the United States in 2002 did not have any noticeable impact on the New Brunswick forestry industry due to the large private woodlot holdings that were exempt from the trade agreement (New Brunswick Dept. of Finance 2007).

Due to limited natural hydro resources, New Brunswick has developed one of the most diverse electricity generation systems in North America, and is the site of the only nuclear power plant in Atlantic Canada. The nuclear reactor at Point Lepreau Generating Station will be undergoing refurbishment in 2008 and will have an impact on future GHG emissions. Currently the plant

provides approximately 25% of the province's power needs. Electricity is also generated from hydro, coal, oil, diesel, Orimulsion® (a bitumen-based proprietary fuel) and wind generating stations (New Brunswick Power Group 2007; Emera 2007).

In 2006, provincial GHG emissions were estimated at 17.9 Mt CO<sub>2</sub> eq, or 23.9 t per person. New Brunswick ranks third in terms of per capita emissions for 2006, slightly above the Canadian average, with emissions from the electricity and heat generation and fossil fuel industries accounting for more than 50% of total provincial GHG emissions.

#### **A10.4.1 Long-Term Trends (1990–2006)**

Emissions in New Brunswick grew by 2.0 Mt (12.9%) between 1990 and 2006. The fossil fuel industry was responsible for 1.4 Mt (67%) of the increase, with HDDVs (0.6 Mt) and LDGTs (0.6 Mt) also increasing over time. Growth was tempered by decreases in manufacturing industries (0.6 Mt) and residential (0.5 Mt) emissions.

Saint John is home to Canada's largest oil refinery. Long-term growth in demand for refined petroleum products is one of the major drivers and the region exports a significant amount of fuel. New Brunswick accounts for over 40% of Canada's total petroleum refinery exports, almost all purchased by the United States (EDC 2006). Increased interest in natural gas exploration, with the development of the McCully field also play a role in long-term emissions growth.

The long-term increase in HDDV emissions can partially be explained by their use to support the fossil fuel industry and the increase in the use of transport trucks to move manufactured goods and raw materials. Long-term LDGT emission increases are mainly due to consumer preferences and a switch to SUVs, vans and pickups from gasoline vehicles.

The long-term decrease in emissions in the manufacturing industries is mostly due to difficulties encountered by the Pulp, Paper & Print Sector. As is the case across the country, lower demand and higher energy prices in recent years have resulted in economic difficulties and in some cases mill and plant closures (Statistics Canada 2007a). Difficulties were greatest in 2005, but improved market conditions in 2006 resulted in the reopening of two pulp and paper mills (New Brunswick Dept. of Finance 2007).

Warmer winters, reflected in a 7.1% decrease in HDDs between 2006 and 1990, likely resulted in decreased emissions from the Residential Sector. Fuel switching from refined petroleum products to lower GHG-emitting natural gas has been observed over the long term, which would be expected with the development of a local supply.

Long-term emission trends in New Brunswick are illustrated in Figure A10-9.

#### **A10.4.2 Short-Term Changes (2005–2006)**

Over the short term, provincial emissions decreased by 3.0 Mt (14.2%). The biggest contributor to the decrease was Electricity and Heat Generation (confidential), followed by Commercial & Institutional (0.3 Mt), and Manufacturing Industries (0.2 Mt). Emissions from Road Transportation, specifically LDGTs, HDDVs and HDGVs, increased emissions slightly but not significantly.

Electricity and heat generation emissions decreased significantly between 2005 and 2006 due mainly to lower demand and all-time record hydro flow. Between 2005 and 2006, the New Brunswick Power Generation Corporation reported hydro production approximately 43% above

the long-term average. Combined with a 6.2% decrease in overall energy demand (including lower winter demand), emissions decreased as a result of less RPP-fired generation being required to meet peak demand (Emera 2007).

Excluding the Electricity and Heat Generation Sector and the Commercial & Institutional Sector, the relatively constant level of emissions between 2005 and 2006 is probably reflective of rising fuel costs. Overall transportation combustion sources (including domestic aviation, road transportation, railways, domestic marine and off-road sources) actually declined by 2.2% over the short term.

Short-term emission trends in New Brunswick are illustrated in Figure A10-10.

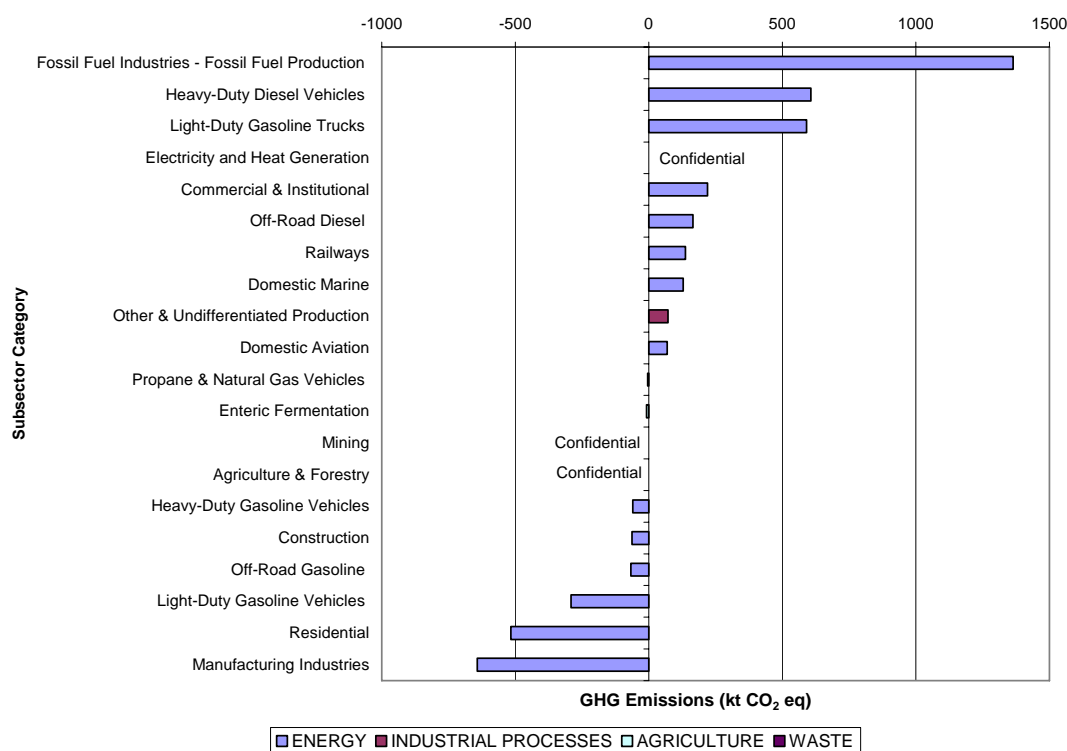


Figure A10-9: New Brunswick Long-Term Emission Trends, 1990–2006

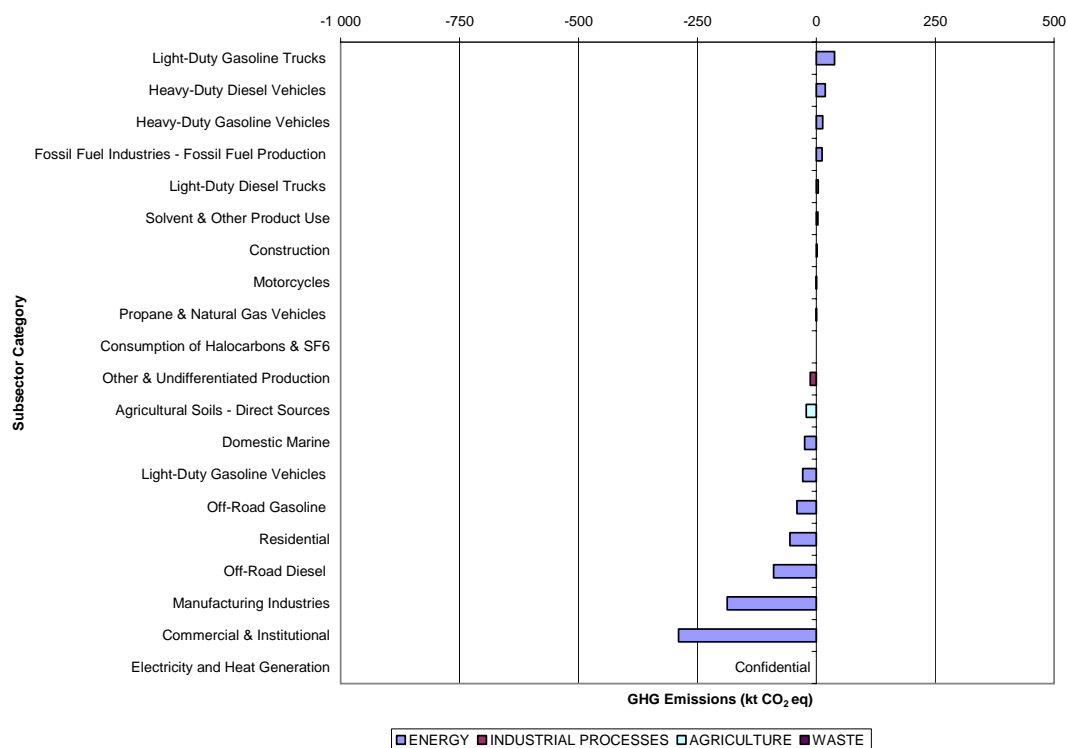


Figure A10-10: New Brunswick Short-Term Emission Changes, 2005–2006

### A10.5 Quebec

Table A10-5: Trends in GHG Emissions and GHG Intensity, Quebec

		1990	1995	2000	2005	2006
<b>Total GHG (Mt)</b>		82.730	79.411	81.943	83.558	81.747
	Growth Since 1990	NA	-4.0%	-1.0%	1.0%	-1.2%
	Annual Change	NA	-1.2%	0.9%	-4.4%	-2.2%
<b>GDP (millions)</b>		161 170	169 239	201 264	221 740	225 729
	Growth Since 1990	NA	5.0%	24.9%	37.6%	40.1%
<b>GHG Intensity (Mt/\$B GDP)</b>		0.51	0.47	0.41	0.38	0.36
<b>GHG Efficiency (\$GDP/Kt GHG)</b>		1.95	2.13	2.46	2.65	2.76
<b>Population (000s)</b>		7 004	7 219	7 357	7 598	7 651
	Growth Since 1990	NA	3.1%	5.0%	8.5%	9.2%
<b>GHG Per Capita (tonnes/person)</b>		11.8	11.0	11.1	11.0	10.7
<b>Energy Production (Primary only) (PJ)</b>		482 430	620 841	641 037	641 720	639 379
	Growth Since 1990	NA	28.7%	32.9%	33.0%	32.5%
<b>Net Supply (Primary &amp; Secondary)(PJ)</b>		1 530 051	1 597 692	1 724 365	1 813 470	1 795 235
	Growth Since 1990	NA	4.4%	12.7%	18.5%	17.3%
<b>Energy Use - Final Demand (Primary &amp; Secondary)(PJ)</b>		1 355 856	1 410 778	1 515 464	1 592 298	1 563 070
	Growth Since 1990	NA	4.1%	11.8%	17.4%	15.3%
<b>Heating Degree Days</b>		4 131	4 570	4 438	4 274	3 862
	Growth Since 1990	NA	10.6%	7.4%	3.5%	-6.5%

Notes:

GDP at basic prices, by North American Industry Classification System (NAICS), 1990–1996: constant 1997 dollars;

1997–2006: chained 1997 dollars

NA = Not applicable.

Quebec contributed 81.7 Mt (11.5%) to Canada's total GHG emissions in 2006 (Table A10-5). The province's emissions have decreased by 1.2% (or 1.0 Mt) since 1990, while GDP grew 43.7% over the same period. Rich in natural resources, Quebec's economy relies extensively on its abundant hydroelectric capacity, which helps to power its mining and manufacturing sectors. This historically cheap electricity supply has meant that a high percentage of homes and businesses are heated with hydro power rather than fossil fuels (Hydro Quebec 2007).

With almost half of the province covered by forests, the Forestry Sector, which ranks second in Canada behind British Columbia, is also an important contributor to the provincial economy. However, over the last 10 years, the provincial economy has diversified from energy, forestry, mining, metallurgy and agriculture to include aerospace and aeronautics, and a growing chemical product industry (Finances Quebec 2006).

Softwood lumber disputes between Canada and the United States have simmered for more than 20 years. The most recent conflict occurred in 2002 when the United States imposed duties of 27%, devastating the forestry industries of Quebec, Ontario and British Columbia (CBC News Online 2006).

The amount of hydroelectricity generated in Quebec in 2006 accounted for 49% of the total hydroelectricity generated in the country, and 30% of the total electricity generated overall (Statistics Canada 2008). This generating potential, along with nuclear facilities and recent developments in wind power, has meant that emissions from the electricity and heat generation industries are low, ranging from a low of 0.3 Mt to a high of 1.9 Mt.

Quebec is Canada's second most populous province, with 23.4% of the population in 2006, and the country's lowest per capita GHG emitter at 10.7 t per person. In 2006, over 34% of GHG emissions were from road transportation, with the majority from gasoline automobiles, LDGTs (i.e. SUVs, vans and pickups) and HDDVs. Manufacturing industries contributed 11% to the provincial total while the aluminium production industry contributed 8%.

### **A10.5.1 Long-Term Trends (1990–2006)**

Over the long term, Quebec's GHG emissions decreased by 1.0 Mt (or 1.2%). The decrease was led by lower emissions from the manufacturing industries (3.1 Mt or 26%), process emissions from magnesium smelters (2.3 Mt or 97%), Residential Sector (2.3 Mt or 33%) and gasoline vehicles (1.7 Mt or 14%). Higher long-term emissions were observed in LDGTs (4.4 Mt or 113%), HDDVs (3.9 Mt or 96%) and the Commercial & Institutional Sector (1.7 Mt or 41%).

The pulp and paper industry in Quebec has a long and rich history. This sector has been under pressure for the last 5 years due to lower demand and competition in the export market (Statistics Canada 2007a). The softwood lumber dispute, rising costs and a stronger Canadian dollar compared to the United States contributed to the decline of this industry in the province and was the biggest reason for the decrease in GHG emissions from the manufacturing industries since 1990.

Relatively inexpensive, reliable electricity has resulted in Quebec attracting industries that are high energy consumers. The province of Quebec is Canada's primary producer of aluminium, with lower-level activities in British Columbia (AAC). In 2006, Quebec accounted for 87% of Canada's process emissions associated with primary aluminium production. Between 1990 and 2006 the aluminium production subsector experienced a process emission decrease of 15%, which can be attributed to better control of anode events in smelters through the use of electronic

monitoring and automated emission controls. Although the GDP of the aluminium industry has grown significantly since 1990, its fuel combustion-related GHG emissions decreased slightly, thanks to an increase in energy efficiency and subsequent reduction in energy usage (Barraso 2006). Research and the use of substitute gas mixtures played an important role in significantly reducing (97% or 2.3 Mt) SF<sub>6</sub> emissions from magnesium production between 1990 and 2006. During the last couple of years, the production decrease in anticipation of the Norsk Hydro's plant closure also contributed, to a lesser extent, to the emission drop seen in the magnesium production industry.

Decreases in long-term residential emissions are the result of the convergence of two different factors. The first involves a long-term decrease in HDDs of 6.5% between 1990 and 2006. The warmer weather resulted in lower heating demand in the winter and fewer emissions from heating equipment. The second factor involves abundant, cheap and reliable hydroelectricity. The vast majority of homes in Quebec are heated using electric heat. Since 1990, residents have also switched from relatively high GHG-intense refined petroleum product (RPP) fuels (like fuel oil) to electricity-based systems, which has increased electricity demand but lowered GHG emissions.

The long-term increase in road transportation related emissions, particularly LDGTs (SUVs, vans and pickups) and HDDVs are observed throughout the country, and Quebec is no exception. The choice to switch from gasoline automobiles to LDGTs is the most obvious reason for increased emissions over the long term. The increase in emissions from HDDVs can also be related to increased usage, although in this case it relates to their role in the mining and production industries and just-in-time shipping.

Long-term emission trends in Quebec are illustrated in Figure A10-11.

### **A10.5.2 Short-Term Changes (2005–2006)**

In the short term, emissions decreased by 1.8 Mt, (2.2%) largely the result of lower emissions from the Manufacturing Industries (0.9 Mt), Commercial & Institutional (0.8 Mt) and Residential (0.5 Mt) sectors. A portion of these decreases were offset by short-term increases in emissions from the Electricity and Heat Generation Sector (0.4 Mt), LDGTs (0.4 Mt) and Other (Undifferentiated Processes) (0.3 Mt).

GHG emission decreases in the Manufacturing Industries Sector were not attributable to one specific industry, and in fact decreases were observed in all subsectors, with the exception of the mining subsector, which showed a slight increase. These decreases are likely the result of higher oil prices, fuel switching, and the appreciation of the Canadian dollar as some sectors were negatively affected while high prices and demand for primary metals tempered the overall totals.

The relatively small short-term increase in emissions from the Electricity and Heat Generation Sector (0.4 Mt) is mostly the result of a new natural gas-fired cogeneration system coming online during 2006. The short-term increase in emissions from LDGTs reflects more vehicles on the road, at the expense of gasoline automobiles. Other & Undifferentiated Processes emissions increased by 0.3 Mt (27%.), which may be due to the increased use of other products (e.g. paraffin and waxes).

Short-term emission changes in Quebec are illustrated in Figure A10-12.

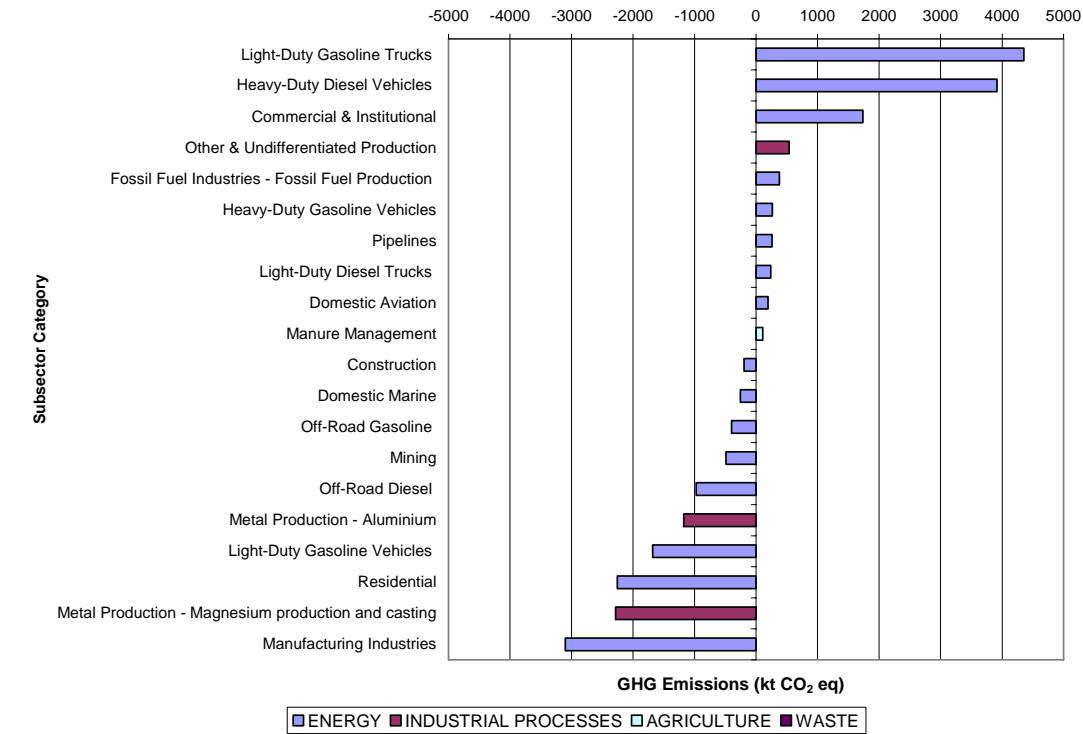


Figure A10-11: Quebec Long-Term Emission Trends, 1990–2006

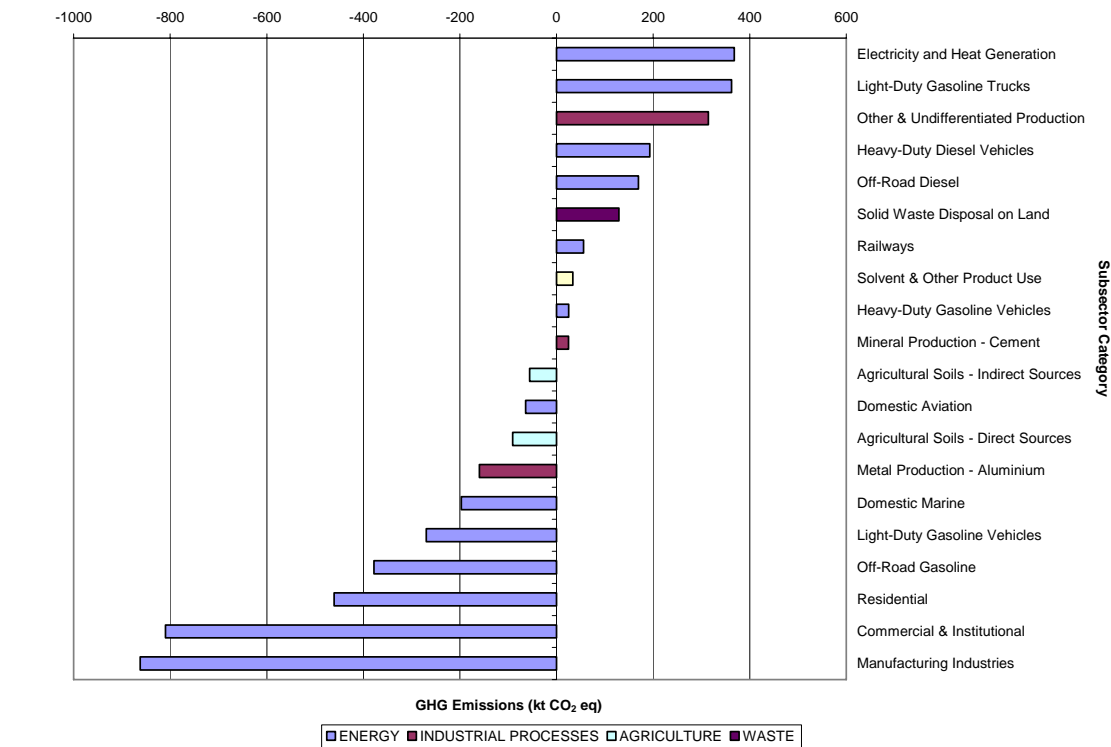


Figure A10-12: Quebec Short-Term Emission Changes, 2005–2006



**A10.6 Ontario****Table A10-6: Trends in GHG Emissions and GHG Intensity, Ontario**

	1990	1995	2000	2005	2006
<b>Total GHG (Mt)</b>	174.155	173.928	199.410	197.972	190.342
Growth Since 1990	NA	-0.1%	14.5%	13.7%	9.3%
Annual Change	NA	2.4%	4.9%	0.7%	-3.9%
<b>GDP (millions)</b>	290 526	313 812	396 520	441 219	450 120
Growth Since 1990	NA	8.0%	36.5%	51.9%	54.9%
<b>GHG Intensity (Mt/\$B GDP)</b>	0.60	0.55	0.50	0.45	0.42
<b>GHG Efficiency (\$GDP/Kt GHG)</b>	1.67	1.80	1.99	2.23	2.36
<b>Population (000s)</b>	10 298	10 950	11 685	12 565	12 705
Growth Since 1990	NA	6.3%	13.5%	22.0%	23.4%
<b>GHG Per Capita (tonnes/person)</b>	16.9	15.9	17.1	15.8	15.0
<b>Energy Production (Primary only) (PJ)</b>	401 420	481 195	382 934	423 610	445 423
Growth Since 1990	NA	19.9%	-4.6%	5.5%	11.0%
<b>Net Supply (Primary &amp; Secondary)(PJ)</b>	2 586 033	2 736 740	2 954 082	3 047 267	3 018 635
Growth Since 1990	NA	5.8%	14.2%	17.8%	16.7%
<b>Energy Use - Final Demand (Primary &amp; Secondary)(PJ)</b>	2 238 688	2 357 291	2 557 696	2 656 468	2 588 176
Growth Since 1990	NA	5.3%	14.2%	18.7%	15.6%
<b>Heating Degree Days</b>	3 257	3 621	3 830	3 797	3 378
Growth Since 1990	NA	11.2%	17.6%	16.6%	3.7%

Notes:

GDP at basic prices, by North American Industry Classification System (NAICS), 1990–1996: constant 1997 dollars; 1997–2006: chained 1997 dollars.

NA = Not applicable.

In 2006, Ontario was the second largest contributor to Canada's total GHG emissions, with 26.7% of the total (or 190 Mt). Provincial emissions grew by 9.3% (16.2 Mt) between 1990 and 2006 while GDP grew by 56% over the same period (Table A10-6). By itself, Ontario made up over 41% of Canada's GDP in 2006. As a province with a significant manufacturing sector, the provincial economy is export-driven, largely relying on the United States market, which accounted for 86% of the province's total exports (on a dollar value basis) in 2006 (Statistics Canada 2007a). Ontario is responsible for almost all automotive exports and is known as the leading auto production jurisdiction in North America. In fact, motor vehicle and part exports made up almost 17% of Canada's total merchandise exports, ranking second only to fossil fuel exports. In Ontario, the automotive industry is so ubiquitous that one in seven jobs is tied directly or indirectly to the sector (Ontario Economic Development).

Other important sectors of the manufacturing economy include Chemical & Petroleum Products, Mining & Primary Metal Manufacturing, Food, Beverages & Tobacco, and Electrical & Electronic Products. The structure of the provincial economy has changed since 1990, due in part to fluctuations in global markets that have affected the export market. In response to lower manufacturing costs abroad for some goods and primary materials, the economy adapted with an increase in service-based industries that has resulted in Toronto becoming the financial capital of Canada (Ontario Economic Development undated).

Electrical demand in Ontario is met primarily through nuclear, hydro and coal-fired generation. Ontario is the home for most of Canada's nuclear capacity and the provincial government pledged in 2003 to shut down all coal-fired generation by the end of the decade. The first of the province's four coal-fired power plants was shut down in 2005. As a result of this policy, investment in wind power and other renewable energy resources has grown substantially and has resulted in Ontario

becoming a leader in new wind construction. In 2006, there was 776 MW of new wind capacity installed in Canada, with 399 MW installed in Ontario (CanWEA 2008b).

With a population of over 12.7 million in 2006 (or 39% of all people in Canada), Ontario is by far Canada's most populous province. In terms of emissions, Ontario ranks in the bottom quarter of per capita emitters, with approximately 15.0 t per person. The transportation of products (both raw materials and finished goods) is an integral part of the manufacturing sector. When one factors in a large population, it is unsurprising that road transportation emissions made up a quarter of the provincial emissions (25% or 47.4 Mt) in 2006, while the Electricity and Heat Generation Sector contributed 16% (29.6 Mt) of the total. The Manufacturing Industries themselves contributed 11% (21.6 Mt) while the Residential and Commercial & Institutional sectors contributed 10% (18.2 Mt) and 7% (12.5 Mt), respectively.

### **A10.6.1 Long-Term Trends (1990–2006)**

Between 1990 and 2006, emissions increased by 16.2 Mt, due mainly to growth in LDGTs (9.5 Mt), HDDVs (5.4 Mt), the commercial & institutional Sector (3.4 Mt) and electricity and heat generation (2.9 Mt). The long-term increase was offset by decreases from adipic acid production (9.5 Mt), gasoline automobiles (3 Mt), and manufacturing industries (1.1 Mt).

With a large population centre spread across a relatively broad geographic area (known as the Golden Horseshoe), the growth in road transportation emissions can be directly related to urban sprawl and consumer preferences for SUVs, vans and pickups. Over the long term, LDGT emissions increased by 123%. According to Statistics Canada, in 2006 there were over 5.6 million commuters in Ontario, with 71% using a car to get to work.

The increase in GHG emissions from HDDVs can also be attributed to the Manufacturing Sector, as production management methods like just-in-time manufacturing result in increasing use of transport trucks for the movement of raw materials and finished goods. The population increase, urban sprawl and expansion of the Retail Sector also adds to the increasing usage of HDDVs over time.

The increase in commercial and institutional emissions is related to the shift in the provincial economy, from a mainly manufacturing base to a diversified service industry, including finance, insurance and real estate (FIRE) (Ontario Economic Development 2008). The growth in the Commercial & Institutional Sector is most notable in employment figures. In 2006, the service industry employed 75.3%, up from 72.9% in 2000, and the manufacturing industry decreased to 15.5% in 2006, from 18.5% in 2000, even though total employment rose over the same period. The subsequent increase in commercial floorspace resulted in greater demand for heating and cooling that is coupled with a long-term HDD increase of 3.7%.

Ontario is the home to the country's only adipic acid production plant. The substantial reductions in process emissions at this facility between 1990 and 2006 are the result of the installation of a catalytic emission abatement system in 1997 and labour disputes in 2005.

Long-term emission trends in Ontario are illustrated in Figure A10-13.

### **A10.6.2 Short-Term Changes (2005–2006)**

Provincial emissions decreased by 7.6 Mt between 2005 and 2006. The bulk of the decrease is observed in Electricity and Heat Generation (4.8 Mt), Residential (1.5 Mt), Adipic Acid Production (1.4 Mt), and Commercial & Institutional (1.4 Mt) sectors. Short-term emission

growth is led by the manufacturing industries (1.6 Mt), iron and steel production (0.7 Mt), and direct agricultural soil emissions (0.6 Mt).

The significant decrease in electricity and heat generation emissions is a result of a combination of factors. Ontario increased its nuclear capacity in 2006, with the return to service of the Pickering A reactor and also lower overall demand for electricity (IESO 2007). A warmer winter (HDDs decreased by 11%), a cooler summer (CDDs decreased by 28%), and a significant focus on energy conservation by the province and a coalition of the six largest electricity distributors in the province contributed to a decrease in electricity consumption of over 200 GWh between 2005 and 2006 (CLD 2007). Lower demand resulted in significantly fewer coal-based GHG emissions from this subsector compared to 2005.

The decrease in residential and commercial and institutional GHG emissions over the short term is mainly because of the warmer winter experienced in 2006 compared to 2005 while the decrease in adipic acid emissions can be partly attributed to lower production that resulted from a prolonged strike at Ontario's only adipic acid-producing facility.

In 2006, emissions coming from adipic acid production decreased by 54% (1.4 Mt) compared to the 2005 level, because of excellent operation of the abatement system. It should be noted that 2005 was a particularly difficult year for Invista's facility in Maitland, Ontario, since there were operational difficulties with the abatement system at the beginning and at the end of the year in addition to a prolonged six-month strike.

The increase observed in energy-related manufacturing industry GHG emissions is mainly due to increases from the chemical manufacturing subsector and the other manufacturing subsector. However, decreases in the pulp and paper subsector kept GHG emissions from rising higher in the short term. The increase in energy-related GHG emissions from the Chemical Sector (which includes basic chemicals, resins, and pharmaceuticals, for example) was likely related to production returning to normal levels as a result of supply shortages that occurred after Hurricanes Katrina and Rita in 2005 (CCPA 2006; Air Products and Chemicals 2005). Decreases in pulp and paper subsector emissions reflect the economic difficulties felt by the subsector during 2006, and also observed in many other provinces (Statistics Canada 2007a).

Process emissions from iron and steel production increased by 0.7 Mt between 2005 and 2006, mainly as a result of increased usage of metallurgical coke.

Agricultural soil emissions rose by 0.9 Mt between 2005 and 2006 because of higher synthetic fertilizer nitrogen consumption and better crop production.

Short-term emission changes in Ontario are illustrated in Figure A10-14.

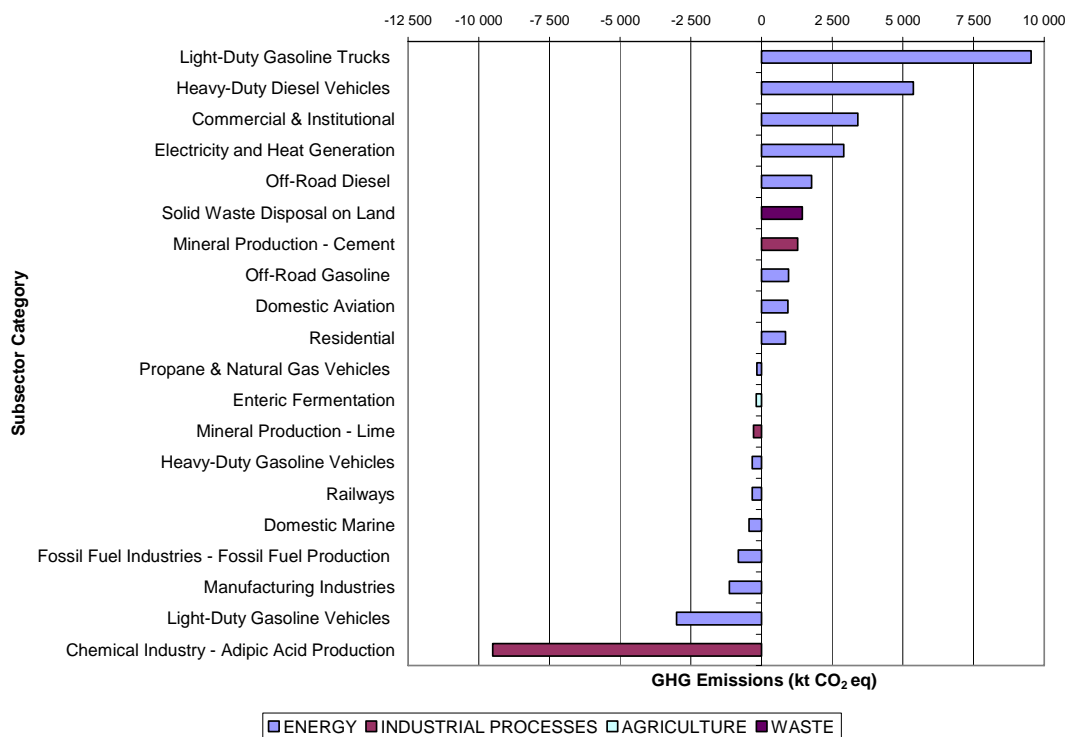


Figure A10-13: Ontario Long-Term Emission Trends, 1990–2006

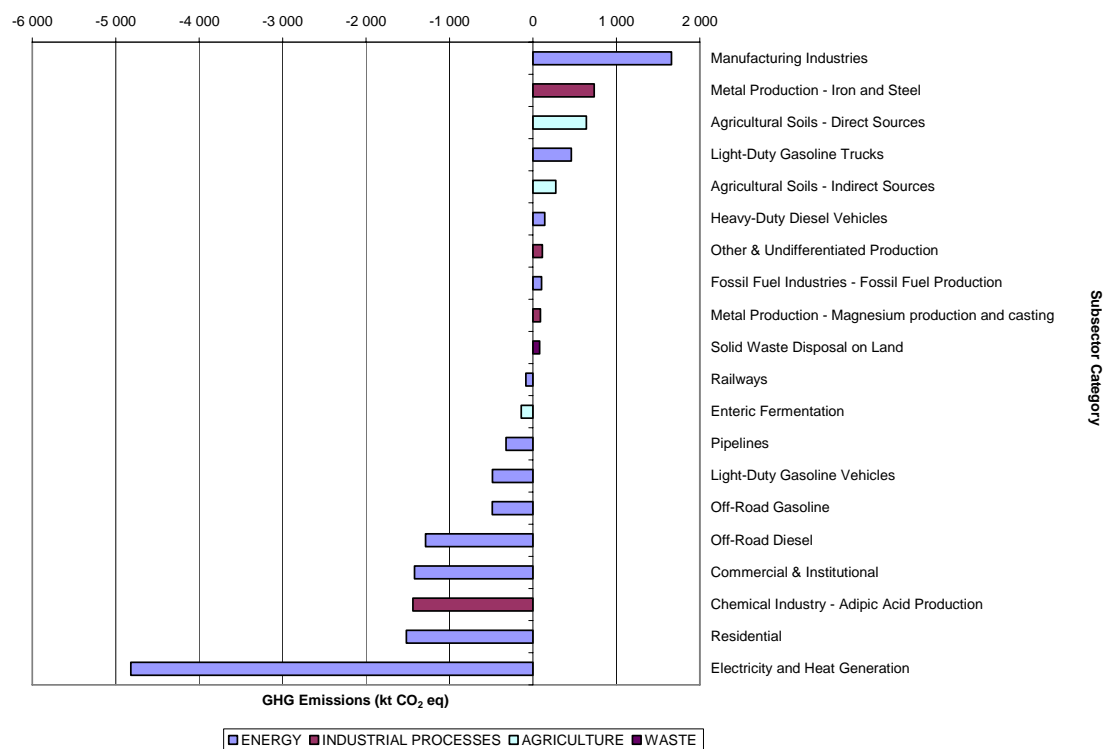


Figure A10-14: Ontario Short-Term Emission Changes, 2005–2006

**A10.7 Manitoba****Table A10-7: Trends in GHG Emissions and GHG Intensity, Manitoba**

	1990	1995	2000	2005	2006
<b>Total GHG (Mt)</b>	18.755	19.935	21.366	21.020	21.177
Growth Since 1990	NA	6.3%	13.9%	12.1%	12.9%
Annual Change	NA	4.2%	3.6%	-1.7%	0.7%
<b>GDP (in millions)</b>	25 379	25 548	30 370	33 078	34 284
Growth Since 1990	NA	0.7%	19.7%	30.3%	35.1%
<b>GHG Intensity (Mt/\$B GDP)</b>	0.74	0.78	0.70	0.64	0.62
<b>GHG Efficiency (\$GDP/Kt GHG)</b>	1.35	1.28	1.42	1.57	1.62
<b>Population (000s)</b>	1 106	1 129	1 147	1 174	1 178
Growth Since 1990	NA	2.1%	3.8%	6.2%	6.6%
<b>GHG Per Capita (tonnes/person)</b>	17.0	17.7	18.6	17.9	18.0
<b>Energy Production (Primary only) (PJ)</b>	97 185	129 636	137 820	162 649	170 038
Growth Since 1990	NA	33.4%	41.8%	67.4%	75.0%
<b>Net Supply (Primary &amp; Secondary) (PJ)</b>	257 656	274 080	279 854	280 652	269 644
Growth Since 1990	NA	6.4%	8.6%	8.9%	4.7%
<b>Energy Use - Final Demand (Primary &amp; Secondary)(PJ)</b>	239 964	253 429	251 299	259 992	250 095
Growth Since 1990	NA	5.6%	4.7%	8.3%	4.2%
<b>Heating Degree Days</b>	5 680	6 085	5 739	5 488	5 127
Growth Since 1990	NA	7.1%	1.0%	-3.4%	-9.7%

Notes:

GDP at basic prices, by North American Industry Classification System (NAICS), 1990–1996: constant 1997 dollars; 1997–2006: chained 1997 dollars.

NA = Not applicable.

In 2006, Manitoba's GHG emissions were up by 13% (2.4 Mt) with respect to 1990 and up 0.7% (0.2 Mt) since 2005 (Table A10-7). The province contributed about 3.0% to Canada's total in 2006, with 3.6% of Canada's population. Over the long term, the province's annual GDP and population increased 38.2% and 6.6%, respectively, contributing 600 kt of GHGs per billion dollars GDP in 2006. The Manitoba economy is one of Canada's most diverse. The province is home to a large agricultural and manufacturing sector, as well as a natural resources sector that includes hydro power exports and mining.

With such a diverse economy, the financial picture can change rapidly. For example, in recent years record prices for primary metals and oil and gas has meant an increase in mining exploration and the development of new mines. Heavy rains and flooding can affect the output from the Agriculture Sector while trading barriers can also have an impact. Key trading partners for the province's manufacturing industry are both Alberta and Ontario, with the United States being the main international market (Manitoba Dept. of Finance 2007). In recent years, lower demand in Ontario for manufactured goods have been offset by strong demand in Alberta (Statistics Canada 2007a).

Manitoba's abundant hydro power resources provide not only cheap, reliable electricity for the economy but also a significant source of income due to electricity exports (Manitoba Hydro 2006). The province is also committed to other sources of renewable energy, specifically wind power. In 2005 and 2006 St. Leon, a small farming community 150 kilometres southwest of Winnipeg, became the home of the province's first large-scale wind farm. At the time, the 99-MW facility was Canada's largest, but it has since been surpassed by farms in other provinces (CanWEA 2008b). The province has also implemented the Ethanol Sales Mandate in a bid to reduce provincial GHGs, requiring fuel suppliers in Manitoba to replace at least 8.5% of their

gasoline available for sale with ethanol in 2008 (Manitoba Science, Technology, Energy and Mines 2008).

Manitoba's abundant hydro resources and relatively small population of just under 1.2 million results in a per capita emission rate of 18.0 t per person, good for sixth lowest in Canada and just behind Newfoundland and Labrador. The province's agricultural base means that the main contributors to GHG emissions in 2006 were mainly from this sector. Emissions from enteric fermentation and agricultural soils were the main contributors in 2006, together accounting for 29% of provincial emissions, with LDGTs and HDDVs contributing 16%.

### **A10.7.1 Long-Term Trends (1990–2006)**

Manitoba's economic structure results in its GHG emissions having the lowest percentage of emissions from the Energy Sector (57%) and the highest percentage from the Agriculture Sector (36%). Over the long term (1990–2006), emissions increased by 12.9%, (2.4 Mt) with the growth in agricultural emissions accounting for 94% (2.3 Mt) of this increase. Decreases in residential emissions (0.7 Mt or 41%), gasoline automobiles (0.5 Mt or 29%) and railways (0.4 Mt or 59%) helped to offset the increases in agricultural emissions and LDGTs (0.9 Mt or 108%) and HDDVs (0.7 Mt or 85%).

Agricultural emissions from all sources increased significantly between 1990 and 2006. CH<sub>4</sub> emissions from enteric fermentation and manure management increased by 71% and 95%, respectively, while N<sub>2</sub>O emissions from manure management increased by 70%, mainly due to increases in beef cattle and swine populations. N<sub>2</sub>O emissions from agricultural soils increased by 15%, mainly because of the increases in nitrogen fertilizer consumption, animal manure on pasture and animal manure applied as fertilizers on cropland.

HDDs decreased by 9.7% between 1990 and 2006, and helped to decrease residential GHG emissions over the long term by 0.7 Mt, while the population increased by 6.6%. This decrease in emissions was also supported by a switch from GHG-intense heating fuels (home heating oil) to natural gas and electricity, which in this hydro-rich province has minimal GHG impacts.

The long-term increase in emissions from HDDVs and LDGTs is reflected in the decrease in emissions from railways and gasoline automobiles. The switch from rail for the transportation of raw materials and finished goods for the manufacturing industry is observed by an increase in HDDV emissions (transport trucks). The preference for LDGTs over gasoline automobiles is also notable.

Long-term emission trends in Manitoba are illustrated in Figure A10-15.

### **A10.7.2 Short-Term Changes (2005–2006)**

From 2005 to 2006, overall provincial emissions increased by less than 0.2 Mt. Emissions from agricultural soils grew by 0.5 Mt but were offset by decreased emissions from off-road diesel transportation (0.3 Mt), commercial and institutional (0.2 Mt) and residential (0.2 Mt) use.

A very favourable year for crop production along with a higher consumption of synthetic nitrogen fertilizers in 2006 helped boost real GDP in agriculture by 16.2% and was attributed to the agricultural soil emission increases (Manitoba Department of Finance 2007). A poor agricultural year in 2005, which included heavy rains and flooding, depressed emissions from this sector in 2005 and thus, when compared to 2006, the year-to-year increase is surprisingly high.

Increases in road transportation emissions between 2005 and 2006 grew in response to better economic conditions for the manufacturing industries and agricultural sector. In 2006, manufacturing shipments rose 5.2%, which helped increase road transportation emissions that were also growing in comparison to 2005, thanks to favourable agricultural conditions and the opening of the United States border to cattle.

Significantly lower off-road diesel emissions (0.3 Mt) can also be attributed to the heavy rains and flooding that occurred in 2005. Increased usage of off-road vehicles and support equipment in response to the flooding likely artificially increased consumption relative to a typical year, resulting in the large decrease observed in 2006.

An almost 7% decrease in HDDs between 2005 and 2006 helped reduce emissions from the Commercial & Institutional and Residential sectors over the short term. Fewer heating degree days meant less fuel and GHG emissions required for space heating.

Short-term emission changes in Manitoba are illustrated in Figure A10-16.

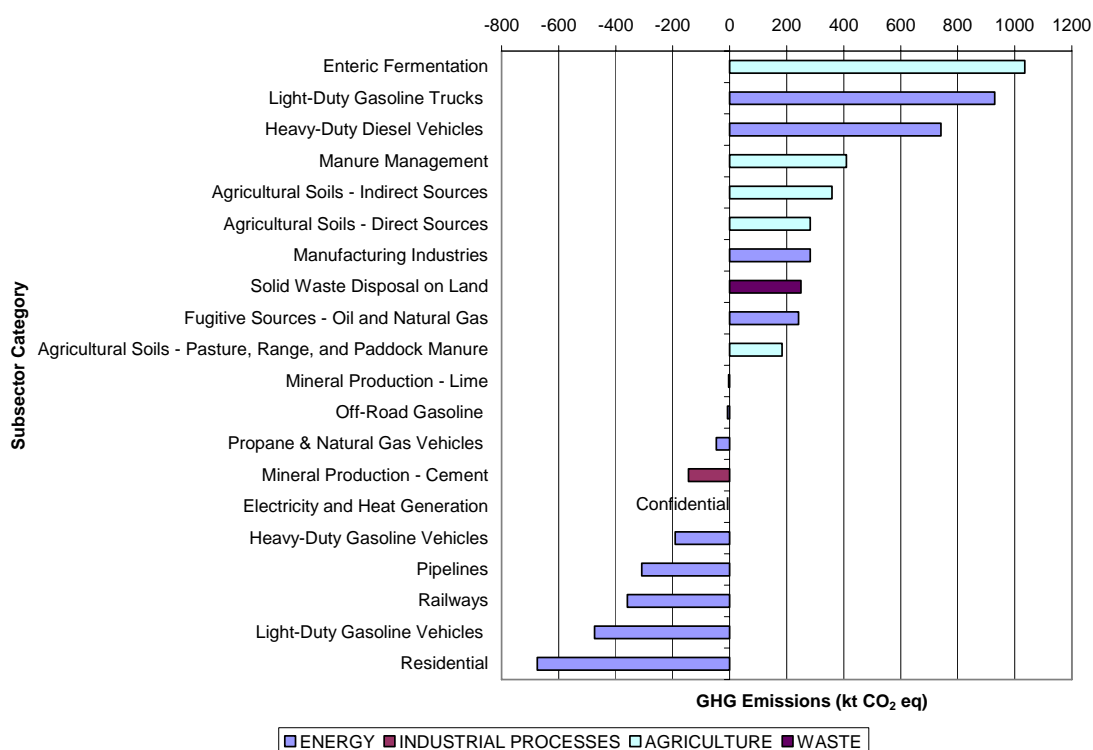


Figure A10-15: Manitoba Long-Term Emission Trends, 1990–2006

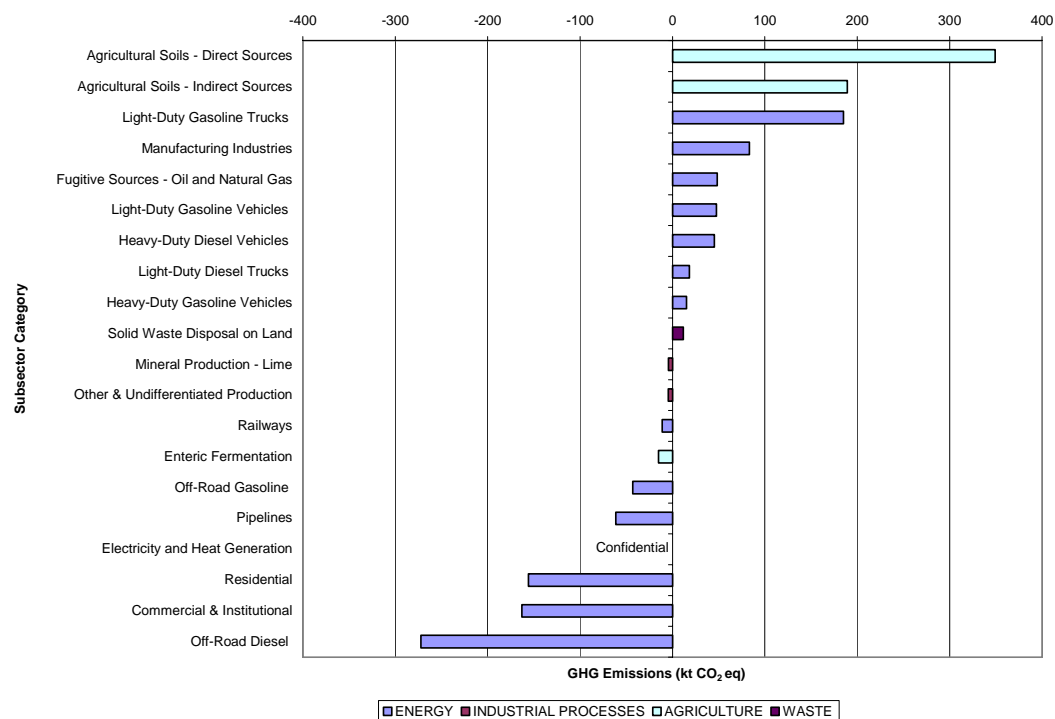


Figure A10-16: Manitoba Short-Term Emission Changes, 2005–2006

## A10.8 Saskatchewan

Table A10-8: Trends in GHG Emissions and GHG Intensity, Saskatchewan

	1990	1995	2000	2005	2006
<b>Total GHG (Mt)</b>	44.033	59.838	67.286	72.855	71.967
Growth Since 1990	NA	35.9%	52.8%	65.5%	63.4%
Annual Change	NA	4.0%	2.1%	0.8%	-1.2%
<b>GDP (millions)</b>	23 145	24 616	28 891	31 499	31 627
Growth Since 1990	NA	6.4%	24.8%	36.1%	36.7%
<b>GHG Intensity (Mt/\$B GDP)</b>	1.90	2.43	2.33	2.31	2.28
<b>GHG Efficiency (\$GDP/Kt GHG)</b>	0.53	0.41	0.43	0.43	0.44
<b>Population (000s)</b>	1 007	1 014	1 008	990	988
Growth Since 1990	NA	0.7%	0.1%	-1.7%	-1.9%
<b>GHG Per Capita (tonnes/person)</b>	43.7	59.0	66.8	73.6	72.9
<b>Energy Production (Primary only) (PJ)</b>	941 824	1 230 985	1 436 463	1 481 665	1 496 709
Growth Since 1990	NA	30.7%	52.5%	57.3%	58.9%
<b>Net Supply (Primary &amp; Secondary)(PJ)</b>	383 228	475 393	501 878	529 951	533 667
Growth Since 1990	NA	24.0%	31.0%	38.3%	39.3%
<b>Energy Use - Final Demand (Primary &amp; Secondary)(PJ)</b>	289 911	363 574	367 240	375 457	379 386
Growth Since 1990	NA	25.4%	26.7%	29.5%	30.9%
<b>Heating Degree Days</b>	5 583	5 942	5 869	5 586	5 345
Growth Since 1990	NA	6.4%	5.1%	0.1%	-4.3%

Notes:

GDP at basic prices, by North American Industry Classification System (NAICS), 1990–1996: constant 1997 dollars; 1997–2006: chained 1997 dollars.

NA = Not applicable



Saskatchewan generated 72.0 Mt GHGs in 2006 (10.1% of Canada's total), a 63% increase over 1990 and a 1.2% decrease compared with 2005 (Table A10-8). GDP output increased 37.3% between 1990 and 2006, while population declined by 1.9%. The production and export of natural resources is the true backbone of the Saskatchewan economy. About 95% of all goods produced in the province directly depend on resources like grains, potash, uranium and oil and gas (Saskatchewan Bureau of Statistics 2007). Agriculture has always been an important part of the provincial economy, although mining, forestry and the oil and gas industry have been growing in importance. With a land area of more than 650 000 km<sup>2</sup> and almost one third devoted to agricultural crops, it is not surprising that Saskatchewan produces more than half of the wheat grown in western Canada. Other important agricultural products include barley, canola, cattle, and hogs.

The relative ease with which the abundant underground natural resources can be extracted in the province has had a tremendous impact on the development of the economy. It is estimated that the province has an estimated 75% of the world's potash reserves and, as of 2002, Saskatchewan was the world's largest uranium-producing region. The province is second in Canada behind Alberta in oil and gas production, and third in coal production (Saskatchewan Energy and Resources).

Over 60% of electricity generation in the province is from coal-fired power plants, although hydro power can also provide anywhere between 14% to 32% of the total generation, depending on hydraulic conditions. The contribution of coal-fired utility generation has been decreasing since 1990, with natural gas fired stations growing in terms of their contribution to overall output (Statistics Canada 2008). Saskatchewan has also invested significantly in renewable energy. In early 2006, the 149.4-MW Centennial Wind Power Facility was commissioned, making Saskatchewan the home of the largest wind farm in Canada—until November of that year when the 189-MW Prince Wind Energy Project in Ontario became the largest facility in Canada. Regardless, over 500 GWh of electricity was generated in the province from wind energy in 2006—almost 16% of Canada's wind energy total (CanWEA 2008b).

Saskatchewan's GHG emission contribution per sector reflects the transition from Canada's central to western provinces—that is, an increasing portion of energy-related emissions, and accounting for 80% of the province's emission sources. The relatively low provincial population of less than 1 million and a resource-based economy involving the oil and gas and mining industries all contribute to Saskatchewan having the highest per capita emissions in Canada. In 2006, this translated to 72.9 t GHGs per person and 2.3 Mt GHGs per billion dollars GDP.

GHG emissions in 2006 were 28 Mt higher than in 1990. The main contributors to provincial emissions in 2006 were the Oil & Gas Sector and the Electricity and Heat Generation Sector. Fugitive emissions from oil and natural gas production contributed 17.5 Mt (or 25%) with fossil fuel production contributing 6.2 Mt (or 9%). Emissions from the Agriculture Sector also made a noticeable contribution, with enteric fermentation and agricultural soil emissions accounting for 6% and 10% of the provincial total for the year.

### **A10.8.1 Long-Term Trends (1990–2006)**

Provincial emissions grew by 28 Mt (63%) between 1990 and 2006. The Energy subsectors were the major contributors to long-term growth, specifically fugitive emissions from oil and natural gas production increasing by 11.4 Mt (189%), electricity and heat generation (confidential), and fossil fuel production increasing by 2.5 Mt (68%). Enteric fermentation emissions increased by 1.9 Mt from 1990 with mining emissions (confidential) also increasing. Minor decreases in

emissions were observed in the Residential Sector (0.4 Mt), HDGVs (0.4 Mt) and the manufacturing industries (0.3 Mt).

Saskatchewan is Canada's second largest oil producer, accounting for 32% of Canadian production (CAPP). Oil production in the province has more than doubled in the last 20 years, with natural gas expanding significantly over the same period. In 2006, over 1500 natural gas wells were drilled in the province, significantly higher than the early 1990s and slightly lower than in 2005 due to lower market prices. This significant growth is behind the large increases observed in fugitive and fossil fuel production emissions.

Electricity generation increased by 33% between 1990 and 2006. Coal-generated capacity is and remains the dominant source of electricity for the province, accounting for 60% of provincial electricity generation in 2006, down from 64% in 1990 (Statistics Canada 2008). Generation from natural gas, hydro and wind resources continues to increase although the growth in demand has played a larger role in the long-term GHG emissions increase than changes in electricity generation.

Agricultural emissions rose by 49% between 1990 and 2006. The main driver is the 61% increase in cattle population, although the 80% increase in the hog population and synthetic nitrogen fertilizer consumption also contributed.

Strong global demand for natural resources like potash and uranium has helped increase emissions from the provincial mining sector over the long term. Provincial potash production reached a record 16.6 million tonnes of muriate of potash (KC1) in 2005 with sales reaching a record \$2.7 billion for the year (Saskatchewan Bureau of Statistics 2007).

Long-term emission trends in Saskatchewan are illustrated in Figure A10-17.

### **A10.8.2 Short-Term Changes (2005–2006)**

Between 2005 and 2006 Saskatchewan's GHG emissions decreased by 0.9 Mt. There were no major fluctuations in emissions between 2005 and 2006, with all year-to-year changes at less than 1 Mt. Fugitive emissions from oil and natural gas increased the most, although only by 0.3 Mt, with HDDVs and off-road diesel vehicles both increasing by 0.1 Mt. Decreases were slightly greater, with electricity and heat generation (confidential) decreasing the most, followed by agricultural soil emissions (0.6 Mt), pipelines (0.3 Mt) and fossil fuel production (0.3 Mt).

Slightly higher fugitive emissions were observed in 2006 compared to slightly lower GHG emissions from fossil fuel production. Higher throughput at fossil fuel production facilities in 2006 contributes to higher fugitive emissions while stationary emission decreases are likely the result of increases in efficiency. Electricity generation was down in 2006 compared to 2005, due to lower demand and may also be an indicator of increasing efficiency. Lower pipeline emissions reflect decreasing demand and production of natural gas due to warmer weather.

The overall reductions in agricultural emissions (enteric fermentation and soil emissions) can be attributed to poor growing conditions experienced in the province in 2006, due to drought-like conditions and a slight decrease in the cattle population, which is likely attributed to the opening of the United States borders in 2005. Provincial crop production in 2006 was down almost 18% from 2005, and slightly below the 15-year average (Marshall and Adam Overview of the Saskatchewan Economy 2008).

Short-term emission changes in Saskatchewan are illustrated in Figure A10-18.

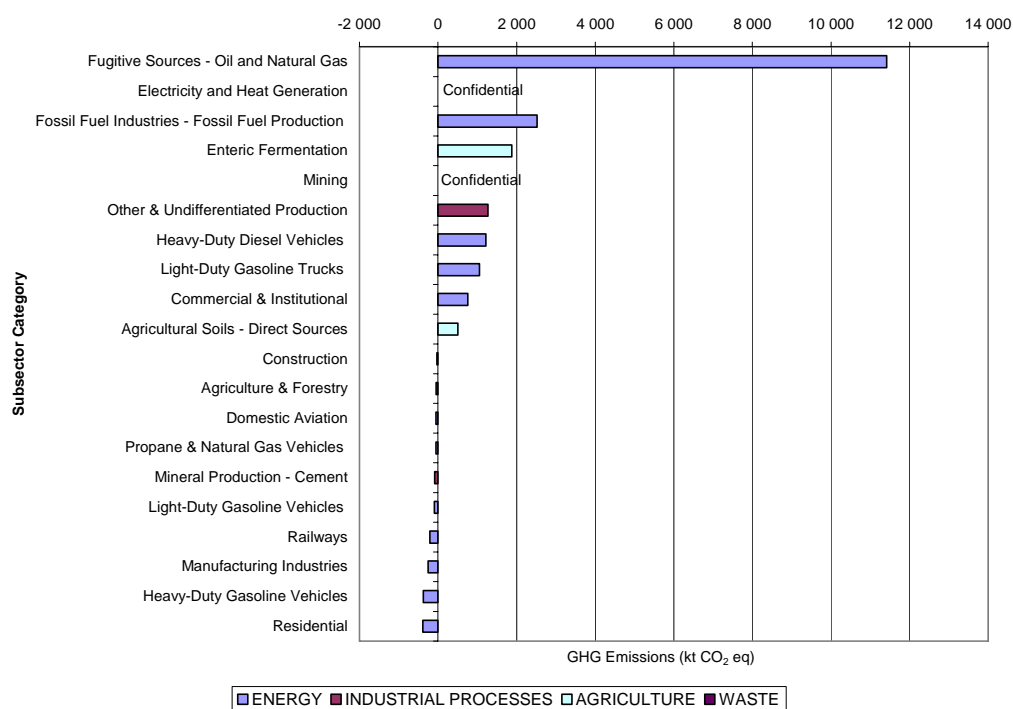


Figure A10-17: Saskatchewan Long-Term Emission Trends, 1990–2006

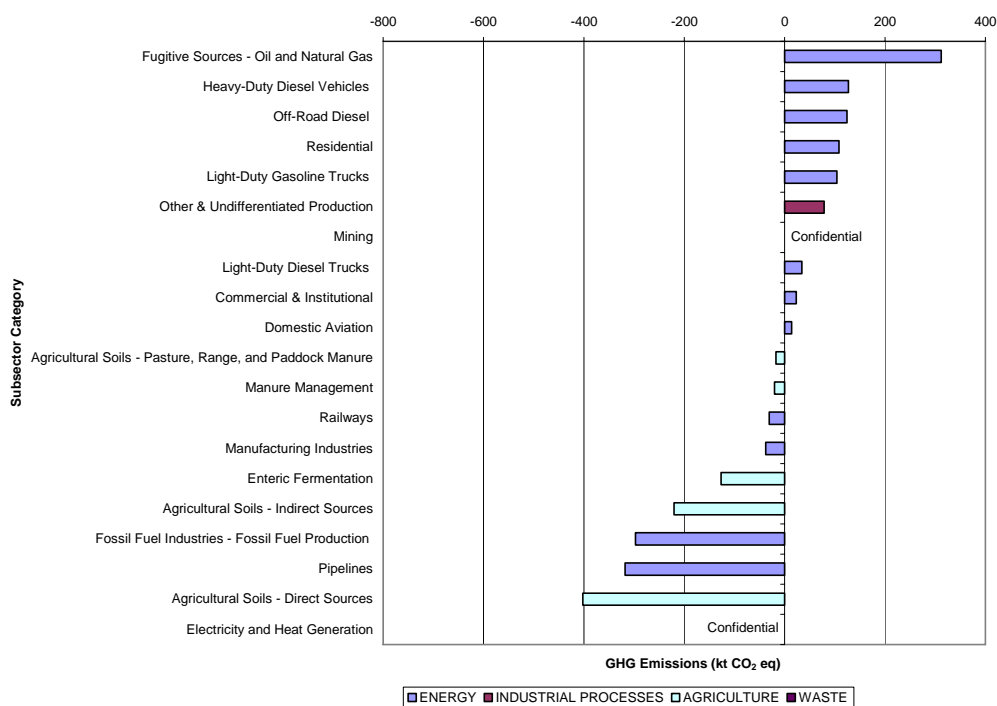


Figure A10-18: Saskatchewan Short-Term Emission Changes, 2005–2006

**A10.9 Alberta****Table A10-9: Trends in GHG Emissions and GHG Intensity, Alberta**

	1990	1995	2000	2005	2006
<b>Total GHG (Mt)</b>	171.520	200.261	226.293	230.573	234.230
Growth Since 1990	NA	16.8%	31.9%	34.4%	36.6%
Annual Change	NA	2.6%	4.1%	-1.5%	1.6%
<b>GDP (millions)</b>	76 753	92 063	116 000	136 498	145 603
Growth Since 1990	NA	19.9%	51.1%	77.8%	89.7%
<b>GHG Intensity (Mt/\$B GDP)</b>	2.23	2.18	1.95	1.69	1.61
<b>GHG Efficiency (\$GDP/Kt GHG)</b>	0.45	0.46	0.51	0.59	0.62
<b>Population (000s)</b>	2 547	2 735	3 005	3 281	3 371
Growth Since 1990	NA	7.4%	18.0%	28.8%	32.3%
<b>GHG Per Capita (tonnes/person)</b>	67.3	73.2	75.3	70.3	69.5
<b>Energy Production (Primary only) (PJ)</b>	7 705 465	9 866 812	10 443 561	10 458 394	10 866 103
Growth Since 1990	NA	28.0%	35.5%	35.7%	41.0%
<b>Net Supply (Primary &amp; Secondary)(PJ)</b>	1 760 641	1 968 538	2 290 094	2 533 839	2 591 382
Growth Since 1990	NA	11.8%	30.1%	43.9%	47.2%
<b>Energy Use - Final Demand (Primary &amp; Secondary)(PJ)</b>	954 940	1 079 912	1 236 765	1 362 234	1 401 070
Growth Since 1990	NA	13.1%	29.5%	42.7%	46.7%
<b>Heating Degree Days</b>	5 064	5 366	5 299	5 061	4 824
Growth Since 1990	NA	6.0%	4.6%	-0.1%	-4.7%

## Notes:

GDP at basic prices, by North American Industry Classification System (NAICS), 1990–1996: constant 1997 dollars;  
1997–2006: chained 1997 dollars.

NA = Not applicable.

In 2006, the province of Alberta generated 234 Mt of GHGs, 13.3% of Canada's GDP, with 10.3% of the total population. Between 1990 and 2006, GDP and GHG output increased 91.7% and 36.6% to \$147.7 billion and 234 Mt, respectively (Table A10-9). Alberta has long been known as Canada's energy province. Home to significant natural gas, crude oil and coal reserves, the province's economy has boomed thanks to growing international demand for its natural resources. When the estimated oil sands reserves are included, the province has the second largest petroleum reserves in the world, second only to Saudi Arabia (Statistics Canada 2007a). Forestry and agriculture are two other key parts of this diverse, resource-rich economy. The strength of the resource sector has helped support a vibrant and diverse manufacturing industry, a sector that includes chemical/petrochemical products, petroleum refining, food processing and forest products.

The Alberta economy has been the key factor behind Canada's economic growth for at least the past 5 years. In 2006, the resource boom (that is, the rise in commodity prices) entered its fifth year. Energy, primary metals and agricultural products all benefit from higher prices and helped in the increasing valuation of the Canadian dollar. In mid-2006, oil prices hit a record of \$78.40 (US) a barrel, a 30% increase from the start of the year, and was one of the underlying factors for increases in oil sands investment. In 2006, oil sands investment was almost \$12 billion, more than twice the \$5.2 billion invested in 2003 when the surge in oil prices began. Oil sands investment was also spurred by steadily declining conventional crude oil production, a result of the depletion of the highly productive conventional oil wells in the Western Canada Sedimentary Basin (Statistics Canada 2007a; Alberta Finance and Enterprise 2007).

For a province with such significant coal and limited hydropower resources, it is not surprising to find that the majority of electricity is generated from coal-fired generating stations. Unlike many other provinces, Alberta's landlocked location means that hydroelectric resources are difficult or uneconomic to access and therefore hydro generates a small percentage of the total for the province. Electricity in Alberta is not solely fossil fuel-based, however. Although landlocked, Alberta's location on the leeward side of the Rocky Mountains means it has excellent wind and solar resource potential. This resulted in the province installing the first commercial wind farm in Canada in 1993 while continuing to lead the way in installed wind capacity.

Alberta provided a remarkable 65% of Canada's primary energy production in 2006. Due to the lack of significant hydro generation, this results in the province having the second highest GHG emission per capita, at 69.5 t GHG per person. The province's total GHG emissions are dominated by emissions related to energy. In 2006, the main contributors were electricity and heat generation (54 Mt, or 23%), fossil fuel production (40 Mt, or 17%), oil and natural gas fugitive emissions (37 Mt, or 16%) and mining (11 Mt, or 5%). In 2006, Alberta accounted for 21.6% of all farms in Canada and 40% of all Canadian cattle. Alberta's total gross farm receipts were \$9.9 billion in 2005, while operating expenses reached \$8.8 billion. Alberta generates 31.5% of Canadian agricultural GHG emissions.

### **A10.9.1 Long-Term Trends (1990–2006)**

Between 1990 and 2006, GHG emissions increased by 62.7 Mt, predominantly driven by increases from electricity and heat generation (13.7 Mt), mining (9.0 Mt), fossil fuel production (8.5 Mt), and fugitive sources from the oil and natural gas industry (8.3 Mt), all of which are constituents of the Energy Sector. As for the non-energy-related subsectors, the Other (Undifferentiated Production subsector (comprised primarily of petrochemical process emissions) showed an increase of 4.1 Mt, while enteric fermentation emissions increased by 3.2 Mt from 1990. Decreases over the long term have been limited to combustion emissions from manufacturing industries (2.4 Mt) and gasoline automobiles (0.9 Mt).

With long-term population growth of over 32%, combined with a booming resource sector, has resulted in increased demand for electricity and subsequently generation. In fact, generation emissions increased by 34% while electricity generation increased by 40%. Due to its very small hydro-electric capacity, readily available GHG-intense fossil fuels are the predominant fuel source, with coal generating over 83% of the electricity in the province in 2006 (Statistics Canada 2008). The growth of the Oil & Gas Sector has been the predominant reason behind increased electrical demand, while population growth has also played a role.

The oil and gas industry has been booming since oil sands exploration and extraction became financially viable in the late 1990s. Rising crude oil prices over the last 5 years has maintained the industry and helped its expansion all while demand for final products has risen steadily both domestically and internationally (Statistics Canada, 2007a). Due to data aggregation, some of the emissions associated with oil sands mining are included in the mining industry total. As a result, the second, third and fourth largest long-term increases can be attributed in whole or in part to the Oil & Gas Sector.

Many of the industries and subsectors that make up the manufacturing industries category have shown long-term increases. These increases have been offset by a 3.5 Mt decrease in emissions from the Other Manufacturing subsector. The exact cause of this significant decrease is difficult to explain with certainty; however, it would be reasonable to assume that shifts in the provincial

economic structure are the most likely cause, as this subsector includes a wide and diverse set of industries.

Methane emissions from enteric fermentation increased by 3.2 Mt since 1990, due mainly to the 44.5% expansion of the cattle industry because of growing demand by the United States market.

Long-term emission trends in Alberta are illustrated in Figure A10-19.

### **A10.9.2 Short-Term Changes (2005–2006)**

Emissions increased by 3.7 Mt between 2005 and 2006. The increase was the result of higher emissions from Electricity and Heat Generation (1.4 Mt), Off-road Diesel (0.8 Mt), HDDVs (0.6 Mt), and Pipelines (0.5 Mt). Offsetting these increases were decreases in the Manufacturing Industries (0.8 Mt), Enteric Fermentation (0.3 Mt) and Commercial & Institutional (0.2 Mt).

A continued increase in electricity generation and demand was the main factor behind the increase in emissions. Between 2005 and 2006, electricity generation increased by 1.6% although more electricity (and heat) was generated using natural gas than coal in 2006—largely on the industrial side. Wind-powered electricity also increased in 2006, although this resource has an insignificant effect on total generation and GHG emissions (Statistics Canada 2008).

The short-term increase in off-road diesel and HDDV emissions reflect support to the Oil & Gas Sector, as the Alberta economy remains red-hot. GDP increased by 6.7% in 2006, compared to 5.0% in 2005 and population grew by 2.7% in 2006 compared to 2.3% in 2005. Demand for goods and services to support the Oil & Gas Sector and the growing population are reflected in increased road transportation emissions.

Strong demand for oil and gas products on the export market has resulted in pipeline capacity being severely strained. Since the majority of fossil fuels in Alberta are exported via pipeline, as fossil fuel production increases, so do pipeline emissions to move commodities (NEB 2007). As new pipelines are constructed to ease congestion, emissions are expected to continue to rise even while efficiency gains are realized.

As observed in the long-term trends, decreases in GHG emissions from the manufacturing industries are largely due to the effect of the other manufacturing subsector. Decreases in commercial and institutional emissions can be attributed to lower heating requirements as HDDs decreased by 4.7% between 2005 and 2006.

Agricultural emissions from enteric fermentation are mainly the result of decreases in the dairy and beef cattle population. The re-opening of the United States border to cattle in March 2005 helped reduce the population, driving down enteric fermentation as exports of livestock products increased in 2006. The United States–Canadian border was closed to beef imports in 2003 when bovine spongiform encephalopathy (BSE) was detected and Canadian exports were severely restricted.

Short-term emission changes in Alberta are illustrated in Figure A10-20.

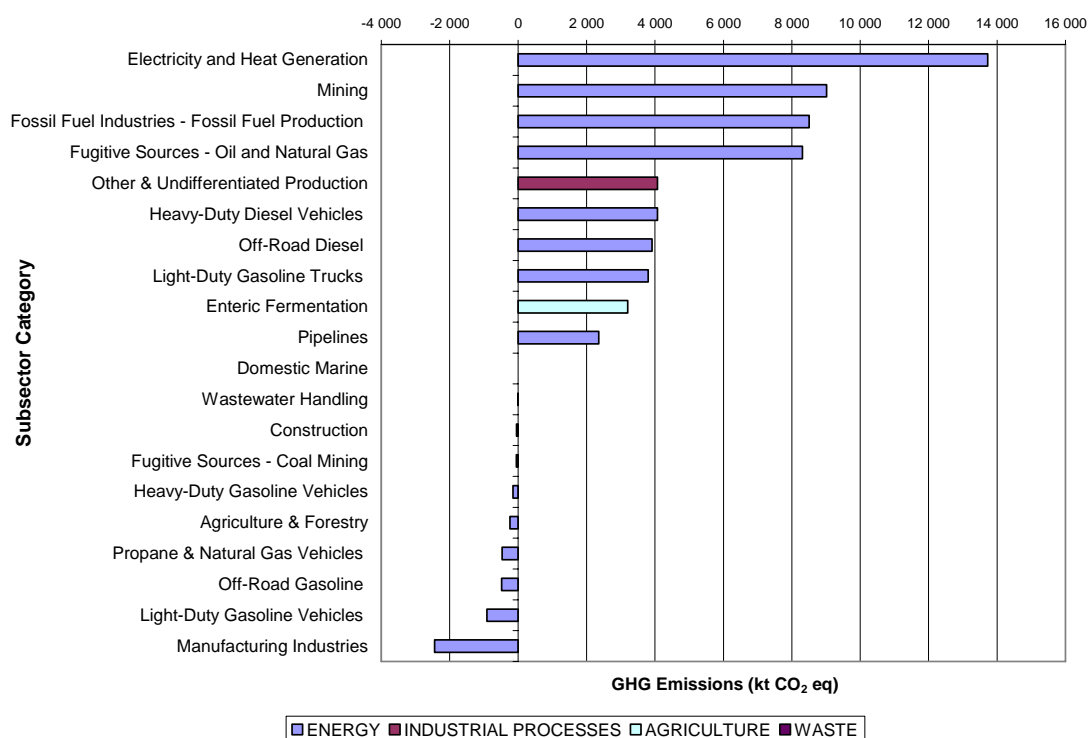


Figure A10-19: Alberta Long-Term Emission Trends, 1990–2006

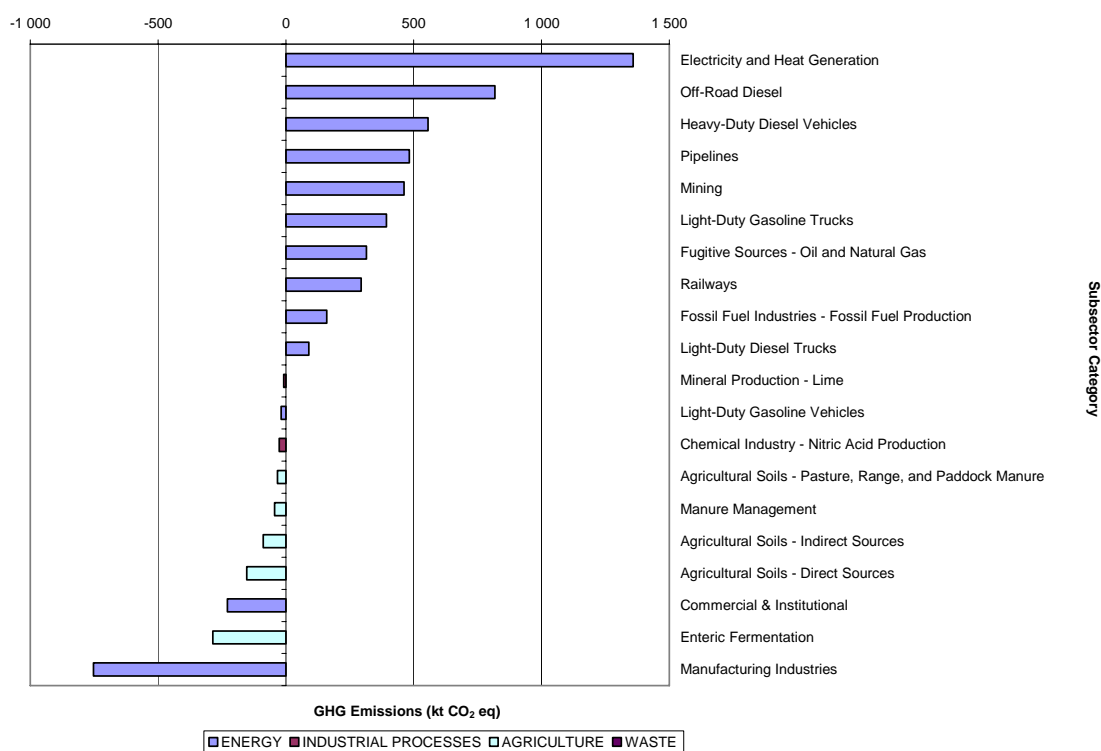


Figure A10-20: Alberta Short-Term Emission Changes, 2005–2006

**A10.10 British Columbia****Table A10-10: Trends in GHG Emissions and GHG Intensity, British Columbia**

	1990	1995	2000	2005	2006
<b>Total GHG (Mt)</b>	48.870	57.150	61.261	64.361	62.318
Growth Since 1990	NA	16.9%	25.4%	31.7%	27.5%
Annual Change	NA	8.3%	1.8%	-1.8%	-3.2%
<b>GDP (millions)</b>	83 920	99 129	113 919	131 139	136 050
Growth Since 1990	NA	18.1%	35.7%	56.3%	62.1%
<b>GHG Intensity (Mt/\$B GDP)</b>	0.58	0.58	0.54	0.49	0.46
<b>GHG Efficiency (\$GDP/Kt GHG)</b>	1.72	1.73	1.86	2.04	2.18
<b>Population (000s)</b>	3 291	3 777	4 039	4 260	4 320
Growth Since 1990	NA	14.8%	22.7%	29.5%	31.3%
<b>GHG Per Capita (tonnes/person)</b>	14.9	15.1	15.2	15.1	14.4
<b>Energy Production (Primary only) (PJ)</b>	1 486 548	1 787 821	1 911 290	2 165 263	2 047 823
Growth Since 1990	NA	20.3%	28.6%	45.7%	37.8%
<b>Net Supply (Primary &amp; Secondary)(PJ)</b>	862 850	962 253	1 039 610	1 077 826	1 052 144
Growth Since 1990	NA	11.5%	20.5%	24.9%	21.9%
<b>Energy Use - Final Demand (Primary &amp; Secondary)(PJ)</b>	740 892	840 332	926 272	904 138	882 432
Growth Since 1990	NA	13.4%	25.0%	22.0%	19.1%
<b>Heating Degree Days</b>	2 911	2 598	2 903	2 694	2 725
Growth Since 1990	NA	-10.8%	-0.3%	-7.5%	-6.4%

Notes:

GDP at basic prices, by North American Industry Classification System (NAICS), 1990–1996: constant 1997 dollars; 1997–2006: chained 1997 dollars.

NA = Not applicable.

In 2006, British Columbia's 4.3 million residents generated a total of 62.3 Mt of GHGs (Table A10-10) and contributed \$135.8 billion to the country's GDP. This represents 8.7% of Canada's total GHG emissions and 12.3% of the total GDP. Between 1990 and 2006, the province's total emissions increased 13.4 Mt (27.5%), while GDP and population increased 60.5% and 31%, respectively.

Historically known for forestry and mining, British Columbia's resource-based economy has matured in recent years. The diversification into many non-resource activities was partly out of necessity, as variability in international markets for natural resources has shown significant fluctuation over the years. For example, at present only about 9% of workers in the province have jobs in natural resource industries, down from 13% in 1990 (B.C. Ministry of Advanced Education 2006). Regardless, forestry, primary metals (copper, gold, and zinc), mining and oil and gas (coal, petroleum and natural gas) continue to play an important role in the economy as do fishing and agriculture.

British Columbia's location has made it the gateway to Asia. Growing global demand for natural resources has lifted resource prices in recent years while dampening prices for domestically manufactured goods. These lower prices have been exacerbated by a strengthening Canadian dollar. Growth in the Mining and Oil & Gas sectors have helped to stabilize the province's economy, which felt the effects of lower United States demand for lumber and pulp and paper. Domestically, the construction industry has been positively affected by the impending 2010 Olympics, while the goods-handling industries have also benefited from increased national trade with Asia (BC Stats 2007; British Columbia Ministry of Finance 2007).



British Columbia is rich in hydroelectric power. More than 90% of the electricity generated in British Columbia is from hydro, with most of the remainder provided by natural gas-powered generators (Statistics Canada 2008). The province has taken advantage of its position and interconnections with Alberta and the northwestern United States to become an important and profitable electricity exporter. The province's significant hydroelectric capacity allows it to take advantage of energy banking, where power is imported during off-peak times to replenish hydro reservoirs for use during high-peak times. As with most provinces with a significant pulp and paper industry, biomass is also used for power production, although it adds little to the total supply. British Columbia is one of the only regions in Canada that does not have any commercial wind farms for electricity supply.

British Columbia's annual GHG generation rate, at 14.4 t GHGs per person in 2006, is slightly below what it was in 1990 (14.9 t GHGs per person), and its GHG per GDP equalled 460 kt per billion dollars in 2006. British Columbia is one of the lowest per capita emitters, ranked tenth, behind the Yukon and ahead of P.E.I.

A review of British Columbia's sector-specific emissions shows that, in 2006, 86% of GHG emissions arose from the Energy Sector. The majority of the province's 62.3 Mt of emissions in 2006 were from fossil fuel production (7.4 Mt), oil and natural gas fugitives (6.1 Mt), manufacturing industries (5.3 Mt), LDGTs (4.9 Mt) and HDDVs (4.6 Mt).

#### **A10.10.1 Long-Term Trends (1990–2006)**

Over the long term, provincial emissions rose by 13.4 Mt (27.5%). This long-term growth was the result of growth in the fossil fuel industries (3.7 Mt), oil and natural gas fugitive emissions (3.2 Mt), LDGTs (2.7 Mt) and HDDVs (2.1 Mt). Decreasing emissions from railways (1.0 Mt), manufacturing industries (0.7 Mt), propane & natural gas vehicles (0.6 Mt) and aluminum production (0.5 Mt) helped slow long-term emissions growth.

British Columbia is Canada's second largest natural gas producer, accounting for 17% of production in 2006 (CAPP), with production up significantly from 1990. The province's fossil fuel industry has grown significantly since 1990, and when combined with strong demand over the last decade, has resulted in significantly higher GHG emissions from this sector.

Population growth and the switch to LDGTs (e.g. SUVs, vans and pickups) from gasoline vehicles has also helped increase emissions since 1990. This pattern has been observed across the country as older vehicles are replaced. Increased emissions from HDDVs are likely the result of decreasing railway emissions, as the transportation of goods and services moves from rail cars to transport trucks, thanks in part to increased international trade with the Pacific Rim. The increased use of these vehicles in the fossil fuel industry also plays a role in the observed long-term emissions growth.

Emissions from the manufacturing industries are down only slightly, mainly due to significant reductions in GHG emissions from the Pulp, Paper & Print subsector offsetting increases in other subsectors, most notably in other manufacturing, cement and mining. Strong demand, both external and domestic, and high commodity prices helped increase the province's GDP by 60.5% from 1990 even though British Columbia's Pulp and Paper Sector felt the effects of a drop in demand and increasing global competition. Many subsectors of the other manufacturing category (such as metal fabrication and food processing) experienced strong growth in 2006 as exports to the Pacific Rim increased while exports to the United States decreased (BC Stats 2007; Statistics Canada 2007a).

Long-term emission trends in British Columbia are illustrated in Figure A10-21.

### **A10.10.2 Short-Term Changes (2005–2006)**

Between 2005 and 2006, British Columbia's GHG emissions decreased by 2.0 Mt (3.2%). The decrease was led by lower year-to-year emissions from fossil fuel production (0.9 Mt), manufacturing industries (0.8 Mt), off-road diesel (0.4 Mt) and pipelines (0.2 Mt). Growth was led by emissions from mining (0.4 Mt), oil and natural gas fugitives (0.4 Mt) and HDDVs (0.2 Mt).

Softening demand and lower prices for natural gas in 2006 were the most likely reasons for lower emissions from the fossil fuel production subsector. Natural gas and crude oil production decreased by 2% and 4.2%, respectively (Statistics Canada, 2007b) after record production in 2005. Softer demand and lower prices for natural gas also helped reduce emissions from pipeline; the value of oil and natural gas production decreased by 21.4% in 2006 (BC Stats, 2007 and BC Ministry of Finance, 2007).

Decreasing emissions from the Other Manufacturing subsector were mainly responsible for the decrease observed in the manufacturing industries. Growth in the metallic mineral products subsector is the likely main driver of growth in Other Manufacturing as the value of these exports rose by 32.5% in 2006 (BC Stats 2007). Decreases were observed in motor vehicle exports, and scientific, photographic and other technical equipment. The shift in the types of industries in this catch-all category has significant impacts on emissions as some are fossil fuel-intensive, while others can be more electricity-intensive and thus open to higher efficiency gains that can reduce GHGs.

The increase in emissions from the mining, oil and natural gas fugitives and HDDVs is indicative of strong demand and high prices for natural resources and commodities. The combination of rising prices for base metals (particularly copper and precious metals) and strong demand from the Pacific Rim (most notably China) helped increase investment and production in the mining and associated subsectors (Statistics Canada 2007a).

Short-term emission changes in British Columbia are illustrated in Figure A10-22.

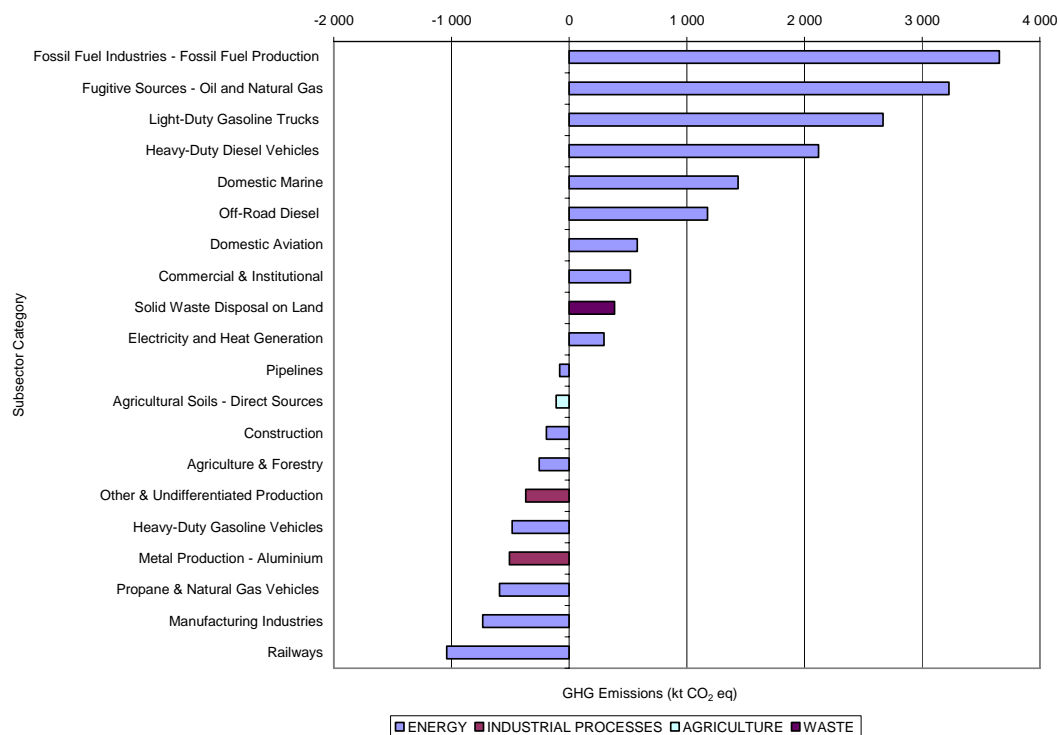


Figure A10-21: British Columbia Long-Term Emission Trends, 1990–2006

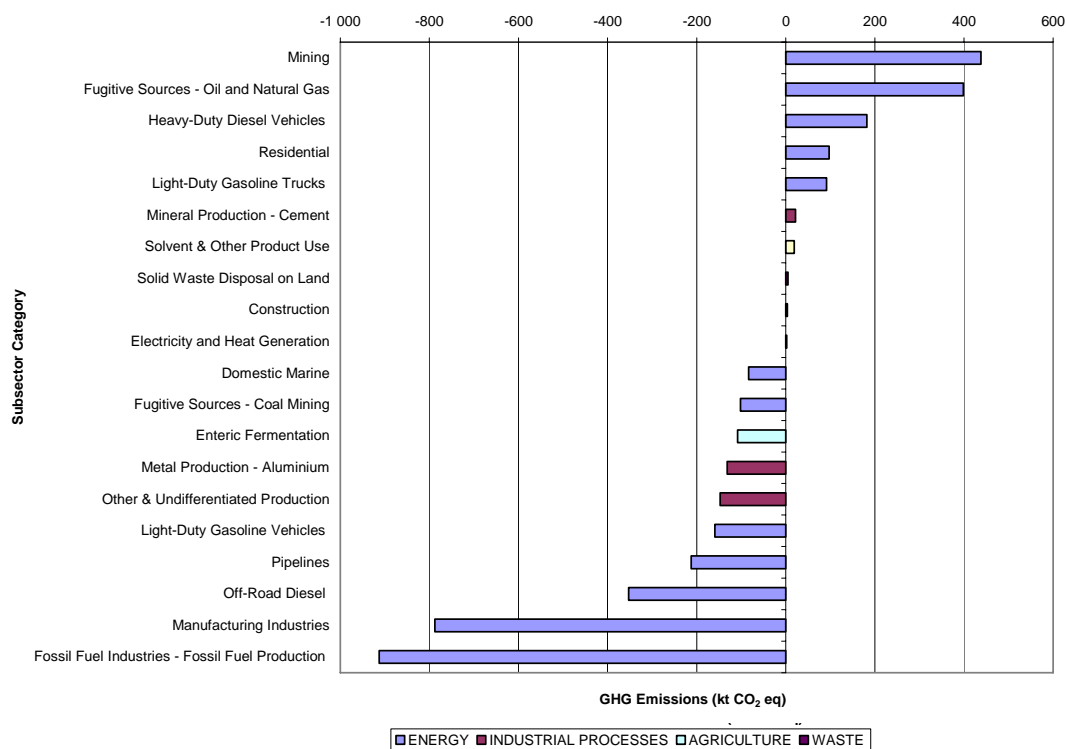


Figure A10-22: British Columbia Short-Term Emission Changes, 2005–2006

**A10.11 Yukon, Northwest Territories, and Nunavut****Table A10-11: Trends in GHG Emissions and GHG Intensity, Total Territories**

	1990	1995	2000	2005	2006
<b>Total GHG (Mt)</b>	2.02	2.38	2.03	1.40	1.68
Growth Since 1990	NA	17.9%	0.4%	-30.6%	-16.8%
Annual Change	NA	7.6%	11.7%	-31.4%	19.9%
<b>GDP (millions)</b>	3 270	3 386	4 073	5 980	6 150
Growth Since 1990	NA	3.5%	24.5%	82.9%	88.1%
<b>GHG Intensity (Mt/\$B GDP)</b>	0.62	0.70	0.50	0.23	0.27
<b>GHG Efficiency (\$GDP/Kt GHG)</b>	1.62	1.42	2.01	4.26	3.65
<b>Population (000s)</b>	87	97	98	104	104
Growth Since 1990	NA	11.7%	13.5%	19.7%	20.0%
<b>GHG Per Capita (tonnes/person)</b>	23.3	24.6	20.6	13.5	16.2
<b>Energy Production (Primary only) (PJ)</b>	84 872	96 288	104 375	71 202	62 298
Growth Since 1990	NA	13.5%	23.0%	-16.1%	-26.6%
<b>Net Supply (Primary &amp; Secondary)(PJ)</b>	28 654	34 489	28 969	27 644	25 463
Growth Since 1990	NA	20.4%	1.1%	-3.5%	-11.1%
<b>Energy Use - Final Demand (Primary &amp; Secondary)(PJ)</b>	24 688	29 439	24 485	24 740	23 200
Growth Since 1990	NA	19.2%	-0.8%	0.2%	-6.0%
<b>Heating Degree Days</b>	7 967	7 414	7 263	6 891	7 124
Growth Since 1990	NA	-6.9%	-8.8%	-13.5%	-10.6%

Notes:

GDP at basic prices, by North American Industry Classification System (NAICS), 1990–1996: constant 1997 dollars; 1997–2006: chained 1997 dollars.

NA = Not applicable.

In 1990 (the NIR base year), there were only two territories in Canada—Yukon (YT) and the Northwest Territories (NWT). However, in 1999, Nunavut (NU) was created from the NWT. Due to data limitations, it is not possible to present economic indicators for each territory separately. Together, Canada's territories contributed 1.7 Mt (Table A10-11) or 0.3% to the national GHG total and \$6.15 billion to the national GDP in 2006. The following discussion presents GHG emissions for Yukon and the combined territories of NWT and NU.

**Table A10-12: Trends in GHG Emissions, Yukon**

	1990	1995	2000	2005	2006
<b>Total GHG Emissions (Mt)</b>	0.54	0.55	0.45	0.40	0.39
Annual Change (%)	NA	14.7	-18.6	-10.6	-1.0
Growth Since 1990 (%)	NA	1.7	-17.2	-26.0	-26.7

Note: NA = Not applicable.

Economic development in the Yukon has been closely linked to the mining industry for more than a century. The impact of mining has been decreasing, with oil and gas development, tourism and public administration growing in importance. The mining sector declined significantly in the late 1990s and early 21st century, although high mineral prices are leading to increases in both mineral and oil and gas exploration. The only hydrocarbon production in the Yukon comes from the Kotaneelee field, with raw natural gas shipped via pipeline for processing in neighbouring British Columbia (Yukon Dept. of Energy, Mines, and Resources).

Utility electricity generation in Yukon is mostly hydro-based with diesel generators used for back-up purposes. There are also two wind turbines installed near Whitehorse, the first turbine being installed in 1993.

Yukon, with a GHG emission total for 2006 of 0.4 Mt (Table A10-12), has shown a 27% reduction since 1990, most of which is due to reductions in combustion emissions from Electricity and Heat Generation, the Commercial & Institutional subsector and gasoline automobiles. While total emissions went down, there were increases in emissions from fossil fuel industries and in transportation-related emissions, primarily HDDVs used to transport goods and support the fossil fuel industry.

The long-term increase in fossil fuel industry emissions is mainly from the natural gas collection and transportation facility, which transports raw natural gas via pipeline to British Columbia for further processing.

Since 1990, Yukon's population has increased by 12%, while per capita emissions have decreased from 19.4 to 12.6 t GHG per person. Yukon is now one of the lowest per capita GHG emitters in Canada, behind only Quebec.

**Table A10-13: Trends in GHG Emissions, Northwest Territories and Nunavut**

	1990	1995	2000	2005	2006
<b>Total GHG Emissions (Mt)</b>	1.49	1.84	1.58	1.01	1.29
Annual Change (%)	NA	5.7	19.7	-38.4	28.2
Growth Since 1990 (%)	NA	23.8	6.7	-32.3	-13.2

Note: NA = Not applicable.

The Territory of Nunavut ("our land" in Inuktitut) was created in 1999 when the Northwest Territories was split into a western part (still known as the Northwest Territories) and an eastern part. Prior to 1999, the entire area's GHG emissions were reported as the Northwest Territories exclusively. The following discusses the Northwest Territories and Nunavut separately, where possible.

The impact of natural resource extraction has been growing in the Northwest Territories and Nunavut since 1990. Diamond mining has been the biggest contributor to growth in the economy, with oil and gas extraction also a noteworthy part of the Northwest Territories economy. The first Northwest Territories diamond mine began production in 1998 with a second mine completed in 2003. Construction commenced on a third diamond mine in 2005, with an expected completion date of 2007 (Northwest Territories Industry, Tourism and Investment 2006). In Nunavut, the first new diamond mine in the area in over 25 years opened in 2006, although three gold, lead and zinc mines closed between 2002 and 2004 (Sakku Investments Corporation 2006).

Electricity in the Northwest Territories is primarily hydro-based with diesel supplying most of the remainder. Since 1990, the utility has made significant improvements to reduce diesel consumption and increase hydro capacity. There has also been an increase in natural gas-fired generation (NWTPC 2006). All electrical power generation in Nunavut is diesel-powered, while all buildings are heated with fuel oil. The remoteness of some communities and lack of roads means that air transport is in some cases the primary means of travel.

The Northwest Territories and Nunavut generated approximately 1.3 Mt of GHGs in 2006 (Table A10-13). This is a 13.2% decrease from 1990 and has been driven mainly by decreases in the

commercial and institutional and fossil fuel industries. Unsurprisingly, considering the long distances between industry and population centres, HDDV and off-road diesel emissions offset the reductions. Since 1990, the combined population of these regions has increased 24% to almost 73 000, while GHG emissions per capita registered 17.7 t in 2006, a 30% decrease from 1990.

The magnitude of the emissions makes discussion of short-term changes difficult, as both uncertainty and variability in reported data may have higher effects than economically driven inter-annual changes.

Long-term emission trends in Yukon and in the Northwest Territories and Nunavut are illustrated in Figure A10-23 and Figure A10-24, respectively. Short-term emission changes in Yukon and in the combined Northwest Territories and Nunavut are illustrated in Figure A10-25 and Figure A10-26, respectively.

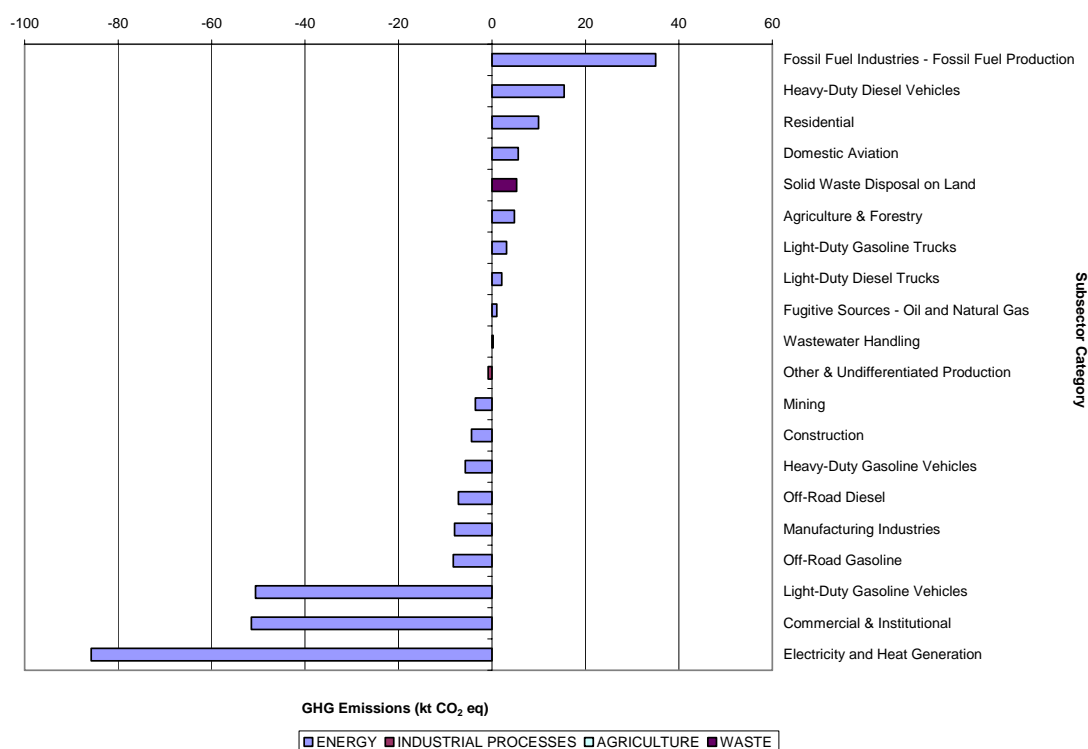


Figure A10-23: Yukon Long-Term Emission Trends, 1990–2006

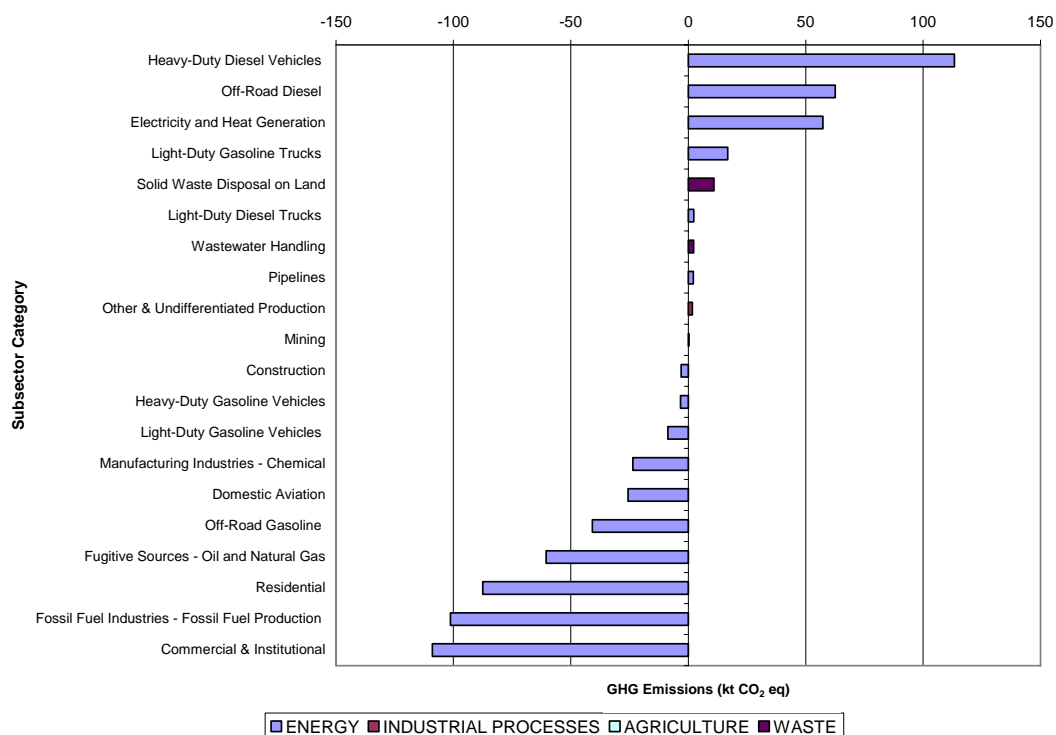


Figure A10-24: Northwest Territories and Nunavut Long-Term Emission Trends, 1990–2006

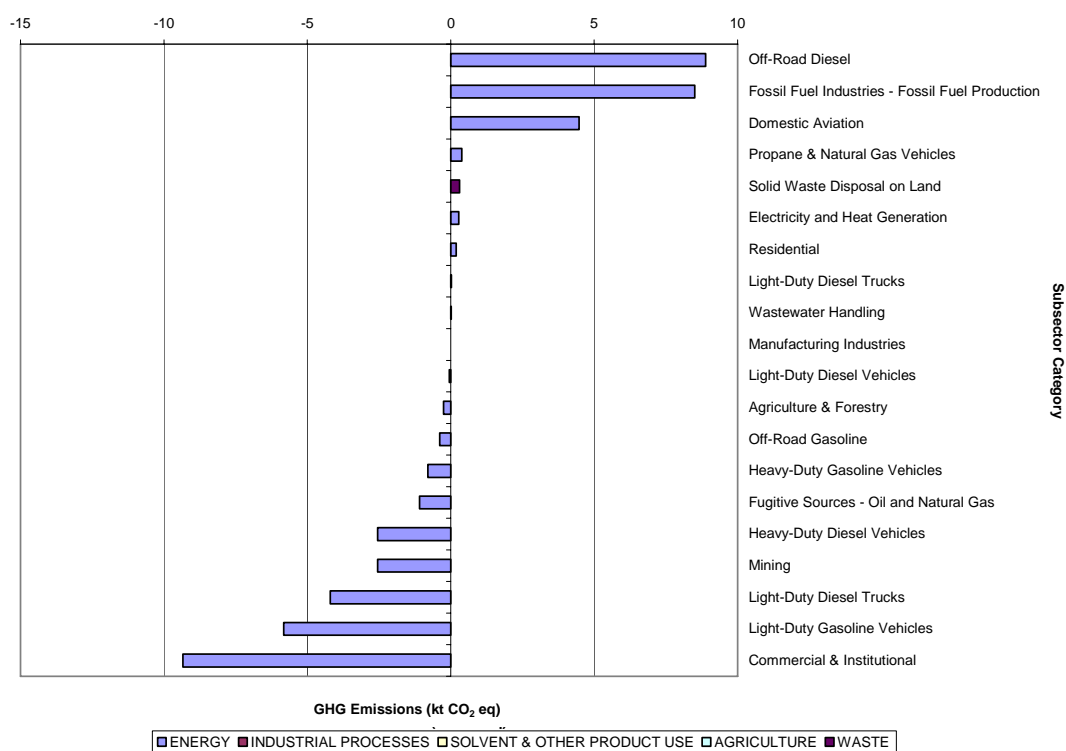


Figure A10-25: Yukon Short-Term Emission Changes, 2005–2006

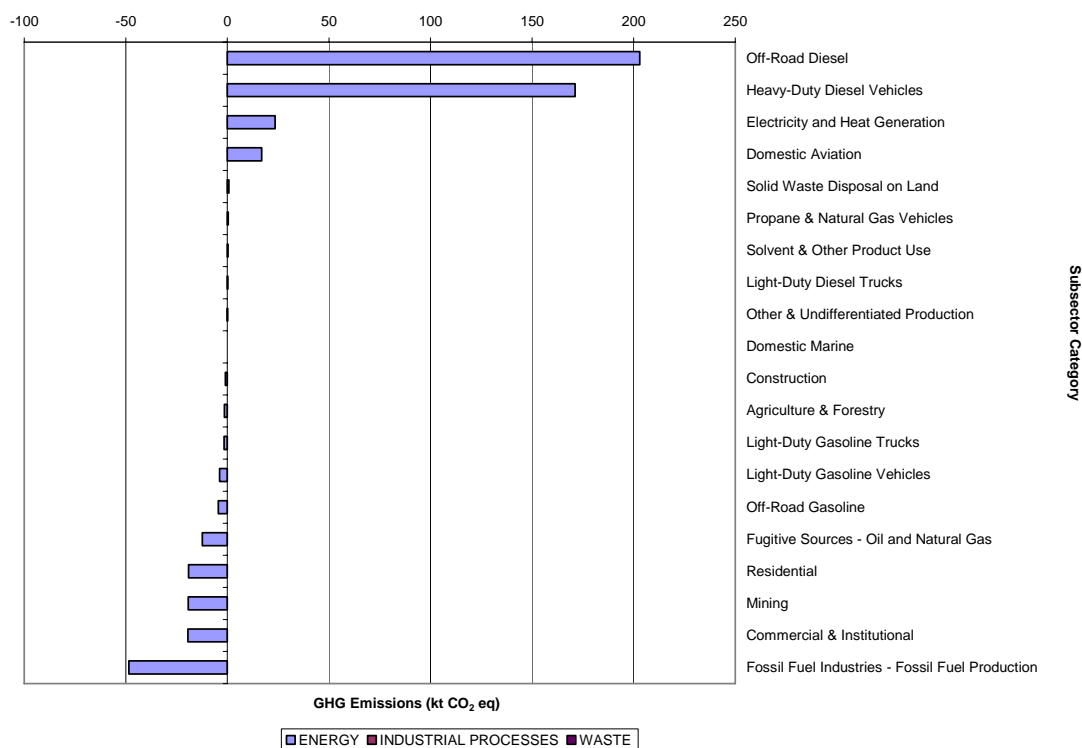


Figure A10-26: Northwest Territories and Nunavut Short-Term Emission Changes, 2005–2006

## References

- Air Products and Chemicals Inc. 2005. Air Products Announces Expected Financial Impact of Recent Hurricanes. News release September 27, 2005. Lehigh Valley (PA). Available online at: <http://www.airproducts.com/PressRoom/CompanyNews/Archived/2005/27Sept05d.htm>
- Alberta Agriculture and Food. 2007. Agriculture Statistics Yearbook 2006. Edmonton (AB). September 2007.
- Alberta Finance and Enterprise. 2007. Economic Outlook – 2006 in Review. Edmonton (AB).
- [AAC] Aluminum Association of Canada. Development of aluminum production in Canada since 1960. [undated; accessed 25/03/2008]. Available online at: [http://www.aac.aluminium.qc.ca/frameset/index\\_en.html](http://www.aac.aluminium.qc.ca/frameset/index_en.html)
- Barrasso Grace. (2006). On the Road Towards Sustainability. Presentation at the CEC Meeting. November 2006.
- BC Stats. 2006. Exports – September 2006. BC Ministry of Labour and Citizens' Services.
- BC Stats. 2007. Exports – October 2007. BC Ministry of Labour and Citizens' Services.
- British Columbia, Ministry of Finance, 2007. 2007 British Columbia Financial and Economic Review – 67<sup>th</sup> Edition (Revised October 18, 2007). Victoria (BC).



British Columbia. Ministry of Advanced Education. 2006. A Guide to the B.C. Economy and Labour Market. Victoria (BC).

[CNSOPB] Canada-Nova Scotia Offshore Petroleum Board. 2007. 2006–2007 Annual Report. Halifax (NS).

[CAPP] Canadian Association of Petroleum Producers. Industry Facts and Information – Saskatchewan, accessed April 29 2008. [http://www.capp.ca/default.asp?V\\_DOC\\_ID=677](http://www.capp.ca/default.asp?V_DOC_ID=677)

[CCPA] Canadian Chemical Producers' Association. 2006. CCPA's 2005 Year-End Survey, Catalyst, volume 3, number 1. Spring 2006.

[CCPA] Canadian Chemical Producers Association. 2006 Year End Survey of Business Conditions in the Basic Chemicals and Resins Industry.

[CanWEA] Canadian Wind Energy Association. 2008a. Canada's Current Installed Capacity. [revised 29/01/2008; accessed 08/02/2008]. Available online at: [http://www.canwea.ca/images/uploads/File/fiche\\_a\\_29\\_janv\\_08.pdf](http://www.canwea.ca/images/uploads/File/fiche_a_29_janv_08.pdf)

[CanWEA] Canadian Wind Energy Association. 2008b. List of Wind Farms. [revised 29/01/2008; accessed 06/02/2008]. Available online at: [http://www.canwea.ca/production\\_stats.cfm](http://www.canwea.ca/production_stats.cfm)

CBC News Online. 2006. Indepth: Softwood Lumber Dispute. [Dated August 23, 2006; accessed 06/02/2008]. Available online at: [http://www.cbc.ca/news/background/softwood\\_lumber/](http://www.cbc.ca/news/background/softwood_lumber/)

[CLD] Coalition of Large Distributors. 2007. "Shifting into future gear" – Progress Report 2006.

Emera. 2007. 2006 Annual Financial Report. Halifax (NS).

[EDC] Export Development Canada. 2006. "New Brunswick exports among best in country, says EDC." News Release. Available online at: [http://edc.ca/english/docs/news/2006/mediaroom\\_10957.htm](http://edc.ca/english/docs/news/2006/mediaroom_10957.htm)

Finances Quebec. 2006. 2006–2007 Budget Plan. Québec City (QC).

Hydro Quebec. 2007. 2006 Annual Report. Montréal (QC).

Independent Electricity System Operator. 2007. 2006 Annual Report. Toronto (ON).

Industry Canada. Chemical Trade Data by Industry. [undated; accessed 26/03/2008]. Available online at: <http://www.ic.gc.ca/epic/site/tldo-dcd.nsf/en/Home>

Laperrière J. 2004. Personal communication (email dated October 27, 2004). Head of Environment, Norsk Hydro. Bécancour (QC).

Manitoba Department of Finance. 2007. Budget 2007 – Budget Paper A – The Economy. Winnipeg (MB).

Manitoba Hydro. 2006. The Manitoba Hydro-Electric Board 55<sup>th</sup> Annual Report for the year ended March 31, 2006. Winnipeg (MB).

Manitoba Science, Technology, Energy and Mines. Manitoba Ethanol Sales mandate. [undated; accessed 25/02/2008]. Available online at: <http://www.gov.mb.ca/stem/energy/ethanol/index.html>

Maritime Electric. Corporate Information. [undated; accessed 02/06/2008]. Available online at: <http://www.maritimeelectric.com/corp.html>

Marshall J, Mills A. 2008. Overview of Saskatchewan Economy. SIPP Provincial Progress Report. Winter 2008. Issue 2.[SIPP] Saskatchewan Institute of Public Policy. Available online at: [http://www.uregina.ca/sipp/documents/pdf/Winter\\_2008\\_Overview\\_online.pdf](http://www.uregina.ca/sipp/documents/pdf/Winter_2008_Overview_online.pdf)

National Energy Board. 2007. 2006 Annual Report to Parliament. Calgary (AB).

New Brunswick Department of Finance. 2004. The New Brunswick Economy 2004 – A Report to the Legislative Assembly. Fredericton (NB). Available online at: <http://www.gnb.ca/0024/index-e.asp>

New Brunswick Department of Finance. 2007. The New Brunswick Economy 2007 – A Report to the Legislative Assembly. Fredericton (NB). Available online at: <http://www.gnb.ca/0024/index-e.asp>

New Brunswick Power Group. 2007. 2005–2006 Annual Report, Fredericton (NB).

Newfoundland and Labrador Department of Finance. 2007. The Economy 2007. St. John's (NL). Available online at: <http://www.economics.gov.nl.ca>

NL Hydro. 2007. 2006 Annual Report. St. John's (NL).

Northwest Territories Industry, Tourism and Investment. 2006. Diamond Facts – 2006 Diamond Industry Report. Yellowknife (NT).

[NWTPEC] Northwest Territories Power Corporation. 2006. Annual Report 2006/2006. Yellowknife (NT).

Nova Scotia Department of Finance. 2006. Nova Scotia Statistical Review 2006 – 24<sup>th</sup> Edition. Halifax (NS).

Nova Scotia Department of Finance. 2007. Nova Scotia Fiscal Overview 2007. Halifax (NS).

Nova Scotia Power. About NSPI. [undated; accessed April 29, 2008]. Available online at: [http://www.nspower.ca/about\\_nsipi/generation/](http://www.nspower.ca/about_nsipi/generation/)

NRCan. [Natural Resources Canada]. Canadian Minerals Yearbook, 1990–2004 (Annual), Minerals and Metals Sector, Natural Resources Canada. Available online at: [http://www.nrcan.gc.ca/mms/cmy/pref\\_e.htm](http://www.nrcan.gc.ca/mms/cmy/pref_e.htm)

Nunavut Department of Finance. 2006. Budget 2006 – Fiscal and Economic Outlook. Iqaluit (NU).

Ontario Economic Development. Ontario Facts. [undated; accessed April 29, 2008]. Available online at: <http://www.2ontario.com/facts/home.asp>

Ontario Ministry of Finance. 2007. 2007 Ontario Economic Outlook and Fiscal Review, Annex 6, Table 9. Available online at: <http://www.fin.gov.on.ca/english/budget/fallstatement/2007/07fs-annex6.html#table9>

Prince Edward Island Department of the Provincial Treasury. 2007. Thirty-third Annual Statistical Review 2006. Charlottetown (PEI).

Sakku Investments Corporation. 2006. Nunavut Economic Review. Rankin Inlet (NU).

Saskatchewan Bureau of Statistics. 2007. Economic Review 2006. Number Sixty. Regina (SK).

Saskatchewan Energy and Resources. Resources. [undated; accessed 26/2/2008]. Available online at: <http://www.er.gov.sk.ca/minerals>

Saskatchewan Office of the Provincial Secretary. Emblems of Saskatchewan. [undated; accessed 26/2/2008]. Available online at: <http://www.ops.gov.sk.ca/Default.aspx?DN=81c94cec-8de8-4199-872f-42cf2ecf3b37>

Statistics Canada. 2006 Census. Community Profiles – Toronto Metropolitan Area.

Statistics Canada. 2007a. Canadian Economic Observer (April 2007). #11-010-XIB.

Statistics Canada., 2007b. Report on Energy Supply–Demand in Canada (Annual). #57-003-XIB.

Statistics Canada. 2008. Energy Statistics Handbook. #57-601-XIE.

Yukon Department of Energy, Mines, and Resources. Yukon Oil and Gas Resource Assessments. [undated; accessed 27/2/2008]. Available online at: [http://www.emr.gov.yk.ca/oilandgas/oilgas\\_resource\\_assessments.html](http://www.emr.gov.yk.ca/oilandgas/oilgas_resource_assessments.html)

## Annex 11 Provincial/Territorial Greenhouse Gas Emission Tables, 1990–2006

Summary tables illustrating GHG emissions (for GHG categories, see Table A11-1) by province/territory, sector, and year are included in Annex 11 (Table A11-2 to Table A11-28). To account for the creation of Nunavut in 1999, a time series from 1999–2006 is provided for both Nunavut and the Northwest Territories (Tables A11-24 and A11-26) and the years 1990–1998 are presented as a combined region in Table A11-28.

Although the UNFCCC reporting guidelines require that only national-level detail be reported, provincial- and territorial-level detail is important, owing to the regional differences in emission levels and trends. Note that provincial and territorial emission estimates may not necessarily sum to the national totals due to rounding and suppression of confidential data. Provincial and territorial emission totals do not include

- HFCs (e.g. fugitive releases from air conditioning and refrigeration systems);
- PFCs used during the fabrication of semiconductors;
- CO<sub>2</sub> from limestone and soda ash use; and
- emissions associated with ammonia production.

The reader should also note that many provinces develop independent inventories of provincial GHG emissions, in some cases making use of alternate methodologies, data inputs and/or inclusions/omissions of GHG source categories. While Canada is developing a national emissions inventory consistent with IPCC guidelines and international obligations, provincial governments may elect to develop an inventory structure in accordance with specific provincial needs. Environment Canada encourages collaboration with provinces for quality assurance and continuous improvement of this annual National Inventory Report. The Department is striving to ensure consistency between different estimates, as some provincial GHG estimates presented in this report used to develop the national estimates may differ from those developed by provincial governments.

**Table A11-1: GHG Category Description**  
**GHG Source Categories**

<b>ENERGY</b>	
<b>a. Stationary Combustion Sources</b>	
Electricity and Heat Generation	Emissions from fuel consumed by:
Electricity Generation	Utility and industry electricity generation
Heat Generation	Steam generation (for sale)
Fossil Fuel Industries	Emissions from fuel consumed by:
Petroleum Refining and Upgrading	Petroleum production (upstream oil industry) refining industries
Fossil Fuel Production	Natural gas production and some conventional and unconventional oil production industries (some refining is included)
Mining & Oil and Gas Extraction	Emissions from commercial fuel sold to:
	Metal and non metal mines, stone quarries, and gravel pits
	Oil and gas extraction industries
	Mineral exploration and contract drilling operations
Manufacturing Industries	Emissions from fuel consumed by the following industries:
	Iron and Steel (steel foundries, casting and rolling mills)
	Non-ferrous metals (aluminium, magnesium, and other production)
	Chemical (fertilizer manufacturing, organic and inorganic chemical manufacturing)
	Pulp and Paper (primarily pulp, paper and paper product manufacturers)
	Cement production
	Other manufacturing industries not listed (such as automobile manufacturing, textiles, food and beverage)
Construction	Emissions from fuels consumed by the construction industry - buildings, highways etc.
Commercial & Institutional	Emissions from fuel consumed by:
	Service industries related to mining, communication, wholesale and retail trade, finance and insurance, real
	Federal, provincial, and municipal establishments
	National Defence and Canadian Coast Guard
	Train stations, airports, and warehouses
Residential	Emissions from fuel consumed for personal residences (homes, apartment hotels, condominiums, and farm
Agriculture & Forestry	Emissions from fuel consumed by:
	Forestry and logging service industry
	Agricultural, hunting, and trapping industry (excluding food processing, farm machinery manufacturing, and
<b>b. Transportation</b>	Emissions resulting from the consumption of fossil fuels (including non-CO <sub>2</sub> emissions from ethanol) by vehicles
Domestic Aviation	Emissions resulting from the consumption of fossil fuels by Canadian registered airlines flying domestically
Road Transportation	Emissions resulting from the consumption of fossil fuels by vehicles licensed to operate on roads
Railways	Emissions resulting from the consumption of fossil fuels by Canadian railways
Domestic Marine	Emissions resulting from the consumption of fossil fuels by Canadian registered marine vessels fuelled
Others - Off Road	Emissions resulting from the consumption of fossil fuels (including non-CO <sub>2</sub> emissions from ethanol) by combustion devices not licensed to operate on roads
Others - Pipelines	Emission resulting from the transportation and distribution of crude oil, natural gas, and other products
<b>c. Fugitive Sources</b>	Intentional and unintentional releases of greenhouse gases from the following activities:
Coal Mining	Underground and surface mining
Oil and Natural Gas	Conventional and unconventional oil and gas exploration, production, transportation, and distribution
<b>INDUSTRIAL PROCESSES</b>	Emissions resulting from the following process activities:
<b>a. Mineral Products</b>	Production of cement and lime; use of soda ash, limestone & dolomite, and magnesite
<b>b. Chemical Industry</b>	Production of ammonia, nitric acid, and adipic acid
<b>c. Metal Production</b>	Production of aluminium, iron and steel, magnesium production and casting
<b>d. Consumption of Halocarbons and SF<sub>6</sub></b>	Use of HFCs and/or PFCs in AC units, refrigeration units, fire extinguishers, aerosol cans, solvents, foam blowing, semiconductor manufacturing, and electronics industry; use of SF <sub>6</sub> in electrical equipment and semiconductors
<b>e. Other &amp; Undifferentiated Production</b>	Non-energy use of fossil fuels
<b>SOLVENT &amp; OTHER PRODUCT USE</b>	Emissions resulting from the use of N <sub>2</sub> O as anaesthetic and propellant
<b>AGRICULTURE</b>	
<b>a. Enteric Fermentation</b>	Emissions resulting from:
	Livestock enteric fermentation
<b>b. Manure Management</b>	Livestock waste management
<b>c. Agricultural Soils</b>	
Direct Sources	Direct N <sub>2</sub> O emissions from synthetic fertilizer, manure on cropland, crop residue, tillage, summerfallow, irrigation,
Manure on Pasture, Range, and Paddock	Direct N <sub>2</sub> O emissions from manure deposited on pasture, range, and paddock
Indirect Sources	Indirect N <sub>2</sub> O emissions from volatilization and leaching of animal manure nitrogen, synthetic fertilizer nitrogen,
<b>WASTE</b>	
<b>a. Solid Waste Disposal on Land</b>	Emissions resulting from:
	Municipal solid waste management sites (landfills) and dedicated wood waste landfills
<b>b. Wastewater Handling</b>	Domestic and industrial wastewater treatment
<b>c. Waste Incineration</b>	Municipal solid waste and sewage sludge incineration

**Table A11-2: 1990–2006 GHG Emission Summary for Newfoundland and Labrador**

Greenhouse Gas Categories	1990	1995	2000	2001	2002	2003	2004	2005	2006
	<i>kt CO<sub>2</sub> equivalent</i>								
<b>TOTAL</b>	<b>9 390</b>	<b>8 190</b>	<b>8 650</b>	<b>9 420</b>	<b>11 500</b>	<b>10 900</b>	<b>10 000</b>	<b>9 990</b>	<b>9 390</b>
<b>ENERGY</b>	<b>8 750</b>	<b>7 490</b>	<b>7 980</b>	<b>8 740</b>	<b>10 900</b>	<b>10 200</b>	<b>9 350</b>	<b>9 230</b>	<b>8 660</b>
<b>a. Stationary Combustion Sources</b>	<b>5 390</b>	<b>4 490</b>	<b>4 220</b>	<b>4 980</b>	<b>5 870</b>	<b>5 580</b>	<b>4 920</b>	<b>4 650</b>	<b>4 060</b>
Electricity and Heat Generation	1 630	1 260	928	X	X	X	X	X	X
Fossil Fuel Industries	1 000	940	1 200	1 200	1 900	1 600	1 500	1 500	1 500
Mining & Oil and Gas Extraction	1 060	906	891	X	X	X	X	X	X
Manufacturing Industries	501	316	243	259	285	292	303	273	201
Construction	32.7	16.9	10.1	18.5	26.8	25.3	24.3	17.1	16.3
Commercial & Institutional	317	315	320	379	437	507	469	439	353
Residential	800	670	540	570	610	560	480	390	380
Agriculture & Forestry	24.3	55.4	46.0	X	X	X	X	X	X
<b>b. Transportation<sup>1</sup></b>	<b>3 400</b>	<b>3 000</b>	<b>3 500</b>	<b>3 500</b>	<b>3 500</b>	<b>3 700</b>	<b>3 700</b>	<b>3 800</b>	<b>3 500</b>
Civil Aviation (Domestic Aviation)	460	350	360	360	320	410	440	460	310
Road Transportation	1 680	1 770	1 770	1 770	1 790	1 830	1 800	1 900	1 900
Light-Duty Gasoline Vehicles	750	700	625	615	617	612	568	582	553
Light-Duty Gasoline Trucks	440	578	654	658	681	712	698	754	759
Heavy-Duty Gasoline Vehicles	127	83.1	45.9	58.5	52.8	53.7	52.3	53.6	51.0
Motorcycles	4.99	4.04	3.57	3.49	3.58	3.91	3.90	4.01	3.84
Light-Duty Diesel Vehicles	1.78	1.47	1.03	1.10	1.13	1.17	1.18	1.21	1.14
Light-Duty Diesel Trucks	5.69	9.72	14.3	16.3	17.2	18.2	18.1	21.0	22.8
Heavy-Duty Diesel Vehicles	349	390	429	422	415	424	453	486	511
Propane & Natural Gas Vehicles	1.4	2.5	1.1	0.98	0.34	0.31	0.32	0.31	0.46
Railways	—	0.01	—	—	—	—	—	—	—
Navigation (Domestic Marine)	700	560	680	610	580	410	640	590	560
Other Transportation	500	300	700	800	900	1 000	800	900	700
Off-Road Gasoline	100	50	80	60	70	60	30	40	30
Off-Road Diesel	400	300	600	700	800	1 000	700	800	600
Pipelines	—	—	—	—	—	34.0	35.3	25.4	25.9
<b>c. Fugitive Sources<sup>2</sup></b>	<b>—</b>	<b>—</b>	<b>252</b>	<b>241</b>	<b>1 450</b>	<b>927</b>	<b>764</b>	<b>778</b>	<b>1 130</b>
Coal Mining <sup>5</sup>	—	—	—	—	—	—	X	X	X
Oil and Natural Gas	—	—	252	241	1 450	927	X	X	X
<b>INDUSTRIAL PROCESSES<sup>3</sup></b>	<b>75.3</b>	<b>84.6</b>	<b>22.8</b>	<b>22.6</b>	<b>25.4</b>	<b>29.3</b>	<b>23.4</b>	<b>93.6</b>	<b>45.7</b>
<b>a. Mineral Products</b>	<b>57</b>	<b>66</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>
Cement Production	57	66	—	—	—	—	—	—	—
Lime Production	—	—	—	—	—	—	—	—	—
<b>b. Chemical Industry</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>
Nitric Acid Production	—	—	—	—	—	—	—	—	—
Adipic Acid Production	—	—	—	—	—	—	—	—	—
<b>c. Metal Production</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>
Iron and Steel Production	—	—	—	—	—	—	—	—	—
Aluminum Production	—	—	—	—	—	—	—	—	—
SF <sub>6</sub> Used in Magnesium Smelters and Casters	—	—	—	—	—	—	—	—	—
<b>d. Consumption of Halocarbons and SF<sub>6</sub></b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>
<b>e. Other &amp; Undifferentiated Production<sup>4</sup></b>	<b>19</b>	<b>19</b>	<b>23</b>	<b>23</b>	<b>25</b>	<b>29</b>	<b>23</b>	<b>94</b>	<b>46</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>	<b>3.7</b>	<b>4.0</b>	<b>4.2</b>	<b>3.6</b>	<b>2.7</b>	<b>3.6</b>	<b>3.4</b>	<b>2.8</b>	<b>5.0</b>
<b>AGRICULTURE</b>	<b>50</b>	<b>52</b>	<b>54</b>	<b>56</b>	<b>58</b>	<b>59</b>	<b>62</b>	<b>64</b>	<b>66</b>
<b>a. Enteric Fermentation</b>	<b>18</b>	<b>19</b>	<b>20</b>	<b>21</b>	<b>22</b>	<b>22</b>	<b>24</b>	<b>26</b>	<b>27</b>
<b>b. Manure Management</b>	<b>13</b>	<b>13</b>	<b>14</b>	<b>14</b>	<b>14</b>	<b>14</b>	<b>15</b>	<b>15</b>	<b>16</b>
<b>c. Agricultural Soils</b>	<b>18</b>	<b>21</b>	<b>20</b>	<b>21</b>	<b>22</b>	<b>22</b>	<b>23</b>	<b>24</b>	<b>24</b>
Direct Sources	8.9	11	10	10	11	11	12	12	12
Pasture, Range and Paddock Manure	1.8	1.9	2.0	2.2	2.2	2.3	2.4	2.5	2.6
Indirect Sources	8	8	8	8	9	9	9	9	10
<b>WASTE</b>	<b>510</b>	<b>560</b>	<b>590</b>	<b>590</b>	<b>600</b>	<b>600</b>	<b>600</b>	<b>600</b>	<b>600</b>
<b>a. Solid Waste Disposal on Land</b>	<b>500</b>	<b>540</b>	<b>560</b>	<b>570</b>	<b>570</b>	<b>570</b>	<b>570</b>	<b>570</b>	<b>580</b>
<b>b. Wastewater Handling</b>	<b>13</b>	<b>14</b>	<b>27</b>	<b>29</b>	<b>29</b>	<b>29</b>	<b>29</b>	<b>29</b>	<b>30</b>
<b>c. Waste Incineration</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>

## Notes:

1. Emissions from Fuel Ethanol are reported within the gasoline transportation subcategories.
  2. Fugitive emissions from refineries and the bitumen industry are only reported at the national level.
  3. Emissions associated with the use of mineral products and consumption of halocarbons & SF<sub>6</sub> are only reported at the national level.
  4. Emissions coming from ammonia production are included in the category Other & Undifferentiated Production at provincial levels.
  5. Fugitive emissions from coal mining activities for 2002 and 2003 have been extrapolated based on publicly available coal production data.
- X Indicates confidential data.  
 — Indicates no emissions.  
 0.0 Indicates emissions truncated due to rounding.

**Table A11-3: 2006 GHG Emission Summary for Newfoundland and Labrador**

Greenhouse Gas Categories		Greenhouse Gases							
Global Warming Potential		CO <sub>2</sub>	CH <sub>4</sub>	CH <sub>4</sub>	N <sub>2</sub> O	N <sub>2</sub> O	PFCs	SF <sub>6</sub>	TOTAL
Unit		kt	kt	kt CO <sub>2</sub> eq	kt	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq
<b>TOTAL</b>		<b>8 230</b>	<b>41</b>	<b>870</b>	<b>0.93</b>	<b>290</b>	—	—	<b>9 390</b>
<b>ENERGY</b>		<b>8 180</b>	<b>11</b>	<b>240</b>	<b>0.8</b>	<b>200</b>	—	—	<b>8 660</b>
<b>a. Stationary Combustion Sources</b>		<b>3 830</b>	<b>9</b>	<b>200</b>	<b>0.2</b>	<b>50</b>	—	—	<b>4 060</b>
Electricity and Heat Generation		X	X	X	X	X	—	—	X
Fossil Fuel Industries		1 430	3	70	0.05	20	—	—	1 500
Mining & Oil and Gas Extraction		X	X	X	X	X	—	—	X
Manufacturing Industries		199	0.01	0.1	0.01	1	—	—	201
Construction		16.2	0.00	0.00	0.00	0.06	—	—	16.3
Commercial & Institutional		350	0.01	0.1	0.01	2	—	—	353
Residential		242	6	100	0.06	20	—	—	380
Agriculture & Forestry		X	X	X	X	X	—	—	X
<b>b. Transportation<sup>1</sup></b>		<b>3 270</b>	<b>0.2</b>	<b>5</b>	<b>0.6</b>	<b>200</b>	—	—	<b>3 500</b>
Civil Aviation (Domestic Aviation)		303	0.01	0.3	0.03	9	—	—	310
Road Transportation		1 850	0.13	2.8	0.15	46	—	—	1 900
Light-Duty Gasoline Vehicles		539	0.04	0.86	0.04	14	—	—	553
Light-Duty Gasoline Trucks		732	0.06	1.3	0.08	26	—	—	759
Heavy-Duty Gasoline Vehicles		49.9	0.00	0.06	0.00	1.0	—	—	51.0
Motorcycles		3.76	0.00	0.05	0.00	0.02	—	—	3.84
Light-Duty Diesel Vehicles		1.11	0.00	0.00	0.00	0.03	—	—	1.14
Light-Duty Diesel Trucks		22.2	0.00	0.01	0.00	0.6	—	—	22.8
Heavy-Duty Diesel Vehicles		506	0.02	0.5	0.02	5	—	—	511
Propane & Natural Gas Vehicles		0.45	0.00	0.00	0.00	0.00	—	—	0.46
Railways		—	—	—	—	—	—	—	0
Navigation (Domestic Marine)		493	0.03	0.6	0.2	60	—	—	560
Other Transportation		620	0.06	1	0.2	70	—	—	700
Off-Road Gasoline		30	0.03	0.7	0.00	0.2	—	—	30
Off-Road Diesel		570	0.03	0.7	0.2	70	—	—	600
Pipelines		24.8	0.00	0.03	0.00	1	—	—	25.9
<b>c. Fugitive Sources<sup>2</sup></b>		<b>1 100</b>	<b>2.5</b>	<b>52</b>	—	—	—	—	<b>1 130</b>
Coal Mining		X	X	X	—	—	—	—	X
Oil and Natural Gas		X	X	X	—	—	—	—	X
<b>INDUSTRIAL PROCESSES<sup>3</sup></b>		<b>46</b>	—	—	—	—	—	—	<b>45.7</b>
<b>a. Mineral Products</b>		—	—	—	—	—	—	—	<b>0</b>
Cement Production		—	—	—	—	—	—	—	0
Lime Production		—	—	—	—	—	—	—	0
<b>b. Chemical Industry</b>		—	—	—	—	—	—	—	<b>0</b>
Nitric Acid Production		—	—	—	—	—	—	—	0
Adipic Acid Production		—	—	—	—	—	—	—	0
<b>c. Metal Production</b>		—	—	—	—	—	—	—	<b>0</b>
Iron and Steel Production		—	—	—	—	—	—	—	0
Aluminum Production		—	—	—	—	—	—	—	0
SF <sub>6</sub> Used in Magnesium Smelters and		—	—	—	—	—	—	—	0
<b>d. Consumption of Halocarbons and SF<sub>6</sub></b>		—	—	—	—	—	—	—	<b>0</b>
<b>e. Other &amp; Undifferentiated Production<sup>4</sup></b>		<b>46</b>	—	—	—	—	—	—	<b>46</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>		—	—	—	<b>0.02</b>	<b>5.0</b>	—	—	<b>5.0</b>
<b>AGRICULTURE</b>		—	<b>1.6</b>	<b>33</b>	<b>0.11</b>	<b>34</b>	—	—	<b>66</b>
<b>a. Enteric Fermentation</b>		—	1.3	27	—	—	—	—	27
<b>b. Manure Management</b>		—	0.29	6.0	0.03	9.5	—	—	16
<b>c. Agricultural Soils</b>		—	—	—	<b>0.08</b>	<b>24</b>	—	—	<b>24</b>
Direct Sources		—	—	—	0.04	12	—	—	12
Pasture, Range and Paddock Manure		—	—	—	0.01	2.6	—	—	2.6
Indirect Sources		—	—	—	0.03	10	—	—	10
<b>WASTE</b>		—	<b>28</b>	<b>590</b>	<b>0.03</b>	<b>10</b>	—	—	<b>600</b>
<b>a. Solid Waste Disposal on Land</b>		—	27	580	—	—	—	—	580
<b>b. Wastewater Handling</b>		—	0.92	19	0.03	10	—	—	30
<b>c. Waste Incineration</b>		—	—	—	—	—	—	—	0

## Notes:

1. Emissions from Fuel Ethanol are reported within the gasoline transportation subcategories.
  2. Fugitive emissions from refineries and the bitumen industry are only reported at the national level.
  3. Emissions associated with the use of mineral products and consumption of halocarbons & SF<sub>6</sub> are only reported at the national level.
  4. Emissions coming from ammonia production are included in the category Other & Undifferentiated Production at provincial levels.
- X Indicates confidential data.  
 — Indicates no emissions.  
 0.0 Indicates emissions truncated due to rounding.

**Table A11-4: 1990–2006 GHG Emission Summary for Prince Edward Island**

Greenhouse Gas Categories	1990	1995	2000	2001	2002	2003	2004	2005	2006
	<i>kt CO<sub>2</sub> equivalent</i>								
<b>TOTAL</b>	<b>1 960</b>	<b>1 890</b>	<b>2 180</b>	<b>2 060</b>	<b>2 090</b>	<b>2 190</b>	<b>2 230</b>	<b>2 160</b>	<b>2 050</b>
<b>ENERGY</b>	<b>1 420</b>	<b>1 320</b>	<b>1 570</b>	<b>1 490</b>	<b>1 490</b>	<b>1 570</b>	<b>1 580</b>	<b>1 530</b>	<b>1 450</b>
<b>a. Stationary Combustion Sources</b>	<b>733</b>	<b>632</b>	<b>736</b>	<b>682</b>	<b>670</b>	<b>727</b>	<b>703</b>	<b>650</b>	<b>591</b>
Electricity and Heat Generation	103	39.2	56.6	X	X	X	X	X	X
Fossil Fuel Industries	0.11	1.5	2.2	4.3	–	–	0.02	–	–
Mining & Oil and Gas Extraction	0.77	0.78	4.97	X	X	X	X	X	X
Manufacturing Industries	54.2	71.1	134	125	120	138	139	137	137
Construction	11.0	6.34	6.60	5.19	5.76	4.20	6.18	7.54	6.17
Commercial & Institutional	158	174	191	191	206	234	236	211	187
Residential	390	300	310	290	300	290	280	260	240
Agriculture & Forestry	18.4	39.1	31.0	X	X	X	X	X	X
<b>b. Transportation<sup>1</sup></b>	<b>690</b>	<b>680</b>	<b>840</b>	<b>810</b>	<b>820</b>	<b>840</b>	<b>870</b>	<b>880</b>	<b>860</b>
Civil Aviation (Domestic Aviation)	13	5.9	7.5	7.4	7.2	9.4	10	12	12
Road Transportation	528	589	591	593	592	605	630	628	632
Light-Duty Gasoline Vehicles	241	246	229	226	224	221	219	215	209
Light-Duty Gasoline Trucks	114	163	198	201	210	218	229	238	245
Heavy-Duty Gasoline Vehicles	67.2	33.0	17.6	25.5	23.5	23.5	24.7	24.4	23.9
Motorcycles	0.98	0.88	1.38	1.68	2.19	2.38	2.54	2.69	2.82
Light-Duty Diesel Vehicles	1.77	1.77	1.41	1.53	1.45	1.48	1.60	1.58	1.53
Light-Duty Diesel Trucks	3.26	5.48	7.40	7.72	8.11	8.48	9.15	10.0	11.0
Heavy-Duty Diesel Vehicles	98.6	138	136	129	123	130	144	136	138
Propane & Natural Gas Vehicles	1.1	0.92	0.70	1.7	0.04	0.05	0.04	–	–
Railways	–	–	–	–	–	–	–	–	–
Navigation (Domestic Marine)	89	63	84	84	78	84	100	99	97
Other Transportation	60	30	200	100	100	100	100	100	100
Off-Road Gasoline	30	20	70	50	70	70	80	80	70
Off-Road Diesel	30	7	90	70	60	70	60	70	50
Pipelines	–	–	–	–	–	–	–	–	–
<b>c. Fugitive Sources<sup>2</sup></b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>
Coal Mining <sup>5</sup>	–	–	–	–	–	–	X	X	X
Oil and Natural Gas	–	–	–	–	–	–	X	X	X
<b>INDUSTRIAL PROCESSES<sup>3</sup></b>	<b>3.33</b>	<b>3.13</b>	<b>2.85</b>	<b>2.58</b>	<b>2.47</b>	<b>2.47</b>	<b>2.52</b>	<b>1.83</b>	<b>1.83</b>
<b>a. Mineral Products</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>
Cement Production	–	–	–	–	–	–	–	–	–
Lime Production	–	–	–	–	–	–	–	–	–
<b>b. Chemical Industry</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>
Nitric Acid Production	–	–	–	–	–	–	–	–	–
Adipic Acid Production	–	–	–	–	–	–	–	–	–
<b>c. Metal Production</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>
Iron and Steel Production	–	–	–	–	–	–	–	–	–
Aluminum Production	–	–	–	–	–	–	–	–	–
SF <sub>6</sub> Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	–	–
<b>d. Consumption of Halocarbons and SF<sub>6</sub></b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>
<b>e. Other &amp; Undifferentiated Production<sup>4</sup></b>	<b>3.3</b>	<b>3.1</b>	<b>2.8</b>	<b>2.6</b>	<b>2.5</b>	<b>2.5</b>	<b>2.5</b>	<b>1.8</b>	<b>1.8</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>	<b>0.82</b>	<b>0.95</b>	<b>1.1</b>	<b>0.94</b>	<b>0.72</b>	<b>0.96</b>	<b>0.91</b>	<b>0.77</b>	<b>1.4</b>
<b>AGRICULTURE</b>	<b>450</b>	<b>480</b>	<b>500</b>	<b>470</b>	<b>500</b>	<b>510</b>	<b>540</b>	<b>520</b>	<b>490</b>
<b>a. Enteric Fermentation</b>	<b>140</b>	<b>140</b>	<b>140</b>	<b>130</b>	<b>130</b>	<b>130</b>	<b>130</b>	<b>130</b>	<b>130</b>
<b>b. Manure Management</b>	<b>55</b>	<b>55</b>	<b>55</b>	<b>55</b>	<b>55</b>	<b>55</b>	<b>55</b>	<b>54</b>	<b>54</b>
<b>c. Agricultural Soils</b>	<b>260</b>	<b>290</b>	<b>310</b>	<b>280</b>	<b>310</b>	<b>330</b>	<b>350</b>	<b>330</b>	<b>300</b>
Direct Sources	140	160	170	150	170	180	200	190	170
Pasture, Range and Paddock Manure	20	21	21	21	21	21	20	20	21
Indirect Sources	100	100	100	100	100	100	100	100	100
<b>WASTE</b>	<b>82</b>	<b>89</b>	<b>99</b>	<b>100</b>	<b>100</b>	<b>100</b>	<b>100</b>	<b>110</b>	<b>110</b>
<b>a. Solid Waste Disposal on Land</b>	<b>69</b>	<b>76</b>	<b>85</b>	<b>86</b>	<b>88</b>	<b>89</b>	<b>90</b>	<b>92</b>	<b>93</b>
<b>b. Wastewater Handling</b>	<b>3.8</b>	<b>4.0</b>	<b>4.2</b>	<b>4.2</b>	<b>4.2</b>	<b>4.2</b>	<b>4.2</b>	<b>4.2</b>	<b>4.1</b>
<b>c. Waste Incineration</b>	<b>9.1</b>	<b>9.1</b>	<b>9.4</b>	<b>9.2</b>	<b>9.3</b>	<b>9.4</b>	<b>9.5</b>	<b>9.5</b>	<b>9.5</b>

## Notes:

- Emissions from Fuel Ethanol are reported within the gasoline transportation subcategories.
  - Fugitive emissions from refineries and the bitumen industry are only reported at the national level.
  - Emissions associated with the use of mineral products and consumption of halocarbons & SF<sub>6</sub> are only reported at the national level.
  - Emissions coming from ammonia production are included in the category Other & Undifferentiated Production at provincial levels.
  - Fugitive emissions from coal mining activities for 2002 and 2003 have been extrapolated based on publicly available coal production data.
- X Indicates confidential data.  
 – Indicates no emissions.  
 0.0 Indicates emissions truncated due to rounding.



Table A11-5: 2006 GHG Emission Summary for Prince Edward Island

Greenhouse Gas Categories		Greenhouse Gases							
Global Warming Potential		CO <sub>2</sub>	CH <sub>4</sub>	CH <sub>4</sub>	N <sub>2</sub> O	N <sub>2</sub> O	PFCs	SF <sub>6</sub>	TOTAL
Unit		kt	kt	kt CO <sub>2</sub> eq	kt	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq
<b>TOTAL</b>		<b>1 390</b>	<b>14</b>	<b>290</b>	<b>1.2</b>	<b>380</b>	—	—	<b>2 050</b>
<b>ENERGY</b>		<b>1 380</b>	<b>1.7</b>	<b>37</b>	<b>0.1</b>	<b>40</b>	—	—	<b>1 450</b>
<b>a. Stationary Combustion Sources</b>		<b>549</b>	<b>2</b>	<b>30</b>	<b>0.03</b>	<b>8</b>	—	—	<b>591</b>
Electricity and Heat Generation		X	X	X	X	X	—	—	X
Fossil Fuel Industries		—	—	—	—	—	—	—	0
Mining & Oil and Gas Extraction		X	X	X	X	X	—	—	X
Manufacturing Industries		136	0.01	0.1	0.00	0.8	—	—	137
Construction		6.15	0.00	0.00	0.00	0.02	—	—	6.17
Commercial & Institutional		186	0.00	0.04	0.00	1	—	—	187
Residential		197	2	30	0.02	6	—	—	240
Agriculture & Forestry		X	X	X	X	X	—	—	X
<b>b. Transportation<sup>1</sup></b>		<b>827</b>	<b>0.1</b>	<b>3</b>	<b>0.1</b>	<b>30</b>	—	—	<b>860</b>
Civil Aviation (Domestic Aviation)		11.3	0.00	0.02	0.00	0.3	—	—	12
Road Transportation		615	0.05	1.0	0.05	16	—	—	632
Light-Duty Gasoline Vehicles		203	0.02	0.37	0.02	5.4	—	—	209
Light-Duty Gasoline Trucks		237	0.02	0.46	0.03	8.4	—	—	245
Heavy-Duty Gasoline Vehicles		23.4	0.00	0.04	0.00	0.44	—	—	23.9
Motorcycles		2.77	0.00	0.04	0.00	0.02	—	—	2.82
Light-Duty Diesel Vehicles		1.50	0.00	0.00	0.00	0.04	—	—	1.53
Light-Duty Diesel Trucks		10.7	0.00	0.01	0.00	0.3	—	—	11.0
Heavy-Duty Diesel Vehicles		137	0.01	0.1	0.00	1	—	—	138
Propane & Natural Gas Vehicles		—	—	—	—	—	—	—	0
Railways		—	—	—	—	—	—	—	0
Navigation (Domestic Marine)		85.5	0.01	0.1	0.04	10	—	—	97
Other Transportation		110	0.08	2	0.02	7	—	—	100
Off-Road Gasoline		70	0.08	2	0.00	0.4	—	—	70
Off-Road Diesel		48	0.00	0.06	0.02	6	—	—	50
Pipelines		—	—	—	—	—	—	—	0
<b>c. Fugitive Sources<sup>2</sup></b>		<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>0</b>
Coal Mining		X	X	X	—	—	—	—	X
Oil and Natural Gas		X	X	X	—	—	—	—	X
<b>INDUSTRIAL PROCESSES<sup>3</sup></b>		<b>1.8</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>1.83</b>
<b>a. Mineral Products</b>		<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>0</b>
Cement Production		—	—	—	—	—	—	—	0
Lime Production		—	—	—	—	—	—	—	0
<b>b. Chemical Industry</b>		<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>0</b>
Nitric Acid Production		—	—	—	—	—	—	—	0
Adipic Acid Production		—	—	—	—	—	—	—	0
<b>c. Metal Production</b>		<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>0</b>
Iron and Steel Production		—	—	—	—	—	—	—	0
Aluminum Production		—	—	—	—	—	—	—	0
SF <sub>6</sub> Used in Magnesium Smelters and		—	—	—	—	—	—	—	0
<b>d. Consumption of Halocarbons and SF<sub>6</sub></b>		<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>0</b>
<b>e. Other &amp; Undifferentiated Production<sup>4</sup></b>		<b>1.8</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>1.8</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>		<b>—</b>	<b>—</b>	<b>—</b>	<b>0.00</b>	<b>1.4</b>	<b>—</b>	<b>—</b>	<b>1.4</b>
<b>AGRICULTURE</b>		<b>—</b>	<b>7.6</b>	<b>160</b>	<b>1.1</b>	<b>330</b>	<b>—</b>	<b>—</b>	<b>490</b>
<b>a. Enteric Fermentation</b>		<b>—</b>	<b>6.4</b>	<b>130</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>130</b>
<b>b. Manure Management</b>		<b>—</b>	<b>1.3</b>	<b>27</b>	<b>0.09</b>	<b>27</b>	<b>—</b>	<b>—</b>	<b>54</b>
<b>c. Agricultural Soils</b>		<b>—</b>	<b>—</b>	<b>—</b>	<b>0.97</b>	<b>300</b>	<b>—</b>	<b>—</b>	<b>300</b>
Direct Sources		—	—	—	0.53	170	—	—	170
Pasture, Range and Paddock Manure		—	—	—	0.07	21	—	—	21
Indirect Sources		—	—	—	0.4	100	—	—	100
<b>WASTE</b>		<b>7.9</b>	<b>4.5</b>	<b>94</b>	<b>0.01</b>	<b>4</b>	<b>—</b>	<b>—</b>	<b>110</b>
<b>a. Solid Waste Disposal on Land</b>		<b>—</b>	<b>4.4</b>	<b>93</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>93</b>
<b>b. Wastewater Handling</b>		<b>—</b>	<b>0.06</b>	<b>1.2</b>	<b>0.01</b>	<b>3</b>	<b>—</b>	<b>—</b>	<b>4.1</b>
<b>c. Waste Incineration</b>		<b>7.9</b>	<b>—</b>	<b>—</b>	<b>0.01</b>	<b>2</b>	<b>—</b>	<b>—</b>	<b>9.5</b>

## Notes:

1. Emissions from Fuel Ethanol are reported within the gasoline transportation subcategories.
  2. Fugitive emissions from refineries and the bitumen industry are only reported at the national level.
  3. Emissions associated with the use of mineral products and consumption of halocarbons & SF<sub>6</sub> are only reported at the national level.
  4. Emissions coming from ammonia production are included in the category Other & Undifferentiated Production at provincial levels.
- X Indicates confidential data.  
 — Indicates no emissions.  
 0.0 Indicates emissions truncated due to rounding.

**Table A11-6: 1990–2006 GHG Emission Summary for Nova Scotia**

Greenhouse Gas Categories	1990	1995	2000	2001	2002	2003	2004	2005	2006
	<i>kt CO<sub>2</sub> equivalent</i>								
<b>TOTAL</b>	<b>19 000</b>	<b>18 600</b>	<b>20 900</b>	<b>20 100</b>	<b>19 500</b>	<b>21 700</b>	<b>22 700</b>	<b>21 700</b>	<b>19 600</b>
<b>ENERGY</b>	<b>17 500</b>	<b>17 000</b>	<b>19 400</b>	<b>18 800</b>	<b>18 000</b>	<b>20 200</b>	<b>21 300</b>	<b>20 400</b>	<b>18 400</b>
<b>a. Stationary Combustion Sources</b>	<b>11 300</b>	<b>11 100</b>	<b>13 500</b>	<b>13 000</b>	<b>12 200</b>	<b>13 800</b>	<b>15 100</b>	<b>14 100</b>	<b>12 600</b>
Electricity and Heat Generation	6 840	6 900	8 840	X	X	X	X	X	X
Fossil Fuel Industries	660	640	990	940	1 200	1 600	1 100	970	950
Mining & Oil and Gas Extraction	35.2	33.4	53.9	X	X	X	X	X	X
Manufacturing Industries	721	872	663	511	691	631	598	471	462
Construction	49.2	34.7	27.2	36.6	54.3	51.5	54.1	38.1	31.3
Commercial & Institutional	790	797	903	1 050	1 020	1 260	1 950	1 990	1 760
Residential	2 100	1 600	1 800	1 800	1 800	1 800	1 300	1 100	1 100
Agriculture & Forestry	103	196	230	X	X	X	X	X	X
<b>b. Transportation<sup>1</sup></b>	<b>5 000</b>	<b>5 100</b>	<b>5 600</b>	<b>5 400</b>	<b>5 500</b>	<b>6 000</b>	<b>6 200</b>	<b>6 300</b>	<b>5 700</b>
Civil Aviation (Domestic Aviation)	390	370	350	320	350	370	490	540	430
Road Transportation	3 170	3 500	3 490	3 530	3 550	3 660	3 750	3 750	3 860
Light-Duty Gasoline Vehicles	1 560	1 500	1 280	1 320	1 320	1 310	1 290	1 250	1 230
Light-Duty Gasoline Trucks	689	924	1 180	1 130	1 180	1 230	1 280	1 310	1 370
Heavy-Duty Gasoline Vehicles	194	153	90.9	114	105	107	111	108	107
Motorcycles	9.59	7.86	7.36	7.46	8.02	8.79	9.26	9.09	9.07
Light-Duty Diesel Vehicles	17.5	16.0	14.7	16.0	16.8	17.3	18.5	18.3	18.4
Light-Duty Diesel Trucks	24.1	41.4	48.3	46.0	49.3	51.9	54.9	58.4	63.7
Heavy-Duty Diesel Vehicles	663	859	866	891	872	921	987	994	1 060
Propane & Natural Gas Vehicles	7.5	5.2	4.2	5.0	4.0	4.0	4.2	4.9	5.1
Railways	70	40	70	70	80	200	100	100	100
Navigation (Domestic Marine)	610	570	670	530	490	680	770	860	590
Other Transportation	700	600	1 000	900	1 000	1 000	1 000	1 000	700
Off-Road Gasoline	300	300	400	300	300	300	300	200	200
Off-Road Diesel	500	300	600	600	700	800	800	700	500
Pipelines	–	–	–	–	–	12.0	30.0	34.3	46.9
<b>c. Fugitive Sources<sup>2</sup></b>	<b>1 170</b>	<b>835</b>	<b>336</b>	<b>354</b>	<b>355</b>	<b>348</b>	<b>75.6</b>	<b>74.6</b>	<b>70.8</b>
Coal Mining <sup>5</sup>	1 000	800	300	300	300	300	X	X	X
Oil and Natural Gas	–	5.86	86.1	84.3	85.2	78.4	X	X	X
<b>INDUSTRIAL PROCESSES<sup>3</sup></b>	<b>272</b>	<b>319</b>	<b>286</b>	<b>195</b>	<b>285</b>	<b>323</b>	<b>296</b>	<b>254</b>	<b>224</b>
<b>a. Mineral Products</b>	<b>170</b>	<b>230</b>	<b>220</b>	<b>130</b>	<b>220</b>	<b>230</b>	<b>230</b>	<b>200</b>	<b>200</b>
Cement Production	170	230	220	130	220	230	230	200	200
Lime Production	–	–	–	–	–	–	–	–	–
<b>b. Chemical Industry</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>
Nitric Acid Production	–	–	–	–	–	–	–	–	–
Adipic Acid Production	–	–	–	–	–	–	–	–	–
<b>c. Metal Production</b>	<b>–</b>	<b>5.89</b>	<b>0.88</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>
Iron and Steel Production	–	5.89	0.88	–	–	–	–	–	–
Aluminum Production	–	–	–	–	–	–	–	–	–
SF <sub>6</sub> Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	–	–
<b>d. Consumption of Halocarbons and SF<sub>6</sub></b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>
<b>e. Other &amp; Undifferentiated Production<sup>4</sup></b>	<b>100</b>	<b>79</b>	<b>69</b>	<b>62</b>	<b>68</b>	<b>97</b>	<b>66</b>	<b>56</b>	<b>23</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>	<b>5.7</b>	<b>6.6</b>	<b>7.4</b>	<b>6.4</b>	<b>4.9</b>	<b>6.5</b>	<b>6.2</b>	<b>5.2</b>	<b>9.2</b>
<b>AGRICULTURE</b>	<b>500</b>	<b>520</b>	<b>500</b>	<b>480</b>	<b>500</b>	<b>510</b>	<b>510</b>	<b>500</b>	<b>480</b>
<b>a. Enteric Fermentation</b>	<b>210</b>	<b>210</b>	<b>200</b>	<b>200</b>	<b>200</b>	<b>200</b>	<b>190</b>	<b>190</b>	<b>190</b>
<b>b. Manure Management</b>	<b>91</b>	<b>92</b>	<b>90</b>	<b>88</b>	<b>88</b>	<b>87</b>	<b>85</b>	<b>84</b>	<b>83</b>
<b>c. Agricultural Soils</b>	<b>200</b>	<b>210</b>	<b>210</b>	<b>200</b>	<b>210</b>	<b>230</b>	<b>230</b>	<b>220</b>	<b>210</b>
Direct Sources	96	100	100	95	100	110	120	110	100
Pasture, Range and Paddock Manure	26	28	26	26	26	26	25	25	25
Indirect Sources	80	80	80	80	80	90	90	90	80
<b>WASTE</b>	<b>710</b>	<b>700</b>	<b>680</b>	<b>670</b>	<b>670</b>	<b>670</b>	<b>600</b>	<b>540</b>	<b>520</b>
<b>a. Solid Waste Disposal on Land</b>	<b>660</b>	<b>660</b>	<b>640</b>	<b>630</b>	<b>630</b>	<b>630</b>	<b>560</b>	<b>500</b>	<b>490</b>
<b>b. Wastewater Handling</b>	<b>26</b>	<b>24</b>	<b>26</b>	<b>27</b>	<b>26</b>	<b>26</b>	<b>26</b>	<b>26</b>	<b>25</b>
<b>c. Waste Incineration</b>	<b>21</b>	<b>16</b>	<b>12</b>	<b>12</b>	<b>12</b>	<b>11</b>	<b>11</b>	<b>11</b>	<b>12</b>

## Notes:

1. Emissions from Fuel Ethanol are reported within the gasoline transportation subcategories.
  2. Fugitive emissions from refineries and the bitumen industry are only reported at the national level.
  3. Emissions associated with the use of mineral products and consumption of halocarbons & SF<sub>6</sub> are only reported at the national level.
  4. Emissions coming from ammonia production are included in the category Other & Undifferentiated Production at provincial levels.
  5. Fugitive emissions from coal mining activities for 2002 and 2003 have been extrapolated based on publicly available coal production data.
- X Indicates confidential data.  
 – Indicates no emissions.  
 0.0 Indicates emissions truncated due to rounding.

Table A11-7: 2006 GHG Emission Summary for Nova Scotia

Greenhouse Gas Categories		Greenhouse Gases							
Global Warming Potential		CO <sub>2</sub>	CH <sub>4</sub>	CH <sub>4</sub>	N <sub>2</sub> O	N <sub>2</sub> O	PFCs	SF <sub>6</sub>	TOTAL
Unit		kt	kt	kt CO <sub>2</sub> eq	kt	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq
<b>TOTAL</b>		<b>18 000</b>	<b>47</b>	<b>980</b>	<b>1.9</b>	<b>580</b>	—	—	<b>19 600</b>
<b>ENERGY</b>		<b>17 800</b>	<b>12</b>	<b>260</b>	<b>1</b>	<b>300</b>	—	—	<b>18 400</b>
<b>a. Stationary Combustion Sources</b>		<b>12 300</b>	<b>9</b>	<b>200</b>	<b>0.3</b>	<b>80</b>	—	—	<b>12 600</b>
	Electricity and Heat Generation	X	X	X	X	X	—	—	X
	Fossil Fuel Industries	925	0.9	20	0.01	4	—	—	950
	Mining & Oil and Gas Extraction	X	X	X	X	X	—	—	X
	Manufacturing Industries	451	0.07	1	0.03	10	—	—	462
	Construction	31.2	0.00	0.01	0.00	0.2	—	—	31.3
	Commercial & Institutional	1 750	0.02	0.4	0.03	10	—	—	1 760
	Residential	872	8	200	0.09	30	—	—	1 100
	Agriculture & Forestry	X	X	X	X	X	—	—	X
<b>b. Transportation<sup>1</sup></b>		<b>5 500</b>	<b>0.6</b>	<b>10</b>	<b>0.7</b>	<b>200</b>	—	—	<b>5 700</b>
	Civil Aviation (Domestic Aviation)	416	0.01	0.3	0.04	10	—	—	430
	Road Transportation	3 770	0.27	5.6	0.29	91	—	—	3 860
	Light-Duty Gasoline Vehicles	1 200	0.09	2.0	0.10	30	—	—	1 230
	Light-Duty Gasoline Trucks	1 320	0.11	2.3	0.15	46	—	—	1 370
	Heavy-Duty Gasoline Vehicles	105	0.01	0.11	0.01	2.3	—	—	107
	Motorcycles	8.90	0.01	0.12	0.00	0.06	—	—	9.07
	Light-Duty Diesel Vehicles	17.9	0.00	0.01	0.00	0.4	—	—	18.4
	Light-Duty Diesel Trucks	62.1	0.00	0.03	0.01	2	—	—	63.7
	Heavy-Duty Diesel Vehicles	1 040	0.05	1	0.03	10	—	—	1 060
	Propane & Natural Gas Vehicles	4.98	0.00	0.04	0.00	0.03	—	—	5.1
	Railways	92.4	0.01	0.1	0.04	10	—	—	100
	Navigation (Domestic Marine)	551	0.04	0.8	0.1	40	—	—	590
	Other Transportation	680	0.3	7	0.2	60	—	—	700
	Off-Road Gasoline	200	0.3	5	0.01	1	—	—	200
	Off-Road Diesel	420	0.02	0.5	0.2	50	—	—	500
	Pipelines	45.6	0.05	0.96	0.00	0.4	—	—	46.9
<b>c. Fugitive Sources<sup>2</sup></b>		<b>7.1</b>	<b>3.0</b>	<b>64</b>	—	—	—	—	<b>70.8</b>
	Coal Mining	X	X	X	—	—	—	—	X
	Oil and Natural Gas	X	X	X	—	—	—	—	X
<b>INDUSTRIAL PROCESSES<sup>3</sup></b>		<b>220</b>	—	—	—	—	—	—	<b>224</b>
<b>a. Mineral Products</b>		<b>200</b>	—	—	—	—	—	—	<b>200</b>
	Cement Production	200	—	—	—	—	—	—	200
	Lime Production	—	—	—	—	—	—	—	0
<b>b. Chemical Industry</b>		—	—	—	—	—	—	—	<b>0</b>
	Nitric Acid Production	—	—	—	—	—	—	—	0
	Adipic Acid Production	—	—	—	—	—	—	—	0
<b>c. Metal Production</b>		—	—	—	—	—	—	—	<b>0</b>
	Iron and Steel Production	—	—	—	—	—	—	—	0
	Aluminum Production	—	—	—	—	—	—	—	0
	SF <sub>6</sub> Used in Magnesium Smelters and	—	—	—	—	—	—	—	0
<b>d. Consumption of Halocarbons and SF<sub>6</sub></b>		—	—	—	—	—	—	—	<b>0</b>
<b>e. Other &amp; Undifferentiated Production<sup>4</sup></b>		<b>23</b>	—	—	—	—	—	—	<b>23</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>		—	—	—	<b>0.03</b>	<b>9.2</b>	—	—	<b>9.2</b>
<b>AGRICULTURE</b>		—	<b>11</b>	<b>220</b>	<b>0.84</b>	<b>260</b>	—	—	<b>480</b>
<b>a. Enteric Fermentation</b>		—	8.9	190	—	—	—	—	190
<b>b. Manure Management</b>		—	1.7	35	0.16	49	—	—	83
<b>c. Agricultural Soils</b>		—	—	—	<b>0.68</b>	<b>210</b>	—	—	<b>210</b>
	Direct Sources	—	—	—	0.34	100	—	—	100
	Pasture, Range and Paddock Manure	—	—	—	0.08	25	—	—	25
	Indirect Sources	—	—	—	0.3	80	—	—	80
<b>WASTE</b>		<b>9.7</b>	<b>23</b>	<b>490</b>	<b>0.07</b>	<b>20</b>	—	—	<b>520</b>
<b>a. Solid Waste Disposal on Land</b>		—	23	490	—	—	—	—	490
<b>b. Wastewater Handling</b>		—	0.29	6.1	0.06	20	—	—	25
<b>c. Waste Incineration</b>		9.7	—	—	0.01	2	—	—	12

## Notes:

1. Emissions from Fuel Ethanol are reported within the gasoline transportation subcategories.

2. Fugitive emissions from refineries and the bitumen industry are only reported at the national level.

3. Emissions associated with the use of mineral products and consumption of halocarbons & SF<sub>6</sub> are only reported at the national level.

4. Emissions coming from ammonia production are included in the category Other &amp; Undifferentiated Production at provincial levels.

X Indicates confidential data.

— Indicates no emissions.

0.0 Indicates emissions truncated due to rounding.

Table A11-8: 1990–2006 GHG Emission Summary for New Brunswick

Greenhouse Gas Categories	1990	1995	2000	2001	2002	2003	2004	2005	2006
	<i>kt CO<sub>2</sub> equivalent</i>								
<b>TOTAL</b>	<b>15 900</b>	<b>16 800</b>	<b>19 900</b>	<b>22 100</b>	<b>20 900</b>	<b>20 600</b>	<b>21 200</b>	<b>20 900</b>	<b>17 900</b>
<b>ENERGY</b>	<b>14 700</b>	<b>15 400</b>	<b>18 600</b>	<b>20 800</b>	<b>19 500</b>	<b>19 100</b>	<b>19 700</b>	<b>19 500</b>	<b>16 600</b>
<b>a. Stationary Combustion Sources</b>	<b>10 700</b>	<b>11 100</b>	<b>13 100</b>	<b>15 400</b>	<b>14 100</b>	<b>13 900</b>	<b>14 200</b>	<b>14 000</b>	<b>11 300</b>
Electricity and Heat Generation	6 130	6 910	8 630	X	X	X	X	X	X
Fossil Fuel Industries	1 100	1 000	1 500	2 600	3 000	2 800	2 500	2 500	2 500
Mining & Oil and Gas Extraction	125	117	134	X	X	X	X	X	X
Manufacturing Industries	1 440	1 470	1 350	1 300	1 250	1 260	1 220	982	795
Construction	68.0	40.7	39.8	26.3	18.3	12.1	10.6	3.86	5.00
Commercial & Institutional	574	545	609	573	485	594	964	1 080	794
Residential	1 200	900	840	710	720	740	730	710	650
Agriculture & Forestry	52.4	127	63.7	X	X	X	X	X	X
<b>b. Transportation<sup>1</sup></b>	<b>4 000</b>	<b>4 300</b>	<b>5 400</b>	<b>5 400</b>	<b>5 300</b>	<b>5 300</b>	<b>5 400</b>	<b>5 400</b>	<b>5 300</b>
Civil Aviation (Domestic Aviation)	75	82	160	150	120	130	130	150	140
Road Transportation	3 030	3 520	3 670	3 620	3 640	3 700	3 790	3 860	3 900
Light-Duty Gasoline Vehicles	1 310	1 230	1 140	1 130	1 130	1 100	1 080	1 050	1 020
Light-Duty Gasoline Trucks	667	889	1 100	1 080	1 110	1 150	1 190	1 220	1 260
Heavy-Duty Gasoline Vehicles	200	137	90.3	119	112	112	116	126	140
Motorcycles	6.83	5.88	6.64	8.15	8.98	9.67	10.2	10.3	10.5
Light-Duty Diesel Vehicles	11.2	9.73	9.04	9.01	9.52	9.67	10.3	10.1	9.93
Light-Duty Diesel Trucks	23.7	40.3	44.6	45.6	46.4	48.2	50.9	54.0	57.9
Heavy-Duty Diesel Vehicles	800	1 200	1 270	1 220	1 220	1 270	1 320	1 390	1 410
Propane & Natural Gas Vehicles	5.1	8.1	6.8	8.0	1.6	1.4	1.3	0.61	0.77
Railways	100	100	200	300	300	300	300	300	300
Navigation (Domestic Marine)	270	300	400	420	390	370	430	420	390
Other Transportation	500	300	900	900	900	800	800	700	600
Off-Road Gasoline	100	60	100	100	200	200	100	100	60
Off-Road Diesel	400	300	800	800	800	600	600	600	500
Pipelines	–	–	–	–	–	–	–	–	–
<b>c. Fugitive Sources<sup>2</sup></b>	<b>1.46</b>	<b>0.71</b>	<b>25.1</b>	<b>28.8</b>	<b>29.2</b>	<b>29.1</b>	<b>29.0</b>	<b>29.2</b>	<b>29.0</b>
Coal Mining <sup>5</sup>	1	0.7	0.6	0.4	0.5	0.4	X	X	X
Oil and Natural Gas	–	–	24.6	28.4	28.7	28.7	X	X	X
<b>INDUSTRIAL PROCESSES<sup>3</sup></b>	<b>149</b>	<b>274</b>	<b>226</b>	<b>260</b>	<b>296</b>	<b>285</b>	<b>296</b>	<b>242</b>	<b>223</b>
<b>a. Mineral Products</b>	<b>76</b>	<b>91</b>	<b>100</b>	<b>92</b>	<b>95</b>	<b>84</b>	<b>90</b>	<b>86</b>	<b>79</b>
Cement Production	–	–	–	–	–	–	–	–	–
Lime Production	76	91	100	92	95	84	90	86	79
<b>b. Chemical Industry</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>
Nitric Acid Production	–	–	–	–	–	–	–	–	–
Adipic Acid Production	–	–	–	–	–	–	–	–	–
<b>c. Metal Production</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>
Iron and Steel Production	–	–	–	–	–	–	–	–	–
Aluminum Production	–	–	–	–	–	–	–	–	–
SF <sub>6</sub> Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	–	–
<b>d. Consumption of Halocarbons and SF<sub>6</sub></b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>
<b>e. Other &amp; Undifferentiated Production<sup>4</sup></b>	<b>72</b>	<b>180</b>	<b>120</b>	<b>170</b>	<b>200</b>	<b>200</b>	<b>210</b>	<b>160</b>	<b>140</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>	<b>4.7</b>	<b>5.3</b>	<b>5.9</b>	<b>5.1</b>	<b>4.0</b>	<b>5.2</b>	<b>5.0</b>	<b>4.2</b>	<b>7.4</b>
<b>AGRICULTURE</b>	<b>480</b>	<b>480</b>	<b>520</b>	<b>510</b>	<b>530</b>	<b>560</b>	<b>580</b>	<b>560</b>	<b>520</b>
<b>a. Enteric Fermentation</b>	<b>170</b>	<b>160</b>	<b>160</b>	<b>160</b>	<b>160</b>	<b>160</b>	<b>160</b>	<b>160</b>	<b>160</b>
<b>b. Manure Management</b>	<b>68</b>	<b>68</b>	<b>74</b>	<b>76</b>	<b>75</b>	<b>74</b>	<b>73</b>	<b>72</b>	<b>71</b>
<b>c. Agricultural Soils</b>	<b>250</b>	<b>250</b>	<b>280</b>	<b>270</b>	<b>290</b>	<b>320</b>	<b>340</b>	<b>320</b>	<b>290</b>
Direct Sources	130	140	160	150	170	180	200	180	160
Pasture, Range and Paddock Manure	21	22	22	22	22	22	21	21	21
Indirect Sources	90	90	100	100	100	100	100	100	100
<b>WASTE</b>	<b>560</b>	<b>590</b>	<b>600</b>	<b>600</b>	<b>600</b>	<b>600</b>	<b>600</b>	<b>600</b>	<b>590</b>
<b>a. Solid Waste Disposal on Land</b>	<b>510</b>	<b>550</b>	<b>570</b>	<b>560</b>	<b>560</b>	<b>560</b>	<b>560</b>	<b>560</b>	<b>560</b>
<b>b. Wastewater Handling</b>	<b>41</b>	<b>38</b>	<b>38</b>	<b>38</b>	<b>38</b>	<b>38</b>	<b>38</b>	<b>38</b>	<b>38</b>
<b>c. Waste Incineration</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>

## Notes:

1. Emissions from Fuel Ethanol are reported within the gasoline transportation subcategories.
  2. Fugitive emissions from refineries and the bitumen industry are only reported at the national level.
  3. Emissions associated with the use of mineral products and consumption of halocarbons & SF<sub>6</sub> are only reported at the national level.
  4. Emissions coming from ammonia production are included in the category Other & Undifferentiated Production at provincial levels.
  5. Fugitive emissions from coal mining activities for 2002 and 2003 have been extrapolated based on publicly available coal production data.
- X Indicates confidential data.  
– Indicates no emissions.  
0.0 Indicates emissions truncated due to rounding.

**Table A11-9: 2006 GHG Emission Summary for New Brunswick**

Greenhouse Gas Categories		Greenhouse Gases							
Global Warming Potential		CO <sub>2</sub>	CH <sub>4</sub>	CH <sub>4</sub>	N <sub>2</sub> O	N <sub>2</sub> O	PFCs	SF <sub>6</sub>	TOTAL
Unit		kt	kt	kt CO <sub>2</sub> eq	kt	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq
<b>TOTAL</b>		<b>16 300</b>	<b>47</b>	<b>990</b>	<b>2.2</b>	<b>670</b>	—	—	<b>17 900</b>
<b>ENERGY</b>		<b>16 000</b>	<b>10</b>	<b>220</b>	<b>1</b>	<b>300</b>	—	—	<b>16 600</b>
<b>a. Stationary Combustion Sources</b>		<b>11 000</b>	<b>9</b>	<b>200</b>	<b>0.3</b>	<b>100</b>	—	—	<b>11 300</b>
Electricity and Heat Generation		X	X	X	X	X	—	—	X
Fossil Fuel Industries		2 490	0.05	1	0.01	4	—	—	2 500
Mining & Oil and Gas Extraction		X	X	X	X	X	—	—	X
Manufacturing Industries		771	0.1	3	0.07	20	—	—	795
Construction		4.97	0.00	0.00	0.00	0.02	—	—	5.00
Commercial & Institutional		788	0.01	0.3	0.02	5	—	—	794
Residential		454	8	200	0.09	30	—	—	650
Agriculture & Forestry		X	X	X	X	X	—	—	X
<b>b. Transportation<sup>1</sup></b>		<b>5 060</b>	<b>0.4</b>	<b>9</b>	<b>0.7</b>	<b>200</b>	—	—	<b>5 300</b>
Civil Aviation (Domestic Aviation)		140	0.01	0.2	0.01	4	—	—	140
Road Transportation		3 810	0.27	5.7	0.28	87	—	—	3 900
Light-Duty Gasoline Vehicles		994	0.08	1.8	0.08	26	—	—	1 020
Light-Duty Gasoline Trucks		1 210	0.11	2.3	0.14	42	—	—	1 260
Heavy-Duty Gasoline Vehicles		137	0.01	0.16	0.01	3.0	—	—	140
Motorcycles		10.3	0.01	0.14	0.00	0.06	—	—	10.5
Light-Duty Diesel Vehicles		9.69	0.00	0.00	0.00	0.2	—	—	9.93
Light-Duty Diesel Trucks		56.4	0.00	0.03	0.01	1	—	—	57.9
Heavy-Duty Diesel Vehicles		1 390	0.06	1	0.04	10	—	—	1 410
Propane & Natural Gas Vehicles		0.76	0.00	0.01	0.00	0.00	—	—	0.77
Railways		236	0.01	0.3	0.1	30	—	—	300
Navigation (Domestic Marine)		353	0.02	0.4	0.1	40	—	—	390
Other Transportation		520	0.1	2	0.2	60	—	—	600
Off-Road Gasoline		60	0.07	1	0.00	0.4	—	—	60
Off-Road Diesel		460	0.03	0.5	0.2	60	—	—	500
Pipelines		—	—	—	—	—	—	—	0
<b>c. Fugitive Sources<sup>2</sup></b>		<b>0.01</b>	<b>1.4</b>	<b>29</b>	—	—	—	—	<b>29.0</b>
Coal Mining		X	X	X	—	—	—	—	X
Oil and Natural Gas		X	X	X	—	—	—	—	X
<b>INDUSTRIAL PROCESSES<sup>3</sup></b>		<b>220</b>	—	—	—	—	—	—	<b>223</b>
<b>a. Mineral Products</b>		<b>79</b>	—	—	—	—	—	—	<b>79</b>
Cement Production		—	—	—	—	—	—	—	0
Lime Production		79	—	—	—	—	—	—	79
<b>b. Chemical Industry</b>		—	—	—	—	—	—	—	<b>0</b>
Nitric Acid Production		—	—	—	—	—	—	—	0
Adipic Acid Production		—	—	—	—	—	—	—	0
<b>c. Metal Production</b>		—	—	—	—	—	—	—	<b>0</b>
Iron and Steel Production		—	—	—	—	—	—	—	0
Aluminum Production		—	—	—	—	—	—	—	0
SF <sub>6</sub> Used in Magnesium Smelters and		—	—	—	—	—	—	—	0
<b>d. Consumption of Halocarbons and SF<sub>6</sub></b>		—	—	—	—	—	—	—	<b>0</b>
<b>e. Other &amp; Undifferentiated Production<sup>4</sup></b>		<b>140</b>	—	—	—	—	—	—	<b>140</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>		—	—	—	<b>0.02</b>	<b>7.4</b>	—	—	<b>7.4</b>
<b>AGRICULTURE</b>		—	<b>9.1</b>	<b>190</b>	<b>1.1</b>	<b>330</b>	—	—	<b>520</b>
<b>a. Enteric Fermentation</b>		—	7.6	160	—	—	—	—	160
<b>b. Manure Management</b>		—	1.5	31	0.13	39	—	—	71
<b>c. Agricultural Soils</b>		—	—	—	<b>0.93</b>	<b>290</b>	—	—	<b>290</b>
Direct Sources		—	—	—	0.53	160	—	—	160
Pasture, Range and Paddock Manure		—	—	—	0.07	21	—	—	21
Indirect Sources		—	—	—	0.3	100	—	—	100
<b>WASTE</b>		—	<b>28</b>	<b>580</b>	<b>0.05</b>	<b>20</b>	—	—	<b>590</b>
<b>a. Solid Waste Disposal on Land</b>		—	26	560	—	—	—	—	560
<b>b. Wastewater Handling</b>		—	1.1	22	0.05	20	—	—	38
<b>c. Waste Incineration</b>		—	—	—	—	—	—	—	0

## Notes:

1. Emissions from Fuel Ethanol are reported within the gasoline transportation subcategories.

2. Fugitive emissions from refineries and the bitumen industry are only reported at the national level.

3. Emissions associated with the use of mineral products and consumption of halocarbons & SF<sub>6</sub> are only reported at the national level.

4. Emissions coming from ammonia production are included in the category Other &amp; Undifferentiated Production at provincial levels.

X Indicates confidential data.

— Indicates no emissions.

0.0 Indicates emissions truncated due to rounding.

**Table A11-10: 1990–2006 GHG Emission Summary for Quebec**

Greenhouse Gas Categories	1990	1995	2000	2001	2002	2003	2004	2005	2006
	<i>kt CO<sub>2</sub> equivalent</i>								
<b>TOTAL</b>	<b>82 700</b>	<b>79 400</b>	<b>81 900</b>	<b>79 900</b>	<b>82 500</b>	<b>87 300</b>	<b>87 400</b>	<b>83 600</b>	<b>81 700</b>
<b>ENERGY</b>	<b>57 600</b>	<b>56 400</b>	<b>60 000</b>	<b>57 800</b>	<b>59 900</b>	<b>65 000</b>	<b>64 900</b>	<b>61 400</b>	<b>59 500</b>
<b>a. Stationary Combustion Sources</b>	<b>29 500</b>	<b>26 800</b>	<b>27 900</b>	<b>26 100</b>	<b>27 000</b>	<b>30 800</b>	<b>29 900</b>	<b>26 900</b>	<b>25 100</b>
Electricity and Heat Generation	1 520	396	582	645	583	1 880	1 660	729	1 100
Fossil Fuel Industries	3 300	3 100	3 400	3 300	3 300	3 500	3 600	3 700	3 700
Mining & Oil and Gas Extraction	734	828	926	842	941	941	449	227	246
Manufacturing Industries	12 100	10 800	11 000	10 000	10 000	10 300	10 900	9 840	8 980
Construction	457	186	188	189	251	295	320	290	264
Commercial & Institutional	4 230	5 020	5 670	5 710	6 460	7 850	6 860	6 780	5 970
Residential	6 800	6 100	5 900	5 200	5 300	5 600	5 700	5 000	4 600
Agriculture & Forestry	288	300	259	225	257	345	312	272	256
<b>b. Transportation<sup>1</sup></b>	<b>28 000</b>	<b>29 000</b>	<b>32 000</b>	<b>31 000</b>	<b>32 000</b>	<b>34 000</b>	<b>35 000</b>	<b>34 000</b>	<b>34 000</b>
Civil Aviation (Domestic Aviation)	950	790	770	820	1 400	1 500	1 400	1 200	1 100
Road Transportation	21 000	23 300	25 900	25 900	26 300	26 700	27 500	27 700	28 000
Light-Duty Gasoline Vehicles	11 900	11 400	11 100	10 900	10 900	10 800	10 800	10 500	10 200
Light-Duty Gasoline Trucks	3 850	5 140	6 600	6 720	6 990	7 250	7 540	7 840	8 200
Heavy-Duty Gasoline Vehicles	608	638	535	766	770	784	826	848	873
Motorcycles	31.2	29.9	46.2	55.7	65.1	71.1	76.2	80.0	84.2
Light-Duty Diesel Vehicles	143	135	140	146	154	158	172	171	171
Light-Duty Diesel Trucks	209	346	390	379	365	380	406	426	448
Heavy-Duty Diesel Vehicles	4 090	5 550	6 170	6 890	7 040	7 190	7 620	7 820	8 010
Propane & Natural Gas Vehicles	110	47	36	56	35	30	39	34	29
Railways	600	500	800	800	700	700	800	700	700
Navigation (Domestic Marine)	1 400	910	1 400	1 600	1 400	1 000	1 400	1 300	1 200
Other Transportation	4 000	4 000	4 000	2 000	3 000	4 000	3 000	3 000	3 000
Off-Road Gasoline	1 000	1 000	900	900	1 000	1 000	1 000	1 000	700
Off-Road Diesel	3 000	2 000	3 000	1 000	1 000	2 000	2 000	2 000	2 000
Pipelines	26.0	24.5	107	203	331	357	251	338	286
<b>c. Fugitive Sources<sup>2</sup></b>	<b>281</b>	<b>396</b>	<b>444</b>	<b>450</b>	<b>490</b>	<b>492</b>	<b>496</b>	<b>500</b>	<b>500</b>
Coal Mining <sup>6</sup>	–	–	–	–	–	–	X	X	X
Oil and Natural Gas	281	396	444	450	490	492	X	X	X
<b>INDUSTRIAL PROCESSES<sup>3</sup></b>	<b>12 800</b>	<b>11 200</b>	<b>10 100</b>	<b>10 200</b>	<b>10 400</b>	<b>10 200</b>	<b>10 100</b>	<b>9 790</b>	<b>9 940</b>
<b>a. Mineral Products</b>	<b>1 600</b>	<b>1 700</b>	<b>1 600</b>	<b>1 500</b>	<b>1 600</b>	<b>1 600</b>	<b>1 700</b>	<b>1 800</b>	<b>1 800</b>
Cement Production	1 300	1 500	1 200	1 200	1 200	1 200	1 200	1 300	1 300
Lime Production	270	250	430	380	400	450	490	460	430
<b>b. Chemical Industry</b>	<b>80</b>	<b>110</b>	–	–	–	–	–	–	–
Nitric Acid Production	79.7	105	–	–	–	–	–	–	–
Adipic Acid Production	–	–	–	–	–	–	–	–	–
<b>c. Metal Production</b>	<b>10 200</b>	<b>8 820</b>	<b>7 640</b>	<b>7 730</b>	<b>7 950</b>	<b>7 640</b>	<b>6 880</b>	<b>6 860</b>	<b>6 710</b>
Iron and Steel Production	–	6.63	11.7	12.1	8.31	8.29	8.14	–	–
Aluminum Production	7 800	7 500	6 400	6 400	6 400	6 400	5 900	6 800	6 600
SF <sub>6</sub> Used in Magnesium Smelters and Casters <sup>5</sup>	2 370	1 340	1 230	1 280	1 540	1 210	950	75.1	81.3
<b>d. Consumption of Halocarbons and SF<sub>6</sub></b>	–	–	–	–	–	–	–	–	–
<b>e. Other &amp; Undifferentiated Production<sup>4</sup></b>	<b>930</b>	<b>590</b>	<b>820</b>	<b>920</b>	<b>890</b>	<b>900</b>	<b>1 500</b>	<b>1 200</b>	<b>1 500</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>	<b>44</b>	<b>51</b>	<b>58</b>	<b>51</b>	<b>39</b>	<b>52</b>	<b>50</b>	<b>42</b>	<b>76</b>
<b>AGRICULTURE</b>	<b>7 600</b>	<b>7 500</b>	<b>7 400</b>	<b>7 600</b>	<b>7 700</b>	<b>7 700</b>	<b>7 900</b>	<b>7 800</b>	<b>7 500</b>
<b>a. Enteric Fermentation</b>	<b>2 700</b>	<b>2 800</b>	<b>2 600</b>	<b>2 700</b>	<b>2 700</b>	<b>2 700</b>	<b>2 900</b>	<b>2 800</b>	<b>2 700</b>
<b>b. Manure Management</b>	<b>1 300</b>	<b>1 300</b>	<b>1 400</b>	<b>1 400</b>	<b>1 400</b>	<b>1 400</b>	<b>1 400</b>	<b>1 400</b>	<b>1 400</b>
<b>c. Agricultural Soils</b>	<b>3 600</b>	<b>3 400</b>	<b>3 400</b>	<b>3 500</b>	<b>3 600</b>	<b>3 500</b>	<b>3 600</b>	<b>3 600</b>	<b>3 400</b>
Direct Sources	2 000	1 800	1 800	1 900	1 900	1 900	1 900	1 900	1 800
Pasture, Range and Paddock Manure	280	300	290	300	300	310	320	320	310
Indirect Sources	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000
<b>WASTE</b>	<b>4 700</b>	<b>4 300</b>	<b>4 500</b>	<b>4 300</b>	<b>4 400</b>	<b>4 400</b>	<b>4 400</b>	<b>4 500</b>	<b>4 600</b>
<b>a. Solid Waste Disposal on Land</b>	<b>4 300</b>	<b>3 900</b>	<b>4 100</b>	<b>4 000</b>	<b>4 000</b>	<b>4 000</b>	<b>4 100</b>	<b>4 100</b>	<b>4 300</b>
<b>b. Wastewater Handling</b>	<b>220</b>	<b>230</b>	<b>250</b>	<b>260</b>	<b>260</b>	<b>260</b>	<b>270</b>	<b>270</b>	<b>270</b>
<b>c. Waste Incineration</b>	<b>170</b>	<b>150</b>	<b>84</b>	<b>85</b>	<b>87</b>	<b>89</b>	<b>91</b>	<b>93</b>	<b>94</b>

## Notes:

1. Emissions from Fuel Ethanol are reported within the gasoline transportation subcategories.
  2. Fugitive emissions from refineries and the bitumen industry are only reported at the national level.
  3. Emissions associated with the use of mineral products and consumption of halocarbons & SF<sub>6</sub> are only reported at the national level.
  4. Emissions coming from ammonia production are included in the category Other & Undifferentiated Production at provincial levels.
  5. Only SF<sub>6</sub> emissions from magnesium smelters are included. Information on SF<sub>6</sub> use in casters is confidential for this province.
  6. Fugitive emissions from coal mining activities for 2002 and 2003 have been extrapolated based on publicly available coal production data.
- X Indicates confidential data.  
 – Indicates no emissions.  
 0.0 Indicates emissions truncated due to rounding.

Table A11-11: 2006 GHG Emission Summary for Quebec

Greenhouse Gas Categories		Greenhouse Gases							
		CO <sub>2</sub>	CH <sub>4</sub>	CH <sub>4</sub>	N <sub>2</sub> O	N <sub>2</sub> O	PFCs	SF <sub>6</sub>	TOTAL
		Global Warming Potential		21		310			
		Unit	kt	kt CO <sub>2</sub> eq	kt	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq
<b>TOTAL</b>			<b>64 800</b>	<b>440</b>	<b>9 200</b>	<b>18</b>	<b>5 500</b>	<b>2 100</b>	<b>81 700</b>
<b>ENERGY</b>			<b>56 900</b>	<b>61</b>	<b>1 300</b>	<b>4</b>	<b>1 000</b>	—	<b>59 500</b>
<b>a. Stationary Combustion Sources</b>			<b>24 100</b>	<b>30</b>	<b>700</b>	<b>0.9</b>	<b>300</b>	—	<b>25 100</b>
Electricity and Heat Generation			1 080	0.21	4.4	0.03	9	—	1 100
Fossil Fuel Industries			3 720	0.07	1	0.04	10	—	3 700
Mining & Oil and Gas Extraction			245	0.01	0.2	0.01	1	—	246
Manufacturing Industries			8 880	0.5	10	0.3	90	—	8 980
Construction			262	0.01	0.1	0.01	2	—	264
Commercial & Institutional			5 930	0.1	2	0.1	40	—	5 970
Residential			3 760	30	700	0.4	100	—	4 600
Agriculture & Forestry			252	0.00	0.08	0.01	4	—	256
<b>b. Transportation<sup>1</sup></b>			<b>32 800</b>	<b>3</b>	<b>70</b>	<b>3</b>	<b>1 000</b>	—	<b>34 000</b>
Civil Aviation (Domestic Aviation)			1 110	0.07	1	0.1	30	—	1 100
Road Transportation			27 400	1.9	40	2.1	640	—	28 000
Light-Duty Gasoline Vehicles			9 960	0.78	16	0.82	250	—	10 200
Light-Duty Gasoline Trucks			7 910	0.64	13	0.90	280	—	8 200
Heavy-Duty Gasoline Vehicles			853	0.05	0.96	0.06	19	—	873
Motorcycles			82.6	0.05	1.1	0.00	0.51	—	84.2
Light-Duty Diesel Vehicles			167	0.00	0.07	0.01	4	—	171
Light-Duty Diesel Trucks			437	0.01	0.2	0.04	10	—	448
Heavy-Duty Diesel Vehicles			7 930	0.4	8	0.2	80	—	8 010
Propane & Natural Gas Vehicles			28.1	0.02	0.5	0.00	0.2	—	29
Railways			664	0.04	0.8	0.3	90	—	700
Navigation (Domestic Marine)			1 090	0.08	2	0.2	50	—	1 200
Other Transportation			2 600	1	20	0.7	200	—	3 000
Off-Road Gasoline			700	0.8	20	0.01	5	—	700
Off-Road Diesel			1 600	0.09	2	0.7	200	—	2 000
Pipelines			277	0.28	5.8	0.01	2	—	286
<b>c. Fugitive Sources<sup>2</sup></b>			<b>0.12</b>	<b>24</b>	<b>500</b>	—	—	—	<b>500</b>
Coal Mining			X	X	X	—	—	—	X
Oil and Natural Gas			X	X	X	—	—	—	X
<b>INDUSTRIAL PROCESSES<sup>3</sup></b>			<b>7 800</b>	—	—	—	—	<b>2 100</b>	<b>9 940</b>
<b>a. Mineral Products</b>			<b>1 800</b>	—	—	—	—	—	<b>1 800</b>
Cement Production			1 300	—	—	—	—	—	1 300
Lime Production			430	—	—	—	—	—	430
<b>b. Chemical Industry</b>			—	—	—	—	—	—	<b>0</b>
Nitric Acid Production			—	—	—	—	—	—	0
Adipic Acid Production			—	—	—	—	—	—	0
<b>c. Metal Production</b>			<b>4 520</b>	—	—	—	—	<b>2 100</b>	<b>6 710</b>
Iron and Steel Production			—	—	—	—	—	—	0
Aluminum Production			4 500	—	—	—	2 100	12.7	6 600
SF <sub>6</sub> Used in Magnesium Smelters and Casters <sup>5</sup>			—	—	—	—	—	81.3	81.3
<b>d. Consumption of Halocarbons and SF<sub>6</sub></b>			—	—	—	—	—	—	<b>0</b>
<b>e. Other &amp; Undifferentiated Production<sup>4</sup></b>			<b>1 500</b>	—	—	—	—	—	<b>1 500</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>			—	—	—	<b>0.24</b>	<b>76</b>	—	<b>76</b>
<b>AGRICULTURE</b>			—	<b>170</b>	<b>3 600</b>	<b>13</b>	<b>4 000</b>	—	<b>7 500</b>
<b>a. Enteric Fermentation</b>			—	130	2 700	—	—	—	2 700
<b>b. Manure Management</b>			—	39	830	1.8	560	—	1 400
<b>c. Agricultural Soils</b>			—	—	—	<b>11</b>	<b>3 400</b>	—	<b>3 400</b>
Direct Sources			—	—	—	5.9	1 800	—	1 800
Pasture, Range and Paddock Manure			—	—	—	1.0	310	—	310
Indirect Sources			—	—	—	4	1 000	—	1 000
<b>WASTE</b>			<b>67</b>	<b>210</b>	<b>4 400</b>	<b>0.6</b>	<b>200</b>	—	<b>4 600</b>
<b>a. Solid Waste Disposal on Land</b>			—	200	4 300	—	—	—	4 300
<b>b. Wastewater Handling</b>			—	5.6	120	0.5	200	—	270
<b>c. Waste Incineration</b>			67	0.07	1	0.08	30	—	94

## Notes:

- Emissions from Fuel Ethanol are reported within the gasoline transportation subcategories.
- Fugitive emissions from refineries and the bitumen industry are only reported at the national level.
- Emissions associated with the use of mineral products and consumption of halocarbons & SF<sub>6</sub> are only reported at the national level.
- Emissions coming from ammonia production are included in the category Other & Undifferentiated Production at provincial levels.
- Only SF<sub>6</sub> emissions from magnesium smelters are included. Information on SF<sub>6</sub> use in casters is confidential for this province.

X Indicates confidential data.

— Indicates no emissions.

0.0 Indicates emissions truncated due to rounding.

**Table A11-12: 1990–2006 GHG Emission Summary for Ontario**

Greenhouse Gas Categories	1990	1995	2000	2001	2002	2003	2004	2005	2006
	<i>kt CO<sub>2</sub> equivalent</i>								
<b>TOTAL</b>	<b>174 000</b>	<b>174 000</b>	<b>199 000</b>	<b>192 000</b>	<b>197 000</b>	<b>202 000</b>	<b>197 000</b>	<b>198 000</b>	<b>190 000</b>
<b>ENERGY</b>	<b>132 000</b>	<b>130 000</b>	<b>165 000</b>	<b>159 000</b>	<b>163 000</b>	<b>167 000</b>	<b>159 000</b>	<b>161 000</b>	<b>153 000</b>
<b>a. Stationary Combustion Sources</b>	<b>83 800</b>	<b>77 000</b>	<b>104 000</b>	<b>99 300</b>	<b>102 000</b>	<b>106 000</b>	<b>96 200</b>	<b>95 300</b>	<b>89 300</b>
Electricity and Heat Generation	26 600	19 100	42 800	40 700	40 600	41 300	32 200	34 400	29 600
Fossil Fuel Industries	6 100	5 500	6 000	6 000	7 500	7 400	7 100	5 200	5 300
Mining & Oil and Gas Extraction	491	665	469	405	413	410	447	584	628
Manufacturing Industries	22 700	21 100	20 800	19 500	20 500	20 600	21 600	19 900	21 600
Construction	571	372	438	390	522	548	546	605	546
Commercial & Institutional	9 140	9 820	13 100	13 600	12 900	14 000	14 100	14 000	12 500
Residential	17 000	19 000	19 000	18 000	19 000	21 000	19 000	20 000	18 000
Agriculture & Forestry	772	1 140	897	760	832	986	966	960	953
<b>b. Transportation<sup>1</sup></b>	<b>47 000</b>	<b>51 000</b>	<b>59 000</b>	<b>58 000</b>	<b>59 000</b>	<b>60 000</b>	<b>61 000</b>	<b>64 000</b>	<b>62 000</b>
Civil Aviation (Domestic Aviation)	1 600	1 300	1 600	1 300	1 200	1 500	1 800	2 400	2 500
Road Transportation	35 600	38 000	42 600	43 600	44 100	45 300	46 400	47 300	47 400
Light-Duty Gasoline Vehicles	18 800	17 800	16 900	17 100	17 000	16 800	16 600	16 300	15 800
Light-Duty Gasoline Trucks	7 740	10 100	13 800	14 500	15 000	15 600	16 000	16 800	17 300
Heavy-Duty Gasoline Vehicles	1 570	1 050	1 070	1 100	1 110	1 160	1 280	1 260	1 240
Motorcycles	43.1	29.5	39.6	47.6	52.6	59.3	64.6	66.1	67.3
Light-Duty Diesel Vehicles	111	99.8	117	123	129	133	142	144	145
Light-Duty Diesel Trucks	148	275	375	391	402	418	441	482	502
Heavy-Duty Diesel Vehicles	6 600	7 810	9 980	9 950	10 200	10 800	11 400	11 800	12 000
Propane & Natural Gas Vehicles	540	790	380	410	260	290	330	350	380
Railways	2 000	2 000	2 000	2 000	1 000	1 000	1 000	2 000	1 000
Navigation (Domestic Marine)	940	660	640	680	660	580	640	590	500
Other Transportation	7 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000
Off-Road Gasoline	2 000	2 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000
Off-Road Diesel	3 000	4 000	6 000	5 000	5 000	5 000	5 000	6 000	5 000
Pipelines	2 270	4 050	3 630	2 520	3 080	2 510	2 090	3 060	2 740
<b>c. Fugitive Sources<sup>2</sup></b>	<b>1 340</b>	<b>1 480</b>	<b>1 700</b>	<b>1 810</b>	<b>1 800</b>	<b>1 800</b>	<b>1 830</b>	<b>1 840</b>	<b>1 840</b>
Coal Mining <sup>5</sup>	—	—	—	—	—	—	X	X	X
Oil and Natural Gas	1 340	1 480	1 700	1 810	1 800	1 800	X	X	X
<b>INDUSTRIAL PROCESSES<sup>3</sup></b>	<b>26 000</b>	<b>27 500</b>	<b>18 700</b>	<b>17 200</b>	<b>18 400</b>	<b>17 700</b>	<b>20 400</b>	<b>19 500</b>	<b>19 100</b>
<b>a. Mineral Products</b>	<b>3 400</b>	<b>3 900</b>	<b>4 200</b>	<b>4 000</b>	<b>4 000</b>	<b>4 100</b>	<b>4 300</b>	<b>4 300</b>	<b>4 400</b>
Cement Production	2 300	2 800	3 300	3 300	3 200	3 300	3 400	3 500	3 600
Lime Production	1 100	1 100	900	750	780	760	820	790	800
<b>b. Chemical Industry</b>	<b>11 000</b>	<b>11 000</b>	<b>990</b>	<b>890</b>	<b>1 300</b>	<b>1 200</b>	<b>3 200</b>	<b>2 700</b>	<b>1 300</b>
Nitric Acid Production	99.4	92.0	88.8	85.3	95.6	90.1	101	67.2	78.9
Adipic Acid Production	11 000	11 000	900	800	1 300	1 100	3 100	2 600	1 200
<b>c. Metal Production</b>	<b>7 780</b>	<b>8 600</b>	<b>9 400</b>	<b>8 330</b>	<b>8 480</b>	<b>8 280</b>	<b>8 400</b>	<b>8 210</b>	<b>9 030</b>
Iron and Steel Production	7 060	7 860	7 880	7 270	7 110	7 040	7 190	7 020	7 760
Aluminum Production	—	—	—	—	—	—	—	—	—
SF <sub>6</sub> Used in Magnesium Smelters and Casters	720	734	1 520	1 060	1 370	1 240	1 210	1 180	1 270
<b>d. Consumption of Halocarbons and SF<sub>6</sub></b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>
<b>e. Other &amp; Undifferentiated Production<sup>4</sup></b>	<b>4 100</b>	<b>4 200</b>	<b>4 100</b>	<b>3 900</b>	<b>4 500</b>	<b>4 100</b>	<b>4 500</b>	<b>4 300</b>	<b>4 400</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>	<b>65</b>	<b>78</b>	<b>92</b>	<b>81</b>	<b>64</b>	<b>86</b>	<b>82</b>	<b>70</b>	<b>130</b>
<b>AGRICULTURE</b>	<b>11 000</b>	<b>11 000</b>	<b>10 000</b>	<b>10 000</b>	<b>10 000</b>	<b>11 000</b>	<b>11 000</b>	<b>10 000</b>	<b>11 000</b>
<b>a. Enteric Fermentation</b>	<b>3 800</b>	<b>3 900</b>	<b>3 700</b>	<b>3 700</b>	<b>3 700</b>	<b>3 800</b>	<b>3 800</b>	<b>3 700</b>	<b>3 600</b>
<b>b. Manure Management</b>	<b>1 500</b>	<b>1 600</b>	<b>1 600</b>	<b>1 600</b>	<b>1 600</b>	<b>1 700</b>	<b>1 700</b>	<b>1 700</b>	<b>1 600</b>
<b>c. Agricultural Soils</b>	<b>5 300</b>	<b>5 200</b>	<b>4 900</b>	<b>4 800</b>	<b>5 000</b>	<b>5 200</b>	<b>5 200</b>	<b>5 000</b>	<b>5 900</b>
Direct Sources	2 900	2 900	2 700	2 600	2 700	2 900	2 900	2 700	3 300
Pasture, Range and Paddock Manure	480	510	490	500	500	520	520	510	490
Indirect Sources	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000
<b>WASTE</b>	<b>5 200</b>	<b>5 900</b>	<b>5 800</b>	<b>5 700</b>	<b>5 900</b>	<b>6 100</b>	<b>6 300</b>	<b>6 600</b>	<b>6 600</b>
<b>a. Solid Waste Disposal on Land</b>	<b>4 800</b>	<b>5 600</b>	<b>5 400</b>	<b>5 400</b>	<b>5 600</b>	<b>5 700</b>	<b>6 000</b>	<b>6 200</b>	<b>6 300</b>
<b>b. Wastewater Handling</b>	<b>230</b>	<b>250</b>	<b>270</b>	<b>290</b>	<b>290</b>	<b>290</b>	<b>300</b>	<b>300</b>	<b>290</b>
<b>c. Waste Incineration</b>	<b>130</b>	<b>99</b>	<b>73</b>	<b>76</b>	<b>45</b>	<b>48</b>	<b>52</b>	<b>56</b>	<b>59</b>

## Notes:

- Emissions from Fuel Ethanol are reported within the gasoline transportation subcategories.
  - Fugitive emissions from refineries and the bitumen industry are only reported at the national level.
  - Emissions associated with the use of mineral products and consumption of halocarbons & SF<sub>6</sub> are only reported at the national level.
  - Emissions coming from ammonia production are included in the category Other & Undifferentiated Production at provincial levels.
  - Fugitive emissions from coal mining activities for 2002 and 2003 have been extrapolated based on publicly available coal production data.
- X Indicates confidential data.  
 — Indicates no emissions.  
 0.0 Indicates emissions truncated due to rounding.



Table A11-13: 2006 GHG Emission Summary for Ontario

Greenhouse Gas Categories		Greenhouse Gases							
		CO <sub>2</sub>	CH <sub>4</sub>	CH <sub>4</sub>	N <sub>2</sub> O	N <sub>2</sub> O	PFCs	SF <sub>6</sub>	TOTAL
		Global Warming Potential		21		310			
		Unit	kt	kt CO <sub>2</sub> eq	kt	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq
<b>TOTAL</b>			<b>165 000</b>	<b>630</b>	<b>13 000</b>	<b>36</b>	<b>11 000</b>	<b>1 300</b>	<b>190 000</b>
<b>ENERGY</b>			<b>148 000</b>	<b>120</b>	<b>2 600</b>	<b>9</b>	<b>3 000</b>	<b>—</b>	<b>153 000</b>
<b>a.</b>	<b>Stationary Combustion Sources</b>		<b>88 100</b>	<b>30</b>	<b>600</b>	<b>2</b>	<b>600</b>	<b>—</b>	<b>89 300</b>
	Electricity and Heat Generation		29 400	1.4	30	0.5	200	—	29 600
	Fossil Fuel Industries		5 300	0.08	2	0.03	10	—	5 300
	Mining & Oil and Gas Extraction		621	0.01	0.2	0.02	7	—	628
	Manufacturing Industries		21 400	0.9	20	0.5	200	—	21 600
	Construction		542	0.01	0.2	0.01	4	—	546
	Commercial & Institutional		12 500	0.2	5	0.3	80	—	12 500
	Residential		17 500	20	500	0.6	200	—	18 000
	Agriculture & Forestry		944	0.02	0.4	0.03	8	—	953
<b>b.</b>	<b>Transportation<sup>1</sup></b>		<b>59 900</b>	<b>10</b>	<b>200</b>	<b>7</b>	<b>2 000</b>	<b>—</b>	<b>62 000</b>
	Civil Aviation (Domestic Aviation)		2 450	0.1	2	0.2	70	—	2 500
	Road Transportation		46 000	3.2	68	4.3	1 300	—	47 400
	Light-Duty Gasoline Vehicles		15 300	1.1	22	1.6	490	—	15 800
	Light-Duty Gasoline Trucks		16 600	1.0	22	2.2	680	—	17 300
	Heavy-Duty Gasoline Vehicles		1 210	0.06	1.3	0.09	29	—	1 240
	Motorcycles		65.8	0.05	1.0	0.00	0.42	—	67.3
	Light-Duty Diesel Vehicles		142	0.00	0.06	0.01	4	—	145
	Light-Duty Diesel Trucks		489	0.01	0.3	0.04	10	—	502
	Heavy-Duty Diesel Vehicles		11 800	0.5	10	0.4	100	—	12 000
	Propane & Natural Gas Vehicles		369	0.5	10	0.01	2	—	380
	Railways		1 290	0.07	1	0.5	200	—	1 000
	Navigation (Domestic Marine)		477	0.04	0.8	0.08	20	—	500
	Other Transportation		9 700	6	100	2	600	—	10 000
	Off-Road Gasoline		3 000	3	70	0.06	20	—	3 000
	Off-Road Diesel		4 300	0.2	5	2	600	—	5 000
	Pipelines		2 660	2.7	56	0.07	20	—	2 740
<b>c.</b>	<b>Fugitive Sources<sup>2</sup></b>		<b>0.78</b>	<b>88</b>	<b>1 800</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>1 840</b>
	Coal Mining		X	X	X	—	—	—	X
	Oil and Natural Gas		X	X	X	—	—	—	X
<b>INDUSTRIAL PROCESSES<sup>3</sup></b>			<b>17 000</b>	<b>—</b>	<b>—</b>	<b>4.15</b>	<b>1 290</b>	<b>—</b>	<b>19 100</b>
<b>a.</b>	<b>Mineral Products</b>		<b>4 400</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>4 400</b>
	Cement Production		3 600	—	—	—	—	—	3 600
	Lime Production		800	—	—	—	—	—	800
<b>b.</b>	<b>Chemical Industry</b>		<b>—</b>	<b>—</b>	<b>—</b>	<b>4.15</b>	<b>1 290</b>	<b>—</b>	<b>1 300</b>
	Nitric Acid Production		—	—	—	0.25	78.9	—	78.9
	Adipic Acid Production		—	—	—	3.9	1 200	—	1 200
<b>c.</b>	<b>Metal Production</b>		<b>7 760</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>1 270</b>	<b>9 030</b>
	Iron and Steel Production		7 760	—	—	—	—	—	7 760
	Aluminum Production		—	—	—	—	—	—	0
	SF <sub>6</sub> Used in Magnesium Smelters and Casters		—	—	—	—	—	1 270	1 270
<b>d.</b>	<b>Consumption of Halocarbons and SF<sub>6</sub></b>		<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>0</b>
<b>e.</b>	<b>Other &amp; Undifferentiated Production<sup>4</sup></b>		<b>4 400</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>4 400</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>			<b>—</b>	<b>—</b>	<b>—</b>	<b>0.40</b>	<b>130</b>	<b>—</b>	<b>130</b>
<b>AGRICULTURE</b>			<b>—</b>	<b>210</b>	<b>4 400</b>	<b>22</b>	<b>6 700</b>	<b>—</b>	<b>11 000</b>
<b>a.</b>	<b>Enteric Fermentation</b>		<b>—</b>	<b>170</b>	<b>3 600</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>3 600</b>
<b>b.</b>	<b>Manure Management</b>		<b>—</b>	<b>38</b>	<b>800</b>	<b>2.6</b>	<b>820</b>	<b>—</b>	<b>1 600</b>
<b>c.</b>	<b>Agricultural Soils</b>		<b>—</b>	<b>—</b>	<b>—</b>	<b>19</b>	<b>5 900</b>	<b>—</b>	<b>5 900</b>
	Direct Sources		—	—	—	11	3 300	—	3 300
	Pasture, Range and Paddock Manure		—	—	—	1.6	490	—	490
	Indirect Sources		—	—	—	7	2 000	—	2 000
<b>WASTE</b>			<b>49</b>	<b>300</b>	<b>6 300</b>	<b>0.9</b>	<b>300</b>	<b>—</b>	<b>6 600</b>
<b>a.</b>	<b>Solid Waste Disposal on Land</b>		<b>—</b>	<b>300</b>	<b>6 300</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>6 300</b>
<b>b.</b>	<b>Wastewater Handling</b>		<b>—</b>	<b>1.6</b>	<b>33</b>	<b>0.8</b>	<b>300</b>	<b>—</b>	<b>290</b>
<b>c.</b>	<b>Waste Incineration</b>		<b>49</b>	<b>—</b>	<b>—</b>	<b>0.03</b>	<b>10</b>	<b>—</b>	<b>59</b>

## Notes:

1. Emissions from Fuel Ethanol are reported within the gasoline transportation subcategories.

2. Fugitive emissions from refineries and the bitumen industry are only reported at the national level.

3. Emissions associated with the use of mineral products and consumption of halocarbons & SF<sub>6</sub> are only reported at the national level.

4. Emissions coming from ammonia production are included in the category Other &amp; Undifferentiated Production at provincial levels.

X Indicates confidential data.

— Indicates no emissions.

0.0 Indicates emissions truncated due to rounding.

**Table A11-14: 1990–2006 GHG Emission Summary for Manitoba**

Greenhouse Gas Categories	1990	1995	2000	2001	2002	2003	2004	2005	2006
	<i>kt CO<sub>2</sub> equivalent</i>								
<b>TOTAL</b>	<b>18 800</b>	<b>19 900</b>	<b>21 400</b>	<b>20 000</b>	<b>20 600</b>	<b>21 300</b>	<b>21 400</b>	<b>21 000</b>	<b>21 200</b>
<b>ENERGY</b>	<b>12 300</b>	<b>12 500</b>	<b>12 900</b>	<b>11 700</b>	<b>12 200</b>	<b>12 300</b>	<b>12 400</b>	<b>12 500</b>	<b>12 100</b>
<b>a. Stationary Combustion Sources</b>	<b>4 840</b>	<b>4 210</b>	<b>5 350</b>	<b>4 570</b>	<b>4 890</b>	<b>4 950</b>	<b>4 690</b>	<b>4 590</b>	<b>4 230</b>
Electricity and Heat Generation	569	219	992	X	X	X	X	X	X
Fossil Fuel Industries	0.14	0.04	0.03	0.03	0.33	0.01	0.01	0.01	0.05
Mining & Oil and Gas Extraction	73.5	12.5	29.2	X	X	X	X	X	X
Manufacturing Industries	1 050	822	1 140	1 060	1 210	1 080	1 210	1 250	1 330
Construction	63.4	33.8	62.1	61.3	68.5	78.8	82.6	85.5	91.6
Commercial & Institutional	1 410	1 590	1 680	1 590	1 710	1 590	1 590	1 460	1 300
Residential	1 600	1 500	1 400	1 200	1 300	1 300	1 300	1 100	960
Agriculture & Forestry	41.9	76.4	62.8	X	X	X	X	X	X
<b>b. Transportation<sup>1</sup></b>	<b>7 000</b>	<b>7 800</b>	<b>7 000</b>	<b>6 600</b>	<b>6 700</b>	<b>6 800</b>	<b>7 100</b>	<b>7 300</b>	<b>7 200</b>
Civil Aviation (Domestic Aviation)	330	360	360	350	360	390	340	350	360
Road Transportation	3 920	4 330	4 400	4 440	4 520	4 580	4 790	4 650	4 960
Light-Duty Gasoline Vehicles	1 630	1 560	1 290	1 260	1 260	1 240	1 230	1 110	1 160
Light-Duty Gasoline Trucks	859	1 150	1 470	1 470	1 530	1 590	1 670	1 600	1 790
Heavy-Duty Gasoline Vehicles	439	227	218	248	239	239	253	233	248
Motorcycles	6.80	6.01	4.21	4.80	7.30	7.90	8.43	7.92	8.61
Light-Duty Diesel Vehicles	10.7	9.18	7.82	7.78	8.09	8.23	8.87	8.08	8.50
Light-Duty Diesel Trucks	40.2	71.2	88.7	90.4	94.9	98.9	105	106	125
Heavy-Duty Diesel Vehicles	868	1 210	1 290	1 330	1 360	1 380	1 500	1 560	1 610
Propane & Natural Gas Vehicles	61	97	36	31	20	22	21	14	15
Railways	600	600	300	200	80	200	300	300	200
Navigation (Domestic Marine)	0.02	—	—	—	—	0.29	0.11	—	—
Other Transportation	2 000	3 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000
Off-Road Gasoline	300	500	400	400	400	400	400	400	300
Off-Road Diesel	1 000	800	700	700	700	800	800	1 000	800
Pipelines	847	1 300	828	543	658	450	432	600	539
<b>c. Fugitive Sources<sup>2</sup></b>	<b>421</b>	<b>476</b>	<b>563</b>	<b>568</b>	<b>584</b>	<b>593</b>	<b>593</b>	<b>614</b>	<b>662</b>
Coal Mining <sup>5</sup>	—	—	—	—	—	—	X	X	X
Oil and Natural Gas	421	476	563	568	584	593	X	X	X
<b>INDUSTRIAL PROCESSES<sup>3</sup></b>	<b>504</b>	<b>330</b>	<b>549</b>	<b>538</b>	<b>481</b>	<b>463</b>	<b>482</b>	<b>545</b>	<b>533</b>
<b>a. Mineral Products</b>	<b>200</b>	<b>69</b>	<b>69</b>	<b>61</b>	<b>63</b>	<b>57</b>	<b>62</b>	<b>58</b>	<b>54</b>
Cement Production	140	—	—	—	—	—	—	—	—
Lime Production	58	69	69	61	63	57	62	58	54
<b>b. Chemical Industry</b>	<b>20</b>	<b>29</b>	<b>44</b>	<b>48</b>	<b>43</b>	<b>42</b>	<b>50</b>	<b>54</b>	<b>50</b>
Nitric Acid Production	20.1	29.1	44.2	48.1	43.4	41.6	50.4	53.7	50.2
Adipic Acid Production	—	—	—	—	—	—	—	—	—
<b>c. Metal Production</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>
Iron and Steel Production	—	—	—	—	—	—	—	—	—
Aluminum Production	—	—	—	—	—	—	—	—	—
SF <sub>6</sub> Used in Magnesium Smelters and Casters	—	—	—	—	—	—	—	—	—
<b>d. Consumption of Halocarbons and SF<sub>6</sub></b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>
<b>e. Other &amp; Undifferentiated Production<sup>4</sup></b>	<b>280</b>	<b>230</b>	<b>440</b>	<b>430</b>	<b>370</b>	<b>360</b>	<b>370</b>	<b>430</b>	<b>430</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>	<b>7.0</b>	<b>8.0</b>	<b>9.0</b>	<b>7.9</b>	<b>6.1</b>	<b>8.1</b>	<b>7.7</b>	<b>6.5</b>	<b>12</b>
<b>AGRICULTURE</b>	<b>5 300</b>	<b>6 300</b>	<b>7 000</b>	<b>6 800</b>	<b>7 000</b>	<b>7 500</b>	<b>7 600</b>	<b>7 000</b>	<b>7 500</b>
<b>a. Enteric Fermentation</b>	<b>1 500</b>	<b>1 800</b>	<b>2 000</b>	<b>2 100</b>	<b>2 200</b>	<b>2 300</b>	<b>2 500</b>	<b>2 500</b>	<b>2 500</b>
<b>b. Manure Management</b>	<b>500</b>	<b>640</b>	<b>740</b>	<b>790</b>	<b>830</b>	<b>860</b>	<b>900</b>	<b>910</b>	<b>910</b>
<b>c. Agricultural Soils</b>	<b>3 300</b>	<b>3 800</b>	<b>4 200</b>	<b>3 900</b>	<b>4 000</b>	<b>4 400</b>	<b>4 200</b>	<b>3 600</b>	<b>4 100</b>
Direct Sources	1 900	2 100	2 300	2 100	2 100	2 300	2 200	1 800	2 100
Pasture, Range and Paddock Manure	220	290	330	340	350	370	400	400	400
Indirect Sources	1 000	1 000	2 000	2 000	2 000	2 000	2 000	1 000	2 000
<b>WASTE</b>	<b>710</b>	<b>810</b>	<b>880</b>	<b>900</b>	<b>910</b>	<b>920</b>	<b>930</b>	<b>950</b>	<b>960</b>
<b>a. Solid Waste Disposal on Land</b>	<b>670</b>	<b>770</b>	<b>850</b>	<b>860</b>	<b>870</b>	<b>890</b>	<b>900</b>	<b>910</b>	<b>920</b>
<b>b. Wastewater Handling</b>	<b>33</b>	<b>33</b>	<b>34</b>	<b>35</b>	<b>34</b>	<b>34</b>	<b>35</b>	<b>34</b>	<b>34</b>
<b>c. Waste Incineration</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>

## Notes:

- Emissions from Fuel Ethanol are reported within the gasoline transportation subcategories.
  - Fugitive emissions from refineries and the bitumen industry are only reported at the national level.
  - Emissions associated with the use of mineral products and consumption of halocarbons & SF<sub>6</sub> are only reported at the national level.
  - Emissions coming from ammonia production are included in the category Other & Undifferentiated Production at provincial levels.
  - Fugitive emissions from coal mining activities for 2002 and 2003 have been extrapolated based on publicly available coal production data.
- X Indicates confidential data.  
 — Indicates no emissions.  
 0.0 Indicates emissions truncated due to rounding.

Table A11-15: 2006 GHG Emission Summary for Manitoba

Greenhouse Gas Categories		Greenhouse Gases							
		CO <sub>2</sub>	CH <sub>4</sub>	CH <sub>4</sub>	N <sub>2</sub> O	N <sub>2</sub> O	PFCs	SF <sub>6</sub>	TOTAL
		Global Warming Potential		21		310			
		Unit	kt	kt CO <sub>2</sub> eq	kt	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq
<b>TOTAL</b>			<b>11 600</b>	<b>220</b>	<b>4 600</b>	<b>16</b>	<b>5 000</b>	–	<b>21 200</b>
<b>ENERGY</b>			<b>11 100</b>	<b>33</b>	<b>700</b>	<b>0.9</b>	<b>300</b>	–	<b>12 100</b>
a.	<b>Stationary Combustion Sources</b>		<b>4 130</b>	<b>3</b>	<b>60</b>	<b>0.1</b>	<b>40</b>	–	<b>4 230</b>
	Electricity and Heat Generation		X	X	X	X	X	–	X
	Fossil Fuel Industries		–	–	–	0.00	0.05	–	0.05
	Mining & Oil and Gas Extraction		X	X	X	X	X	–	X
	Manufacturing Industries		1 320	0.06	1	0.03	10	–	1 330
	Construction		91.0	0.00	0.04	0.00	0.6	–	91.6
	Commercial & Institutional		1 290	0.02	0.5	0.03	9	–	1 300
	Residential		894	3	50	0.05	10	–	960
	Agriculture & Forestry		X	X	X	X	X	–	X
b.	<b>Transportation<sup>1</sup></b>		<b>6 970</b>	<b>1</b>	<b>30</b>	<b>0.8</b>	<b>200</b>	–	<b>7 200</b>
	Civil Aviation (Domestic Aviation)		347	0.03	0.6	0.03	10	–	360
	Road Transportation		4 840	0.37	7.8	0.36	110	–	4 960
	Light-Duty Gasoline Vehicles		1 130	0.10	2.2	0.10	29	–	1 160
	Light-Duty Gasoline Trucks		1 730	0.16	3.3	0.19	59	–	1 790
	Heavy-Duty Gasoline Vehicles		242	0.02	0.32	0.02	5.2	–	248
	Motorcycles		8.44	0.01	0.11	0.00	0.05	–	8.61
	Light-Duty Diesel Vehicles		8.29	0.00	0.00	0.00	0.2	–	8.50
	Light-Duty Diesel Trucks		122	0.00	0.07	0.01	3	–	125
	Heavy-Duty Diesel Vehicles		1 590	0.07	2	0.05	20	–	1 610
	Propane & Natural Gas Vehicles		14.4	0.01	0.3	0.00	0.09	–	15
	Railways		221	0.01	0.3	0.09	30	–	200
	Navigation (Domestic Marine)		–	–	–	–	–	–	0
	Other Transportation		1 600	0.9	20	0.3	100	–	2 000
	Off-Road Gasoline		300	0.4	8	0.01	2	–	300
	Off-Road Diesel		710	0.04	0.8	0.3	90	–	800
	Pipelines		523	0.53	11	0.01	4	–	539
c.	<b>Fugitive Sources<sup>2</sup></b>		<b>49</b>	<b>29</b>	<b>610</b>	–	–	–	<b>662</b>
	Coal Mining		X	X	X	–	–	–	X
	Oil and Natural Gas		X	X	X	–	–	–	X
<b>INDUSTRIAL PROCESSES<sup>3</sup></b>			<b>480</b>	–	–	<b>0.16</b>	<b>50.2</b>	–	<b>533</b>
a.	<b>Mineral Products</b>		<b>54</b>	–	–	–	–	–	<b>54</b>
	Cement Production		–	–	–	–	–	–	0
	Lime Production		54	–	–	–	–	–	54
b.	<b>Chemical Industry</b>		–	–	–	<b>0.16</b>	<b>50.2</b>	–	<b>50</b>
	Nitric Acid Production		–	–	–	0.16	50.2	–	50.2
	Adipic Acid Production		–	–	–	–	–	–	0
c.	<b>Metal Production</b>		–	–	–	–	–	–	<b>0</b>
	Iron and Steel Production		–	–	–	–	–	–	0
	Aluminum Production		–	–	–	–	–	–	0
	SF <sub>6</sub> Used in Magnesium Smelters and Casters		–	–	–	–	–	–	0
d.	<b>Consumption of Halocarbons and SF<sub>6</sub></b>		–	–	–	–	–	–	<b>0</b>
e.	<b>Other &amp; Undifferentiated Production<sup>4</sup></b>		<b>430</b>	–	–	–	–	–	<b>430</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>			–	–	–	<b>0.04</b>	<b>12</b>	–	<b>12</b>
<b>AGRICULTURE</b>			–	<b>140</b>	<b>2 900</b>	<b>15</b>	<b>4 600</b>	–	<b>7 500</b>
a.	<b>Enteric Fermentation</b>		–	120	2 500	–	–	–	2 500
b.	<b>Manure Management</b>		–	21	430	1.5	480	–	910
c.	<b>Agricultural Soils</b>		–	–	–	<b>13</b>	<b>4 100</b>	–	<b>4 100</b>
	Direct Sources		–	–	–	6.9	2 100	–	2 100
	Pasture, Range and Paddock Manure		–	–	–	1.3	400	–	400
	Indirect Sources		–	–	–	5	2 000	–	2 000
<b>WASTE</b>			–	<b>44</b>	<b>930</b>	<b>0.08</b>	<b>20</b>	–	<b>960</b>
a.	<b>Solid Waste Disposal on Land</b>		–	44	920	–	–	–	920
b.	<b>Wastewater Handling</b>		–	0.46	9.6	0.08	20	–	34
c.	<b>Waste Incineration</b>		–	–	–	–	–	–	0

Notes:

1. Emissions from Fuel Ethanol are reported within the gasoline transportation subcategories.

2. Fugitive emissions from refineries and the bitumen industry are only reported at the national level.

3. Emissions associated with the use of mineral products and consumption of halocarbons & SF<sub>6</sub> are only reported at the national level.

4. Emissions coming from ammonia production are included in the category Other &amp; Undifferentiated Production at provincial levels.

X Indicates confidential data.

– Indicates no emissions.

0.0 Indicates emissions truncated due to rounding.

**Table A11-16: 1990–2006 GHG Emission Summary for Saskatchewan**

Greenhouse Gas Categories	1990	1995	2000	2001	2002	2003	2004	2005	2006
	<i>kt CO<sub>2</sub> equivalent</i>								
<b>TOTAL</b>	<b>44 000</b>	<b>59 800</b>	<b>67 300</b>	<b>66 600</b>	<b>67 500</b>	<b>69 900</b>	<b>72 300</b>	<b>72 900</b>	<b>72 000</b>
<b>ENERGY</b>	<b>34 700</b>	<b>47 600</b>	<b>53 700</b>	<b>53 500</b>	<b>54 900</b>	<b>55 900</b>	<b>57 400</b>	<b>57 500</b>	<b>57 300</b>
<b>a. Stationary Combustion Sources</b>	<b>19 400</b>	<b>25 400</b>	<b>27 000</b>	<b>27 500</b>	<b>28 300</b>	<b>28 700</b>	<b>29 700</b>	<b>28 900</b>	<b>28 000</b>
Electricity and Heat Generation	10 400	13 900	14 700	X	X	X	X	X	X
Fossil Fuel Industries	3 700	4 800	5 300	5 700	6 100	5 500	6 300	6 500	6 200
Mining & Oil and Gas Extraction	964	1 690	2 000	X	X	X	X	X	X
Manufacturing Industries	857	1 300	935	794	715	696	652	640	602
Construction	70.6	73.1	49.8	40.8	39.1	37.6	42.6	42.0	44.7
Commercial & Institutional	1 010	1 210	1 710	1 590	2 040	1 980	1 810	1 750	1 770
Residential	2 100	2 100	2 000	2 000	2 000	1 800	1 800	1 700	1 800
Agriculture & Forestry	300	327	280	X	X	X	X	X	X
<b>b. Transportation<sup>1</sup></b>	<b>9 200</b>	<b>11 000</b>	<b>11 000</b>	<b>9 700</b>	<b>10 000</b>	<b>10 000</b>	<b>10 000</b>	<b>11 000</b>	<b>12 000</b>
Civil Aviation (Domestic Aviation)	210	170	110	120	130	120	110	140	150
Road Transportation	4 100	4 930	5 530	4 940	5 500	5 750	5 940	5 810	6 080
Light-Duty Gasoline Vehicles	1 150	1 390	1 260	996	1 200	1 220	1 190	1 060	1 060
Light-Duty Gasoline Trucks	828	1 350	1 710	1 370	1 700	1 840	1 890	1 780	1 880
Heavy-Duty Gasoline Vehicles	722	472	345	300	359	374	386	346	347
Motorcycles	1.96	2.73	5.56	4.81	6.04	6.82	7.11	6.97	7.66
Light-Duty Diesel Vehicles	6.73	6.68	7.49	6.29	8.08	8.55	9.01	8.23	8.39
Light-Duty Diesel Trucks	51.4	135	192	162	210	227	237	240	274
Heavy-Duty Diesel Vehicles	1 270	1 520	1 980	2 080	1 990	2 060	2 210	2 360	2 490
Propane & Natural Gas Vehicles	65	50	27	31	19	14	17	11	10
Railways	600	500	400	300	200	200	200	400	400
Navigation (Domestic Marine)	0.10	0.01	0.02	0.04	0.01	0.01	0.01	-	-
Other Transportation	4 000	6 000	5 000	4 000	4 000	4 000	4 000	5 000	5 000
Off-Road Gasoline	1 000	800	700	1 000	700	700	700	1 000	1 000
Off-Road Diesel	2 000	2 000	2 000	1 000	2 000	2 000	2 000	2 000	2 000
Pipelines	1 640	2 600	2 410	1 720	2 000	1 590	1 450	1 950	1 640
<b>c. Fugitive Sources<sup>2</sup></b>	<b>6 060</b>	<b>11 000</b>	<b>15 800</b>	<b>16 300</b>	<b>16 500</b>	<b>17 100</b>	<b>17 500</b>	<b>17 200</b>	<b>17 500</b>
Coal Mining <sup>5</sup>	10	10	10	10	10	10	X	X	X
Oil and Natural Gas	6 050	11 000	15 800	16 300	16 500	17 100	X	X	X
<b>INDUSTRIAL PROCESSES<sup>3</sup></b>	<b>285</b>	<b>912</b>	<b>1 280</b>	<b>1 360</b>	<b>1 330</b>	<b>1 280</b>	<b>1 450</b>	<b>1 410</b>	<b>1 490</b>
<b>a. Mineral Products</b>	<b>83</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>
Cement Production	83	-	-	-	-	-	-	-	-
Lime Production	-	-	-	-	-	-	-	-	-
<b>b. Chemical Industry</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>28</b>	<b>13</b>	<b>14</b>
Nitric Acid Production	-	-	-	-	-	-	27.7	12.7	13.6
Adipic Acid Production	-	-	-	-	-	-	-	-	-
<b>c. Metal Production</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>
Iron and Steel Production	-	-	-	-	-	-	-	-	-
Aluminum Production	-	-	-	-	-	-	-	-	-
SF <sub>6</sub> Used in Magnesium Smelters and Casters	-	-	-	-	-	-	-	-	-
<b>d. Consumption of Halocarbons and SF<sub>6</sub></b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>
<b>e. Other &amp; Undifferentiated Production<sup>4</sup></b>	<b>200</b>	<b>910</b>	<b>1 300</b>	<b>1 400</b>	<b>1 300</b>	<b>1 300</b>	<b>1 400</b>	<b>1 400</b>	<b>1 500</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>	<b>6.4</b>	<b>7.2</b>	<b>7.9</b>	<b>6.8</b>	<b>5.3</b>	<b>6.9</b>	<b>6.6</b>	<b>5.5</b>	<b>9.8</b>
<b>AGRICULTURE</b>	<b>8 200</b>	<b>10 000</b>	<b>11 000</b>	<b>11 000</b>	<b>10 000</b>	<b>12 000</b>	<b>12 000</b>	<b>13 000</b>	<b>12 000</b>
<b>a. Enteric Fermentation</b>	<b>2 500</b>	<b>3 400</b>	<b>3 400</b>	<b>3 600</b>	<b>3 700</b>	<b>4 000</b>	<b>4 300</b>	<b>4 500</b>	<b>4 400</b>
<b>b. Manure Management</b>	<b>690</b>	<b>910</b>	<b>950</b>	<b>1 000</b>	<b>1 000</b>	<b>1 100</b>	<b>1 200</b>	<b>1 200</b>	<b>1 200</b>
<b>c. Agricultural Soils</b>	<b>5 000</b>	<b>6 200</b>	<b>7 000</b>	<b>6 200</b>	<b>5 500</b>	<b>6 600</b>	<b>6 900</b>	<b>7 200</b>	<b>6 600</b>
Direct Sources	2 800	3 400	3 800	3 200	2 700	3 400	3 600	3 700	3 300
Pasture, Range and Paddock Manure	440	610	640	680	700	760	810	840	820
Indirect Sources	2 000	2 000	3 000	2 000	2 000	2 000	3 000	3 000	2 000
<b>WASTE</b>	<b>790</b>	<b>870</b>	<b>930</b>	<b>940</b>	<b>950</b>	<b>960</b>	<b>970</b>	<b>980</b>	<b>990</b>
<b>a. Solid Waste Disposal on Land</b>	<b>750</b>	<b>830</b>	<b>890</b>	<b>900</b>	<b>910</b>	<b>920</b>	<b>930</b>	<b>940</b>	<b>950</b>
<b>b. Wastewater Handling</b>	<b>39</b>	<b>39</b>	<b>39</b>	<b>40</b>	<b>40</b>	<b>39</b>	<b>40</b>	<b>40</b>	<b>39</b>
<b>c. Waste Incineration</b>	<b>0.52</b>	<b>0.04</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>

## Notes:

1. Emissions from Fuel Ethanol are reported within the gasoline transportation subcategories.
  2. Fugitive emissions from refineries and the bitumen industry are only reported at the national level.
  3. Emissions associated with the use of mineral products and consumption of halocarbons & SF<sub>6</sub> are only reported at the national level.
  4. Emissions coming from ammonia production are included in the category Other & Undifferentiated Production at provincial levels.
  5. Fugitive emissions from coal mining activities for 2002 and 2003 have been extrapolated based on publicly available coal production data.
- X Indicates confidential data.  
 - Indicates no emissions.  
 0.0 Indicates emissions truncated due to rounding.

Table A11-17: 2006 GHG Emission Summary for Saskatchewan

Greenhouse Gas Categories		Greenhouse Gases							
		CO <sub>2</sub>	CH <sub>4</sub>	CH <sub>4</sub>	N <sub>2</sub> O	N <sub>2</sub> O	PFCs	SF <sub>6</sub>	TOTAL
		Global Warming Potential		21		310			
		Unit	kt	kt CO <sub>2</sub> eq	kt	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq
<b>TOTAL</b>			<b>41 900</b>	<b>1 000</b>	<b>22 000</b>	<b>26</b>	<b>8 200</b>	—	<b>72 000</b>
<b>ENERGY</b>			<b>40 400</b>	<b>770</b>	<b>16 000</b>	<b>2</b>	<b>700</b>	—	<b>57 300</b>
a.	<b>Stationary Combustion Sources</b>		<b>27 500</b>	<b>20</b>	<b>300</b>	<b>0.6</b>	<b>200</b>	—	<b>28 000</b>
	Electricity and Heat Generation		X	X	X	X	X	—	X
	Fossil Fuel Industries		5 920	10	300	0.1	40	—	6 200
	Mining & Oil and Gas Extraction		X	X	X	X	X	—	X
	Manufacturing Industries		594	0.05	1	0.02	7	—	602
	Construction		44.4	0.00	0.02	0.00	0.3	—	44.7
	Commercial & Institutional		1 760	0.03	0.7	0.04	10	—	1 770
	Residential		1 710	2	30	0.04	10	—	1 800
	Agriculture & Forestry		X	X	X	X	X	—	X
b.	<b>Transportation<sup>1</sup></b>		<b>11 200</b>	<b>4</b>	<b>80</b>	<b>1</b>	<b>500</b>	—	<b>12 000</b>
	Civil Aviation (Domestic Aviation)		146	0.02	0.4	0.01	4	—	150
	Road Transportation		5 940	0.48	10	0.41	130	—	6 080
	Light-Duty Gasoline Vehicles		1 030	0.11	2.4	0.09	28	—	1 060
	Light-Duty Gasoline Trucks		1 820	0.20	4.1	0.20	61	—	1 880
	Heavy-Duty Gasoline Vehicles		339	0.03	0.58	0.02	7.1	—	347
	Motorcycles		7.51	0.00	0.10	0.00	0.05	—	7.66
	Light-Duty Diesel Vehicles		8.19	0.00	0.00	0.00	0.2	—	8.39
	Light-Duty Diesel Trucks		267	0.01	0.1	0.02	7	—	274
	Heavy-Duty Diesel Vehicles		2 460	0.1	2	0.08	20	—	2 490
	Propane & Natural Gas Vehicles		9.74	0.01	0.3	0.00	0.06	—	10
	Railways		337	0.02	0.4	0.1	40	—	400
	Navigation (Domestic Marine)		—	—	—	—	—	—	0
	Other Transportation		4 800	3	70	0.9	300	—	5 000
	Off-Road Gasoline		1 000	1	30	0.03	8	—	1 000
	Off-Road Diesel		2 000	0.1	2	0.8	300	—	2 000
	Pipelines		1 590	1.6	34	0.04	10	—	1 640
c.	<b>Fugitive Sources<sup>2</sup></b>		<b>1 700</b>	<b>750</b>	<b>16 000</b>	<b>0.01</b>	<b>5</b>	—	<b>17 500</b>
	Coal Mining		X	X	X	X	X	—	X
	Oil and Natural Gas		X	X	X	X	X	—	X
<b>INDUSTRIAL PROCESSES<sup>3</sup></b>			<b>1 500</b>	—	—	<b>0.04</b>	<b>13.6</b>	—	<b>1 490</b>
a.	<b>Mineral Products</b>		—	—	—	—	—	—	<b>0</b>
	Cement Production		—	—	—	—	—	—	0
	Lime Production		—	—	—	—	—	—	0
b.	<b>Chemical Industry</b>		—	—	—	<b>0.04</b>	<b>13.6</b>	—	<b>14</b>
	Nitric Acid Production		—	—	—	0.04	13.6	—	13.6
	Adipic Acid Production		—	—	—	—	—	—	0
c.	<b>Metal Production</b>		—	—	—	—	—	—	<b>0</b>
	Iron and Steel Production		—	—	—	—	—	—	0
	Aluminum Production		—	—	—	—	—	—	0
	SF <sub>6</sub> Used in Magnesium Smelters and Casters		—	—	—	—	—	—	0
d.	<b>Consumption of Halocarbons and SF<sub>6</sub></b>		—	—	—	—	—	—	<b>0</b>
e.	<b>Other &amp; Undifferentiated Production<sup>4</sup></b>		<b>1 500</b>	—	—	—	—	—	<b>1 500</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>			—	—	—	<b>0.03</b>	<b>9.8</b>	—	<b>9.8</b>
<b>AGRICULTURE</b>			—	<b>230</b>	<b>4 700</b>	<b>24</b>	<b>7 500</b>	—	<b>12 000</b>
a.	<b>Enteric Fermentation</b>		—	210	4 400	—	—	—	4 400
b.	<b>Manure Management</b>		—	16	340	2.8	860	—	1 200
c.	<b>Agricultural Soils</b>		—	—	—	<b>21</b>	<b>6 600</b>	—	<b>6 600</b>
	Direct Sources		—	—	—	11	3 300	—	3 300
	Pasture, Range and Paddock Manure		—	—	—	2.7	820	—	820
	Indirect Sources		—	—	—	8	2 000	—	2 000
<b>WASTE</b>			—	<b>46</b>	<b>970</b>	<b>0.07</b>	<b>20</b>	—	<b>990</b>
a.	<b>Solid Waste Disposal on Land</b>		—	45	950	—	—	—	950
b.	<b>Wastewater Handling</b>		—	0.89	19	0.07	20	—	39
c.	<b>Waste Incineration</b>		—	—	—	—	—	—	0

## Notes:

1. Emissions from Fuel Ethanol are reported within the gasoline transportation subcategories.

2. Fugitive emissions from refineries and the bitumen industry are only reported at the national level.

3. Emissions associated with the use of mineral products and consumption of halocarbons & SF<sub>6</sub> are only reported at the national level.

4. Emissions coming from ammonia production are included in the category Other &amp; Undifferentiated Production at provincial levels.

X Indicates confidential data.

— Indicates no emissions.

0.0 Indicates emissions truncated due to rounding.

**Table A11-18: 1990–2006 GHG Emission Summary for Alberta**

Greenhouse Gas Categories	1990	1995	2000	2001	2002	2003	2004	2005	2006
	<i>kt CO<sub>2</sub> equivalent</i>								
<b>TOTAL</b>	<b>172 000</b>	<b>200 000</b>	<b>226 000</b>	<b>227 000</b>	<b>227 000</b>	<b>234 000</b>	<b>234 000</b>	<b>231 000</b>	<b>234 000</b>
<b>ENERGY</b>	<b>147 000</b>	<b>172 000</b>	<b>194 000</b>	<b>195 000</b>	<b>195 000</b>	<b>202 000</b>	<b>199 000</b>	<b>195 000</b>	<b>199 000</b>
<b>a. Stationary Combustion Sources</b>	<b>96 200</b>	<b>111 000</b>	<b>126 000</b>	<b>125 000</b>	<b>128 000</b>	<b>134 000</b>	<b>129 000</b>	<b>125 000</b>	<b>126 000</b>
Electricity and Heat Generation	40 100	49 200	52 100	53 500	53 000	54 600	53 300	52 500	53 800
Fossil Fuel Industries	32 000	34 000	44 000	45 000	46 000	45 000	43 000	40 000	40 000
Mining & Oil and Gas Extraction	2 390	3 340	5 500	5 900	7 530	11 000	10 400	10 900	11 400
Manufacturing Industries	9 410	9 940	9 610	7 900	7 760	7 820	7 880	7 730	6 970
Construction	235	187	172	168	171	159	158	166	187
Commercial & Institutional	4 950	5 520	5 290	4 760	5 720	6 070	6 100	5 470	5 240
Residential	6 600	7 600	8 300	7 200	8 000	8 200	8 100	7 400	7 500
Agriculture & Forestry	469	335	360	286	300	270	266	235	234
<b>b. Transportation<sup>1</sup></b>	<b>22 000</b>	<b>24 000</b>	<b>29 000</b>	<b>31 000</b>	<b>30 000</b>	<b>31 000</b>	<b>32 000</b>	<b>33 000</b>	<b>36 000</b>
Civil Aviation (Domestic Aviation)	1 100	1 000	1 200	1 300	1 300	1 300	1 400	1 500	1 600
Road Transportation	13 700	15 300	16 700	17 800	17 800	18 000	18 900	19 600	20 700
Light-Duty Gasoline Vehicles	4 460	4 020	3 780	3 850	3 800	3 670	3 620	3 560	3 540
Light-Duty Gasoline Trucks	3 270	4 140	5 600	5 780	6 030	6 140	6 420	6 670	7 070
Heavy-Duty Gasoline Vehicles	1 830	1 440	1 200	1 690	1 590	1 570	1 630	1 640	1 680
Motorcycles	22.8	20.7	26.7	29.0	31.6	33.6	35.6	36.5	38.0
Light-Duty Diesel Vehicles	22.9	17.7	17.5	19.5	21.3	21.3	22.8	22.9	23.2
Light-Duty Diesel Trucks	165	337	457	509	560	573	606	673	762
Heavy-Duty Diesel Vehicles	3 330	4 780	5 350	5 630	5 500	5 860	6 380	6 850	7 400
Propane & Natural Gas Vehicles	630	520	270	270	220	190	190	120	170
Railways	2 000	1 000	2 000	2 000	2 000	2 000	2 000	2 000	3 000
Navigation (Domestic Marine)	0.32	0.61	0.00	0.02	0.02	0.01	0.01	–	–
Other Transportation	5 000	6 000	10 000	10 000	9 000	9 000	10 000	10 000	10 000
Off-Road Gasoline	1 000	900	1 000	1 000	1 000	900	900	800	900
Off-Road Diesel	3 000	3 000	6 000	5 000	4 000	5 000	6 000	6 000	7 000
Pipelines	1 270	2 670	2 670	3 410	3 470	3 090	3 110	3 140	3 630
<b>c. Fugitive Sources<sup>2</sup></b>	<b>29 100</b>	<b>37 300</b>	<b>39 100</b>	<b>38 800</b>	<b>36 900</b>	<b>37 500</b>	<b>37 600</b>	<b>37 100</b>	<b>37 400</b>
Coal Mining <sup>5</sup>	200	300	200	200	200	200	X	X	X
Oil and Natural Gas	28 900	37 000	38 900	38 600	36 700	37 300	X	X	X
<b>INDUSTRIAL PROCESSES<sup>3</sup></b>	<b>8 200</b>	<b>9 630</b>	<b>10 500</b>	<b>10 700</b>	<b>10 000</b>	<b>11 300</b>	<b>13 000</b>	<b>12 900</b>	<b>12 900</b>
<b>a. Mineral Products</b>	<b>850</b>	<b>930</b>	<b>1 100</b>	<b>1 100</b>	<b>1 200</b>	<b>1 100</b>	<b>1 100</b>	<b>1 200</b>	<b>1 200</b>
Cement Production	740	800	960	940	1 000	1 000	1 000	1 000	1 100
Lime Production	100	130	150	150	130	120	130	120	110
<b>b. Chemical Industry</b>	<b>810</b>	<b>780</b>	<b>1 100</b>	<b>1 200</b>	<b>1 100</b>	<b>1 100</b>	<b>1 000</b>	<b>1 100</b>	<b>1 100</b>
Nitric Acid Production	813	778	1 100	1 150	1 120	1 130	1 050	1 120	1 090
Adipic Acid Production	–	–	–	–	–	–	–	–	–
<b>c. Metal Production</b>	<b>–</b>	<b>10.7</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>
Iron and Steel Production	–	10.7	–	–	–	–	–	–	–
Aluminum Production	–	–	–	–	–	–	–	–	–
SF <sub>6</sub> Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	–	–
<b>d. Consumption of Halocarbons and SF<sub>6</sub></b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>
<b>e. Other &amp; Undifferentiated Production<sup>4</sup></b>	<b>6 500</b>	<b>7 900</b>	<b>8 300</b>	<b>8 500</b>	<b>7 700</b>	<b>9 100</b>	<b>11 000</b>	<b>11 000</b>	<b>11 000</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>	<b>16</b>	<b>19</b>	<b>24</b>	<b>21</b>	<b>16</b>	<b>22</b>	<b>21</b>	<b>18</b>	<b>33</b>
<b>AGRICULTURE</b>	<b>14 000</b>	<b>17 000</b>	<b>20 000</b>	<b>20 000</b>	<b>19 000</b>	<b>19 000</b>	<b>19 000</b>	<b>20 000</b>	<b>19 000</b>
<b>a. Enteric Fermentation</b>	<b>6 000</b>	<b>7 600</b>	<b>8 900</b>	<b>9 300</b>	<b>9 300</b>	<b>8 800</b>	<b>9 000</b>	<b>9 400</b>	<b>9 200</b>
<b>b. Manure Management</b>	<b>1 500</b>	<b>1 900</b>	<b>2 200</b>	<b>2 300</b>	<b>2 300</b>	<b>2 200</b>	<b>2 200</b>	<b>2 300</b>	<b>2 300</b>
<b>c. Agricultural Soils</b>	<b>6 700</b>	<b>7 400</b>	<b>8 500</b>	<b>7 900</b>	<b>7 300</b>	<b>7 800</b>	<b>8 200</b>	<b>8 300</b>	<b>8 100</b>
Direct Sources	3 500	3 700	4 100	3 600	3 100	3 600	3 800	3 800	3 700
Pasture, Range and Paddock Manure	920	1 200	1 500	1 600	1 600	1 500	1 500	1 600	1 500
Indirect Sources	2 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000
<b>WASTE</b>	<b>1 900</b>	<b>1 900</b>	<b>2 100</b>	<b>2 100</b>	<b>2 100</b>	<b>2 200</b>	<b>2 300</b>	<b>2 300</b>	<b>2 400</b>
<b>a. Solid Waste Disposal on Land</b>	<b>1 800</b>	<b>1 800</b>	<b>2 000</b>	<b>2 000</b>	<b>2 100</b>	<b>2 100</b>	<b>2 200</b>	<b>2 300</b>	<b>2 300</b>
<b>b. Wastewater Handling</b>	<b>73</b>	<b>70</b>	<b>71</b>	<b>71</b>	<b>68</b>	<b>67</b>	<b>69</b>	<b>70</b>	<b>69</b>
<b>c. Waste Incineration</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>

## Notes:

- Emissions from Fuel Ethanol are reported within the gasoline transportation subcategories.
  - Fugitive emissions from refineries and the bitumen industry are only reported at the national level.
  - Emissions associated with the use of mineral products and consumption of halocarbons & SF<sub>6</sub> are only reported at the national level.
  - Emissions coming from ammonia production are included in the category Other & Undifferentiated Production at provincial levels.
  - Fugitive emissions from coal mining activities for 2002 and 2003 have been extrapolated based on publicly available coal production data.
- X Indicates confidential data.  
 – Indicates no emissions.  
 0.0 Indicates emissions truncated due to rounding.

Table A11-19: 2006 GHG Emission Summary for Alberta

Greenhouse Gas Categories		Greenhouse Gases							
	Global Warming Potential	CO <sub>2</sub>	CH <sub>4</sub>	CH <sub>4</sub>	N <sub>2</sub> O	N <sub>2</sub> O	PFCs	SF <sub>6</sub>	TOTAL
	Unit	kt	kt	kt CO <sub>2</sub> eq	kt	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq
<b>TOTAL</b>		<b>179 000</b>	<b>2 000</b>	<b>41 000</b>	<b>43</b>	<b>13 000</b>	—	—	<b>234 000</b>
<b>ENERGY</b>		<b>168 000</b>	<b>1 400</b>	<b>29 000</b>	<b>8</b>	<b>2 000</b>	—	—	<b>199 000</b>
<b>a. Stationary Combustion Sources</b>		<b>123 000</b>	<b>70</b>	<b>2 000</b>	<b>3</b>	<b>800</b>	—	—	<b>126 000</b>
Electricity and Heat Generation		53 500	1.6	33	1	300	—	—	53 800
Fossil Fuel Industries		38 700	70	1 000	0.9	300	—	—	40 000
Mining & Oil and Gas Extraction		11 300	0.2	5	0.3	80	—	—	11 400
Manufacturing Industries		6 900	0.4	8	0.2	70	—	—	6 970
Construction		185	0.00	0.07	0.01	2	—	—	187
Commercial & Institutional		5 210	0.1	2	0.1	30	—	—	5 240
Residential		7 380	2	40	0.2	50	—	—	7 500
Agriculture & Forestry		232	0.00	0.09	0.01	2	—	—	234
<b>b. Transportation<sup>1</sup></b>		<b>34 500</b>	<b>7</b>	<b>100</b>	<b>5</b>	<b>2 000</b>	—	—	<b>36 000</b>
Civil Aviation (Domestic Aviation)		1 510	0.09	2	0.1	40	—	—	1 600
Road Transportation		20 200	1.5	31	1.4	450	—	—	20 700
Light-Duty Gasoline Vehicles		3 450	0.32	6.7	0.29	90	—	—	3 540
Light-Duty Gasoline Trucks		6 820	0.58	12	0.75	230	—	—	7 070
Heavy-Duty Gasoline Vehicles		1 640	0.09	1.8	0.12	38	—	—	1 680
Motorcycles		37.3	0.02	0.49	0.00	0.23	—	—	38.0
Light-Duty Diesel Vehicles		22.7	0.00	0.01	0.00	0.6	—	—	23.2
Light-Duty Diesel Trucks		743	0.02	0.4	0.06	20	—	—	762
Heavy-Duty Diesel Vehicles		7 330	0.3	7	0.2	70	—	—	7 400
Propane & Natural Gas Vehicles		166	0.09	2	0.00	1	—	—	170
Railways		2 460	0.1	3	1	300	—	—	3 000
Navigation (Domestic Marine)		—	—	—	—	—	—	—	0
Other Transportation		10 000	5	100	3	800	—	—	10 000
Off-Road Gasoline		800	1	20	0.02	6	—	—	900
Off-Road Diesel		6 000	0.3	7	2	800	—	—	7 000
Pipelines		3 520	3.5	74	0.09	30	—	—	3 630
<b>c. Fugitive Sources<sup>2</sup></b>		<b>9 700</b>	<b>1 300</b>	<b>28 000</b>	<b>0.01</b>	<b>3</b>	—	—	<b>37 400</b>
Coal Mining		X	X	X	X	X	—	—	X
Oil and Natural Gas		X	X	X	X	X	—	—	X
<b>INDUSTRIAL PROCESSES<sup>3</sup></b>		<b>12 000</b>	—	—	<b>3.52</b>	<b>1 090</b>	—	—	<b>12 900</b>
<b>a. Mineral Products</b>		<b>1 200</b>	—	—	—	—	—	—	<b>1 200</b>
Cement Production		1 100	—	—	—	—	—	—	1 100
Lime Production		110	—	—	—	—	—	—	110
<b>b. Chemical Industry</b>		—	—	—	<b>3.52</b>	<b>1 090</b>	—	—	<b>1 100</b>
Nitric Acid Production		—	—	—	3.52	1 090	—	—	1 090
Adipic Acid Production		—	—	—	—	—	—	—	0
<b>c. Metal Production</b>		—	—	—	—	—	—	—	<b>0</b>
Iron and Steel Production		—	—	—	—	—	—	—	0
Aluminum Production		—	—	—	—	—	—	—	0
SF <sub>6</sub> Used in Magnesium Smelters and Casters		—	—	—	—	—	—	—	0
<b>d. Consumption of Halocarbons and SF<sub>6</sub></b>		—	—	—	—	—	—	—	<b>0</b>
<b>e. Other &amp; Undifferentiated Production<sup>4</sup></b>		<b>11 000</b>	—	—	—	—	—	—	<b>11 000</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>		—	—	—	<b>0.11</b>	<b>33</b>	—	—	<b>33</b>
<b>AGRICULTURE</b>		—	<b>470</b>	<b>9 800</b>	<b>31</b>	<b>9 700</b>	—	—	<b>19 000</b>
<b>a. Enteric Fermentation</b>		—	440	9 200	—	—	—	—	9 200
<b>b. Manure Management</b>		—	30	630	5.3	1 600	—	—	2 300
<b>c. Agricultural Soils</b>		—	—	—	<b>26</b>	<b>8 100</b>	—	—	<b>8 100</b>
Direct Sources		—	—	—	12	3 700	—	—	3 700
Pasture, Range and Paddock Manure		—	—	—	5.0	1 500	—	—	1 500
Indirect Sources		—	—	—	9	3 000	—	—	3 000
<b>WASTE</b>		—	<b>110</b>	<b>2 300</b>	<b>0.2</b>	<b>70</b>	—	—	<b>2 400</b>
<b>a. Solid Waste Disposal on Land</b>		—	110	2 300	—	—	—	—	2 300
<b>b. Wastewater Handling</b>		—	—	—	0.2	70	—	—	69
<b>c. Waste Incineration</b>		—	—	—	—	—	—	—	0

## Notes:

1. Emissions from Fuel Ethanol are reported within the gasoline transportation subcategories.
  2. Fugitive emissions from refineries and the bitumen industry are only reported at the national level.
  3. Emissions associated with the use of mineral products and consumption of halocarbons & SF<sub>6</sub> are only reported at the national level.
  4. Emissions coming from ammonia production are included in the category Other & Undifferentiated Production at provincial levels.
- X Indicates confidential data.  
 — Indicates no emissions.  
 0.0 Indicates emissions truncated due to rounding.

**Table A11-20: 1990–2006 GHG Emission Summary for British Columbia**

Greenhouse Gas Categories	1990	1995	2000	2001	2002	2003	2004	2005	2006
	<i>kt CO<sub>2</sub> equivalent</i>								
<b>TOTAL</b>	<b>48 900</b>	<b>57 100</b>	<b>61 300</b>	<b>60 800</b>	<b>59 300</b>	<b>61 300</b>	<b>65 600</b>	<b>64 400</b>	<b>62 300</b>
<b>ENERGY</b>	<b>40 600</b>	<b>48 000</b>	<b>51 400</b>	<b>51 800</b>	<b>50 400</b>	<b>52 100</b>	<b>56 200</b>	<b>55 200</b>	<b>53 700</b>
<b>a. Stationary Combustion Sources</b>	<b>18 900</b>	<b>21 000</b>	<b>22 500</b>	<b>22 600</b>	<b>21 000</b>	<b>21 500</b>	<b>24 200</b>	<b>23 900</b>	<b>22 700</b>
Electricity and Heat Generation	1 170	2 700	2 480	3 070	1 180	1 330	1 850	1 470	1 470
Fossil Fuel Industries	3 700	3 800	4 100	3 500	4 400	5 800	7 800	8 300	7 400
Mining & Oil and Gas Extraction	252	163	316	232	270	155	491	297	735
Manufacturing Industries	6 000	6 250	7 190	7 400	6 500	6 590	6 450	6 050	5 260
Construction	303	198	75.2	70.0	73.1	81.1	99.8	106	110
Commercial & Institutional	2 810	3 360	3 380	3 430	4 120	3 420	3 490	3 360	3 330
Residential	4 300	4 400	4 600	4 500	4 300	4 100	3 900	4 300	4 400
Agriculture & Forestry	319	152	313	353	124	80.0	67.4	66.0	65.7
<b>b. Transportation<sup>1</sup></b>	<b>18 000</b>	<b>22 000</b>	<b>24 000</b>	<b>23 000</b>	<b>24 000</b>	<b>25 000</b>	<b>26 000</b>	<b>25 000</b>	<b>24 000</b>
Civil Aviation (Domestic Aviation)	1 100	1 200	1 400	1 100	1 400	1 300	1 500	1 700	1 600
Road Transportation	11 400	13 200	14 700	14 500	14 600	14 800	15 700	15 300	15 400
Light-Duty Gasoline Vehicles	3 850	4 430	4 450	4 330	4 310	4 270	4 440	4 170	4 010
Light-Duty Gasoline Trucks	2 200	3 390	4 470	4 540	4 620	4 680	5 000	4 780	4 870
Heavy-Duty Gasoline Vehicles	2 040	1 830	1 670	1 570	1 500	1 620	1 720	1 640	1 560
Motorcycles	17.5	13.1	16.4	18.2	20.0	21.9	26.3	27.2	26.8
Light-Duty Diesel Vehicles	26.4	29.1	37.5	37.5	39.2	38.9	43.9	45.7	45.6
Light-Duty Diesel Trucks	35.3	63.3	64.8	54.3	47.1	54.1	57.1	56.1	55.7
Heavy-Duty Diesel Vehicles	2 490	2 860	3 630	3 610	3 740	3 880	4 190	4 430	4 610
Propane & Natural Gas Vehicles	780	570	330	320	290	260	260	190	190
Railways	1 000	2 000	1 000	1 000	800	600	400	400	400
Navigation (Domestic Marine)	1 000	1 200	1 200	1 600	1 900	3 000	2 700	2 500	2 500
Other Transportation	3 000	5 000	5 000	5 000	5 000	5 000	6 000	5 000	5 000
Off-Road Gasoline	400	400	500	400	400	500	500	400	400
Off-Road Diesel	2 000	3 000	3 000	3 000	3 000	4 000	4 000	4 000	3 000
Pipelines	845	1 370	1 630	1 840	1 340	1 050	1 120	977	765
<b>c. Fugitive Sources<sup>2</sup></b>	<b>3 320</b>	<b>4 980</b>	<b>5 270</b>	<b>5 730</b>	<b>5 850</b>	<b>5 740</b>	<b>6 100</b>	<b>6 210</b>	<b>6 500</b>
Coal Mining <sup>6</sup>	500	600	500	500	500	400	X	X	X
Oil and Natural Gas	2 830	4 410	4 790	5 210	5 370	5 310	X	X	X
<b>INDUSTRIAL PROCESSES<sup>3</sup></b>	<b>3 060</b>	<b>3 320</b>	<b>3 880</b>	<b>2 910</b>	<b>2 820</b>	<b>2 960</b>	<b>3 150</b>	<b>3 020</b>	<b>2 750</b>
<b>a. Mineral Products</b>	<b>770</b>	<b>950</b>	<b>1 300</b>	<b>1 200</b>	<b>1 300</b>	<b>1 200</b>	<b>1 400</b>	<b>1 300</b>	<b>1 300</b>
Cement Production	610	760	1 100	1 000	1 100	1 100	1 200	1 100	1 200
Lime Production	160	190	220	190	200	180	190	180	170
<b>b. Chemical Industry</b>	–	–	–	–	–	–	–	–	–
Nitric Acid Production	–	–	–	–	–	–	–	–	–
Adipic Acid Production	–	–	–	–	–	–	–	–	–
<b>c. Metal Production</b>	<b>1 510</b>	<b>1 690</b>	<b>1 820</b>	<b>1 270</b>	<b>1 060</b>	<b>1 230</b>	<b>1 360</b>	<b>1 130</b>	<b>999</b>
Iron and Steel Production	–	–	–	–	–	–	–	–	–
Aluminum Production	1 500	1 700	1 800	1 300	1 100	1 200	1 400	1 100	1 000
SF <sub>6</sub> Used in Magnesium Smelters and Casters <sup>5</sup>	–	–	–	–	–	–	–	–	–
<b>d. Consumption of Halocarbons and SF<sub>6</sub></b>	–	–	–	–	–	–	–	–	–
<b>e. Other &amp; Undifferentiated Production<sup>4</sup></b>	<b>780</b>	<b>680</b>	<b>790</b>	<b>420</b>	<b>490</b>	<b>480</b>	<b>430</b>	<b>560</b>	<b>410</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>	<b>21</b>	<b>27</b>	<b>32</b>	<b>28</b>	<b>22</b>	<b>29</b>	<b>28</b>	<b>24</b>	<b>43</b>
<b>AGRICULTURE</b>	<b>2 200</b>	<b>2 400</b>	<b>2 400</b>	<b>2 500</b>	<b>2 500</b>	<b>2 600</b>	<b>2 700</b>	<b>2 700</b>	<b>2 400</b>
<b>a. Enteric Fermentation</b>	<b>1 000</b>	<b>1 200</b>	<b>1 200</b>	<b>1 200</b>	<b>1 300</b>	<b>1 300</b>	<b>1 400</b>	<b>1 400</b>	<b>1 200</b>
<b>b. Manure Management</b>	<b>340</b>	<b>390</b>	<b>410</b>	<b>420</b>	<b>430</b>	<b>440</b>	<b>450</b>	<b>440</b>	<b>410</b>
<b>c. Agricultural Soils</b>	<b>830</b>	<b>840</b>	<b>760</b>	<b>840</b>	<b>800</b>	<b>850</b>	<b>850</b>	<b>850</b>	<b>740</b>
Direct Sources	400	370	300	350	320	340	340	350	280
Pasture, Range and Paddock Manure	150	180	190	190	200	210	220	210	190
Indirect Sources	300	300	300	300	300	300	300	300	300
<b>WASTE</b>	<b>3 000</b>	<b>3 400</b>	<b>3 500</b>	<b>3 600</b>	<b>3 600</b>	<b>3 600</b>	<b>3 500</b>	<b>3 400</b>	<b>3 400</b>
<b>a. Solid Waste Disposal on Land</b>	<b>2 900</b>	<b>3 200</b>	<b>3 400</b>	<b>3 400</b>	<b>3 400</b>	<b>3 400</b>	<b>3 300</b>	<b>3 200</b>	<b>3 300</b>
<b>b. Wastewater Handling</b>	<b>90</b>	<b>100</b>	<b>110</b>	<b>110</b>	<b>110</b>	<b>110</b>	<b>110</b>	<b>110</b>	<b>110</b>
<b>c. Waste Incineration</b>	<b>66</b>	<b>73</b>	<b>70</b>	<b>67</b>	<b>69</b>	<b>69</b>	<b>69</b>	<b>68</b>	<b>68</b>

## Notes:

1. Emissions from Fuel Ethanol are reported within the gasoline transportation subcategories.
  2. Fugitive emissions from refineries and the bitumen industry are only reported at the national level.
  3. Emissions associated with the use of mineral products and consumption of halocarbons & SF<sub>6</sub> are only reported at the national level.
  4. Emissions coming from ammonia production are included in the category Other & Undifferentiated Production at provincial levels.
  5. Information on SF<sub>6</sub> use in casters is confidential for this province.
  6. Fugitive emissions from coal mining activities for 2002 and 2003 have been extrapolated based on publicly available coal production data.
- X Indicates confidential data.  
 – Indicates no emissions.  
 0.0 Indicates emissions truncated due to rounding.



Table A11-21: 2006 GHG Emission Summary for British Columbia

Greenhouse Gas Categories		Greenhouse Gases							TOTAL
		CO <sub>2</sub>	CH <sub>4</sub>	CH <sub>4</sub>	N <sub>2</sub> O	N <sub>2</sub> O	PFCs	SF <sub>6</sub>	
		Global Warming Potential		21		310			
		Unit	kt	kt CO <sub>2</sub> eq	kt	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	
<b>TOTAL</b>			<b>51 300</b>	<b>380</b>	<b>8 000</b>	<b>8.1</b>	<b>2 500</b>	<b>520</b>	<b>62 300</b>
<b>ENERGY</b>			<b>49 000</b>	<b>160</b>	<b>3 400</b>	<b>4</b>	<b>1 000</b>	—	<b>53 700</b>
a.	<b>Stationary Combustion Sources</b>		<b>21 900</b>	<b>30</b>	<b>600</b>	<b>0.8</b>	<b>300</b>	—	<b>22 700</b>
	Electricity and Heat Generation		1 450	0.22	4.7	0.04	10	—	1 470
	Fossil Fuel Industries		6 960	20	400	0.2	60	—	7 400
	Mining & Oil and Gas Extraction		730	0.01	0.3	0.02	5	—	735
	Manufacturing Industries		5 130	0.8	20	0.4	100	—	5 260
	Construction		109	0.00	0.04	0.00	0.7	—	110
	Commercial & Institutional		3 310	0.06	1	0.06	20	—	3 330
	Residential		4 170	7	200	0.2	50	—	4 400
	Agriculture & Forestry		65.2	0.00	0.02	0.00	0.5	—	65.7
b.	<b>Transportation<sup>1</sup></b>		<b>23 300</b>	<b>3</b>	<b>60</b>	<b>3</b>	<b>1 000</b>	—	<b>24 000</b>
	Civil Aviation (Domestic Aviation)		1 600	0.08	2	0.1	50	—	1 600
	Road Transportation		14 900	1.1	23	1.4	440	—	15 400
	Light-Duty Gasoline Vehicles		3 850	0.32	6.7	0.50	150	—	4 010
	Light-Duty Gasoline Trucks		4 650	0.32	6.7	0.68	210	—	4 870
	Heavy-Duty Gasoline Vehicles		1 520	0.10	2.1	0.10	31	—	1 560
	Motorcycles		26.2	0.02	0.39	0.00	0.16	—	26.8
	Light-Duty Diesel Vehicles		44.4	0.00	0.02	0.00	1	—	45.6
	Light-Duty Diesel Trucks		54.3	0.00	0.03	0.00	1	—	55.7
	Heavy-Duty Diesel Vehicles		4 560	0.2	4	0.1	40	—	4 610
	Propane & Natural Gas Vehicles		188	0.1	2	0.00	1	—	190
	Railways		354	0.02	0.4	0.1	50	—	400
	Navigation (Domestic Marine)		2 320	0.2	4	0.4	100	—	2 500
	Other Transportation		4 200	1	30	1	400	—	5 000
	Off-Road Gasoline		400	0.5	10	0.01	3	—	400
	Off-Road Diesel		3 000	0.2	3	1	400	—	3 000
	Pipelines		743	0.74	16	0.02	6	—	765
c.	<b>Fugitive Sources<sup>2</sup></b>		<b>3 700</b>	<b>130</b>	<b>2 800</b>	—	—	—	<b>6 500</b>
	Coal Mining		X	X	X	—	—	—	X
	Oil and Natural Gas		X	X	X	—	—	—	X
<b>INDUSTRIAL PROCESSES<sup>3</sup></b>			<b>2 200</b>	—	—	—	—	<b>520</b>	<b>2 750</b>
a.	<b>Mineral Products</b>		<b>1 300</b>	—	—	—	—	—	<b>1 300</b>
	Cement Production		1 200	—	—	—	—	—	1 200
	Lime Production		170	—	—	—	—	—	170
b.	<b>Chemical Industry</b>		—	—	—	—	—	—	<b>0</b>
	Nitric Acid Production		—	—	—	—	—	—	0
	Adipic Acid Production		—	—	—	—	—	—	0
c.	<b>Metal Production</b>		<b>480</b>	—	—	—	—	<b>520</b>	<b>999</b>
	Iron and Steel Production		—	—	—	—	—	—	0
	Aluminum Production		480	—	—	—	—	520	1 000
	SF <sub>6</sub> Used in Magnesium Smelters and Casters <sup>5</sup>		—	—	—	—	—	—	0
d.	<b>Consumption of Halocarbons and SF<sub>6</sub></b>		—	—	—	—	—	—	<b>0</b>
e.	<b>Other &amp; Undifferentiated Production<sup>4</sup></b>		<b>410</b>	—	—	—	—	—	<b>410</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>			—	—	—	<b>0.14</b>	<b>43</b>	—	<b>43</b>
<b>AGRICULTURE</b>			—	<b>65</b>	<b>1 400</b>	<b>3.3</b>	<b>1 000</b>	—	<b>2 400</b>
a.	<b>Enteric Fermentation</b>		—	59	1 200	—	—	—	1 200
b.	<b>Manure Management</b>		—	6.0	130	0.93	290	—	410
c.	<b>Agricultural Soils</b>		—	—	—	<b>2.4</b>	<b>740</b>	—	<b>740</b>
	Direct Sources		—	—	—	0.92	280	—	280
	Pasture, Range and Paddock Manure		—	—	—	0.62	190	—	190
	Indirect Sources		—	—	—	0.8	300	—	300
<b>WASTE</b>			<b>57</b>	<b>160</b>	<b>3 300</b>	<b>0.3</b>	<b>100</b>	—	<b>3 400</b>
a.	<b>Solid Waste Disposal on Land</b>		—	150	3 300	—	—	—	3 300
b.	<b>Wastewater Handling</b>		—	0.99	21	0.3	90	—	110
c.	<b>Waste Incineration</b>		57	—	—	0.04	10	—	68

## Notes:

1. Emissions from Fuel Ethanol are reported within the gasoline transportation subcategories.
2. Fugitive emissions from refineries and the bitumen industry are only reported at the national level.
3. Emissions associated with the use of mineral products and consumption of halocarbons & SF<sub>6</sub> are only reported at the national level.
4. Emissions coming from ammonia production are included in the category Other & Undifferentiated Production at provincial levels.
5. Information on SF<sub>6</sub> use in casters is confidential for this province.

X Indicates confidential data.

— Indicates no emissions.

0.0 Indicates emissions truncated due to rounding.

**Table A11-22: 1990–2006 GHG Emission Summary for Yukon**

Greenhouse Gas Categories	1990	1995	2000	2001	2002	2003	2004	2005	2006
	<i>kt CO<sub>2</sub> equivalent</i>								
<b>TOTAL</b>	<b>538</b>	<b>547</b>	<b>445</b>	<b>433</b>	<b>444</b>	<b>440</b>	<b>414</b>	<b>398</b>	<b>394</b>
<b>ENERGY</b>	<b>526</b>	<b>532</b>	<b>430</b>	<b>418</b>	<b>428</b>	<b>424</b>	<b>398</b>	<b>382</b>	<b>377</b>
<b>a. Stationary Combustion Sources</b>	<b>226</b>	<b>248</b>	<b>191</b>	<b>168</b>	<b>169</b>	<b>163</b>	<b>131</b>	<b>126</b>	<b>123</b>
Electricity and Heat Generation	93.6	53.3	17.0	14.6	17.2	10.7	7.99	7.53	7.81
Fossil Fuel Industries	2.9	91	84	56	48	28	11	29	38
Mining & Oil and Gas Extraction	4.12	10.3	1.54	2.09	2.90	2.11	1.73	3.08	0.53
Manufacturing Industries	8.01	0.47	–	0.03	–	–	–	–	–
Construction	5.46	4.45	2.40	1.64	1.58	2.65	1.95	1.07	1.06
Commercial & Institutional	81.9	60.8	52.9	51.2	53.1	58.5	40.0	39.8	30.4
Residential	29	19	33	29	31	41	55	39	39
Agriculture & Forestry	1.24	7.56	0.95	13.9	14.7	19.9	13.2	6.27	6.02
<b>b. Transportation<sup>1</sup></b>	<b>300</b>	<b>280</b>	<b>240</b>	<b>250</b>	<b>250</b>	<b>260</b>	<b>260</b>	<b>250</b>	<b>250</b>
Civil Aviation (Domestic Aviation)	21	21	23	16	15	20	22	22	27
Road Transportation	180	218	162	165	168	164	160	157	144
Light-Duty Gasoline Vehicles	79.1	72.5	48.9	47.2	45.6	45.0	39.1	34.3	28.5
Light-Duty Gasoline Trucks	30.4	41.7	39.6	41.4	42.5	44.2	40.3	37.7	33.5
Heavy-Duty Gasoline Vehicles	10.2	9.69	5.89	6.28	6.08	6.31	5.83	5.28	4.49
Motorcycles	0.46	0.41	0.32	0.32	0.35	0.38	0.35	0.32	0.27
Light-Duty Diesel Vehicles	0.55	0.51	0.35	0.34	0.33	0.34	0.32	0.28	0.24
Light-Duty Diesel Trucks	0.60	0.96	2.51	2.55	2.58	2.71	2.53	2.65	2.68
Heavy-Duty Diesel Vehicles	57.2	88.0	63.5	65.5	69.0	63.6	69.9	75.2	72.7
Propane & Natural Gas Vehicles	1.5	4.0	0.68	1.0	1.6	1.9	2.1	1.1	1.5
Railways	–	–	–	–	–	–	–	–	–
Navigation (Domestic Marine)	–	–	–	–	–	–	–	–	–
Other Transportation	100	40	50	70	70	70	80	70	80
Off-Road Gasoline	10	8	10	10	10	10	3	3	2
Off-Road Diesel	90	30	40	60	60	60	80	70	80
Pipelines	–	–	–	–	–	–	–	–	–
<b>c. Fugitive Sources<sup>2</sup></b>	<b>–</b>	<b>3.77</b>	<b>2.71</b>	<b>2.15</b>	<b>5.40</b>	<b>3.54</b>	<b>2.71</b>	<b>2.12</b>	<b>1.03</b>
Coal Mining <sup>5</sup>	–	–	–	–	–	–	X	X	X
Oil and Natural Gas	–	3.77	2.71	2.15	5.40	3.54	X	X	X
<b>INDUSTRIAL PROCESSES<sup>3</sup></b>	<b>1.38</b>	<b>2.09</b>	<b>0.71</b>	<b>0.61</b>	<b>0.99</b>	<b>0.75</b>	<b>0.49</b>	<b>0.56</b>	<b>0.56</b>
<b>a. Mineral Products</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>
Cement Production	–	–	–	–	–	–	–	–	–
Lime Production	–	–	–	–	–	–	–	–	–
<b>b. Chemical Industry</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>
Nitric Acid Production	–	–	–	–	–	–	–	–	–
Adipic Acid Production	–	–	–	–	–	–	–	–	–
<b>c. Metal Production</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>
Iron and Steel Production	–	–	–	–	–	–	–	–	–
Aluminum Production	–	–	–	–	–	–	–	–	–
SF <sub>6</sub> Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	–	–
<b>d. Consumption of Halocarbons and SF<sub>6</sub></b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>
<b>e. Other &amp; Undifferentiated Production<sup>4</sup></b>	<b>1.4</b>	<b>2.1</b>	<b>0.71</b>	<b>0.61</b>	<b>0.99</b>	<b>0.75</b>	<b>0.48</b>	<b>0.56</b>	<b>0.56</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>	<b>0.18</b>	<b>0.22</b>	<b>0.24</b>	<b>0.21</b>	<b>0.16</b>	<b>0.21</b>	<b>0.20</b>	<b>0.17</b>	<b>0.31</b>
<b>AGRICULTURE</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>
<b>a. Enteric Fermentation</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>
<b>b. Manure Management</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>
<b>c. Agricultural Soils</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>
Direct Sources	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pasture, Range and Paddock Manure	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Indirect Sources	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<b>WASTE</b>	<b>10</b>	<b>12</b>	<b>14</b>	<b>14</b>	<b>14</b>	<b>15</b>	<b>15</b>	<b>16</b>	<b>16</b>
<b>a. Solid Waste Disposal on Land</b>	<b>7.6</b>	<b>9.3</b>	<b>11</b>	<b>11</b>	<b>12</b>	<b>12</b>	<b>12</b>	<b>13</b>	<b>13</b>
<b>b. Wastewater Handling</b>	<b>2.9</b>	<b>3.2</b>	<b>2.9</b>	<b>2.8</b>	<b>2.8</b>	<b>3.0</b>	<b>3.1</b>	<b>3.1</b>	<b>3.1</b>
<b>c. Waste Incineration</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>

## Notes:

1. Emissions from Fuel Ethanol are reported within the gasoline transportation subcategories.
  2. Fugitive emissions from refineries and the bitumen industry are only reported at the national level.
  3. Emissions associated with the use of mineral products and consumption of halocarbons & SF<sub>6</sub> are only reported at the national level.
  4. Emissions coming from ammonia production are included in the category Other & Undifferentiated Production at provincial levels.
  5. Fugitive emissions from coal mining activities for 2002 and 2003 have been extrapolated based on publicly available coal production data.
- X Indicates confidential data.  
 – Indicates no emissions.  
 0.0 Indicates emissions truncated due to rounding.

Table A11-23: 2006 GHG Emission Summary for Yukon

Greenhouse Gas Categories		Greenhouse Gases							
		CO <sub>2</sub>	CH <sub>4</sub>	CH <sub>4</sub>	N <sub>2</sub> O	N <sub>2</sub> O	PFCs	SF <sub>6</sub>	TOTAL
		Global Warming Potential		21		310			
		Unit	kt	kt CO <sub>2</sub> eq	kt	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq
<b>TOTAL</b>			<b>359</b>	<b>0.97</b>	<b>20</b>	<b>0.05</b>	<b>15</b>	–	<b>394</b>
<b>ENERGY</b>			<b>359</b>	<b>0.24</b>	<b>5.0</b>	<b>0.04</b>	<b>10</b>	–	<b>377</b>
a.	<b>Stationary Combustion Sources</b>		<b>117</b>	<b>0.2</b>	<b>4</b>	<b>0.00</b>	<b>1</b>	–	<b>123</b>
	Electricity and Heat Generation		7.46	0.00	0.01	0.00	0.3	–	7.81
	Fossil Fuel Industries		35.6	0.1	2	0.00	0.3	–	38
	Mining & Oil and Gas Extraction		0.53	0.00	0.00	0.00	0.00	–	0.53
	Manufacturing Industries		–	–	–	–	–	–	0
	Construction		1.05	0.00	0.00	0.00	0.00	–	1.06
	Commercial & Institutional		30.3	0.00	0.01	0.00	0.1	–	30.4
	Residential		36.3	0.1	2	0.00	0.4	–	39
	Agriculture & Forestry		6.00	0.00	0.00	0.00	0.02	–	6.02
b.	<b>Transportation<sup>1</sup></b>		<b>240</b>	<b>0.02</b>	<b>0.4</b>	<b>0.04</b>	<b>10</b>	–	<b>250</b>
	Civil Aviation (Domestic Aviation)		25.9	0.00	0.07	0.00	0.7	–	27
	Road Transportation		141	0.01	0.23	0.01	2.6	–	144
	Light-Duty Gasoline Vehicles		27.7	0.00	0.06	0.00	0.71	–	28.5
	Light-Duty Gasoline Trucks		32.4	0.00	0.07	0.00	1.1	–	33.5
	Heavy-Duty Gasoline Vehicles		4.38	0.00	0.01	0.00	0.10	–	4.49
	Motorcycles		0.26	0.00	0.00	0.00	0.00	–	0.27
	Light-Duty Diesel Vehicles		0.23	0.00	0.00	0.00	0.01	–	0.24
	Light-Duty Diesel Trucks		2.61	0.00	0.00	0.00	0.06	–	2.68
	Heavy-Duty Diesel Vehicles		71.9	0.00	0.07	0.00	0.7	–	72.7
	Propane & Natural Gas Vehicles		1.43	0.00	0.01	0.00	0.01	–	1.5
	Railways		–	–	–	–	–	–	0
	Navigation (Domestic Marine)		–	–	–	–	–	–	0
	Other Transportation		74	0.01	0.1	0.03	9	–	80
	Off-Road Gasoline		2	0.00	0.05	0.00	0.01	–	2
	Off-Road Diesel		71	0.00	0.08	0.03	9	–	80
	Pipelines		–	–	–	–	–	–	0
c.	<b>Fugitive Sources<sup>2</sup></b>		<b>0.89</b>	<b>0.01</b>	<b>0.14</b>	–	–	–	<b>1.03</b>
	Coal Mining		X	X	X	–	–	–	X
	Oil and Natural Gas		X	X	X	–	–	–	X
<b>INDUSTRIAL PROCESSES<sup>3</sup></b>			<b>0.56</b>	–	–	–	–	–	<b>0.56</b>
a.	<b>Mineral Products</b>		–	–	–	–	–	–	<b>0</b>
	Cement Production		–	–	–	–	–	–	0
	Lime Production		–	–	–	–	–	–	0
b.	<b>Chemical Industry</b>		–	–	–	–	–	–	<b>0</b>
	Nitric Acid Production		–	–	–	–	–	–	0
	Adipic Acid Production		–	–	–	–	–	–	0
c.	<b>Metal Production</b>		–	–	–	–	–	–	<b>0</b>
	Iron and Steel Production		–	–	–	–	–	–	0
	Aluminum Production		–	–	–	–	–	–	0
	SF <sub>6</sub> Used in Magnesium Smelters and Casters		–	–	–	–	–	–	0
d.	<b>Consumption of Halocarbons and SF<sub>6</sub></b>		–	–	–	–	–	–	<b>0</b>
e.	<b>Other &amp; Undifferentiated Production<sup>4</sup></b>		<b>0.56</b>	–	–	–	–	–	<b>0.56</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>			–	–	–	<b>0.00</b>	<b>0.31</b>	–	<b>0.31</b>
<b>AGRICULTURE</b>			–	–	–	–	–	–	–
a.	<b>Enteric Fermentation</b>		–	–	–	–	–	–	–
b.	<b>Manure Management</b>		–	–	–	–	–	–	–
c.	<b>Agricultural Soils</b>		–	–	–	–	–	–	–
	Direct Sources		–	–	–	–	–	–	–
	Pasture, Range and Paddock Manure		–	–	–	–	–	–	–
	Indirect Sources		–	–	–	–	–	–	–
<b>WASTE</b>			–	<b>0.73</b>	<b>15</b>	<b>0.00</b>	<b>0.6</b>	–	<b>16</b>
a.	<b>Solid Waste Disposal on Land</b>		–	0.61	13	–	–	–	13
b.	<b>Wastewater Handling</b>		–	0.12	2.5	0.00	0.6	–	3.1
c.	<b>Waste Incineration</b>		–	–	–	–	–	–	0

## Notes:

1. Emissions from Fuel Ethanol are reported within the gasoline transportation subcategories.
  2. Fugitive emissions from refineries and the bitumen industry are only reported at the national level.
  3. Emissions associated with the use of mineral products and consumption of halocarbons & SF<sub>6</sub> are only reported at the national level.
  4. Emissions coming from ammonia production are included in the category Other & Undifferentiated Production at provincial levels.
- X Indicates confidential data.  
 – Indicates no emissions.  
 0.0 Indicates emissions truncated due to rounding.

**Table A11-24: 1999–2006 GHG Emission Summary for Northwest Territories**

Greenhouse Gas Categories	1999	2000	2001	2002	2003	2004	2005	2006
	<i>kt CO<sub>2</sub> equivalent</i>							
<b>TOTAL</b>	<b>1 120</b>	<b>1 300</b>	<b>1 730</b>	<b>1 340</b>	<b>1 210</b>	<b>1 180</b>	<b>832</b>	<b>1 160</b>
<b>ENERGY</b>	<b>1 100</b>	<b>1 280</b>	<b>1 710</b>	<b>1 310</b>	<b>1 180</b>	<b>1 160</b>	<b>808</b>	<b>1 130</b>
<b>a. Stationary Combustion Sources</b>	<b>527</b>	<b>745</b>	<b>942</b>	<b>816</b>	<b>739</b>	<b>708</b>	<b>650</b>	<b>587</b>
Electricity and Heat Generation	205	242	261	199	232	211	245	268
Fossil Fuel Industries	3.3	170	320	280	170	190	130	82
Mining & Oil and Gas Extraction	67.8	74.2	98.9	98.9	86.9	69.3	60.8	49.0
Manufacturing Industries	0.00	0.00	0.01	0.00	0.08	0.18	0.25	0.00
Construction	0.77	0.41	0.51	1.26	1.12	1.71	1.68	0.78
Commercial & Institutional	163	146	136	112	144	141	130	120
Residential	87	110	100	100	89	90	81	66
Agriculture & Forestry	0.01	0.00	19.6	21.8	13.5	1.75	1.53	–
<b>b. Transportation<sup>1</sup></b>	<b>570</b>	<b>530</b>	<b>770</b>	<b>500</b>	<b>440</b>	<b>450</b>	<b>160</b>	<b>550</b>
Civil Aviation (Domestic Aviation)	91	84	180	110	100	110	87	99
Road Transportation	222	219	219	207	203	206	49.3	214
Light-Duty Gasoline Vehicles	38.0	38.8	40.1	35.8	34.8	33.2	23.3	19.4
Light-Duty Gasoline Trucks	27.5	27.6	29.5	27.3	28.0	28.3	20.7	18.1
Heavy-Duty Gasoline Vehicles	3.37	3.74	4.28	3.73	3.65	3.74	2.69	2.25
Motorcycles	0.21	0.24	0.27	0.26	0.28	0.29	0.20	0.17
Light-Duty Diesel Vehicles	0.28	0.31	0.32	0.29	0.29	0.30	0.21	0.18
Light-Duty Diesel Trucks	1.42	1.67	1.87	1.75	1.85	1.90	1.57	1.56
Heavy-Duty Diesel Vehicles	150	146	143	137	133	137	–	171
Propane & Natural Gas Vehicles	0.83	0.34	0.51	0.78	0.95	1.0	0.54	0.73
Railways	3	3	3	4	3	3	3	3
Navigation (Domestic Marine)	4.6	5.8	12	7.3	–	–	–	–
Other Transportation	300	200	400	200	100	100	20	200
Off-Road Gasoline	20	20	30	10	20	20	20	10
Off-Road Diesel	200	200	300	200	100	100	–	200
Pipelines	4.72	5.66	6.04	3.64	2.93	2.88	2.51	2.23
<b>c. Fugitive Sources<sup>2</sup></b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>
Coal Mining <sup>5</sup>	–	–	–	–	–	X	X	X
Oil and Natural Gas	–	–	–	–	–	X	X	X
<b>INDUSTRIAL PROCESSES<sup>3</sup></b>	<b>2.37</b>	<b>4.15</b>	<b>5.23</b>	<b>5.40</b>	<b>5.36</b>	<b>3.52</b>	<b>4.65</b>	<b>4.79</b>
<b>a. Mineral Products</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>
Cement Production	–	–	–	–	–	–	–	–
Lime Production	–	–	–	–	–	–	–	–
<b>b. Chemical Industry</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>
Nitric Acid Production	–	–	–	–	–	–	–	–
Adipic Acid Production	–	–	–	–	–	–	–	–
<b>c. Metal Production</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>
Iron and Steel Production	–	–	–	–	–	–	–	–
Aluminum Production	–	–	–	–	–	–	–	–
SF <sub>6</sub> Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	–
<b>d. Consumption of Halocarbons and SF<sub>6</sub></b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>
<b>e. Other &amp; Undifferentiated Production<sup>4</sup></b>	<b>2.4</b>	<b>4.1</b>	<b>5.2</b>	<b>5.4</b>	<b>5.4</b>	<b>3.5</b>	<b>4.7</b>	<b>4.8</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>	<b>0.29</b>	<b>0.32</b>	<b>0.28</b>	<b>0.22</b>	<b>0.29</b>	<b>0.28</b>	<b>0.24</b>	<b>0.42</b>
<b>AGRICULTURE</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>
<b>a. Enteric Fermentation</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>
<b>b. Manure Management</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>
<b>c. Agricultural Soils</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>
Direct Sources	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pasture, Range and Paddock Manure	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Indirect Sources	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<b>WASTE</b>	<b>17</b>	<b>17</b>	<b>18</b>	<b>18</b>	<b>19</b>	<b>19</b>	<b>19</b>	<b>20</b>
<b>a. Solid Waste Disposal on Land</b>	<b>13</b>	<b>13</b>	<b>13</b>	<b>14</b>	<b>14</b>	<b>15</b>	<b>15</b>	<b>15</b>
<b>b. Wastewater Handling</b>	<b>4.2</b>	<b>4.2</b>	<b>4.3</b>	<b>4.4</b>	<b>4.4</b>	<b>4.5</b>	<b>4.5</b>	<b>4.4</b>
<b>c. Waste Incineration</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>

## Notes:

1. Emissions from Fuel Ethanol are reported within the gasoline transportation subcategories.
  2. Fugitive emissions from refineries and the bitumen industry are only reported at the national level.
  3. Emissions associated with the use of mineral products and consumption of halocarbons & SF<sub>6</sub> are only reported at the national level.
  4. Emissions coming from ammonia production are included in the category Other & Undifferentiated Production at provincial levels.
  5. Fugitive emissions from coal mining activities for 2002 and 2003 have been extrapolated based on publicly available coal production data.
- X Indicates confidential data.  
 – Indicates no emissions.  
 0.0 Indicates emissions truncated due to rounding.

Table A11-25: 2006 GHG Emission Summary for Northwest Territories

Greenhouse Gas Categories		Greenhouse Gases							
		CO <sub>2</sub>	CH <sub>4</sub>	CH <sub>4</sub>	N <sub>2</sub> O	N <sub>2</sub> O	PFCs	SF <sub>6</sub>	TOTAL
		Global Warming Potential		21		310			
		Unit	kt	kt CO <sub>2</sub> eq	kt	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq
<b>TOTAL</b>			<b>1 090</b>	<b>1.4</b>	<b>29</b>	<b>0.14</b>	<b>44</b>	—	<b>1 160</b>
<b>ENERGY</b>			<b>1 080</b>	<b>0.50</b>	<b>10</b>	<b>0.1</b>	<b>40</b>	—	<b>1 130</b>
a.	<b>Stationary Combustion Sources</b>		<b>565</b>	<b>0.5</b>	<b>10</b>	<b>0.04</b>	<b>10</b>	—	<b>587</b>
	Electricity and Heat Generation		259	0.01	0.23	0.03	9	—	268
	Fossil Fuel Industries		77.4	0.2	4	0.00	0.6	—	82
	Mining & Oil and Gas Extraction		48.7	0.00	0.01	0.00	0.2	—	49.0
	Manufacturing Industries		0.00	0.00	0.00	0.00	0.00	—	0.00
	Construction		0.78	0.00	0.00	0.00	0.00	—	0.78
	Commercial & Institutional		119	0.00	0.04	0.00	0.6	—	120
	Residential		60.4	0.2	5	0.00	0.9	—	66
	Agriculture & Forestry		—	—	—	—	—	—	0
b.	<b>Transportation<sup>1</sup></b>		<b>515</b>	<b>0.05</b>	<b>1</b>	<b>0.1</b>	<b>30</b>	—	<b>550</b>
	Civil Aviation (Domestic Aviation)		96.5	0.01	0.2	0.01	3	—	99
	Road Transportation		210	0.01	0.26	0.01	2.8	—	214
	Light-Duty Gasoline Vehicles		18.8	0.00	0.04	0.00	0.49	—	19.4
	Light-Duty Gasoline Trucks		17.5	0.00	0.04	0.00	0.56	—	18.1
	Heavy-Duty Gasoline Vehicles		2.20	0.00	0.00	0.00	0.04	—	2.25
	Motorcycles		0.17	0.00	0.00	0.00	0.00	—	0.17
	Light-Duty Diesel Vehicles		0.18	0.00	0.00	0.00	0.00	—	0.18
	Light-Duty Diesel Trucks		1.52	0.00	0.00	0.00	0.04	—	1.56
	Heavy-Duty Diesel Vehicles		169	0.01	0.2	0.01	2	—	171
	Propane & Natural Gas Vehicles		0.72	0.00	0.01	0.00	0.00	—	0.73
	Railways		2.40	0.00	0.00	0.00	0.3	—	3
	Navigation (Domestic Marine)		—	—	—	—	—	—	0
	Other Transportation		210	0.02	0.5	0.08	20	—	200
	Off-Road Gasoline		10	0.01	0.3	0.00	0.07	—	10
	Off-Road Diesel		190	0.01	0.2	0.08	20	—	200
	Pipelines		2.13	0.00	0.00	0.00	0.1	—	2.23
c.	<b>Fugitive Sources<sup>2</sup></b>		—	—	—	—	—	—	<b>0</b>
	Coal Mining		X	X	X	—	—	—	X
	Oil and Natural Gas		X	X	X	—	—	—	X
<b>INDUSTRIAL PROCESSES<sup>3</sup></b>			<b>4.8</b>	—	—	—	—	—	<b>4.79</b>
a.	<b>Mineral Products</b>		—	—	—	—	—	—	<b>0</b>
	Cement Production		—	—	—	—	—	—	0
	Lime Production		—	—	—	—	—	—	0
b.	<b>Chemical Industry</b>		—	—	—	—	—	—	<b>0</b>
	Nitric Acid Production		—	—	—	—	—	—	0
	Adipic Acid Production		—	—	—	—	—	—	0
c.	<b>Metal Production</b>		—	—	—	—	—	—	<b>0</b>
	Iron and Steel Production		—	—	—	—	—	—	0
	Aluminum Production		—	—	—	—	—	—	0
	SF <sub>6</sub> Used in Magnesium Smelters and Casters		—	—	—	—	—	—	0
d.	<b>Consumption of Halocarbons and SF<sub>6</sub></b>		—	—	—	—	—	—	<b>0</b>
e.	<b>Other &amp; Undifferentiated Production<sup>4</sup></b>		<b>4.8</b>	—	—	—	—	—	<b>4.8</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>			—	—	—	<b>0.00</b>	<b>0.42</b>	—	<b>0.42</b>
<b>AGRICULTURE</b>			—	—	—	—	—	—	—
a.	<b>Enteric Fermentation</b>		—	—	—	—	—	—	—
b.	<b>Manure Management</b>		—	—	—	—	—	—	—
c.	<b>Agricultural Soils</b>		—	—	—	—	—	—	—
	Direct Sources		—	—	—	—	—	—	—
	Pasture, Range and Paddock Manure		—	—	—	—	—	—	—
	Indirect Sources		—	—	—	—	—	—	—
<b>WASTE</b>			—	<b>0.89</b>	<b>19</b>	<b>0.00</b>	<b>0.9</b>	—	<b>20</b>
a.	<b>Solid Waste Disposal on Land</b>		—	0.72	15	—	—	—	15
b.	<b>Wastewater Handling</b>		—	0.17	3.6	0.00	0.9	—	4.4
c.	<b>Waste Incineration</b>		—	—	—	—	—	—	0

## Notes:

1. Emissions from Fuel Ethanol are reported within the gasoline transportation subcategories.
  2. Fugitive emissions from refineries and the bitumen industry are only reported at the national level.
  3. Emissions associated with the use of mineral products and consumption of halocarbons & SF<sub>6</sub> are only reported at the national level.
  4. Emissions coming from ammonia production are included in the category Other & Undifferentiated Production at provincial levels.
- X Indicates confidential data.  
 — Indicates no emissions.  
 0.0 Indicates emissions truncated due to rounding.

**Table A11-26: 1999–2006 GHG Emission Summary for Nunavut**

Greenhouse Gas Categories	1999	2000	2001	2002	2003	2004	2005	2006
	<i>kt CO<sub>2</sub> equivalent</i>							
<b>TOTAL</b>	<b>201</b>	<b>275</b>	<b>382</b>	<b>397</b>	<b>416</b>	<b>432</b>	<b>159</b>	<b>129</b>
<b>ENERGY</b>	<b>189</b>	<b>263</b>	<b>369</b>	<b>385</b>	<b>403</b>	<b>419</b>	<b>145</b>	<b>115</b>
<b>a. Stationary Combustion Sources</b>	<b>105</b>	<b>72.9</b>	<b>66.2</b>	<b>88.5</b>	<b>65.5</b>	<b>78.0</b>	<b>26.5</b>	<b>4.83</b>
Electricity and Heat Generation	91.2	45.1	35.3	54.4	34.9	47.6	–	–
Fossil Fuel Industries	0.08	0.09	0.08	0.08	0.04	0.10	0.06	–
Mining & Oil and Gas Extraction	2.20	4.25	4.54	6.07	5.80	5.00	7.47	–
Manufacturing Industries	0.00	0.00	0.01	0.00	0.00	0.00	0.00	–
Construction	0.05	0.11	0.17	0.13	0.13	0.12	0.12	–
Commercial & Institutional	6.40	14.3	15.5	15.1	16.3	19.5	14.3	4.83
Residential	4.7	9.1	11	13	8.3	5.7	4.6	–
Agriculture & Forestry	0.01	0.00	0.00	–	–	–	–	–
<b>b. Transportation<sup>1</sup></b>	<b>84</b>	<b>190</b>	<b>300</b>	<b>300</b>	<b>340</b>	<b>340</b>	<b>120</b>	<b>110</b>
Civil Aviation (Domestic Aviation)	23	26	29	30	35	39	34	39
Road Transportation	19.2	25.2	25.6	25.5	27.7	29.1	25.5	27.1
Light-Duty Gasoline Vehicles	3.84	5.28	5.03	4.45	4.77	4.67	3.71	3.84
Light-Duty Gasoline Trucks	8.39	12.7	12.7	11.6	13.1	13.6	11.3	12.3
Heavy-Duty Gasoline Vehicles	0.11	0.15	0.15	0.13	0.17	0.19	0.14	0.15
Motorcycles	0.02	0.03	0.03	0.03	0.04	0.04	0.03	0.03
Light-Duty Diesel Vehicles	0.03	0.05	0.05	0.05	0.05	0.05	0.04	0.04
Light-Duty Diesel Trucks	0.46	0.72	0.73	0.69	0.78	0.84	0.80	1.01
Heavy-Duty Diesel Vehicles	5.53	5.91	6.44	7.76	7.78	8.66	8.99	9.02
Propane & Natural Gas Vehicles	0.83	0.34	0.51	0.78	0.95	1.0	0.54	0.73
Railways	–	–	–	–	–	–	–	–
Navigation (Domestic Marine)	3.6	4.6	4.9	2.3	–	–	–	–
Other Transportation	40	100	200	200	300	300	60	40
Off-Road Gasoline	–	2	2	–	1	1	–	–
Off-Road Diesel	40	100	200	200	300	300	60	40
Pipelines	–	–	–	–	–	–	–	–
<b>c. Fugitive Sources<sup>2</sup></b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>
Coal Mining <sup>5</sup>	–	–	–	–	–	X	X	X
Oil and Natural Gas	–	–	–	–	–	X	X	X
<b>INDUSTRIAL PROCESSES<sup>3</sup></b>	<b>0.08</b>	<b>0.08</b>	<b>0.18</b>	<b>0.02</b>	<b>0.02</b>	<b>0.02</b>	<b>–</b>	<b>–</b>
<b>a. Mineral Products</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>
Cement Production	–	–	–	–	–	–	–	–
Lime Production	–	–	–	–	–	–	–	–
<b>b. Chemical Industry</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>
Nitric Acid Production	–	–	–	–	–	–	–	–
Adipic Acid Production	–	–	–	–	–	–	–	–
<b>c. Metal Production</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>
Iron and Steel Production	–	–	–	–	–	–	–	–
Aluminum Production	–	–	–	–	–	–	–	–
SF <sub>6</sub> Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	–
<b>d. Consumption of Halocarbons and SF<sub>6</sub></b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>
<b>e. Other &amp; Undifferentiated Production<sup>4</sup></b>	<b>0.08</b>	<b>0.08</b>	<b>0.18</b>	<b>0.02</b>	<b>0.02</b>	<b>0.02</b>	<b>–</b>	<b>–</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>	<b>0.19</b>	<b>0.22</b>	<b>0.19</b>	<b>0.15</b>	<b>0.20</b>	<b>0.20</b>	<b>0.17</b>	<b>0.30</b>
<b>AGRICULTURE</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>
<b>a. Enteric Fermentation</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>
<b>b. Manure Management</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>
<b>c. Agricultural Soils</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>
Direct Sources	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pasture, Range and Paddock Manure	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Indirect Sources	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<b>WASTE</b>	<b>11</b>	<b>12</b>	<b>12</b>	<b>13</b>	<b>13</b>	<b>13</b>	<b>14</b>	<b>14</b>
<b>a. Solid Waste Disposal on Land</b>	<b>8.5</b>	<b>8.9</b>	<b>9.3</b>	<b>9.5</b>	<b>9.8</b>	<b>10</b>	<b>10</b>	<b>11</b>
<b>b. Wastewater Handling</b>	<b>2.8</b>	<b>2.9</b>	<b>2.9</b>	<b>3.0</b>	<b>3.1</b>	<b>3.1</b>	<b>3.2</b>	<b>3.2</b>
<b>c. Waste Incineration</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>

## Notes:

1. Emissions from Fuel Ethanol are reported within the gasoline transportation subcategories.
  2. Fugitive emissions from refineries and the bitumen industry are only reported at the national level.
  3. Emissions associated with the use of mineral products and consumption of halocarbons & SF<sub>6</sub> are only reported at the national level.
  4. Emissions coming from ammonia production are included in the category Other & Undifferentiated Production at provincial levels.
  5. Fugitive emissions from coal mining activities for 2002 and 2003 have been extrapolated based on publicly available coal production data.
- X Indicates confidential data.  
 – Indicates no emissions.  
 0.0 Indicates emissions truncated due to rounding.

Table A11-27: 2006 GHG Emission Summary for Nunavut

Greenhouse Gas Categories		Greenhouse Gases							
		CO <sub>2</sub>	CH <sub>4</sub>	CH <sub>4</sub>	N <sub>2</sub> O	N <sub>2</sub> O	PFCs	SF <sub>6</sub>	TOTAL
		Global Warming Potential		21		310			
		Unit	kt	kt	kt CO <sub>2</sub> eq	kt	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq	kt CO <sub>2</sub> eq
<b>TOTAL</b>			<b>108</b>	<b>0.65</b>	<b>14</b>	<b>0.02</b>	<b>7.6</b>	—	<b>129</b>
<b>ENERGY</b>			<b>108</b>	<b>0.01</b>	<b>0.13</b>	<b>0.02</b>	<b>7</b>	—	<b>115</b>
a.	<b>Stationary Combustion Sources</b>		<b>4.81</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.02</b>	—	<b>4.83</b>
	Electricity and Heat Generation		—	—	—	—	—	—	0
	Fossil Fuel Industries		—	—	—	—	—	—	0
	Mining & Oil and Gas Extraction		—	—	—	—	—	—	0
	Manufacturing Industries		—	—	—	—	—	—	0
	Construction		—	—	—	—	—	—	0
	Commercial & Institutional		4.81	0.00	0.00	0.00	0.02	—	4.83
	Residential		—	—	—	—	—	—	0
	Agriculture & Forestry		—	—	—	—	—	—	0
b.	<b>Transportation<sup>1</sup></b>		<b>103</b>	<b>0.01</b>	<b>0.1</b>	<b>0.02</b>	<b>7</b>	—	<b>110</b>
	Civil Aviation (Domestic Aviation)		38.1	0.00	0.03	0.00	1	—	39
	Road Transportation		26.5	0.00	0.05	0.00	0.60	—	27.1
	Light-Duty Gasoline Vehicles		3.73	0.00	0.01	0.00	0.10	—	3.84
	Light-Duty Gasoline Trucks		11.9	0.00	0.03	0.00	0.38	—	12.3
	Heavy-Duty Gasoline Vehicles		0.15	0.00	0.00	0.00	0.00	—	0.15
	Motorcycles		0.03	0.00	0.00	0.00	0.00	—	0.03
	Light-Duty Diesel Vehicles		0.04	0.00	0.00	0.00	0.00	—	0.04
	Light-Duty Diesel Trucks		0.99	0.00	0.00	0.00	0.02	—	1.01
	Heavy-Duty Diesel Vehicles		8.92	0.00	0.01	0.00	0.08	—	9.02
	Propane & Natural Gas Vehicles		0.72	0.00	0.01	0.00	0.00	—	0.73
	Railways		—	—	—	—	—	—	0
	Navigation (Domestic Marine)		—	—	—	—	—	—	0
	Other Transportation		39	0.00	0.04	0.02	5	—	40
	Off-Road Gasoline		—	—	—	—	—	—	0
	Off-Road Diesel		39	0.00	0.04	0.02	5	—	40
	Pipelines		—	—	—	—	—	—	0
c.	<b>Fugitive Sources<sup>2</sup></b>		—	—	—	—	—	—	<b>0</b>
	Coal Mining		X	X	X	—	—	—	X
	Oil and Natural Gas		X	X	X	—	—	—	X
<b>INDUSTRIAL PROCESSES<sup>3</sup></b>			—	—	—	—	—	—	<b>0</b>
a.	<b>Mineral Products</b>		—	—	—	—	—	—	<b>0</b>
	Cement Production		—	—	—	—	—	—	0
	Lime Production		—	—	—	—	—	—	0
b.	<b>Chemical Industry</b>		—	—	—	—	—	—	<b>0</b>
	Nitric Acid Production		—	—	—	—	—	—	0
	Adipic Acid Production		—	—	—	—	—	—	0
c.	<b>Metal Production</b>		—	—	—	—	—	—	<b>0</b>
	Iron and Steel Production		—	—	—	—	—	—	0
	Aluminum Production		—	—	—	—	—	—	0
	SF <sub>6</sub> Used in Magnesium Smelters and Casters		—	—	—	—	—	—	0
d.	<b>Consumption of Halocarbons and SF<sub>6</sub></b>		—	—	—	—	—	—	<b>0</b>
e.	<b>Other &amp; Undifferentiated Production<sup>4</sup></b>		—	—	—	—	—	—	<b>0</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>			—	—	—	<b>0.00</b>	<b>0.30</b>	—	<b>0.30</b>
<b>AGRICULTURE</b>			—	—	—	—	—	—	—
a.	<b>Enteric Fermentation</b>		—	—	—	—	—	—	—
b.	<b>Manure Management</b>		—	—	—	—	—	—	—
c.	<b>Agricultural Soils</b>		—	—	—	—	—	—	—
	Direct Sources		—	—	—	—	—	—	—
	Pasture, Range and Paddock Manure		—	—	—	—	—	—	—
	Indirect Sources		—	—	—	—	—	—	—
<b>WASTE</b>			—	<b>0.64</b>	<b>13</b>	<b>0.00</b>	<b>0.6</b>	—	<b>14</b>
a.	<b>Solid Waste Disposal on Land</b>		—	0.52	11	—	—	—	11
b.	<b>Wastewater Handling</b>		—	0.12	2.6	0.00	0.6	—	3.2
c.	<b>Waste Incineration</b>		—	—	—	—	—	—	0

Notes:

1. Emissions from Fuel Ethanol are reported within the gasoline transportation subcategories.

2. Fugitive emissions from refineries and the bitumen industry are only reported at the national level.

3. Emissions associated with the use of mineral products and consumption of halocarbons & SF<sub>6</sub> are only reported at the national level.

4. Emissions coming from ammonia production are included in the category Other &amp; Undifferentiated Production at provincial levels.

X Indicates confidential data.

— Indicates no emissions.

0.0 Indicates emissions truncated due to rounding.

**Table A11-28: 1990–1998 GHG Emission Summary for Northwest Territories (including Nunavut)**

Greenhouse Gas Categories	1990	1991	1992	1993	1994	1995	1996	1997	1998
	<i>kt CO<sub>2</sub> equivalent</i>								
<b>TOTAL</b>	<b>1 490</b>	<b>1 450</b>	<b>1 260</b>	<b>1 550</b>	<b>1 740</b>	<b>1 840</b>	<b>1 960</b>	<b>1 670</b>	<b>1 510</b>
<b>ENERGY</b>	<b>1 460</b>	<b>1 410</b>	<b>1 240</b>	<b>1 500</b>	<b>1 610</b>	<b>1 730</b>	<b>1 870</b>	<b>1 640</b>	<b>1 490</b>
<b>a. Stationary Combustion Sources</b>	<b>860</b>	<b>902</b>	<b>768</b>	<b>868</b>	<b>932</b>	<b>1 070</b>	<b>976</b>	<b>906</b>	<b>679</b>
Electricity and Heat Generation	211	212	183	194	195	365	344	341	367
Fossil Fuel Industries	180	110	15	30	20	22	14	3.8	2.8
Mining & Oil and Gas Extraction	48.8	53.5	38.1	61.8	146	98.3	43.9	48.9	42.7
Manufacturing Industries	23.6	14.2	16.3	6.58	12.7	19.8	17.6	9.17	0.00
Construction	3.76	3.28	3.49	4.22	3.15	20.4	0.67	0.69	0.57
Commercial & Institutional	234	324	317	350	368	437	370	331	174
Residential	150	180	180	220	190	110	190	170	92
Agriculture & Forestry	2.30	8.75	11.8	2.02	1.03	0.01	–	0.01	0.01
<b>b. Transportation<sup>1</sup></b>	<b>540</b>	<b>440</b>	<b>410</b>	<b>570</b>	<b>640</b>	<b>610</b>	<b>860</b>	<b>730</b>	<b>800</b>
Civil Aviation (Domestic Aviation)	160	170	180	200	220	180	250	210	170
Road Transportation	120	105	103	115	136	147	159	155	208
Light-Duty Gasoline Vehicles	31.9	30.7	30.6	38.4	40.5	36.1	37.0	38.2	31.0
Light-Duty Gasoline Trucks	13.7	14.0	14.8	20.3	23.5	22.5	24.6	28.2	23.2
Heavy-Duty Gasoline Vehicles	5.67	4.74	4.33	5.19	3.88	3.68	3.66	3.43	2.83
Motorcycles	0.19	0.18	0.18	0.23	0.24	0.22	0.23	0.24	0.17
Light-Duty Diesel Vehicles	0.23	0.22	0.22	0.28	0.29	0.26	0.27	0.28	0.23
Light-Duty Diesel Trucks	0.23	0.24	0.28	0.39	0.49	0.49	0.88	1.57	1.33
Heavy-Duty Diesel Vehicles	66.8	53.2	49.7	48.4	61.3	79.7	90.5	81.3	148
Propane & Natural Gas Vehicles	1.5	1.5	2.9	2.3	5.9	4.0	2.2	1.9	1.8
Railways	3	2	2	2	1	2	1	3	2
Navigation (Domestic Marine)	0.15	0.23	0.59	0.51	0.11	70	89	13	31
Other Transportation	300	200	100	300	300	200	400	400	400
Off-Road Gasoline	50	40	40	60	60	50	60	60	30
Off-Road Diesel	200	100	80	200	200	200	300	300	400
Pipelines	–	–	–	–	2.28	0.14	0.09	0.04	5.11
<b>c. Fugitive Sources<sup>2</sup></b>	<b>63.0</b>	<b>67.5</b>	<b>57.7</b>	<b>61.3</b>	<b>41.4</b>	<b>41.3</b>	<b>38.6</b>	<b>6.20</b>	<b>4.92</b>
Coal Mining <sup>5</sup>	–	–	–	–	–	–	–	–	–
Oil and Natural Gas	63.0	67.5	57.7	61.3	41.4	41.3	38.6	6.20	4.92
<b>INDUSTRIAL PROCESSES<sup>3</sup></b>	<b>3.04</b>	<b>11.4</b>	<b>2.23</b>	<b>24.3</b>	<b>104</b>	<b>84.5</b>	<b>64.6</b>	<b>3.00</b>	<b>1.35</b>
<b>a. Mineral Products</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>
Cement Production	–	–	–	–	–	–	–	–	–
Lime Production	–	–	–	–	–	–	–	–	–
<b>b. Chemical Industry</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>
Nitric Acid Production	–	–	–	–	–	–	–	–	–
Adipic Acid Production	–	–	–	–	–	–	–	–	–
<b>c. Metal Production</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>
Iron and Steel Production	–	–	–	–	–	–	–	–	–
Aluminum Production	–	–	–	–	–	–	–	–	–
SF <sub>6</sub> Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	–	–
<b>d. Consumption of Halocarbons and SF<sub>6</sub></b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>
<b>e. Other &amp; Undifferentiated Production<sup>4</sup></b>	<b>3.0</b>	<b>11</b>	<b>2.2</b>	<b>24</b>	<b>100</b>	<b>85</b>	<b>65</b>	<b>3.0</b>	<b>1.4</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>	<b>0.37</b>	<b>0.36</b>	<b>0.30</b>	<b>0.34</b>	<b>0.38</b>	<b>0.47</b>	<b>0.48</b>	<b>0.51</b>	<b>0.46</b>
<b>AGRICULTURE</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>
<b>a. Enteric Fermentation</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>
<b>b. Manure Management</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>
<b>c. Agricultural Soils</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>
Direct Sources	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pasture, Range and Paddock Manure	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Indirect Sources	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<b>WASTE</b>	<b>20</b>	<b>22</b>	<b>23</b>	<b>24</b>	<b>24</b>	<b>25</b>	<b>26</b>	<b>27</b>	<b>28</b>
<b>a. Solid Waste Disposal on Land</b>	<b>15</b>	<b>16</b>	<b>16</b>	<b>17</b>	<b>18</b>	<b>18</b>	<b>19</b>	<b>20</b>	<b>21</b>
<b>b. Wastewater Handling</b>	<b>5.3</b>	<b>6.1</b>	<b>6.5</b>	<b>6.6</b>	<b>6.7</b>	<b>7.0</b>	<b>6.9</b>	<b>7.0</b>	<b>6.9</b>
<b>c. Waste Incineration</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>

## Notes:

1. Emissions from Fuel Ethanol are reported within the gasoline transportation subcategories.
  2. Fugitive emissions from refineries and the bitumen industry are only reported at the national level.
  3. Emissions associated with the use of mineral products and consumption of halocarbons & SF<sub>6</sub> are only reported at the national level.
  4. Emissions coming from ammonia production are included in the category Other & Undifferentiated Production at provincial levels.
  5. Fugitive emissions from coal mining activities for 2002 and 2003 have been extrapolated based on publicly available coal production data.
- X Indicates confidential data.  
 – Indicates no emissions.  
 0.0 Indicates emissions truncated due to rounding.



## Annex 12 Emission Factors

This annex summarizes the development and selection of emission factors used to prepare the national GHG inventory.

### ***A12.1 Fuel Combustion***

#### **A12.1.1 Natural Gas and Natural Gas Liquids**

##### ***A12.1.1.1 CO<sub>2</sub>***

CO<sub>2</sub> emission factors for fossil fuel combustion are dependent primarily on the properties of the fuel and, to a lesser extent, on the combustion technology.

For natural gas, there are two major qualities of fuel combusted in Canada: marketable fuel (processed for commercial sale) and non-marketable fuel (unprocessed for internal use). Emission factors have been developed for these two categories (Table A12-1) based on data from the chemical analysis of representative natural gas samples (McCann 2000) and an assumed fuel combustion efficiency of 99.5% (IPCC/OECD/IEA 1997). The emission factor for marketable fuel matches closely with previous factors based on energy contents reported in Statistics Canada's RESD (Jaques 1992). The factor for non-marketable natural gas is higher than that for marketable fuels as a result of its raw nature, which includes ethane, propane, and butane in addition to methane in the fuel mix.

Natural gas liquids (NGL) (ethane, propane, butane) emission factors were developed based on chemical analysis data for marketable fuels (McCann 2000) and an assumed fuel combustion efficiency of 99.5% (IPCC/OECD/IEA 1997). The emission factors are lower than those developed on the assumption of pure fuels (Jaques 1992) owing to the presence of impurities in the fuels.

##### ***A12.1.1.2 CH<sub>4</sub>***

Emissions of CH<sub>4</sub> from fuel combustion are technology-dependent. Sectoral emission factors (Table A12-1) have been developed based on technologies typically used in Canada. The factors were developed based on a review of emission factors for combustion technologies (SGA Energy 2000). The emission factor for producer consumption of natural gas was developed based on a technology split for the UOG industry (CAPP 1999) and technology-specific emission factors from the U.S. EPA report AP 42 (EPA 1996).

##### ***A12.1.1.3 N<sub>2</sub>O***

Emissions of N<sub>2</sub>O from fuel combustion are technology-dependent. Emission factors (Table A12-1) have been developed based on technologies typically used in Canada. The factors were developed from a review of emission factors for and an analysis of combustion technologies (SGA Energy 2000).

**Table A12-1: Emission Factors for Natural Gas and NGLs**

Source	Emission Factors		
	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O
	g/m <sup>3</sup>	g/m <sup>3</sup>	g/m <sup>3</sup>
<b>Natural Gas</b>			
Electric Utilities	1891 <sup>1</sup>	0.49 <sup>2</sup>	0.049 <sup>2</sup>
Industrial	1891 <sup>1</sup>	0.037 <sup>2</sup>	0.033 <sup>2</sup>
Producer Consumption	2389 <sup>1</sup>	6.5 <sup>3,4</sup>	0.06 <sup>2</sup>
Pipelines	1891 <sup>1</sup>	1.9 <sup>2</sup>	0.05 <sup>2</sup>
Cement	1891 <sup>1</sup>	0.037 <sup>2</sup>	0.034 <sup>2</sup>
Manufacturing Industries	1891 <sup>1</sup>	0.037 <sup>2</sup>	0.033 <sup>2</sup>
Residential, Construction, Commercial/Institutional, Agriculture	1891 <sup>1</sup>	0.037 <sup>2</sup>	0.035 <sup>2</sup>
	g/L	g/L	g/L
<b>Propane</b>			
Residential	1510 <sup>1</sup>	0.027 <sup>2</sup>	0.108 <sup>2</sup>
All Other Uses	1510 <sup>1</sup>	0.024 <sup>2</sup>	0.108 <sup>2</sup>
<b>Ethane</b>	976 <sup>1</sup>	N/A	N/A
<b>Butane</b>	1730 <sup>1</sup>	0.024 <sup>2</sup>	0.108 <sup>2</sup>

Notes:

1. Adapted from McCann (2000).

2. SGA Energy (2000).

3. EPA (1996).

4. CAPP (1999).

N/A = Not available.

## A12.1.2 Refined Petroleum Products

### A12.1.2.1 CO<sub>2</sub>

CO<sub>2</sub> emission factors for fossil fuel combustion are dependent primarily on the properties of the fuel and, to a lesser extent, on the combustion technology.

Emission factors have been developed for each major class of RPP based on standard fuel properties (McCann 2000) and an assumed fuel combustion efficiency of 99% (IPCC/OECD/IEA 1997). CO<sub>2</sub> emissions associated with the combustion of liquid fuels were recalculated for the complete time series from 1990 to 2005 to ensure that the estimates are neither overestimated nor underestimated according to the *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000). CO<sub>2</sub> emission factors for liquid fuels were revised based on Canadian specific fuel density and carbon content information as provided in the McCann 2000 report. Previously, CO<sub>2</sub> emission factors were based on carbon content provided in the 1992 Jaques report. Also, to ensure consistency with the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, an oxidation rate of 99% was applied (IPCC/OECD/IEA 1997) to all liquid fuel emission factors as opposed to the previous assumption of 98.5% used by Jaques.

The composition of petroleum coke is process specific. Factors have been developed for both catalytic cracker-derived cokes and coke used in upgrading facilities. These factors (Table A12-3) have been developed based on data provided by industry to CIEEDAC in their *Review of Energy Consumption* reports on the refining and upgrading industry (CIEEDAC 2003, 2006). The bulk of the coke consumed by refineries is catalytic cracker-derived, and the emission factor is an average of petroleum coke and catalytic cracker coke emission factors. Factors were provided by industry on a mass basis and were converted to a volumetric basis for comparability with the national energy data using the density of coke provided by Statistics Canada.

Factors for still gas (Table A12-3) from refining operations and upgrading facilities were also developed based on data provided by industry (CIEEDAC 2003, 2006).

### A12.1.2.2 CH<sub>4</sub>

Emissions of CH<sub>4</sub> from fuel combustion are technology-dependent. Emission factors have been developed (Table A12-2) based on technologies typically used in Canada. The factors were developed from a review of emission factors for and an analysis of combustion technologies (SGA Energy 2000).

The emission factor for petroleum coke was assumed to be the same for both types. An emission factor for still gas is not available, according to the 2000 SGA Energy study.

### A12.1.2.3 N<sub>2</sub>O

Emissions of N<sub>2</sub>O from fuel combustion are technology-dependent. Emission factors for RPPs, with the exception of petroleum coke, have been developed (Table A12-2) based on technologies typically used in Canada. The factors were developed from a review of emission factors for and an analysis of combustion technologies (SGA Energy 2000). Emission factors for petroleum coke (Table A12-3) were based on 2006 IPCC default emission factors and were calculated on an annual basis using energy conversion factors provided by CIEEDAC (2003).

**Table A12-2: Emission Factors for Refined Petroleum Products**

Source	Emission Factors (g/L)		
	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O
<b>Light Fuel Oil</b>			
Electric Utilities	2725 <sup>1</sup>	0.18 <sup>2</sup>	0.031 <sup>2</sup>
Industrial	2725 <sup>1</sup>	0.006 <sup>2</sup>	0.031 <sup>2</sup>
Producer Consumption	2643 <sup>1</sup>	0.006 <sup>2</sup>	0.031 <sup>2</sup>
Residential	2725 <sup>1</sup>	0.026 <sup>2</sup>	0.006 <sup>2</sup>
Forestry, Construction, Public Administration, and Commercial/Institutional	2725 <sup>1</sup>	0.026 <sup>2</sup>	0.031 <sup>2</sup>
<b>Heavy Fuel Oil</b>			
Electric Utilities	3124 <sup>1</sup>	0.034 <sup>2</sup>	0.064 <sup>2</sup>
Industrial	3124 <sup>1</sup>	0.12 <sup>2</sup>	0.064 <sup>2</sup>
Producer Consumption	3158 <sup>1</sup>	0.12 <sup>2</sup>	0.064 <sup>2</sup>
Residential, Forestry, Construction, Public Administration, and Commercial/Institutional	3124 <sup>1</sup>	0.057 <sup>2</sup>	0.064 <sup>2</sup>
<b>Kerosene</b>			
Electric Utilities	2534 <sup>1,3</sup>	0.006 <sup>2</sup>	0.031 <sup>2</sup>
Industrial	2534 <sup>1,3</sup>	0.006 <sup>2</sup>	0.031 <sup>2</sup>
Producer Consumption	2534 <sup>1,3</sup>	0.006 <sup>2</sup>	0.031 <sup>2</sup>
Residential	2534 <sup>1,3</sup>	0.026 <sup>2</sup>	0.006 <sup>2</sup>
Forestry, Construction, Public Administration, and Commercial/Institutional	2534 <sup>1,3</sup>	0.026 <sup>2</sup>	0.031 <sup>2</sup>
<b>Diesel</b>	2663 <sup>1</sup>	0.133 <sup>2</sup>	0.4 <sup>2</sup>
<b>Petroleum Coke</b>	(see Table A12-3)	0.12 <sup>2</sup> (see Table A12-4)	
<b>Still Gas</b>	(see Table A12-3)	N/A	0.000 02 2

Notes:

1. Adapted from McCann (2000).

2. SGA Energy (2000).

3. Assumed McCann (2000) aviation turbo fuel emission factor.

N/A = Not available.

**Table A12-3: CO<sub>2</sub> Emission Factors for Petroleum Coke and Still Gas**

CO <sub>2</sub> Emission Factors										
	1990	1998	1999	2000	2001	2002	2003	2004	2005	2006
<b>Petroleum Coke</b>	<b>g/L</b>									
Upgrading Facilities <sup>1</sup>	3556	3528	3506	3481	3494	3494	3494	3494	3494 <sup>3</sup>	3494 <sup>4</sup>
Refineries & Others <sup>2</sup>	3766	3760	3777	3711	3763	3806	3828	3806	3826 <sup>3</sup>	3826 <sup>4</sup>
<b>Still Gas</b>	<b>g/m<sup>3</sup></b>									
Upgrading Facilities <sup>1</sup>	2310	2300	2110	2120	2140	2140	2140	2140 <sup>4</sup>	2140 <sup>4</sup>	2140 <sup>4</sup>
Refineries & Others <sup>2</sup>	1680	1680	1800	1720	1690	1690	1740	1750 <sup>4</sup>	1750 <sup>4</sup>	1750 <sup>4</sup>

Notes:

1. Source: CIEEDAC (2003).

2. Source: CIEEDAC (2006).

3. Source: Nyboer (2006).

4. Emission factors kept constant from previous year.

**Table A12-4: N<sub>2</sub>O Emission Factors for Petroleum Coke**

	N <sub>2</sub> O Emission Factors (g/L) <sup>1</sup>			
	1990–1995	1996	1997	1998–2006
Petroleum Coke				
Upgrading Facilities	0.0226	0.0231	0.0231	0.0231
Refineries & Others	0.0254	0.0254	0.0254	0.0265

Source:

1. IPCC (2006)

### A12.1.3 Coal and Coal Products

#### A12.1.3.1 CO<sub>2</sub>

CO<sub>2</sub> emission factors for coal combustion are dependent primarily on the properties of the fuel and, to a lesser extent, on the combustion technology.

Coal emission factors (Table A12-5) have been developed for each province based on the rank of the coal and the region of supply. Emission factors have been developed based on data from chemical analysis of coal samples for electric utilities, which comprise the vast majority of coal consumption, and a fuel combustion efficiency of 99.0% (Jaques 1992). The factors for coal were reviewed in 1999 because the supply and quality of coal used may change over time. Based on this review, it was determined that updated factors should be used for the more recent years. The factors for the year 1990 are based on supply and quality data from 1988 (Jaques 1992). For 1998 to the present, factors are based on 1998 coal quality and supply (McCann 2000). The factors for 1991–1997 are based on both studies. In order to address the change in emission factors introduced by the 2000 study, a linear interpolation method was used to derive coal-specific emission factors for 1991–1997 using the 1990 (Jaques 1992) and 1998 (McCann 2000) emission factors as the end points. In cases where consumption was only identified in later years, the 1998 value was selected as the appropriate factor.

Coke and coke oven gas emission factors were developed based on industry data (Jaques 1992). The emission factors for coke represent coke use in the cement, non-ferrous metal, and other manufacturing industries.

Table A12-5: CO<sub>2</sub> Emission Factors for Coal and Coal Products

Province	Coals	CO <sub>2</sub> Emission Factors (g/kg)								
		1990	1991	1992	1993	1994	1995	1996	1997	1998–2006
Newfoundland and Labrador	Canadian Bituminous	2 300 <sup>1, 2</sup>	2 290	2 280	2 280	2 270	2 270	2 260	2 250	2 250 <sup>3</sup>
	Anthracite	NO	NO	NO	NO	NO	NO	NO	NO	2 390 <sup>2</sup>
Prince Edward Island	Canadian Bituminous	2 300 <sup>1, 2</sup>	2 290	2 280	2 280	2 270	2 270	2 260	2 250	2 250
Nova Scotia	Canadian Bituminous	2 300 <sup>1, 2</sup>	2 290	2 280	2 280	2 270	2 270	2 260	2 250	2 250 <sup>3</sup>
	U.S. Bituminous	2 500 <sup>2, 5</sup>	2 470	2 450	2 420	2 390	2 370	2 340	2 310	2 290 <sup>3</sup>
	Sub-bituminous <sup>4</sup>	NO	NO	NO	NO	NO	NO	NO	NO	1 730 <sup>3, 5</sup>
New Brunswick	Canadian Bituminous	2 330 <sup>2</sup>	2 290	2 250	2 210	2 160	2 120	2 080	2 040	2 000 <sup>3</sup>
	U.S. Bituminous	2 500 <sup>2, 5</sup>	2 480	2 450	2 430	2 410	2 380	2 360	2 330	2 310 <sup>3</sup>
Quebec	Canadian Bituminous	2 300 <sup>1, 2</sup>	2 290	2 280	2 280	2 270	2 270	2 260	2 250	2 250 <sup>3</sup>
	U.S. Bituminous	2 500 <sup>2, 5</sup>	2 480	2 460	2 440	2 420	2 400	2 380	2 360	2 340 <sup>3</sup>
	Anthracite	2 390 <sup>2</sup>	2 390	2 390	2 390	2 390	2 390	2 390	2 390	2 390
Ontario	Canadian Bituminous	2 520 <sup>2</sup>	2 490	2 460	2 420	2 390	2 350	2 320	2 290	2 250 <sup>3</sup>
	U.S. Bituminous	2 500 <sup>2, 5</sup>	2 490	2 480	2 480	2 470	2 460	2 450	2 440	2 430 <sup>3</sup>
	Sub-bituminous <sup>4</sup>	NO	NO	NO	NO	NO	NO	1 730	1 730	1 730 <sup>3, 5</sup>
	Lignite	1 490 <sup>2</sup>	1 490	1 490	1 490	1 480	1 480	1 480	1 480	1 480 <sup>3</sup>
	Anthracite	NO	NO	NO	NO	NO	NO	NO	NO	2 390 <sup>2</sup>
Manitoba	Canadian Bituminous	2 520 <sup>2</sup>	2 490	2 460	2 420	2 390	2 350	2 320	2 290	2 250 <sup>3</sup>
	U.S. Bituminous	NO	NO	NO	2 480 <sup>2, 5</sup>	2 470	2 460	NO	NO	2 430 <sup>3</sup>
	Sub-bituminous <sup>4</sup>	NO	NO	NO	NO	NO	NO	1 730	1 730	1 730 <sup>3, 5</sup>
	Lignite	1 520	1 510	1 500	1 490	1 470	1 460	1 450	1 440	1 420
	Anthracite	2 390 <sup>2</sup>	2 390	2 390	2 390	2 390	2 390	2 390	2 390	2 390
Saskatchewan	Canadian Bituminous	1 700	1 720	1 740	1 760	1 780	1 800	1 810	1 830	1 850 <sup>3</sup>
	Sub-bituminous <sup>4</sup>	NO	NO	NO	NO	1 750 <sup>2, 6</sup>	1 750	NO	NO	NO
	Lignite	1 340 <sup>2</sup>	1 350	1 360	1 370	1 380	1 400	1 410	1 420	1 430 <sup>3</sup>
Alberta	Canadian Bituminous	1 700 <sup>2, 6</sup>	1 720	1 740	1 760	1 780	1 800	1 810	1 830	1 850 <sup>3</sup>
	Sub-bituminous <sup>4</sup>	1 740 <sup>2, 6</sup>	1 740	1 740	1 750	1 750	1 750	1 760	1 760	1 770 <sup>3</sup>
	Anthracite	2 390 <sup>2</sup>	2 390	2 390	2 390	2 390	2 390	2 390	2 390	2 390
British Columbia	Canadian Bituminous	1 700 <sup>2, 6</sup>	1 750	1 790	1 840	1 890	1 930	1 980	2 030	2 070 <sup>3</sup>
	U.S. Bituminous	NO	NO	NO	NO	NO	NO	NO	NO	2 430 <sup>3</sup>
	Sub-bituminous <sup>4</sup>	NO	NO	NO	NO	NO	NO	NO	NO	1 770 <sup>3</sup>

Notes:

CO<sub>2</sub> Emission Factors: Coke (2 480 g/kg)<sup>3</sup>; Coke Oven Gas (1 600 g/m<sup>3</sup>)<sup>3</sup>

1. Assumed source was from Nova Scotia.

2. Source: Jaques (1992).

3. Adapted from McCann (2000).

4. Represents both domestic and imported sub-bituminous.

5. Assumed source was from Ontario.

6. Assumed source was from Alberta.

NO = Not occurring

### A12.1.3.2 CH<sub>4</sub>

Emissions of CH<sub>4</sub> from fuel combustion are technology-dependent. Emission factors for sectors (Table A12-6) have been developed based on technologies typically used in Canada. The factors were developed from a review of emission factors for and an analysis of combustion technologies (SGA Energy 2000).

### A12.1.3.3 N<sub>2</sub>O

Emissions of N<sub>2</sub>O from fuel combustion are technology-dependent. Emission factors for sectors (Table A12-6) have been developed based on technologies typically used in Canada. The factors were developed from a review of emission factors for and an analysis of combustion technologies (SGA Energy 2000).

**Table A12-6: CH<sub>4</sub> and N<sub>2</sub>O Emission Factors for Coals <sup>1</sup>**

Source	Emission Factors	
	CH <sub>4</sub>	N <sub>2</sub> O
	g/kg	g/kg
<b>Coal</b>		
Electric Utilities	0.022	0.032
Industry and Heat & Steam Plants	0.03	0.02
Residential, Public Administration	4	0.02
<b>Coke</b>	0.03	0.02
	g/m <sup>3</sup>	g/m <sup>3</sup>
<b>Coke Oven Gas</b>	0.037	0.035

Note:

1. SGA Energy (2000).

## A12.1.4 Mobile Combustion

### A12.1.4.1 CO<sub>2</sub>

CO<sub>2</sub> emission factors for mobile combustion are dependent on fuel properties and are the same as those used for stationary combustion for all fuels (Table A12-7).

### A12.1.4.2 CH<sub>4</sub>

Emissions of CH<sub>4</sub> from fuel combustion are technology-dependent. Emission factors for sectors have been developed (Table A12-7) based on technologies typically used in Canada. The factors were developed from a review of emission factors for and an analysis of combustion technologies (SGA Energy 2000).

### A12.1.4.3 N<sub>2</sub>O

Emissions of N<sub>2</sub>O from fuel combustion are technology-dependent. Emission factors for sectors have been developed (Table A12-7) based on technologies typically used in Canada. The factors were developed from a review of emission factors for and an analysis of combustion technologies (SGA Energy 2000).

**Table A12-7: Emission Factors for Energy Mobile Combustion Sources**

Mode	Emission Factors (g/L fuel)		
	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O
<b>Road Transport</b>			
Gasoline Vehicles			
Light-Duty Gasoline Vehicles (LDGVs)			
Tier 1	2289 <sup>3</sup>	0.12 <sup>2</sup>	0.16 <sup>4</sup>
Tier 0	2289 <sup>3</sup>	0.32 <sup>2</sup>	0.66 <sup>5</sup>
Oxidation Catalyst	2289 <sup>3</sup>	0.52 <sup>4</sup>	0.20 <sup>2</sup>
Non-Catalytic Controlled	2289 <sup>3</sup>	0.46 <sup>4</sup>	0.028 <sup>2</sup>
Light-Duty Gasoline Trucks (LDGTs)			
Tier 1	2289 <sup>3</sup>	0.13 <sup>4</sup>	0.25 <sup>4</sup>
Tier 0	2289 <sup>3</sup>	0.21 <sup>4</sup>	0.66 <sup>5</sup>
Oxidation Catalyst	2289 <sup>3</sup>	0.43 <sup>4</sup>	0.20 <sup>2</sup>
Non-Catalytic Controlled	2289 <sup>3</sup>	0.56 <sup>2</sup>	0.028 <sup>2</sup>
Heavy-Duty Gasoline Vehicles (HDGVs)			
Three-Way Catalyst	2289 <sup>3</sup>	0.068 <sup>4</sup>	0.20 <sup>4</sup>
Non-Catalytic Controlled	2289 <sup>3</sup>	0.29 <sup>2</sup>	0.047 <sup>2</sup>
Uncontrolled	2289 <sup>3</sup>	0.49 <sup>2</sup>	0.084 <sup>2</sup>
Motorcycles			
Non-Catalytic Controlled	2289 <sup>3</sup>	1.4 <sup>2</sup>	0.045 <sup>2</sup>
Uncontrolled	2289 <sup>3</sup>	2.3 <sup>2</sup>	0.048 <sup>2</sup>
Diesel Vehicles			
Light-Duty Diesel Vehicles (LDDVs)			
Advance Control	2663 <sup>3</sup>	0.051 <sup>2</sup>	0.22 <sup>2</sup>
Moderate Control	2663 <sup>3</sup>	0.068 <sup>2</sup>	0.21 <sup>2</sup>
Uncontrolled	2663 <sup>3</sup>	0.10 <sup>2</sup>	0.16 <sup>2</sup>
Light-Duty Diesel Trucks (LDDTs)			
Advance Control	2663 <sup>3</sup>	0.068 <sup>2</sup>	0.22 <sup>2</sup>
Moderate Control	2663 <sup>3</sup>	0.068 <sup>2</sup>	0.21 <sup>2</sup>
Uncontrolled	2663 <sup>3</sup>	0.085 <sup>2</sup>	0.16 <sup>2</sup>
Heavy-Duty Diesel Vehicles (HDDVs)			
Advance Control	2663 <sup>3</sup>	0.12 <sup>2</sup>	0.082 <sup>2</sup>
Moderate Control	2663 <sup>3</sup>	0.14 <sup>2</sup>	0.082 <sup>2</sup>
Uncontrolled	2663 <sup>3</sup>	0.15 <sup>2</sup>	0.075 <sup>2</sup>
Natural Gas Vehicles	1.89 <sup>3</sup>	9 × 10 <sup>-3</sup> <sup>2</sup>	6 × 10 <sup>-5</sup> <sup>2</sup>
Propane Vehicles	1510 <sup>3</sup>	0.64 <sup>2</sup>	0.028 <sup>2</sup>
<b>Off-Road</b>			
Off-road Gasoline	2289 <sup>3</sup>	2.7 <sup>2</sup>	0.050 <sup>2</sup>
Off-road Diesel	2663 <sup>3</sup>	0.15 <sup>2</sup>	1.1 <sup>2</sup>
<b>Railways</b>			
Diesel Train	2663 <sup>3</sup>	0.15 <sup>2</sup>	1.1 <sup>2</sup>
<b>Marine</b>			
Gasoline Boats	2289 <sup>3</sup>	1.3 <sup>2</sup>	0.066 <sup>2</sup>
Diesel Ships	2663 <sup>3</sup>	0.15 <sup>2</sup>	1.1 <sup>2</sup>

Mode	Emission Factors (g/L fuel)		
	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O
Light Fuel Oil Ships	2725 <sup>3</sup>	0.26 <sup>2</sup>	0.073 <sup>2</sup>
Heavy Fuel Oil Ships	3124 <sup>3</sup>	0.28 <sup>2</sup>	0.079 <sup>2</sup>
<b>Aviation</b>			
Aviation Gasoline	2342 <sup>1</sup>	2.2 <sup>1</sup>	0.23 <sup>1</sup>
Aviation Turbo Fuel	2534 <sup>3</sup>	0.080 <sup>1</sup>	0.23 <sup>1</sup>
<b>Renewable Fuels</b>			
Ethanol	1494 <sup>6</sup>	**	**

Notes:

1. Jaques (1992).

2. SGA Energy (2000).

3. McCann (2000).

4. ICF Consulting (2004).

5. Barton & Simpson (1994).

6. See Chapter 3.

\* Tier 1 or advanced control emission factors are used for Tier 2 vehicle populations.

\*\* Gasoline CH<sub>4</sub> and N<sub>2</sub>O emission factors (by mode and technology) are used for ethanol.

## ***A12.2 Fugitive Emission Factors: Coal Mining***

Fugitive emissions from coal mining are predominantly CH<sub>4</sub>. These emissions result from the release of entrained CH<sub>4</sub> from coal formation during mining. The emission factors have been developed (Table A12-8) based on mine-specific and basin-specific data (King 1994). The development of the factors is described in the fugitive emissions section (Section 3.3) of the inventory report.

**Table A12-8: Emission Factors for Fugitive Sources—Coal Mining**

Province	Method	Coal Type	Emission Factors (t CH <sub>4</sub> /kt coal)
Nova Scotia	Underground	Bituminous	13.79
Nova Scotia	Surface	Bituminous	0.13
New Brunswick	Surface	Bituminous	0.13
Saskatchewan	Surface	Lignite	0.06
Alberta	Surface	Bituminous	0.45
Alberta	Underground	Bituminous	1.76
Alberta	Surface	Sub-bituminous	0.19
British Columbia	Surface	Bituminous	0.58
British Columbia	Underground	Bituminous	4.1

Source: Adapted from King (1994).

## ***A12.3 Industrial Processes***

### **A12.3.1 Mineral, Chemical, and Metal Industries**

Emissions from industrial processes are process- and technology-specific. The development of the factors for each source (Table A12-9) is described in the Industrial Processes chapter of the inventory report (Chapter 4).



Table A12-9: Emission Factors for Industrial Process Sources

Source	Description	Emission Factors			
		CO <sub>2</sub>	N <sub>2</sub> O	CF <sub>4</sub>	C <sub>2</sub> F <sub>6</sub>
<b>Mineral Use</b>		<b>g/kg feed</b>			
Limestone Use	In iron and steel, glass, non-ferrous metal production, pulp and paper mills, and other chemical uses	418	—	—	—
Dolomite Use	In iron and steel	468			
Soda Ash Use	In glass manufacturing	415	—	—	—
Magnesite Use	Calcination of magnesite in magnesium production	506			
<b>Mineral Products</b>		<b>g/kg product</b>			
Cement Production	Limestone calcination	507.1	—	—	—
Lime Production	Limestone calcination (high-calcium lime)	750			
	Limestone calcination (dolomitic lime)	860	—	—	—
<b>Chemical Industry</b>		<b>kg/t product</b>			
Ammonia Production	From natural gas reforming, which produces the hydrogen needed	1560	—	—	—
Nitric Acid Production					
	Dual-pressure plants with extended absorption “Type 1”	—	9.4	—	—
	Dual-pressure plants with extended absorption “Type 2”	—	12	—	—
	High-pressure plants with NSCR	—	0.66	—	—
	High-pressure plants with SCR	—	8.5	—	—
		<b>kg/kg product</b>			
Adipic Acid Production	Plants without abatement	—	0.3	—	—
<b>Metal Production</b>		<b>kg/t product</b>			
Primary Aluminium	Electrolysis process—cell technology				
	Side-worked pre-baked	1600	—	1.6	0.4
	Centre-worked pre-baked	1600	—	0.4	0.04
	Horizontal stud Söderberg	1700	—	0.04	0.03
	Vertical stud Söderberg	1700	—	0.8	0.04
		<b>t/t coke used</b>			
Iron and Steel Production	Iron ore reduction with coke	2.479	—	—	—
		<b>kg/t steel</b>			
	Steel production in EAFs	5			

Sources:

**CO<sub>2</sub> Emission Factors:**

Limestone Use—ORTECH Corporation (1994).  
Dolomite Use—AMEC Earth & Environmental (2006).  
Soda Ash Use—AMEC Earth & Environmental (2006).  
Magnesite Use—AMEC Earth & Environmental (2006).  
Lime Production—IPCC (2000).  
Cement Production—IPCC/OECD/IEA (1997).  
Ammonia Production—Jaques (1992).  
Primary Aluminum Production—AAC (2002).  
Iron and Steel—Jaques (1992); IPCC (2000).

**N<sub>2</sub>O Emission Factors:**

Nitric Acid—Collis (1992); IPCC (2000).  
Adipic Acid Production—IPCC (2000).

**CF<sub>4</sub> and C<sub>2</sub>F<sub>6</sub> Emission Factors:**

Primary Aluminum Production—IAI (2006).

### A12.3.2 Consumption of Halocarbons

The use of halocarbons in various applications, such as air conditioning (AC), refrigeration, aerosols, foam blowing, solvents, fire extinguishing, and semiconductor manufacturing (for PFCs only), can result in HFC/PFC emissions.

As mentioned in Chapter 4 of this report, detailed 1995 HFC activity data were not available. Therefore, a modified Tier 1, instead of Tier 2, methodology was used to estimate 1995 HFC emissions for the following use types: aerosols, foam blowing, AC Original Equipment Manufacturing OEM, AC servicing, refrigeration, and total flooding systems. Shown in Table A12-10 are the emission factors used in the modified Tier 1 estimation method and the assumptions made to derive and to use these factors.

**Table A12-10: Emission Factors for Consumption of HFCs in 1995**

Application	HFC Emission Factors (kg loss/kg consumed)	Assumptions
Aerosols	0.8	For aerosol products, IPCC (2000) suggests a default emission factor of 50% of the initial charge per year. It was assumed that 1994 production was 50% of that of 1995, meaning that emissions from 1994 production that occurred in 1995 would be equivalent to 25% of production in 1995. Therefore, the emission factor applied to the 1995 production was 75% or 80% (rounded).
Foams	1	For foam blowing, it was assumed that all HFCs used for foam blowing in 1995 were for the open cell type. According to the <i>Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories</i> (IPCC/OECD/IEA 1997), emissions equal 100% of the quantity sold for blowing open cell foam.
AC OEM	0.04	For AC OEM, a typical range of 2–5% loss rate is mentioned in the <i>Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories</i> (IPCC/OECD/IEA 1997). Therefore, a loss rate of 4% was assumed here.
AC Service	1	For AC Service, it was assumed that most service HFCs were used to replace operating losses. In other words, it was assumed that service HFCs replace an identical amount of HFCs that was previously vented. Hence, the loss rate was 100%.
Refrigeration	0.1	As shown in Equation 4-14 of Chapter 4, the emission factor for refrigeration is (0.17/1.17), which equals roughly 0.1.
Total Flooding Systems	0.35	For total flooding systems, the default loss rate, as shown in the <i>Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories</i> (IPCC/OECD/IEA 1997), is 35%.

Table A12-11 summarizes emission rates used to estimate 1996–2006 HFC emissions and 1995–2006 PFC emissions.

**Table A12-11: Emission Rates for Consumption of HFCs and PFCs <sup>1</sup>**

<b>HFC Applications</b>	<b>HFC Emission Rates (%)</b>	<b>PFC Applications</b>	<b>PFC Emission Rates (%)</b>
Residential Refrigeration Equipment—assembly	2% (of charge)	Refrigeration Equipment—assembly	3.5% (of charge) <sup>2</sup>
Commercial Refrigeration Equipment—assembly	3.5% (of charge) <sub>2</sub>	Stationary AC Equipment—assembly	3.5% (of charge) <sup>2</sup>
Stationary AC Equipment—assembly	3.5% (of charge) <sub>2</sub>	Mobile AC Equipment—assembly	4.5% (of charge) <sup>3</sup>
Mobile AC Equipment—assembly	4.5% (of charge) <sub>3</sub>	Refrigeration Equipment—operation	17% (of stock in existing systems)
Residential Refrigeration Equipment—operation	1% (of stock in existing systems)	Stationary AC Equipment—operation	17% (of stock in existing systems)
Commercial Refrigeration Equipment—operation	17% (of stock in existing systems)	Mobile AC Equipment—operation	30% (of stock in existing systems)
Stationary AC Equipment—operation	17% (of stock in existing systems)	Foam Blowing—open cell	100% (of use)
Mobile AC Equipment—operation	15% (of stock in existing systems) <sup>4</sup>	Foam Blowing—closed cell	10% of charge released during manufacturing and 4.5% of the original quantity charge released per year over the product's lifetime
Foam Blowing—open cell	100% (of use)	Solvents	50% (of use) in the first year and the other 50% (of use) in the second year
Foam Blowing—closed cell	10% of charge released during manufacturing and 4.5% of the original quantity charge released per year over the product's lifetime	Semiconductor Manufacturing	See Table 4-7 in Chapter 4
Fire Extinguishing—portable	60% (of HFC use in new systems)	Other Products—contained	1% of the quantity sold is emitted during manufacturing and 2% of stock is emitted per year during the product's lifetime
Fire Extinguishing—total flooding systems	35% (of HFC use in new systems)	Other Products—emissive	50% (of use) in the first year and the other 50% (of use) in the second year
Aerosol Products	50% (of use) in the first year and the other 50% (of use) in the second year		
Solvents	50% (of use) in the first year and the other 50% (of use) in the second year		

Notes:

1. Source: IPCC/OECD/IEA (1997).

2. The *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* provide two ranges of values: 2–3% and 4–5%. The midpoint of the two ranges was used.3. The *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* provide a range of 4–5% as values. The average value was used.4. The *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* provide a range of 10–20% as values. The average value was used.

### A12.3.3 Other and Undifferentiated Production

The use of fossil fuels as feedstock or for other non-energy uses may result in emissions during the life of manufactured products. To estimate CO<sub>2</sub> emissions from non-energy use of natural gas, an emission factor of 1522 g CO<sub>2</sub>/m<sup>3</sup> was used (Cheminfo Services 2005). Table A12-12 and Table A12-13 show the emission factors used to develop CO<sub>2</sub> emission estimates for non-energy applications of natural gas liquids and non-energy petroleum products, respectively. Please refer to Table A12-3 for emission factors for petroleum coke and still gas, and to Table A12-5 for emission factors for coal and coal products.

**Table A12-12: CO<sub>2</sub> Emission Factors for Natural Gas Liquids**

	Fraction of carbon stored in products	Emission Factors (g CO <sub>2</sub> /L)	Sources
Propane	0.8	303	IPCC/OECD/IEA (1997); McCann (2000)
Butane	0.8	349	IPCC/OECD/IEA (1997); McCann (2000)
Ethane	0.8	197	IPCC/OECD/IEA (1997); McCann (2000)

**Table A12-13: CO<sub>2</sub> Emission Factors for Non-Energy Petroleum Products**

Non-Energy Products	Carbon Factor (g C/L) <sup>1</sup>	Molecular Weight Ratio between CO <sub>2</sub> and Carbon	Fraction of Carbon Stored <sup>2</sup>	Resulting CO <sub>2</sub> Emission Factor (g CO <sub>2</sub> /L)
	A	B	C	D = A × B × (1 - C)
Petrochemical Feedstocks	680	44/12	0.8	500
Naphthas	680	44/12	0.75	625
Lubricating Oils and Greases	770	44/12	0.5	1 410
Petroleum Used for Other Products	790	44/12	0.5	1 450

Sources:

1. Jaques (1992).
2. IPCC/OECD/IEA (1997).

### A12.4 Solvent and Other Product Use

N<sub>2</sub>O emissions can result from its use as anaesthetic and propellant. The development of the emission factors shown in Table A12-14 is described in the Solvent and Other Product Use chapter of the inventory report (Chapter 5).

**Table A12-14: Emission Factors for Solvent and Other Product Use**

Product	Application	N <sub>2</sub> O Emission Rates (%)
N <sub>2</sub> O Use	Anaesthetic Usage	97.5
	Propellant Usage	100

Source: Cheminfo Services (2006).

## A12.5 Agriculture

Emissions from agriculture result from enteric fermentation, manure management, and agricultural soils. Methodologies for generating these emission estimates are detailed in Section A3.3, along with country-specific CH<sub>4</sub> emission factors for enteric fermentation (cattle only) and manure management. Other emission factors and related information are provided below, in Table A12-5 to Table A12-18.

**Table A12-15: CH<sub>4</sub> Emission Factors for Enteric Fermentation for Non-Cattle Animals**

Non-Cattle Animal Categories	Enteric Fermentation Emission Factors EF(EF) <sup>1</sup> (kg CH <sub>4</sub> /head per year)
<b>Pigs</b>	
Boars	1.51
Sows	1.51
Pigs < 20 kg	1.51
Pigs 20–60 kg	1.51
Pigs > 60 kg	1.51
Other Livestock	
<b>Sheep</b>	81
Lambs	81
Goats	51
Horses	181
Buffalo	551
<b>Poultry</b>	
Chickens	N/A
Hens	N/A
Turkeys	N/A

Notes:

1. IPCC Tier 1 default emission factors (IPCC/OECD/IEA 1997).

N/A = Not available.

**Table A12-16: Values of Maximum CH<sub>4</sub> Producing Potential (B<sub>0</sub>) for Various Livestock Types<sup>1</sup>**

Animal Category	Maximum CH <sub>4</sub> Producing Potential (B <sub>0</sub> ) (m <sup>3</sup> /kg VS)
Dairy Cattle	0.24
Non-Dairy Cattle <sup>2</sup>	0.19
Sheep	0.19
Goat	0.18
Horse	0.30
Swine	0.48
Hen	0.39
Broiler	0.36
Turkey	0.36

Notes:

1. Data source: IPCC (2006), Volume 4: Agriculture, Forestry and Other Land Uses, Tables 10A-5 to 10A-9.

2. Non-dairy cattle value also used for buffalo.

**Table A12-17: CH<sub>4</sub> Conversion Factor (MCF) by animal category and manure management system<sup>1</sup>**

Animal Categories	Liquid	Solid Storage	Pasture and Paddock	Others <sup>3</sup>
Dairy Cattle	0.20	0.02	0.01	0.01
Non-Dairy Cattle <sup>2</sup>	0.20	0.02	0.01	0.01
Swine	0.20	0.02	NA	0.01
Poultry	0.015	0.015	0.015	NA
Horse	NA	0.01	0.01	NA
Goat	NA	0.01	0.01	NA
Sheep	NA	0.01	0.01	NA
Lamb	NA	0.01	0.01	NA

Notes:

1. Data source: IPCC (2006), Volume 4: Agriculture, Forestry and Other Land Uses, Tables 10A-5 to 10A-9 (cool climate, average annual temperature 12°C).

2. Non-dairy cattle values also used for buffalo.

3. NA = Not applicable.

**Table A12-18: Percentage of Manure N Lost as N<sub>2</sub>O-N for Specific Animal Waste Management Systems (IPCC/OECD/IEA (1997))**

Animal Category	% of Manure N Lost as N <sub>2</sub> O-N			
	Liquid Systems (EFL)	Solid Storage and Drylot (EFSSD)	Pasture, Range and Paddock (EFPRP)	Other Systems (EFO)
Non-Dairy Cattle	0.1	2.0	2.0	0.5
Dairy Cattle	0.1	2.0	2.0	0.5
Poultry	0.1	2.0	2.0	0.5
Sheep & Lamb	0.1	2.0	1.01	0.5
Swine	0.1	2.0	2.0	0.5
Goat	0.1	2.0	1.01	0.5
Horse	0.1	2.0	1.0 1	0.5
Buffalo	0.1	2.0	2.0	0.5

Notes:

Data source: IPCC (2006), Volume 4, Agriculture, Forestry and Other Land Uses, Table 11.1.

## **A12.6 Biomass Combustion**

### **A12.6.1 CO<sub>2</sub>**

Emissions of CO<sub>2</sub> from the combustion of biomass (whether for energy use, from prescribed burning, or from wildfires) are not included in national inventory totals. These emissions are estimated and recorded as a loss of biomass stock in the LULUCF Sector.

The emissions related to energy use are reported as memo items in the CRF tables as required by the UNFCCC. Emissions from this source are dependent primarily on the characteristics of the fuel being combusted. The methodology for deriving the emission factors (Table A12-19) is described in the biomass combustion section of the inventory report (see Section A3.4.2).

CO<sub>2</sub> emissions occur during forest wildfires and from controlled burning during forest conversion activities. The carbon emitted as CO<sub>2</sub> (CO<sub>2</sub>-C) during forest fires is considered in the forest carbon balance, whereas the CO<sub>2</sub>-C emitted during controlled burns is reported under the new land-use categories. There is no unique CO<sub>2</sub> emission factor applicable to all fires, as the

proportion of CO<sub>2</sub>-C emitted for each pool can be specific to the pool, the type of forest and disturbance, and the ecological zone (see Section A3.4.2 ).

### **A12.6.2 CH<sub>4</sub>**

Emissions of CH<sub>4</sub> from biomass fuel combustion are technology-dependent. The emission factors (Table A12-19) were derived from a review of emission factors for combustion technologies (SGA Energy 2000). The factors are from the U.S. EPA AP 42 Supplement B (EPA 1996), with the exception of landfill gas, which are from the IPCC (2006).

Emissions of carbon as CH<sub>4</sub> (CH<sub>4</sub>-C) from wildfires and controlled burning are always equal to 1/90th of CO<sub>2</sub>-C emissions.

### **A12.6.3 N<sub>2</sub>O**

Emissions of N<sub>2</sub>O from biomass fuel combustion are technology-dependent. The emission factors (Table A12-19) were developed from a review of emission factors for combustion technologies and an analysis of combustion technologies typically used in Canada (SGA Energy 2000). The factors are from the U.S. EPA AP 42 Supplement B (EPA 1996), with the exception of landfill gas, which are from the IPCC (2006).

N<sub>2</sub>O emissions from wildfires and controlled burning are equal to 0.017% vol/vol of CO<sub>2</sub> emissions. Since both gases have the same molecular weight, the same ratio can be applied on a mass basis (see Section A3.4.2).

**Table A12-19: Emission Factors for Biomass<sup>1</sup>**

Source	Description	Emission Factors (g/kg fuel)		
		CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O
Landfill Gas	Industrial Combustion	29 890 <sup>2</sup>	0.6	0.06
Wood Fuel/Wood Waste	Industrial Combustion	950	0.05	0.02
Forest Wildfires	Open Combustion	NA	NA <sup>3</sup>	NA <sup>4</sup>
Controlled Burning	Open Combustion	NA	NA <sup>3</sup>	NA <sup>4</sup>
Spent Pulping Liquor	Industrial Combustion	1428	0.05	0.02
Stoves and Fireplaces	Residential Combustion			
Conventional Stoves		1500	15	0.16
Conventional Fireplaces and Inserts		1500	15	0.16
Stoves/Fireplaces with Advanced Technology or Catalytic Control		1500	6.9	0.16
Other Wood-Burning Equipment		1500	15	0.16

Notes:

1<sup>1</sup> Landfill gas emission factor is converted from energy units (net calorific value) to physical units.

2. Emission ratio for CH<sub>4</sub> is 1/90th CO<sub>2</sub>. See Section A3.4 in Annex 3.

3<sup>3</sup> Emission ratio for N<sub>2</sub>O is 0.017% CO<sub>2</sub>. See Section A3.4 in Annex 3.

4. CO<sub>2</sub> emissions from biomass combusted for energy purposes are not included in inventory totals, whereas CH<sub>4</sub> and N<sub>2</sub>O emissions from these sources are inventoried under the Energy Sector. All GHG emissions including CO<sub>2</sub> from biomass burned in managed forests (wildfires and controlled burning) are reported under LULUCF and excluded from national inventory totals.

NA = not applicable.

Sources:

**CO<sub>2</sub> Emission Factors:**

Landfill Gas—IPCC (2006).

Wood Fuel/Wood Waste—EPA (1996).

Conventional Stoves and Fireplaces—ORTECH (1994).

**CH<sub>4</sub> Emission Factors:**

Landfill Gas—IPCC (2006).

Wood Fuel/Wood Waste—EPA (1996); EPA (1985); SGA Energy (2000).

Stoves and Fireplaces—SGA Energy (2000).

**N<sub>2</sub>O Emission Factors:**

Landfill Gas—IPCC (2006).

Wood Fuel/Wood Waste—EPA (1996); Rosland and Steen (1990); Radke et al. (1991); SGA Energy (2000).

Stoves and Fireplaces—SGA Energy (2000).

## References

[AAC] Aluminum Association of Canada. 2002. Calculating Direct GHG Emissions from Primary Aluminum Metal Production. Montréal(QC): Aluminum Association of Canada.

AMEC Earth & Environmental. 2006. Identifying and Updating Industrial Process Activity Data in the Minerals Sector for the Canadian Greenhouse Gas Inventory. AMEC Earth & Environmental. March.

Barton P, Simpson J. 1994. The Effects of Aged Catalysts and Cold Ambient Temperatures on Nitrous Oxide Emissions. Mobile Sources Emissions Division, Environment Canada. MSED Report no. 94-21.



[CAPP] Canadian Association of Petroleum Producers. 1999. CH<sub>4</sub> and VOC Emissions from the Canadian Upstream Oil and Gas Industry. Vols. 1 and 2. Prepared for the Canadian Association of Petroleum Producers. Calgary (AB): Clearstone Engineering. Publication no. 1999-0010.

Cheminfo Services. 2005. Improvements to Canada's Greenhouse Gas Emissions Inventory Related to Non-Energy Use of Hydrocarbon Products. Markham (ON): Cheminfo Services Inc.

Cheminfo Services. 2006. Improvements and Updates to Certain Industrial Process and Solvent Use-Related Sections in Canada's Greenhouse Gas Inventory. Final Report. Markham (ON): Cheminfo Services. September.

[CIEEDAC] Canadian Industrial Energy End-Use Data Analysis Centre. 2003. A Review of Energy Consumption in Canadian Oil Sands Operations, Heavy Oil Upgrading 1990, 1994 to 2001. Burnaby (BC): Simon Fraser University. March.

[CIEEDAC] Canadian Industrial Energy End-Use Data Analysis Centre. 2006. A Review of Energy Consumption in Canadian Oil Refineries 1990, 1994 to 2004. Burnaby (BC): Simon Fraser University. March.

Collis GA. 1992. Personal communication (March 1992). Canadian Fertilizer Institute.

[EPA] United States Environmental Protection Agency. 1985. Compilation of Air Pollutant Emission Factors. Vol. I, Stationary Point and Area Sources, AP 42, 4th Edition. Washington (DC): U.S. Environmental Protection Agency.

[EPA] United States Environmental Protection Agency. 1996. Compilation of Air Pollutant Emission Factors—Vol. I: Stationary Point and Area Sources, AP 42, 5th Edition, Supplement B. U.S. Washington (DC): Environmental Protection Agency. January.

[IAI] International Aluminum Institute. 2006. The Aluminum Sector Greenhouse Gas Protocol (Addendum to the WRI/WBCSD Greenhouse Gas Protocol). International Aluminum Institute. October.

ICF Consulting. 2004. Update of Methane and Nitrous Oxide Emission Factors for On-Highway Vehicles. Prepared by ICF Consulting for the U.S. Environmental Protection Agency. Report no. 420-P-04-16.

[IPCC] Intergovernmental Panel on Climate Change. 2000. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at: <http://www.ipcc-nggip.iges.or.jp/public/gp/english/>

[IPCC] Intergovernmental Panel on Climate Change. 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at: <http://www.ipcc-nggip.iges.or.jp/public/2006gl/>

[IPCC/OECD/IEA] Intergovernmental Panel on Climate Change, Organisation for Economic Co-operation and Development, and International Energy Agency. 1997. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Available online at: <http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm>

Jaques A. 1992. Canada's Greenhouse Gas Emissions: Estimates for 1990. Environmental Protection, Conservation and Protection, Environment Canada. December. EPS 5/AP/4.

King B. 1994. Management of Methane Emissions from Coal Mines: Environmental, Engineering, Economic and Institutional Implication of Options. Halifax (NS): Neil and Gunter Ltd. March.

McCann TJ. 2000. 1998 Fossil Fuel and Derivative Factors, prepared by T.J. McCann and Associates for Environment Canada. March.

Nyboer J. 2006. Personal communication. Simon Fraser University, Burnaby, British Columbia, Canada.

ORTECH Corporation. 1994. Inventory Methods Manual for Estimating Canadian Emissions of Greenhouse Gases. Unpublished report prepared for the Regulatory Affairs and Program Integration Branch, Conservation and Protection, Environment Canada. Report no. 93-T61-P7013-FG.

Radke LF, Hegg DA, Hobbs PV, Nance JD, Lyons JH, Laursen KK, Weiss RE, Riggan PJ, Ward DE. 1991. Particulate and trace gas emissions from large biomass fires in North America. In: Levine JS (Ed.) Global Biomass Burning: Atmospheric Climatic and Biospheric Implications. Cambridge (MA): Massachusetts Institute of Technology U.S.A.

Rosland A, Steen M. 1990. Klimgass-Regnshap for Norge, Statens Forurensningstilsyn. Oslo, Norway.

SGA Energy. 2000. Emission Factors and Uncertainties for CH<sub>4</sub> & N<sub>2</sub>O from Fuel Combustion. Unpublished report prepared by SGA Energy Limited for the Greenhouse Gas Division, Environment Canada. August.

## Annex 13 Rounding Protocol

A rounding protocol has been developed for the emission and removal estimates in order to provide context on their uncertainty levels. The accuracy of a value is reflected by presenting the emission and removal estimates rounded to an appropriate number of significant figures based on the uncertainty of the specific category. The number of significant figures to which each source and sink category has been rounded, using the rounding rules provided in this protocol, can be found in Table A13-1.

Most of the uncertainty ranges that are used for various categories were developed by Monte Carlo analysis, as performed by ICF Consulting (ICF Consulting 2004, 2005), using the 2001 inventory estimates (submitted in NIR 2003). Default uncertainty values published by the IPCC (IPCC/OECD/IEA 1997; IPCC 2001) and those resulting from expert elicitation were also utilized for some ranges. Uncertainty ranges have been calculated around the mean values, as determined by Monte Carlo analysis. In cases where uncertainty ranges are asymmetric about the mean, the range with a greater absolute distance from the mean has been employed to represent that uncertainty.

Some recently developed uncertainty values have been adopted for categories in the Energy, Industrial Processes, Solvent and Other Product Use, and Agriculture sectors. These new uncertainty estimates have been considered in developing Table A13-1. For a more complete description of the analysis of uncertainty in Canada's emission estimates, please refer to Annex 7.

The following uncertainty ranges have been used to establish the number of significant figures to which the estimates have been rounded:

- one significant figure: uncertainty equal to and greater than 50%;
- two significant figures: uncertainty between 10% and 50%; and
- three significant figures: uncertainty equal to and less than 10%.

The LULUCF Sector has not been formally assessed for uncertainty. New methodologies, which were not available during the 2004 ICF Consulting study, have been used to develop estimates for the 2008 UNFCCC submission. For this sector, the number of significant figures for each category was determined by expert opinion.

All calculations, including summing of emission totals, have been made using unrounded data. The rounding protocol has been applied only after the calculations have been completed. The reader should also note that formatting in Annex 8 and Annex 11 limits the maximum number of decimal places and, therefore, even though a zero entry is recorded, some emissions may exist in that category (zero emissions are identified with a dash “-”). Because of these procedures, individual values in the emission tables may not add up to the subtotals and/or overall totals.

**Table A13-1: Number of Significant Figures Applied to GHG Summary Tables**

GHG Source/Sink Categories	Number of Significant Figures						
	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O	HFCs	PFCs	SF <sub>6</sub>	TOTAL
<b>TOTAL</b>	3	2	2	2	2	2	3
<b>ENERGY</b>	3	2	1				3
a. <b>Stationary Combustion Sources</b>	3	1	1				3
Electricity and Heat Generation	3	2	1				3
Fossil Fuel Industries	3	1	1				2
Petroleum Refining and Upgrading	2	1	1				2
Fossil Fuel Production	3	1	1				2
Mining & Oil and Gas Extraction	3	1	1				3
Manufacturing Industries	3	1	1				3
Iron and Steel	3	1	1				3
Non-Ferrous Metals	3	1	1				3
Chemical	3	2	1				3
Pulp and Paper	3	1	1				3
Cement	3	1	1				3
Other Manufacturing	3	1	1				3
Construction	3	1	1				3
Commercial & Institutional	3	1	1				3
Residential	3	1	1				2
Agriculture & Forestry	3	1	1				3
b. <b>Transportation</b>	3	1	1				2
Domestic Aviation	3	1	1				2
Road Transportation	3	2	2				3
Light-Duty Gasoline Vehicles	3	2	2				3
Light-Duty Gasoline Trucks	3	2	2				3
Heavy-Duty Gasoline Vehicles	3	2	2				3
Motorcycles	3	2	2				3
Light-Duty Diesel Vehicles	3	1	1				3
Light-Duty Diesel trucks	3	1	1				3
Heavy-Duty Diesel Vehicles	3	1	1				3
Propane & Natural Gas Vehicles	3	1	1				2
Railways	3	1	1				1
Domestic Marine	3	1	1				2
Others	2	1	1				1
Off-Road Gasoline	1	1	1				1
Off-Road Diesel	2	1	1				1
Pipelines	3	2	1				3
c. <b>Fugitive Sources</b>	3	3	1				3
Coal Mining		1					1
Oil and Natural Gas	3	3	1				3
Oil	2	3	1				3
Natural Gas	3	3					3
Venting	3	3	3				3
Flaring	2	2	1				2
<b>INDUSTRIAL PROCESSES</b>	2		3	2	2	2	3
a. <b>Mineral Production</b>	2						2
Cement Production	2						2
Lime Production	2						2
Mineral Product Use	3						3
b. <b>Chemical Industry</b>	2		3				2
Ammonia Production	2						2
Nitric Acid Production			3				3
Adipic Acid Production			2				2
c. <b>Metal Production</b>	3				2	3	3
Iron and Steel Production	3						3
Aluminum Production	2				2	3	2
SF <sub>6</sub> Used in Magnesium Smelters and Casters						3	3
d. <b>Consumption of Halocarbons and SF<sub>6</sub></b>				2	1	2	2

GHG Source/Sink Categories	Number of Significant Figures						
	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O	HFCs	PFCs	SF <sub>6</sub>	TOTAL
e. Other & Undifferentiated Production	2						2
<b>SOLVENT AND OTHER PRODUCT USE</b>			2				2
AGRICULTURE		2	2				2
a. Enteric Fermentation		2					2
b. Manure Management		2	2				2
c. <b>Agricultural Soils</b>			2				2
Direct Sources			2				2
Pasture, Range, and Paddock Manure			2				2
Indirect Sources			1				1
WASTE	2	2	1				2
a. Solid Waste Disposal on Land		2					2
b. Wastewater Handling		2	1				2
c. Waste Incineration	2	1	1				2
<b>LAND USE, LAND-USE CHANGE AND FORESTRY</b>	2	2	2				2
a. Forest Land	2	2	2				2
b. Cropland	2	1	1				2
c. Grassland							
d. Wetlands	1	1	1				1
e. Settlements	1	1	1				1

## References

ICF Consulting. 2004. Quantitative Assessment of Uncertainty in Canada's National GHG Inventory Estimates for 2001. Unpublished report. Contract # K-2362-3-0060. Submitted to Environment Canada.

ICF Consulting 2005. Quantitative Assessment of Uncertainty in Canada's National GHG Inventory Estimates for 2001—Supplementary Analysis. Unpublished report. Contract # K2362-04-0121. Submitted to Environment Canada.

[IPCC] Intergovernmental Panel on Climate Change. 2001. Climate Change 2001: The Scientific Basis. Contribution of Working Group 1 to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge (UK): Cambridge University Press.

[IPCC/OECD/IEA] Intergovernmental Panel on Climate Change, Organisation for Economic Co-operation and Development, and International Energy Agency. 1997. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Available online at: <http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm>

## Annex 14 Ozone and Aerosol Precursors

National summary tables for SO<sub>x</sub>, NO<sub>x</sub>, CO, and NMVOCs are included in this annex (Table A14-1 to Table A14-4). These gases are reported to the United Nations Economic Commission for the Environment by the Criteria Air Contaminants Section of Environment Canada under the Convention on Long Range Transboundary Air Pollution. As recommended by the Conference of the Parties to the UNFCCC (FCCC/SBSTA/2004/8), Annex I Parties should provide information on indirect GHGs such as CO, NO<sub>x</sub>, NMVOCs, and SO<sub>x</sub> in the NIR.

These gases do not have a direct global warming effect, but either influence the creation and destruction of tropospheric and stratospheric ozone or affect the terrestrial radiation absorption, as in the case of SO<sub>x</sub>. These gases can impact the climate by acting as short-lived GHGs, alter atmospheric lifetimes of other GHGs, and form GHGs, as in the case of CO reacting with hydroxyl radical to form CO<sub>2</sub> in the atmosphere. These emissions are produced by a number of sources, such as fossil fuel combustion in the energy and transportation sectors, industrial production, and biomass combustion.

Table A14-1: Carbon Monoxide Emissions Summary for Canada

CRF Sector Categories	Carbon Monoxide																
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
	kt CO																
National Total	15 171	14 265	14 433	13 974	13 591	13 658	12 537	12 253	11 627	11 667	11 381	11 060	10 921	10 728	10 206	9 372	9 240
1 A 1 a Public Electricity and Heat Production	65	68	65	24	25	24	25	24	24	25	28	29	44	32	32	35	32
1 A 1 b Petroleum Refining	13	13	13	19	19	18	18	19	19	19	17	17	59	16	16	16	25
1 A 1 c Manufacture of Solid Fuels and Other Energy Industries																	
1 A 2 Manufacturing Industries and Construction	193	186	196	216	245	262	272	305	318	328	339	355	379	430	466	397	389
1 A 3 a ii (i) Civil Aviation (Domestic, LTO)	633	605	667	998	891	921	929	928	876	913	709	715	657	716	727	392	455
1 A 3 a ii (ii) Civil Aviation (Domestic, Cruise)	40	36	34	33	33	33	33	35	36	37	37	37	35	36	36	30	25
1 A 3 b Road Transportation	27	24	23	22	23	23	22	22	24	23	23	23	21	22	22	21	35
1 A 3 c Railways	9 561	9 260	9 262	8 836	8 508	7 882	7 357	7 061	6 438	6 415	6 410	6 009	5 732	5 391	4 731	4 389	4 206
1 A 3 d ii National Navigation	22	22	21	21	23	23	22	23	22	20	21	21	22	23	20	16	16
1 A 3 e Other	11	10	10	10	10	10	9	9	9	9	9	9	9	9	9	10	9
1 A 4 a Commercial / Institutional	2 086	2 130	2 174	2 218	2 262	2 307	2 309	2 301	2 322	2 343	2 370	2 413	2 461	2 510	2 556	2 608	2 685
1 A 4 b Residential	5	5	5	6	6	6	6	6	6	6	8	10	7	11	11	20	19
1 A 4 c Agriculture / Forestry / Fishing	1 041	650	645	619	637	632	623	626	626	623	676	655	729	679	690	704	717
1 A 5 a Other, Stationary (Including military)	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1 A 5 b Other, Mobile (Including military)	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1 B 1 Fugitive Emissions from Solid Fuels	4	4	4	1	1	1	1	1	1	1	2	2	2	2	2	2	2
1 B 2 Oil and Natural Gas	37	36	37	32	35	37	38	42	44	45	84	94	101	126	146	119	69
2 A Mineral Products <sup>1</sup>	4.96	5.02	4.74	36.58	23.1	25.14	27.23	24.01	30.08	26.97	13.45	14.17	19.8	14.02	14.28	18.70	19.66
2 B Chemical Industry	16	16	16	21	21	21	21	21	21	21	21	20	14	23	25	13	12
2 C Metal Production	360	320	313	339	311	326	312	330	328	316	254	275	403	333	340	471	409
2 D Other Production <sup>1</sup>	54	63	61	111	114	104	107	107	107	110	102	101	96	85	86	58	48
2 G Other	24	23	25	34	32	31	32	32	31	32	30	30	30	30	30	21	14
3 A Paint Application	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3 B Degreasing and Dry Cleaning	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3 C Chemical Products, Manufacture and Processing	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3 D Other (Including products containing HMs and POPs)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA
4 B Manure Management <sup>2</sup>	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
4 C Rice Cultivation	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
4 D 1 Direct Soil Emission	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
4 F Field Burning of Agricultural Wastes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA
4 G Other <sup>3</sup>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5 B Forest and Grassland Conversion	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA
6 A Solid Waste Disposal on Land	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6 B Wastewater Handling	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6 C Waste Incineration <sup>4</sup>	10	10	9	6	5	5	5	5	5	5	6	7	11	7	7	8	16
6 D Other Waste <sup>5</sup>	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
7 Other	965	779	849	372	367	967	368	329	339	347	221	225	88	234	239	24	37

Notes:

1. Including product handling.

2. Including NH<sub>3</sub> from enteric fermentation.

3. Including particulate matter sources.

4. Excludes waste incineration for energy (this is included in 1 A 1).

5. Includes accidental fires.

Totals may not add up due to rounding.

NA = Not applicable; IE = Included elsewhere; LTO = Landing and takeoff; HM = Heavy metals; POPs = Persistent organic pollutants.

**Table A14-2: Nitrogen Oxides Emissions Summary for Canada**

CRF Sector Categories	Nitrogen Oxides																
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
	kt NO <sub>x</sub>																
National Total	2 355	2 434	2 420	2 366	2 451	2 455	2 371	2 426	2 440	2 418	2 463	2 478	2 473	2 493	2 491	2 379	2 312
1 A 1 a Public Electricity and Heat Production	249	256	245	248	250	242	252	247	251	253	282	280	264	263	242	235	215
1 A 1 b Petroleum Refining	30	26	26	23	22	23	22	22	22	22	24	22	24	22	22	24	28
1 A 1 c Manufacture of Solid Fuels and Other Energy Industries	136	196	208	234	265	280	293	334	336	353	371	391	431	477	520	457	440
1 A 2 Manufacturing Industries and Construction	120	174	172	134	136	144	132	134	133	134	114	112	135	118	121	125	105
1 A 3 a ii (i) Civil Aviation (Domestic, LTO)	6	5	5	5	5	5	5	5	6	6	6	6	5	6	6	5	8
1 A 3 a ii (ii) Civil Aviation (Domestic, Cruise)	66	56	52	51	50	55	58	59	60	60	66	66	58	59	60	57	59
1 A 3 b Road Transportation	870.1	816.19	801.66	780.27	807.17	774.73	703.23	703.61	715.61	686.3	667.98	657.27	623.59	586.46	556.03	529.26	499.77
1 A 3 c Railways	114	115	112	111	118	118	114	122	114	107	109	118	120	111	112	117	111
1 A 3 d ii National Navigation	135	129	130	123	127	125	117	118	118	113	111	111	112	114	115	117	113
1 A 3 e Other	387	395	404	412	421	430	435	439	441	442	442	440	438	434	426	419	488
1 A 4 a Commercial / Institutional	24	24	24	29	30	29	29	29	29	29	30	32	34	38	36	34	33
1 A 4 b Residential	49	46	46	45	47	46	45	46	46	45	47	46	47	46	46	45	43
1 A 4 c Agriculture / Forestry / Fishing	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1 A 5 a Other, Stationary (Including military)	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1 A 5 b Other, Mobile (Including military)	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1 B 1 Fugitive Emissions from Solid Fuels	14	14	13	14	14	13	14	13	14	14	15	15	14	14	13	13	12
1 B 2 Oil and Natural Gas	25	24	25	25	24	24	24	24	24	23	52	58	31	74	85	79	60
2 A Mineral Products <sup>1</sup>	34	27	27	32	32	34	31	31	34	31	33	32	38	34	34	40	38
2 B Chemical Industry	21	26	27	27	28	28	24	26	25	25	29	29	23	29	29	19	19
2 C Metal Production	13	36	35	14	14	14	14	14	14	16	12	11	12	13	14	12	14
2 D Other Production <sup>1</sup>	24	30	30	24	25	26	24	24	24	24	23	23	25	23	24	20	2
2 G Other	19	20	20	20	20	20	19	19	19	19	15	15	21	16	16	22	14
3 A Paint Application	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3 B Degreasing and Dry Cleaning	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3 C Chemical Products, Manufacture and Processing	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3 D Other (Including products containing HMs and POPs)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA
4 B Manure Management <sup>2</sup>	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
4 C Rice Cultivation	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
4 D 1 Direct Soil Emission	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	NA	NA
4 F Field Burning of Agricultural Wastes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA
4 G Other <sup>3</sup>	0	0	0	1	1	0	1	1	1	1	0	0	0	0	0	0	0
5 B Forest and Grassland Conversion	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA
6 A Solid Waste Disposal on Land	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6 B Wastewater Handling	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6 C Waste Incineration <sup>4</sup>	2	3	2	3	3	3	3	3	3	3	6	6	7	6	6	4	2
6 D Other Waste <sup>5</sup>	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
7 Other	17	15	15	13	13	22	13	13	13	13	8	8	7	8	8	5	9

Notes:

1. Including product handling.

2. Including NH<sub>3</sub> from enteric fermentation.

3. Including particulate matter sources.

4. Excludes waste incineration for energy (this is included in 1 A 1).

5. Includes accidental fires.

Totals may not add up due to rounding.

Nitrogen Oxides (NO<sub>x</sub>) consists of nitric oxide (NO) and nitrogen dioxide (NO<sub>2</sub>) and are reported as NO<sub>x</sub> on a NO<sub>2</sub> mass basis

NA = Not applicable; IE = Included elsewhere; LTO = Landing and takeoff; HM = Heavy metals; POPs = Persistent organic pollutants.



**Table A14-3: Non-Methane Volatile Organic Compounds Emissions Summary for Canada**

CRF Sector Categories	Volatile Organic Compounds (Non-Methane)																
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
	kt NMVOC																
National Total	2 808	2 590	2 586	2 321	2 333	2 471	2 273	2 249	2 236	2 207	2 443	2 438	2 420	2 473	2 472	2 256	2 313
1 A 1 a Public Electricity and Heat Production	2	2	2	3	3	3	3	3	3	3	2	2	4	3	4	2	2
1 A 1 b Petroleum Refining	6	6	6	3	3	3	3	3	3	3	2	2	1	2	2	1	3
1 A 1 c Manufacture of Solid Fuels and Other Energy Industries	9	9	10	11	11	12	12	12	13	12	13	12	12	12	12	12	14
1 A 2 Manufacturing Industries and Construction	58.26	55.67	59.84	60.41	58.95	58.99	57.64	58.8	56.71	59.01	50.51	50.53	52.29	48.44	49.18	44.53	61.38
1 A 3 a ii (i) Civil Aviation (Domestic, LTO)	8	8	7	7	7	8	8	8	8	9	9	8	8	8	8	8	6
1 A 3 a ii (ii) Civil Aviation (Domestic, Cruise)	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4
1 A 3 b Road Transportation	675.9	651.4	638.03	595.17	575.51	528.16	482.4	456.89	426.74	425.74	420.3	396	359.64	333.97	303	274	259
1 A 3 c Railways	6	6	6	6	6	6	6	6	6	5	6	6	6	5	5	3	3
1 A 3 d ii National Navigation	10	9	9	9	9	9	8	8	8	8	8	7	8	8	8	8	4
1 A 3 e Other	294	299	303	308	313	318	312	305	305	307	310	309	310	309	305	299	296
1 A 4 a Commercial / Institutional	0	0	0	0	0	0	0	0	0	0	0	1	0	2	2	0	1
1 A 4 b Residential	347	145	144	137	140	139	137	138	138	138	150	145	162	150	153	155	158
1 A 4 c Agriculture / Forestry / Fishing	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1 A 5 a Other, Stationary (Including military)	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1 A 5 b Other, Mobile (Including military)	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1 B 1 Fugitive Emissions from Solid Fuels	2	2	1	2	2	2	2	2	2	2	1	1	2	1	1	1	1
1 B 2 Oil and Natural Gas	557	567	591	590	603	625	657	657	677	651	680	709	669	736	750	657	708
2 A Mineral Products <sup>1</sup>	5	5	4	4	4	3	4	4	4	4	2	2	2	1	1	0	1
2 B Chemical Industry	31	31	30	23	23	22	22	22	22	22	11	12	11	15	17	8	8
2 C Metal Production	20	18	18	18	18	17	18	18	18	18	15	16	3	15	15	4	3
2 D Other Production <sup>1</sup>	20	22	22	27	28	27	27	27	27	27	25	27	29	27	27	26	23
2 G Other	112	111	110	111	112	113	111	112	112	112	123	153	141	150	153	123	112
3 A Paint Application	148	153	147	121	119	127	111	119	116	113	102	95	94	107	109	66	126
3 B Degreasing and Dry Cleaning	265.99	279.45	276.73	239.37	249.16	217.51	243.03	243.96	244	242.82	269.56	256.69	249.16	305.13	309.79	239.73	199.26
3 C Chemical Products, Manufacture and Processing	1.23	1.23	1.26	2.09	2.15	2.09	2.13	2.11	2.12	2.12	2.74	2.62	2.59	2.76	2.83	3.03	2.39
3 D Other (Including products containing HMs and POPs)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA
4 B Manure Management <sup>2</sup>	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	300.3	NA
4 C Rice Cultivation	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
4 D 1 Direct Soil Emission	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
4 F Field Burning of Agricultural Wastes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA
4 G Other <sup>3</sup>	174	165	150	14	13	174	15	13	13	13	215	198	272	205	209	0	292
5 B Forest and Grassland Conversion	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA
6 A Solid Waste Disposal on Land	7	5	5	5	5	7	5	5	5	5	9	7	8	7	7	13	13
6 B Wastewater Handling	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6 C Waste Incineration <sup>4</sup>	2	2	2	2	2	2	2	2	2	2	2	2	3	2	2	2	5
6 D Other Waste <sup>5</sup>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA
7 Other	45	37	40	23	23	46	23	21	22	22	15	15	11	16	16	5	7

Notes:

1. Including product handling.

2. Including NH<sub>3</sub> from enteric fermentation.

3. Including particulate matter sources.

4. Excludes waste incineration for energy (this is included in 1 A 1).

5. Includes accidental fires.

Totals may not add up due to rounding.

NA = Not applicable; IE = Included elsewhere; LTO = Landing and takeoff; HM = Heavy metals; POPs = Persistent organic pollutants.

**Table A14-4: Sulphur Oxides Emissions Summary for Canada**

CRF Sector Categories	Sulphur Oxides																
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
	kt SO <sub>x</sub>																
National Total	3 187	3 497	3 009	2 347	2 310	2 446	2 359	2 389	2 386	2 365	2 265	2 312	2 273	2 228	2 304	2 066	2 012
1 A 1 a Public Electricity and Heat Production	680	692	666	539	536	523	538	527	540	546	625	613	607	612	605	508	449
1 A 1 b Petroleum Refining	99	109	110	137	126	120	120	124	122	124	101	100	84	95	96	78	72
1 A 1 c Manufacture of Solid Fuels and Other Energy Industries	240	157	165	182	204	215	222	249	244	250	265	274	278	324	348	197	217
1 A 2 Manufacturing Industries and Construction	245	278	280	203	209	203	226	219	207	212	129	133	137	135	136	155	141
1 A 3 a ii (i) Civil Aviation (Domestic, LTO)	1	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
1 A 3 a ii (ii) Civil Aviation (Domestic, Cruise)	4	3	3	3	3	3	3	3	3	3	4	4	3	3	3	3	4
1 A 3 b Road Transportation	35	33	34	38	40	31	27	30	22	21	21	21	18	14	9	8	5
1 A 3 c Railways	5	5	5	5	5	5	5	6	5	5	5	5	5	5	5	5	5
1 A 3 d ii National Navigation	45	42	42	42	41	40	36	36	36	35	33	32	31	31	32	32	78
1 A 3 e Other	24	22	24	26	23	21	24	27	16	16	15	17	16	16	16	17	17
1 A 4 a Commercial / Institutional	20	19	20	13	13	14	13	13	13	13	20	22	21	39	39	37	35
1 A 4 b Residential	33	33	33	18	19	19	18	19	19	18	16	16	13	15	15	13	11
1 A 4 c Agriculture / Forestry / Fishing	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1 A 5 a Other, Stationary (Including military)	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1 A 5 b Other, Mobile (Including military)	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1 B 1 Fugitive Emissions from Solid Fuels	20.93	20.9	19.25	18.06	17.67	17.51	17.57	17.3	17.32	17.68	16.69	16.42	16.6	16.45	16.3	15.4	14.0
1 B 2 Oil and Natural Gas	175	177	185	199	194	193	189	190	192	188	121	123	130	132	137	168	794
2 A Mineral Products <sup>1</sup>	34	39	37	28	29	31	27	28	29	28	30	31	38	31	31	36	36
2 B Chemical Industry	8	4	5	4	4	5	3	3	3	3	7	6	8	7	6	12	11
2 C Metal Production	1,464	1,799	1,322	856	808	971	844	858	879	845	829	869	836	721	778	743	81
2 D Other Production <sup>1</sup>	27	36	36	18	19	18	18	18	18	18	17	18	18	18	18	15	15
2 G Other	19	17	16	12	12	12	12	12	12	12	6	9	9	9	9	20	16
3 A Paint Application	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3 B Degreasing and Dry Cleaning	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3 C Chemical Products, Manufacture and Processing	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3 D Other (Including products containing HMs and POPs)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4 B Manure Management <sup>2</sup>	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
4 C Rice Cultivation	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
4 D 1 Direct Soil Emission	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
4 F Field Burning of Agricultural Wastes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA
4 G Other <sup>3</sup>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5 B Forest and Grassland Conversion	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA
6 A Solid Waste Disposal on Land	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6 B Wastewater Handling	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6 C Waste Incineration <sup>4</sup>	2	2	2	1	1	1	1	1	1	1	1	2	2	2	2	3	2
6 D Other Waste <sup>5</sup>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA
7 Other	6	7	7	4	6	5	11	9	6	6	1	1	1	2	2	1	9

Notes:

1. Including product handling.

2. Including NH<sub>3</sub> from enteric fermentation.

3. Including particulate matter sources.

4. Excludes waste incineration for energy (this is included in 1 A 1).

5. Includes accidental fires.

Totals may not add up due to rounding.

NA = Not applicable; IE = Included elsewhere; LTO = Landing and takeoff; HM = Heavy metals; POPs = Persistent organic pollutants.