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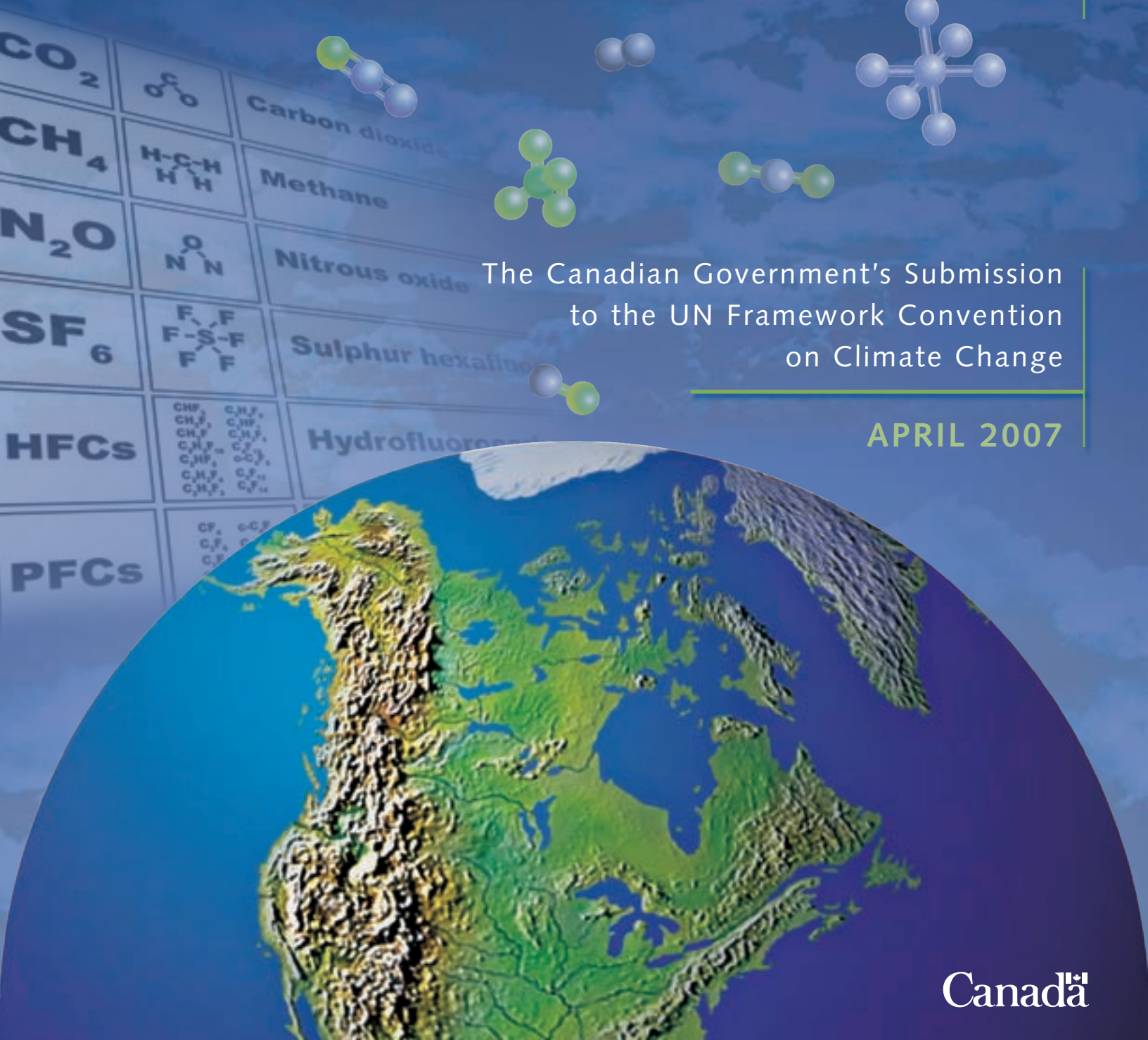
Environnement
Canada

National Inventory Report



1990–2005

Greenhouse Gas Sources and Sinks in Canada



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

APRIL 2007

Canada

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National Inventory Report

**Greenhouse Gas
Sources and Sinks in Canada
1990–2005**

**Greenhouse Gas Division
Environment Canada**

**Submission to the United Nations
Framework Convention on Climate Change**

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Reader's Comments

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Foreword

On December 4, 1992, Canada ratified the United Nations Framework Convention on Climate Change (UNFCCC), which subsequently entered into force in March of 1994. 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.

The UNFCCC reporting guidelines for national inventories, agreed to at the Eighth and Ninth Conferences of the Parties, 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 inventory report serves as a much better tool from which to generate indicators to compare Parties' performance under the UNFCCC. The Framework Convention also commits Parties to improve the quality of national and regional emissions data and to provide support to developing countries.

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 2006. In addition to the inventory data, the inventory report contains relevant supplementary information 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 2007 National Inventory Report contains a summary of the greenhouse gas emissions data reported by industrial facilities in Canada for the year 2005, 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. 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.

Art Jaques, P. Eng.
April 30, 2007

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

List of Acronyms, Abbreviations, and Units

AAC	Aluminium Association of Canada
AC	air conditioning
AC OEM	air conditioning original equipment manufacture
Al	aluminium
Al ₂ O ₃	alumina
ASH	manure ash content
AWMS	animal waste management system
B ₀	maximum methane production potential
BCEF	biomass conversion/expansion factor
C	carbon
CAC	Criteria Air Contaminant
CaCO ₃	calcium carbonate
CaMg(CO ₃) ₂	dolomite
CanFI	Canada Forest Inventory
CanSIS	Canadian Soil Information System
CaO	lime
CAPP	Canadian Association of Petroleum Producers
CBM	Carbon Budget Model
CBM-CFS	Carbon Budget Model of the Canadian Forest Sector
CCFM	Canadian Council of Forest Ministers
CCS	Census Consolidated Subdivision
CEA	Canadian Electricity Association
CEPA 1999	<i>Canadian Environmental Protection Act, 1999</i>
CF ₄	carbon tetrafluoride
C ₂ F ₆	carbon hexafluoride
CFC	chlorofluorocarbon
CH ₄	methane
CIEEDAC	Canadian Industrial Energy End-Use Data Analysis Centre
CKD	cement kiln dust
CO	carbon monoxide
CO ₂	carbon dioxide
CPPI	Canadian Petroleum Products Institute
CRF	Common Reporting Format
CVS	Canadian Vehicle Survey
DE	digestible energy
DHI	Dairy Herd Improvement
DMI	dry matter intake
EAF	electric arc furnace
ECR	Environmental Commitment and Responsibilities
EF	emission factor
EPA	Environmental Protection Agency (United States)
EPWG	Emissions and Projections Working Group

LIST OF ACRONYMS, ABBREVIATIONS, AND UNITS

eq	equivalent
ERT	Expert Review Team
FCR	fuel consumption ratio
FEMS	Farm Environmental Management Survey
g	gram
GDP	gross domestic product
GE	gross energy
Gg	gigagram
GHG	greenhouse gas
GHV	gross heating value
GIS	geographic information system
GL	gigalitre
Gt	gigatonne
GWP	global warming potential
ha	hectare
HCFC	hydrochlorofluorocarbon
HDD	heating degree-day
HDDT	heavy-duty diesel truck
HDDV	heavy-duty diesel vehicle
HDGV	heavy-duty gasoline vehicle
HFC	hydrofluorocarbon
HM	heavy metal
HNO ₃	nitric acid
HWP	harvested wood product
HWP-C	carbon stored in harvested wood products
IPCC	Intergovernmental Panel on Climate Change
kg	kilogram
kha	kilohectare
kPa	kilopascal
kt	kilotonne
kWh	kilowatt-hour
L	litre
lb.	pound
LDDT	light-duty diesel truck
LDDV	light-duty diesel vehicle
LDGT	light-duty gasoline truck
LDGV	light-duty gasoline vehicle
LDV	light-duty vehicle
LPG	liquefied petroleum gas
LTO	landing and takeoff
LUCF	Land-Use Change and Forestry
LULUCF	Land Use, Land-Use Change and Forestry
m	metre
m ³	cubic metre
MAI	mean annual increment
MARS	Monitoring, Accounting and Reporting System

LIST OF ACRONYMS, ABBREVIATIONS, AND UNITS

MC	motorcycle
MCF	methane conversion factor
MgCO ₃	dolomite
M-GEM	Mobile Greenhouse Gas Emission Model
MgO	dolomitic lime
Mha	megahectare
mol	mole
MS	manure system distribution factor
MSW	municipal solid waste
Mt	megatonne
mV	millivolt
MW	megawatt
N	nitrogen
N ₂	nitrogen gas
Na ₂ CO ₃	sodium carbonate
Na ₃ AlF ₆	cryolite
NAICS	North American Industrial Classification System
NFI	National Forest Inventory
NGL	natural gas liquid
NH ₃	ammonia
NH ₄ ⁺	ammonium
NHV	net heating value
NIR	National Inventory Report
NMVOC	non-methane volatile organic compound
NO	nitric oxide
NO ₃ ⁻	nitrate
NO _x	nitrogen oxides
N ₂ O	nitrous oxide
NPRI	National Pollutant Release Inventory
NRCan	Natural Resources Canada
ODS	ozone-depleting substance
OECD	Organisation for Economic Co-operation and Development
OEM	original equipment manufacturer
PFC	perfluorocarbon
PJ	petajoule
POP	persistent organic pollutant
ppb	part per billion
ppbv	part per billion by volume
ppm	part per million
QA	quality assurance
QC	quality control
RESO	<i>Report on Energy Supply–Demand in Canada</i>
SF ₆	sulphur hexafluoride
SIC	Standard Industrial Classification
SLC	Soil Landscapes of Canada
SO ₂	sulphur dioxide

LIST OF ACRONYMS, ABBREVIATIONS, AND UNITS

SO _x	sulphur oxides
SOC	soil organic carbon
STP	standard temperature and pressure
SUV	sport utility vehicle
t	tonne
t-km	tonne-kilometre
TJ	terajoule
TWh	terrawatt-hour
UNECE	United Nations Economic Commission for the Environment
UNFCCC	United Nations Framework Convention on Climate Change
VIO	vehicle in operation
Vkmt	vehicle kilometres travelled
VOC	volatile organic compound
VS	volatile solids

Table of Contents

Acknowledgements	ii
Foreword	iv
List of Acronyms, Abbreviations, and Units	v
List of Tables	xvii
List of Figures	xxiv
EXECUTIVE SUMMARY	1
ES.1 GREENHOUSE GAS INVENTORIES AND CLIMATE CHANGE	1
ES.1.1 <i>Developing Canada's National Greenhouse Gas Inventory</i>	2
ES.2 SUMMARY OF NATIONAL TRENDS IN GREENHOUSE GAS EMISSIONS AND REMOVALS	3
ES.3 EMISSIONS AND REMOVALS ESTIMATES AND TRENDS	7
ES.3.1 <i>2005 Emissions and Removals</i>	7
ES.3.2 <i>Sector Trends</i>	9
ES.4 OTHER INFORMATION	15
ES.4.1 <i>Emissions Associated with the Export of Oil and Natural Gas</i>	15
ES.4.2 <i>Provincial/Territorial Greenhouse Gas Emissions</i>	17
ES.4.3 <i>The International Context</i>	18
1 INTRODUCTION	19
1.1 GHG INVENTORIES AND CLIMATE CHANGE	19
1.1.1 <i>CO₂</i>	21
1.1.2 <i>CH₄</i>	21
1.1.3 <i>N₂O</i>	22
1.1.4 <i>HFCs, PFCs, and SF₆</i>	23
1.1.5 <i>GHGs and the Use of GWPs</i>	23
1.1.6 <i>Canada's Contribution</i>	25
1.2 INSTITUTIONAL ARRANGEMENTS FOR INVENTORY PREPARATION	26
1.2.1 <i>The National Inventory System</i>	26
1.2.2 <i>Institutional Arrangements</i>	27
1.3 PROCESS FOR INVENTORY PREPARATION	30
1.4 METHODOLOGIES AND DATA SOURCES	31
1.4.1 <i>Mandatory Reporting System for GHGs</i>	34
1.5 KEY CATEGORIES	39
1.6 QA/QC	40
1.7 INVENTORY UNCERTAINTY	41
1.8 COMPLETENESS ASSESSMENT	42
2 GREENHOUSE GAS EMISSION TRENDS, 1990–2005	43
2.1 SUMMARY OF EMISSION TRENDS	43
2.2 EMISSION TRENDS BY GAS	43
2.3 EMISSION TRENDS BY CATEGORY	44
2.3.1 <i>Energy Sector</i>	44
2.3.2 <i>Industrial Processes Sector</i>	52
2.3.3 <i>Solvent and Other Product Use Sector</i>	54
2.3.4 <i>Agriculture Sector</i>	54
2.3.5 <i>Land Use, Land-Use Change and Forestry Sector</i>	56
2.3.6 <i>Waste Sector</i>	58
2.4 EMISSION TRENDS FOR OZONE AND AEROSOL PRECURSORS	61
3 ENERGY (CRF SECTOR 1)	62
3.1 OVERVIEW	62
3.2 FUEL COMBUSTION (CRF CATEGORY 1.A)	63
3.2.1 <i>Energy Industries (CRF Category 1.A.1)</i>	64
3.2.2 <i>Manufacturing Industries and Construction (CRF Category 1.A.2)</i>	69

3.2.3	Transport (CRF Category 1.A.3)	73
3.2.4	Other Sectors (CRF Category 1.A.4)	80
3.2.5	Other: Energy — Fuel Combustion Activities (CRF Category 1.A.5)	83
3.3	FUGITIVE EMISSIONS (CRF CATEGORY 1.B)	83
3.3.1	Solid Fuels (CRF Category 1.B.1)	84
3.3.2	Oil and Natural Gas (CRF Category 1.B.2)	86
3.4	MEMO ITEMS (CRF CATEGORY 1.C)	95
3.4.1	International Bunker Fuels (CRF Category 1.C.1)	95
3.4.2	CO ₂ Emissions from Biomass	96
3.5	OTHER ISSUES	99
3.5.1	Comparison of Sectoral and Reference Approaches	99
3.5.2	Feedstocks and Non-Energy Use of Fuels	101
3.5.3	CO ₂ Capture and Storage	101
3.5.4	Country-Specific Issues — Emissions Associated with the Export of Fossil Fuels	101
4	INDUSTRIAL PROCESSES (CRF SECTOR 2)	103
4.1	OVERVIEW	103
4.2	MINERAL PRODUCTS (CRF CATEGORY 2.A)	105
4.2.1	Source Category Description	105
4.2.2	Methodological Issues	107
4.2.3	Uncertainties and Time-Series Consistency	111
4.2.4	Category-Specific QA/QC and Verification	113
4.2.5	Category-Specific Recalculations	114
4.2.6	Category-Specific Planned Improvements	115
4.3	AMMONIA PRODUCTION (CRF CATEGORY 2.B.1)	115
4.3.1	Source Category Description	115
4.3.2	Methodological Issues	117
4.3.3	Uncertainties and Time-Series Consistency	117
4.3.4	Category-Specific QA/QC and Verification	118
4.3.5	Category-Specific Recalculations	118
4.3.6	Category-Specific Planned Improvements	118
4.4	NITRIC ACID PRODUCTION (CRF CATEGORY 2.B.2)	118
4.4.1	Source Category Description	118
4.4.2	Methodological Issues	120
4.4.3	Uncertainties and Time-Series Consistency	121
4.4.4	Category-Specific QA/QC and Verification	121
4.4.5	Category-Specific Recalculations	121
4.4.6	Category-Specific Planned Improvements	122
4.5	ADIPIC ACID PRODUCTION (CRF CATEGORY 2.B.3)	122
4.5.1	Source Category Description	122
4.5.2	Methodological Issues	122
4.5.3	Uncertainties and Time-Series Consistency	123
4.5.4	Category-Specific QA/QC and Verification	124
4.5.5	Category-Specific Recalculations	124
4.5.6	Category-Specific Planned Improvements	124
4.6	IRON AND STEEL PRODUCTION (CRF CATEGORY 2.C.1)	124
4.6.1	Source Category Description	124
4.6.2	Methodological Issues	125
4.6.3	Uncertainties and Time-Series Consistency	126
4.6.4	Category-Specific QA/QC and Verification	126
4.6.5	Category-Specific Recalculations	126
4.6.6	Category-Specific Planned Improvements	127
4.7	ALUMINIUM METAL PRODUCTION (CRF CATEGORY 2.C.3)	127
4.7.1	Source Category Description	127
4.7.2	Methodological Issues	129
4.7.3	Uncertainties and Time-Series Consistency	131
4.7.4	Category-Specific QA/QC and Verification	132

4.7.5	Category-Specific Recalculations.....	132
4.7.6	Category-Specific Planned Improvements.....	132
4.8	MAGNESIUM METAL PRODUCTION AND CASTING (CRF CATEGORIES 2.C.4 & 2.C.5)	132
4.8.1	Source Category Description.....	132
4.8.2	Methodological Issues	133
4.8.3	Uncertainties and Time-Series Consistency	134
4.8.4	Category-Specific QA/QC and Verification.....	134
4.8.5	Category-Specific Recalculations.....	135
4.8.6	Category-Specific Planned Improvements.....	135
4.9	PRODUCTION AND CONSUMPTION OF HALOCARBONS (CRF CATEGORIES 2.E & 2.F).....	135
4.9.1	Source Category Description.....	135
4.9.2	Methodological Issues	136
4.9.3	Uncertainties and Time-Series Consistency	143
4.9.4	Category-Specific QA/QC and Verification.....	144
4.9.5	Category-Specific Recalculations.....	144
4.9.6	Category-Specific Planned Improvements.....	144
4.10	PRODUCTION AND CONSUMPTION OF SF ₆ (CRF CATEGORIES 2.E & 2.F).....	145
4.10.1	Source Category Description.....	145
4.10.2	Methodological Issues	145
4.10.3	Uncertainties and Time-Series Consistency	146
4.10.4	Category-Specific QA/QC and Verification.....	147
4.10.5	Category-Specific Recalculations.....	147
4.10.6	Category-Specific Planned Improvements.....	147
4.11	OTHER AND UNDIFFERENTIATED PRODUCTION (CRF CATEGORY 2.G).....	147
4.11.1	Source Category Description.....	147
4.11.2	Methodological Issues	148
4.11.3	Uncertainties and Time-Series Consistency	148
4.11.4	Category-Specific QA/QC and Verification.....	148
4.11.5	Category-Specific Recalculations.....	149
4.11.6	Category-Specific Planned Improvements.....	149
5	SOLVENT AND OTHER PRODUCT USE (CRF SECTOR 3).....	150
5.1	OVERVIEW	150
5.1.1	Source Category Description.....	151
5.1.2	Methodological Issues	151
5.1.3	Uncertainties and Time-Series Consistency	153
5.1.4	QA/QC and Verification	153
5.1.5	Recalculations	153
5.1.6	Planned Improvements	153
6	AGRICULTURE (CRF SECTOR 4).....	154
6.1	OVERVIEW	154
6.2	ENTERIC FERMENTATION (CRF CATEGORY 4.A).....	155
6.2.1	Source Category Description.....	155
6.2.2	Methodological Issues	156
6.2.3	Uncertainties and Time-Series Consistency	157
6.2.4	QA/QC and Verification	157
6.2.5	Recalculations	158
6.2.6	Planned Improvements	158
6.3	MANURE MANAGEMENT (CRF CATEGORY 4.B).....	158
6.3.1	CH ₄ Emissions from Manure Management (CRF Category 4.B (a)).....	158
6.3.2	N ₂ O Emissions from Manure Management (CRF Category 4.B (b))	160
6.4	N ₂ O EMISSIONS FROM AGRICULTURAL SOILS (CRF CATEGORY 4.D).....	162
6.4.1	Direct N ₂ O Emissions from Soils (CRF Category 4.D.1)	163
6.4.2	Manure on Pasture, Range, and Paddock (CRF Category 4.D.2).....	172
6.4.3	Indirect Emissions of N ₂ O from Soils (CRF Category 4.D.3).....	173

7	LAND USE, LAND-USE CHANGE AND FORESTRY (CRF SECTOR 5)	177
7.1	OVERVIEW	177
7.2	CHANGES SINCE PREVIOUS SUBMISSION	179
7.3	LAND CATEGORY DEFINITION AND REPRESENTATION OF MANAGED LANDS	180
7.4	FOREST LAND	183
7.4.1	Forest Land Remaining Forest Land	184
7.4.2	Land Converted to Forest Land	190
7.5	CROPLAND	192
7.5.1	Cropland Remaining Cropland	192
7.5.2	Land Converted to Cropland	201
7.6	GRASSLAND	205
7.7	WETLANDS	205
7.7.1	Managed Peatlands	206
7.7.2	Flooded Lands (Reservoirs)	209
7.8	SETTLEMENTS	211
7.8.1	Settlements Remaining Settlements	212
7.8.2	Lands Converted to Settlements	212
7.9	FOREST CONVERSION	213
7.9.1	Methodological Issues	214
7.9.2	Uncertainties and Time-Series Consistency	215
7.9.3	QA/QC and Verification	215
7.9.4	Recalculations	215
7.9.5	Planned Improvements	216
8	WASTE (CRF SECTOR 6)	217
8.1	OVERVIEW	217
8.2	SOLID WASTE DISPOSAL ON LAND (CRF CATEGORY 6.A)	218
8.2.1	Source Category Description	218
8.2.2	Methodological Issues	220
8.2.3	Uncertainties and Time-Series Consistency	225
8.2.4	QA/QC and Verification	226
8.2.5	Recalculations	226
8.2.6	Planned Improvements	227
8.3	WASTEWATER HANDLING (CRF CATEGORY 6.B)	228
8.3.1	Source Category Description	228
8.3.2	Methodological Issues	228
8.3.3	Uncertainties and Time-Series Consistency	230
8.3.4	QA/QC and Verification	231
8.3.5	Recalculations	231
8.3.6	Planned Improvements	231
8.4	WASTE INCINERATION (CRF CATEGORY 6.C)	232
8.4.1	Source Category Description	232
8.4.2	Methodological Issues	233
8.4.3	Uncertainties and Time-Series Consistency	234
8.4.4	QA/QC and Verification	235
8.4.5	Recalculations	235
8.4.6	Planned Improvements	235
9	RECALCULATIONS AND IMPROVEMENTS	236
9.1	EXPLANATIONS AND JUSTIFICATIONS FOR RECALCULATIONS	236
9.1.1	Energy	237
9.1.2	Industrial Processes	240
9.1.3	Solvent and Other Product Use	241
9.1.4	Agriculture	241
9.1.5	Land Use, Land-Use Change and Forestry	241
9.1.6	Waste	242
9.2	IMPLICATIONS FOR EMISSION LEVELS	243

9.3	IMPLICATIONS FOR EMISSION TRENDS	244
9.4	PLANNED IMPROVEMENTS.....	245
9.4.1	<i>Quality Assurance/Quality Control</i>	245
9.4.2	<i>Uncertainties</i>	245
9.4.3	<i>Key Categories</i>	246
9.4.4	<i>Data Management System</i>	246
9.4.5	<i>Energy Sector</i>	246
9.4.6	<i>Industrial Processes Sector</i>	247
9.4.7	<i>Agriculture Sector</i>	248
9.4.8	<i>Land Use, Land-Use Change and Forestry Sector</i>	248
9.4.9	<i>Waste Sector</i>	248
	REFERENCES	250
ANNEX 1	KEY CATEGORIES	270
A1.1	KEY CATEGORIES — METHODOLOGY	270
A1.1.1	<i>Summary Assessment</i>	273
A1.2	KEY CATEGORY TABLES	277
A1.2.1	<i>Level Assessment with and without LULUCF</i>	277
A1.2.2	<i>Trend Assessment with and without LULUCF</i>	279
A1.2.3	<i>Qualitative Assessment</i>	281
	REFERENCES	284
ANNEX 2	METHODOLOGY AND DATA FOR ESTIMATING EMISSIONS FROM FOSSIL FUEL COMBUSTION	286
A2.1	METHODOLOGY.....	286
A2.2	ACTIVITY DATA – STATISTICS CANADA.....	287
A2.3	FUEL COMBUSTION EMISSION FACTORS	288
A2.3.1	<i>CO₂ Emission Factors</i>	288
A2.3.2	<i>Non-CO₂ Emission Factors</i>	289
A2.3.3	<i>Biomass</i>	289
A2.4	METHODOLOGY.....	290
A2.4.1	<i>Stationary Combustion</i>	290
A2.4.2	<i>Transport (CRF 1.A.3)</i>	309
	REFERENCES	316
ANNEX 3	ADDITIONAL METHODOLOGIES.....	318
A3.1	METHODOLOGY FOR FUGITIVE EMISSIONS FROM FOSSIL FUEL PRODUCTION, PROCESSING, TRANSMISSION AND DISTRIBUTION.....	318
A3.1.1	<i>Solid Fuels</i>	318
A3.1.2	<i>Oil and Natural Gas</i>	321
A3.2	METHODOLOGY FOR INDUSTRIAL PROCESSES	336
A3.2.1	<i>CO₂ Emissions from Iron and Steel Production</i>	336
A3.2.2	<i>CO₂ Emissions from Other and Undifferentiated Production</i>	338
A3.2.3	<i>CO₂ Emissions from Ammonia Production</i>	342
A3.3	METHODOLOGY FOR SOLVENT AND OTHER PRODUCT USE.....	345
A3.4	METHODOLOGY FOR THE AGRICULTURE SECTOR.....	345
A3.4.1	<i>Animal Population Data Sources</i>	345
A3.4.2	<i>CH₄ Emissions from Enteric Fermentation</i>	346
A3.4.3	<i>CH₄ Emissions from Manure Management</i>	355
A3.4.4	<i>N₂O Emissions from Manure Management</i>	362
A3.4.5	<i>N₂O Emissions from Agricultural Soils</i>	364
A3.5	METHODOLOGY FOR LAND USE, LAND-USE CHANGE AND FORESTRY.....	382
A3.5.1	<i>Spatial Framework for LULUCF Estimate Development and Area Reconciliation</i>	382
A3.5.2	<i>Forest Land and Forest-Related Land-Use Change</i>	384
A3.5.3	<i>Cropland</i>	403
A3.5.4	<i>Grasslands</i>	429
A3.5.5	<i>Wetlands</i>	431
A3.5.6	<i>Settlements</i>	439

A3.5.7	<i>Estimation of Delayed CO₂ Emissions from Harvested Wood Products</i>	442
A3.6	METHODOLOGY FOR WASTE	444
A3.6.1	<i>CH₄ Emissions from Solid Waste Disposal on Land</i>	444
A3.6.2	<i>CH₄ Emissions from Wastewater Treatment</i>	461
A3.6.3	<i>N₂O Emissions from Wastewater Treatment</i>	468
A3.6.4	<i>CO₂ Emissions from Municipal Waste Incineration</i>	470
A3.6.5	<i>N₂O Emissions from Waste Incineration</i>	473
A3.6.6	<i>CH₄ Emissions from Waste Incineration</i>	475
	References	477
ANNEX 4	COMPARISON OF SECTORAL AND REFERENCE APPROACHES	499
A4.1	COMPARISON OF REFERENCE APPROACH TO SECTORAL APPROACH	499
A4.2	REFERENCE APPROACH METHODOLOGY	502
A4.2.1	<i>Crude Oil</i>	502
A4.2.2	<i>Natural Gas Liquids (NGLs)</i>	503
A4.2.3	<i>Gasoline</i>	503
A4.2.4	<i>Gas/Diesel Oil</i>	503
A4.2.5	<i>Other Kerosene</i>	503
A4.2.6	<i>Jet Kerosene</i>	503
A4.2.7	<i>Coke Oven Gas and Coal Coke</i>	503
A4.2.8	<i>Petroleum Coke</i>	504
A4.2.9	<i>Liquefied Petroleum Gas (LPG)</i>	504
A4.2.10	<i>Bitumen</i>	504
A4.2.11	<i>Other Oils</i>	504
A4.2.12	<i>Other Bituminous and Sub-Bituminous Coal</i>	504
A4.2.13	<i>Natural Gas</i>	504
A4.2.14	<i>Biomass</i>	505
A4.3	NATIONAL ENERGY BALANCE	505
	REFERENCES	507
ANNEX 5	ASSESSMENT OF COMPLETENESS	508
A5.1	ENERGY	508
A5.1.1	<i>Fuel Combustion</i>	508
A5.1.2	<i>Emissions from Combustion of Landfill Gas</i>	508
A5.1.3	<i>Fuel Combustion - Transportation</i>	508
A5.2	INDUSTRIAL PROCESSES	509
A5.2.1	<i>Mineral Products</i>	509
A5.2.2	<i>Chemical Production</i>	509
A5.2.3	<i>Metal Production</i>	509
A5.2.4	<i>Production and Consumption of Halocarbons and SF₆</i>	510
A5.2.5	<i>Other and Undifferentiated Production</i>	510
A5.3	SOLVENT AND OTHER PRODUCT USE	510
A5.4	AGRICULTURE	511
A5.4.1	<i>Enteric Fermentation and Manure Management</i>	511
A5.4.2	<i>Residue Burning</i>	511
A5.4.3	<i>Rice Production</i>	511
A5.5	LAND USE, LAND-USE CHANGE AND FORESTRY	511
A5.5.1	<i>Forest Land</i>	511
A5.5.2	<i>Cropland</i>	512
A5.5.3	<i>Grassland</i>	512
A5.5.4	<i>Wetlands</i>	512
A5.5.5	<i>Settlements</i>	513
A5.6	WASTE	513
A5.6.1	<i>Domestic and Commercial Wastewater</i>	513
A5.6.2	<i>Industrial Wastewater</i>	513
A5.6.3	<i>Waste Incineration</i>	514
	REFERENCES	514

ANNEX 6	QUALITY ASSURANCE AND QUALITY CONTROL	515
A6.1	CHARACTERISTICS OF THE QA/QC PLAN FOR THE NATIONAL INVENTORY	515
A6.2	ANNUAL INVENTORY DEVELOPMENT PROCESS	516
A6.3	QC PROCEDURES	517
A6.3.1	Tier 1 QC	517
A6.3.2	Tier 2 QC	518
A6.4	QA PROCEDURES	518
A6.5	VERIFICATION	518
A6.6	KEY QA/QC ACHIEVEMENTS IN THE 2007 INVENTORY SUBMISSION	519
	REFERENCES	519
ANNEX 7	UNCERTAINTY	520
A7.1	INTRODUCTION	520
A7.2	OVERALL INVENTORY UNCERTAINTY FOR 2001 (REPORTED IN NIR 2003)	521
A7.3	SCOPE OF 2004/2005 UNCERTAINTY STUDY	523
A7.3.1	General Concepts	523
A7.3.2	Input Data for the Uncertainty Model	524
A7.3.3	Level of Aggregation Adopted for Uncertainty Analysis	529
A7.3.4	Sensitivity Analysis	531
A7.4	SUMMARY OF SECTOR UNCERTAINTIES	531
A7.4.1	Energy	549
A7.4.2	Industrial Processes	550
A7.4.3	Solvent and Other Product Use	552
A7.4.4	Agriculture	552
A7.4.5	Land Use, Land-Use Change and Forestry	552
A7.4.6	Waste	553
	REFERENCES	554
ANNEX 8	CANADA'S GREENHOUSE GAS EMISSION TABLES, 1990–2005	556
ANNEX 9	ELECTRICITY INTENSITY TABLES	575
A9.1	METHODOLOGY AND LIMITATIONS	575
A9.2	NATIONAL TRENDS	576
A9.3	REGIONAL DISCUSSION	578
A9.4	GHG EMISSIONS INTENSITIES	579
	REFERENCES	593
ANNEX 10	PROVINCIAL/TERRITORIAL ANALYSIS	594
A10.1	NEWFOUNDLAND AND LABRADOR	594
A10.1.1	Long-Term Trends (1990–2005)	595
A10.1.2	Short-Term Trends (2003–2005)	596
A10.2	PRINCE EDWARD ISLAND	597
A10.2.1	Long-Term Trends (1990–2005)	598
A10.2.2	Short-Term Trends (2003–2005)	598
A10.3	NOVA SCOTIA	600
A10.3.1	Long-Term Trends (1990–2005)	600
A10.3.2	Short-Term Trends (2003–2005)	601
A10.4	NEW BRUNSWICK	602
A10.4.1	Long-Term Trends (1990–2005)	603
A10.4.2	Short-Term Trends (2003–2005)	603
A10.5	QUEBEC	605
A10.5.1	Long-Term Trends (1990–2005)	605
A10.5.2	Short-Term Trends (2003–2005)	606
A10.6	ONTARIO	608
A10.6.1	Long-Term Trends (1990–2005)	608
A10.6.2	Short-Term Trends (2003–2005)	608
A10.7	MANITOBA	610
A10.7.1	Long-Term Trends (1990–2005)	610
A10.7.2	Short-Term Trends (2003–2005)	611

A10.8	SASKATCHEWAN	612
A10.8.1	Long-Term Trends (1990–2005).....	613
A10.8.2	Short-Term Trends (2003–2005).....	613
A10.9	ALBERTA.....	615
A10.9.1	Long-Term Trends (1990–2005).....	615
A10.9.2	Short-Term Trends (2003–2005).....	616
A10.10	BRITISH COLUMBIA	617
A10.10.1	Long-Term Trends (1990–2005).....	618
A10.10.2	Short-Term Trends (2003–2005).....	618
A10.11	YUKON, NORTHWEST TERRITORIES, AND NUNAVUT.....	620
	REFERENCES	623
ANNEX 11	PROVINCIAL/TERRITORIAL GHG EMISSIONS TABLES, 1990–2005	624
ANNEX 12	EMISSION FACTORS.....	650
A12.1	FUEL COMBUSTION	650
A12.1.1	Natural Gas and NGLs.....	650
A12.1.2	Refined Petroleum Products	651
A12.1.3	Coal and Coal Products	655
A12.1.4	Mobile Combustion.....	657
A12.2	FUGITIVE EMISSION FACTORS: COAL MINING.....	659
A12.3	INDUSTRIAL PROCESSES	659
A12.3.1	Mineral, Chemical, and Metal Industries.....	659
A12.3.2	Consumption of Halocarbons	661
A12.3.3	Other and Undifferentiated Production.....	663
A12.4	SOLVENT AND OTHER PRODUCT USE	664
A12.5	AGRICULTURE	665
A12.6	BIOMASS COMBUSTION	667
A12.6.1	CO ₂	667
A12.6.2	CH ₄	667
A12.6.3	N ₂ O.....	668
	REFERENCES	669
ANNEX 13	ROUNDING PROTOCOL	672
	REFERENCES	674
ANNEX 14	OZONE AND AEROSOL PRECURSORS	676

List of Tables

Table S-1: Canada's GHG Emissions and Accompanying Variables, 1990–2005	5
Table S-2: Canada's GHG Emissions by Gas and Sector, 2005.....	8
Table S-3: Canada's GHG Emissions by Sector, 1990–2005.....	12
Table S-4: Crude Oil: Production, Export, and GHG Emission Trends, 1990–2005	16
Table S-5: Natural Gas: Production, Export, and GHG Emission Trends, 1990–2005....	17
Table S-6: Combined Crude Oil and Natural Gas: Production, Export, and GHG Emission Trends, 1990–2005.....	17
Table 1-1: GWPs and Atmospheric Lifetimes.....	24
Table 1-2: Facility Reported 2005 GHG Emissions by Gas.....	35
Table 1-3: Facility Reported 2005 GHG Emissions by Province/Territory	36
Table 1-4: Total Facility Reported 2005 GHG Emissions Contribution by Sector.....	36
Table 1-5: Total Facility Reported GHG Emissions, 2004 and 2005.....	38
Table 1-6: Comparable Facilities Reported GHG Emissions, 2004 and 2005	38
Table 2-1: GHG Emissions from Energy by UNFCCC CRF Sector, 1990–2005.....	44
Table 2-2: GHG Emissions from Petroleum Refining and Manufacture of Solid Fuels and Other Energy Industries, 1990–2005	46
Table 2-3: GHG Emissions from Manufacturing, Mining, and Construction, 1990–2005.....	47
Table 2-4: GHG Emissions from Transport, 1990–2005.....	48
Table 2-5: Trends in Vehicle Populations for Canada, 1990–2005.....	49
Table 2-6: GHG Emissions from Industrial Processes by Category, Selected Years.....	53
Table 2-7: GHG Emissions from Waste, Selected Years	58
Table 3-1: GHG Emissions from Energy, Selected Years.....	62
Table 3-2: Energy Industries GHG Contribution.....	64
Table 3-3: Manufacturing Industries and Construction GHG Contribution	70
Table 3-4: Transport GHG Contribution	73
Table 3-5: Other Sectors GHG Contribution.....	81
Table 3-6: Fugitive GHG Contribution.....	84
Table 3-7: Uncertainty in Oil Production Industry Fugitive Emissions	92
Table 3-8: Uncertainty in Natural Gas Production Industry Fugitive Emissions	92
Table 3-9: Uncertainty in Oil Refining Fugitive Emissions	93
Table 3-10: GHG Emissions from Domestic and International Aviation , 1990-2005	95
Table 3-11: GHG Emissions from Domestic and International Navigation, 1990-2005	96
Table 3-12: Ethanol Used for Transport in Canada, 1990-2005.....	99
Table 3-13: Reconciliation of Reference Approach and Sectoral Approach for Canada.....	100
Table 4-1: GHG Emissions from Industrial Processes Sector, Selected Years	105
Table 4-2: Nitric Acid Industry Typical Emission Factors.....	120
Table 4-3: Default Slope and Overvoltage Coefficients.....	131
Table 4-4: PFC Emission Factors	131
Table 4-5: Equipment Categories and k Values	138
Table 4-6: Annual Leakage Rate	139

Table 4-7: PFC Emission Rates	142
Table 5-1: Solvent and Other Product Use Sector GHG Emission Summary, Selected Years	150
Table 6-1: Short- and Long-Term Changes in GHG Emissions from the Agriculture Sector	155
Table 6-2: Animal Categories and Sources of Population Data	157
Table 6-3: Percentage of Manure Nitrogen Handled by Animal Waste Management Systems	161
Table 7-1: LULUCF Sector Net GHG Flux Estimates, Selected Years	178
Table 7-2: 2004 GHG Estimates in the 2006 and 2007 Submissions	180
Table 7-3: Managed Land Areas in the 2005 LULUCF accounting system	182
Table 7-4: GHG Balance of Managed Forests by Reporting Zone, 2005	184
Table 7-5: Managed Forest Area in Recent Submissions	189
Table 7-6: Average Net Forest Primary Productivity in the 2006 and 2007 Submissions	189
Table 7-7: Forest Area Burned in Managed Forests, Recent Submissions	190
Table 7-8: Emissions and Removals Associated with Various Land Management Changes on Croplands Since 1990	193
Table 7-9: Level and Trend Uncertainty Estimates for Various Land Management Changes in Mineral Soils of Cropland Remaining Cropland	196
Table 8-1: Waste Sector GHG Emissions Summary, Selected Years	218
Table 8-2: MSW Landfill k Value Estimates for Each Province/Territory	223
Table 8-3: CH ₄ Generation Potential from 1941 to Present	224
Table 8-4: N ₂ O Emission Factors	230
Table 9-1: Recalculations Summary	243
Table A1-1: Key Category Analysis Summary, 2005 Inventory	274
Table A1-2: 2005 Key Categories by Level Assessment with and without LULUCF ..	277
Table A1-3: 2005 Key Categories by Trend Assessment with and without LULUCF ..	279
Table A1-4: Key Categories by Significant Mitigation Techniques and Technologies ..	281
Table A1-5: Key Categories Identified from Anticipated High Emissions Growth	282
Table A1-6: Key Categories with a High Composite Uncertainty	283
Table A2-1: General Fuel Type Categories for Stationary Combustion Methodology ..	291
Table A2-2: Stationary Combustion GHG Estimation Methodology	295
Table A2-3: Fuels Reference List	307
Table A2.4: Activity Data Model References:	307
Table A2.5: Emission Factor References:	308
Table A2-6: Technology Penetration for HDGVs, HDDVs, LDDVs & LDDTs, and MCs	311
Table A3.1-1: Fugitive Emissions Factors For Coal Mining	320
Table A3.1-2: Allocation of UOG Inventory Emissions to CRF Fugitive Categories ...	321
Table A3.1-3: Required Activity Data and its Source	325
Table A3.1-4: Activity Data Used to Prorate Emissions Sectors and Sources	326
Table A3.1-5: Natural Gas Transmission Emission Factors for 1997 to 2005	328
Table A3.1-6: CH ₄ Emission Factors for Fugitive Natural Gas Distribution Emissions	331
Table A3.1-7: Emission Source Categories and Process Areas in the Bitumen Report ..	333
Table A3.1-8: Activity Data Required for the Extrapolation Model	335

Table A3.2-1: CO ₂ Emission Factors for Coal and Coal Products	340
Table A3.2-2: CO ₂ Emission Factors for Various Refined Petroleum Products	341
Table A3.2-3: CO ₂ Emission Factors for Natural Gas Liquids	341
Table A3.2-4: CO ₂ Emission Factors for Non-Energy Petroleum Products.....	342
Table A3.2-5: Derivation for Ammonia Production-Based Emission Factor.....	343
Table A3.4-1: Data Sources for Animal Populations	346
Table A3.4-2: CH ₄ Emission Factors for Enteric Fermentation and Manure Management by Animal Category except Dairy Cows	347
Table A3.4-3: CH ₄ Emission Factors for Enteric Fermentation and Manure Management for Dairy Cows from 1990 to 2005	348
Table A3.4-4: Characteristics of Dairy Production in Canada	349
Table A3.4-5: Average Milk Production from 1990 to 2005 and Number of Milking Days at a Provincial Level	350
Table A3.4-6: Characteristics of Beef Production in Canada.....	352
Table A3.4-7: Provincial and National CH ₄ Emission Factors for Enteric Fermentation from Various Beef Cattle in Canada.....	354
Table A3.4-8: Provincial and National CH ₄ Emission Factors for Enteric Fermentation from Dairy Cows from 1990 to 2005	354
Table A3.4-9: Approximate Digestible Energy for Selected Livestock and Data Sources	358
Table A3.4-10: Manure Ash Content for Selected Livestock and Data Sources.....	358
Table A3.4-11: Dry Matter Intake for Selected Livestock	359
Table A3.4-12: Mean VS and Associated 95% Confidence Interval Expressed as a Percentage of the Mean for Each Non-Cattle Category in Each Province	360
Table A3.4-13: Values of Maximum CH ₄ Producing Potential for Various Livestock Types	361
Table A3.4-14: CH ₄ Conversion Factor for Each Animal Type.....	361
Table A3.4-15: Percentage of Manure Handled by Animal Waste Management Systems	362
Table A3.4-16: Nitrogen Excretion Rate for Each Specific Animal Category.....	363
Table A3.4-17: Percentage of Manure Nitrogen Lost as N ₂ O-N for Specific	364
Table A3.4-18: Total and NH ₃ and NO _x Nitrogen Losses Associated with Various Livestock and Manure Management Systems.....	366
Table A3.5-1: Spatial Analysis Units of Managed Forests.....	382
Table A3.5-2: Land and Water Areas of Reporting Zones.....	384
Table A3.5-3: Forest Carbon Pools in IPCC and CBM-CFS3	385
Table A3.5-4: Main Sources of Information and Data, Managed Forests.....	390
Table A3.5-5: Distribution of Managed Forests in Reporting Zones	391
Table A3.5-6: GHG Emissions/Removals of Managed Forests, 2005	401
Table A3.5-7: Generalized Values of Parameters to Predict Change from Land Management Change and Effective Linear Coefficients of SOC Change.....	411
Table A3.5-8: SOC for Forested and Agricultural Land in Eastern and Western Canada from the Canadian Soil Information System Database.....	425
Table A3.5-9: Parameters and Emission Factors for Estimating CO ₂ -C Emissions from Wetlands (Peatlands).....	434

Table A3.6-1: Multiple Linear Regression Polynomial Coefficients Used in Estimating the Amount of MSW Landfilled for 1991–1997 and 2005	447
Table A3.6-2: MSW Landfilled for 1990–2005	449
Table A3.6-3: Wood Waste Generated and Landfilled in Canada for 1990–2005	451
Table A3.6-4: Mean Annual Precipitation and MSW Landfill k Value Estimates for Provincial Landfill Sites	452
Table A3.6-5: MSW Landfill k Value Estimates for Each Province	455
Table A3.6-6: Solid Waste Disposal Site CH ₄ Correction Factors	456
Table A3.6-7: Canadian CH ₄ Generation Potential Values Derived from Waste Audit Data for 1990–2003	457
Table A3.6-8: CH ₄ Generation Potential from 1941 to Present	458
Table A3.6-9: Estimated MSW CH ₄ Captured, Flared and Emitted for 1990–2005	460
Table A3.6-10: Percentage of Wastewater Treated Anaerobically (by Province)	464
Table A3.6-11: Multiple Linear Regression Polynomial Coefficients Used in Estimating the Amount of Industrial Wastewater Treated for 1987–1990 and 1992–1995	465
Table A3.6-12: Volume of Wastewater Treated per Industry Type for 1986–2005	466
Table A3.6-13: COD Values Used in CH ₄ Emission Estimates per Industry Type	467
Table A3.6-14: Canadian Protein Consumption	469
Table A3.6-15: Estimated MSW Incinerated (by Province) for 1990–2005	471
Table A3.6-16: Estimated MSW Organic Composition	472
Table A3.6-17: Estimated Sewage Sludge Incinerated for 1990–2005	476
Table A4-1: Comparison of Adjusted Reference Approach and Sectoral Approach for Canada	500
Table A4-2: Reference Approach Conversion Factors for Canada	501
Table A7-1: Quantitative Tier 2 Uncertainty Assessment of Overall National Inventory GHG Emissions and Trends for 2001 by Gas	522
Table A7-2: Sample Input Parameter Uncertainty Estimates Obtained from Expert Elicitation — Activity Data for Quantity of Fuel Consumed	527
Table A7-3: Sample Input Parameter Uncertainty Estimates Obtained from Expert Elicitation and Source Reference Research — Emission Factor Data for Stationary Fuel Combustion	528
Table A7-4: Level of Aggregation Adopted for the Uncertainty Analysis, by Key Source Category (2001 Inventory Submitted in 2003)	530
Table A7-5: Tier 2 Uncertainty Reporting — CO ₂ Energy (Stationary Combustion) ...	534
Table A7-6: Tier 2 Uncertainty Reporting — CH ₄ Energy (Stationary Combustion) ...	536
Table A7-7: Tier 2 Uncertainty Reporting — N ₂ O Energy (Stationary Combustion) ...	538
Table A7-8: Tier 2 Uncertainty Reporting — CO ₂ Energy (Transport)	540
Table A7-9: Tier 2 Uncertainty Reporting — CH ₄ Energy (Transport)	541
Table A7-10: Tier 2 Uncertainty Reporting — N ₂ O Energy (Transport)	542
Table A7-11: Tier 2 Uncertainty Reporting — CO ₂ Energy (Fugitives)	543
Table A7-12: Tier 2 Uncertainty Reporting — CH ₄ Energy (Fugitives)	544
Table A7-13: Tier 2 Uncertainty Reporting — Industrial Processes, Solvent and Other Product Use	545
Table A7-14: Tier 2 Uncertainty Reporting — Agriculture	547
Table A7-15: Tier 2 Uncertainty Reporting — Waste	548
Table A8-1: GHG Category Description	557

Table A8-2: Canada's 1990–2005 Greenhouse Gas Emissions by Sector	558
Table A8-3: 2005 GHG Emissions Summary for Canada.....	559
Table A8-4: 2004 GHG Emissions Summary for Canada.....	560
Table A8-5: 2003 GHG Emissions Summary for Canada.....	561
Table A8-6: 2002 GHG Emissions Summary for Canada.....	562
Table A8-7: 2001 GHG Emissions Summary for Canada.....	563
Table A8-8: 2000 GHG Emissions Summary for Canada.....	564
Table A8-9: 1999 GHG Emissions Summary for Canada.....	565
Table A8-10: 1998 GHG Emissions Summary for Canada.....	566
Table A8-11: 1997 GHG Emissions Summary for Canada.....	567
Table A8-12: 1996 GHG Emissions Summary for Canada.....	568
Table A8-13: 1995 GHG Emissions Summary for Canada.....	569
Table A8-14: 1994 GHG Emissions Summary for Canada.....	570
Table A8-15: 1993 GHG Emissions Summary for Canada.....	571
Table A8-16: 1992 GHG Emissions Summary for Canada.....	572
Table A8-17: 1991 GHG Emissions Summary for Canada.....	573
Table A8-18: 1990 GHG Emissions Summary for Canada.....	574
Table A9-1: Electricity Generation and GHG Emission Details for Canada	581
Table A9-2: Electricity Generation and GHG Emission Details for Newfoundland and Labrador	582
Table A9-3: Electricity Generation and GHG Emission Details for Prince Edward Island.....	583
Table A9-4: Electricity Generation and GHG Emission Details for Nova Scotia.....	584
Table A9-5: Electricity Generation and GHG Emission Details for New Brunswick ...	585
Table A9-6: Electricity Generation and GHG Emission Details for Quebec	586
Table A9-7: Electricity Generation and GHG Emission Details for Ontario	587
Table A9-8: Electricity Generation and GHG Emission Details for Manitoba.....	588
Table A9-9: Electricity Generation and GHG Emission Details for Saskatchewan.....	589
Table A9-10: Electricity Generation and GHG Emission Details for Alberta	590
Table A9-11: Electricity Generation and GHG Emission Details for British Columbia.....	591
Table A9-12: Electricity Generation and GHG Emission Details for Yukon, Northwest Territories, and Nunavut	592
Table A10-1: Trends in GHG Emissions and GHG Intensity, Newfoundland and Labrador.....	594
Table A10-2: Trends in GHG Emissions and GHG Intensity, Prince Edward Island....	597
Table A10-3: Trends in GHG Emissions and GHG Intensity, Nova Scotia.....	600
Table A10-4: Trends in GHG Emissions and GHG Intensity, New Brunswick	602
Table A10-5: Trends in GHG Emissions and GHG Intensity, Quebec	605
Table A10-6: Trends in GHG Emissions and GHG Intensity, Ontario	608
Table A10-7: Trends in GHG Emissions and GHG Intensity, Manitoba	610
Table A10-8: Trends in GHG Emissions and GHG Intensity, Saskatchewan.....	612
Table A10-9: Trends in GHG Emissions and GHG Intensity, Alberta	615
Table A10-10: Trends in GHG Emissions and GHG Intensity, British Columbia.....	617
Table A10-11: Trends in GHG Emissions and GHG Intensity, Total Territories	620
Table A10-12: Trends in GHG Emissions, Yukon.....	620

Table A10-13: Trends in GHG Emissions, Northwest Territories and Nunavut.....	620
Table A11-1: GHG Category Description	625
Table A11-2: 1990–2005 GHG Emissions Summary for Newfoundland and Labrador	626
Table A11-3: 2005 GHG Emissions Summary for Newfoundland and Labrador.....	627
Table A11-4: 1990–2005 GHG Emissions Summary for Prince Edward Island	628
Table A11-5: 2005 GHG Emissions Summary for Prince Edward Island	629
Table A11-6: 1990–2005 GHG Emissions Summary for Nova Scotia	630
Table A11-7: 2005 GHG Emissions Summary for Nova Scotia	631
Table A11-8: 1990–2005 GHG Emissions Summary for New Brunswick.....	632
Table A11-9: 2005 GHG Emissions Summary for New Brunswick.....	633
Table A11-10: 1990–2005 GHG Emissions Summary for Quebec.....	634
Table A11-11: 2005 GHG Emissions Summary for Quebec.....	635
Table A11-12: 1990–2005 GHG Emissions Summary for Ontario.....	636
Table A11-13: 2005 GHG Emissions Summary for Ontario.....	637
Table A11-14: 1990–2005 GHG Emissions Summary for Manitoba	638
Table A11-15: 2005 GHG Emissions Summary for Manitoba	639
Table A11-16: 1990–2005 GHG Emissions Summary for Saskatchewan	640
Table A11-17: 2005 GHG Emissions Summary for Saskatchewan	641
Table A11-18: 1990–2005 GHG Emissions Summary for Alberta.....	642
Table A11-19: 2005 GHG Emissions Summary for Alberta.....	643
Table A11-20: 1990–2005 GHG Emissions Summary for British Columbia	644
Table A11-21: 2005 GHG Emissions Summary for British Columbia	645
Table A11-22: 1990–2005 GHG Emissions Summary for Yukon.....	646
Table A11-23: 2005 GHG Emissions Summary for Yukon.....	647
Table A11-24: 1990–2005 GHG Emissions Summary for Northwest Territories and Nunavut.....	648
Table A11-25: 2005 GHG Emissions Summary for Northwest Territories and Nunavut.....	649
Table A12-1: Emission Factors for Natural Gas and NGLs	651
Table A12-2: Emission Factors for Refined Petroleum Products.....	653
Table A12-3: CO ₂ Emission Factors for Petroleum Coke and Still Gas	654
Table A12-4: N ₂ O Emission Factors for Petroleum Coke.....	654
Table A12-5: CO ₂ Emission Factors for Coal and Coal Products.....	656
Table A12-6: CH ₄ and N ₂ O Emission Factors for Coals ¹	657
Table A12-7: Emission Factors for Energy Mobile Combustion Sources	658
Table A12-8: Emission Factors for Fugitive Sources — Coal Mining	659
Table A12-9: Emission Factors for Industrial Process Sources.....	660
Table A12-10: Emission Factors for Consumption of HFCs in 1995	661
Table A12-11: Emission Rates for Consumption of HFCs and PFCs.....	662
Table A12-12: CO ₂ Emission Factors for Coal and Coal Products.....	663
Table A12-13: CO ₂ Emission Factors for Various Refined Petroleum Products	664
Table A12-14: CO ₂ Emission Factors for Natural Gas Liquids	664
Table A12-15: CO ₂ Emission Factors for Non-Energy Petroleum Products.....	664
Table A12-16: Emission Factors for Solvent and Other Product Use.....	664
Table A12-17: CH ₄ Emission Factors for Livestock and Manure.....	665

Table A12-18: Enteric Fermentation and Manure Management Emission Factors for Dairy Cattle from 1990 to 2004	666
Table A12-19: Nitrogen Excretion Rate by Animal Type.....	666
Table A12-20: Percentage of Manure Nitrogen Handled by Animal Waste Management Systems	666
Table A12-21: Percentage of Manure Nitrogen Lost as N ₂ O by Animal Type.....	667
Table A12-22: Emission Factors for Biomass	668
Table A13-1: Number of Significant Figures Applied to GHG Summary Tables	673
Table A14-1: Carbon Monoxide Emissions Summary for Canada	677
Table A14-2: Nitrogen Oxides Emissions Summary for Canada.....	678
Table A14-3: Non-Methane Volatile Organic Compounds Emissions Summary for Canada.....	679
Table A14-4: Sulphur Oxides Emissions Summary for Canada	680

List of Figures

Figure S-1: Canadian GHG Emission Trend and Kyoto Target	4
Figure S-2: Trends in GHG Emissions per Capita and per Unit GDP, 1990–2005.....	6
Figure S-3: Sectoral Breakdown of Canada’s GHG Emissions, 2005.....	7
Figure S-4: Total Provincial/Territorial GHG Emissions, 1990 and 2005	18
Figure 1-1: Annual Canadian Temperature Departures and Long-Term Trend, 1948–2005.....	19
Figure 1-2: Global Atmospheric Concentrations of CO ₂ , 1992–2005.....	20
Figure 1-3: Global Atmospheric Concentrations of CH ₄ , 1992–2005.....	22
Figure 1-4: Global Atmospheric Concentrations of N ₂ O, 1993–2005	23
Figure 1-5: Per Capita GHG Emission Trend for Canada, 1990–2005	25
Figure 1-6: Change in Aggregate GHG Emissions for Annex I Parties, 1990–2004	26
Figure 1-7: Partners of the National Inventory System	28
Figure 1-8: Reported GHG Emissions for Subsectors of Manufacturing (NAICS 31-33).....	37
Figure 1-9: Reported GHG Emissions for Subsectors of Mining and Oil & Gas Extraction (NAICS 21)	38
Figure 2-1: Canada’s GHG Emissions by Gas, 1990 and 2005 (excluding LULUCF)....	43
Figure 2-2: GHG Emissions from the Residential and Commercial Sectors Relative to HDDs, 1990–2005	51
Figure 2-3: GHG Emissions from Industrial Processes by Category, 1990–2005	52
Figure 2-4: GHG Emissions from Agriculture, 1990–2005	55
Figure 2-5: GHG Emissions from LULUCF Relative to Total Canadian Emissions, 1990–2005.....	56
Figure 2-6: Selected GHG Emissions and Removals in LULUCF, 1990–2005.....	57
Figure 2-7: GHG Emissions from Waste, 1990–2005.....	59
Figure 2-8: Per Capita GHG Emission Trend for Waste, 1990–2005	61
Figure 3-1: GHG Emissions from Fuel Combustion, 1990–2005	63
Figure 7-1: Reporting Zones.....	183
Figure 7-2: Large Annual Carbon Fluxes to and from the Atmosphere in Managed Forests, 1990-2005.....	186
Figure 7-3: Trends in the Forest Land Category Reported in the 2006 and 2007 Submissions	188
Figure 7-4: Areas and CO ₂ Emissions from Managed Peatlands in 1990–2005	207
Figure A1-1: Contributions of Key Categories to Level Assessment with and without LULUCF	278
Figure A1-2: Contributions of Key Categories to Trend Assessment with and without LULUCF	280
Figure A2-1: GHG Estimation Process Flow	287
Figure A2-2: Technology Penetration for Light Duty Gasoline Vehicles and Trucks ...	311
Figure A3.4-1: N ₂ O Emissions as a Function of P/PE	368
Figure A3.4-2: Determination of the Ecodistrict Frac _{LEACH} Values	381
Figure A3.5-1: Carbon Transfers Between Pools at Each Annual Time Step as Modelled in CBM-CFS3	388

Figure A3.5-2: 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).....	390
Figure A3.5-3: Generic Data Inputs to the CBM-CFS3	389
Figure A3.5-4: Managed and Unmanaged Forests in Canada	392
Figure A3.5-5: Deforestation Strata and Areas Sampled for the 2006 and 2007 Submissions	393
Figure A3.5-6: Sampling Grids over Imagery for Forest Conversion Mapping and Delineated Forest Conversion Events	394
Figure A3.5-7: Procedure to Develop a Consistent Time Series of Rates of Forest Conversion	396
Figure A3.5-8: Annual Rates of Forest Conversion in Canada	397
Figure A3.5-9: Soil Carbon for a Base Crop Mix and for Perennial (Alfalfa) Substituted for Annual Crops (Wheat) and for No-Till Substituted for Intensive Till Based on CENTURY Runs for a Lethbridge Loam	408
Figure A3.5-10: Change in SOC for Simulations with Substitutions Relative to Simulations with Base Crop Mix	408
Figure A3.5-11: F_{LMC} from Exponential Equation	410
Figure A3.5-12: Soil Carbon Change since Breaking of Grassland to Cropland	422
Figure A3.5-13: CENTURY-Simulated SOC Following Deforestation of Long-Term Deciduous Forest to Cropland	425
Figure A3.5-14: Logarithmic Curve Fits for Taiga/Boreal Reservoirs and Cordillera Reservoirs	436
Figure A3.5-15: Cumulative Areas in the Category “Lands Converted to Wetlands (Flooded Lands)”	438
Figure A3.5-16: Study Areas for the Determination of Aboveground Biomass	441
Figure A3.6-1: Scholl Canyon Model Representation of Landfill Degradation.....	446
Figure A4-1: Sample of an Energy Balance Flow Diagram for Canada	506
Figure A4-2: Fossil Fuel and Energy Data Input.....	506
Figure A6-1: Typical Inventory Process.....	516
Figure A9-1: Utility Generated Electricity by Source	576
Figure A9-2: Electricity Generation By Region and Source 1990 & 2005	578
Figure A10-1: Newfoundland and Labrador Long-Term Emission Trends, 1990–2005.....	596
Figure A10-2: Newfoundland and Labrador Short-Term Emission Trends, 2003–2005.....	597
Figure A10-3: Prince Edward Island Long-Term Emission Trends, 1990–2005	599
Figure A10-4: Prince Edward Island Short-Term Emission Trends, 2003–2005.....	599
Figure A10-5: Nova Scotia Long-Term Emission Trends, 1990–2005.....	601
Figure A10-6: Nova Scotia Short-Term Emission Trends, 2003–2005	602
Figure A10-7: New Brunswick Long-Term Emission Trends, 1990–2005	604
Figure A10-8: New Brunswick Short-Term Emission Trends, 2003–2005	604
Figure A10-9: Quebec Long-Term Emission Trends, 1990–2005	607
Figure A10-10: Quebec Short-Term Emission Trends, 2003–2005	607
Figure A10-11: Ontario Long-Term Emission Trends, 1990–2005	609
Figure A10-12: Ontario Short-Term Emission Trends, 2003–2005	610

Figure A10-13: Manitoba Long-Term Emission Trends, 1990–2005	611
Figure A10-14: Manitoba Short-Term Emission Trends, 2003–2005	612
Figure A10-15: Saskatchewan Long-Term Emission Trends, 1990–2005	614
Figure A10-16: Saskatchewan Short-Term Emission Trends, 2003–2005	614
Figure A10-17: Alberta Long-Term Emission Trends, 1990–2005	616
Figure A10-18: Alberta Short-Term Emission Trends, 2003–2005	617
Figure A10-19: British Columbia Long-Term Emission Trends, 1990–2005	619
Figure A10-20: British Columbia Short-Term Emission Trends, 2003–2005	619
Figure A10-21: Yukon Long-Term Emission Trends, 1990–2005	621
Figure A10-22: Northwest Territories and Nunavut Long-Term Emission Trends, 1990–2005	622
Figure A10-23: Yukon Short-Term Emission Trends, 2003–2005	622
Figure A10-24: Northwest Territories and Nunavut Short-Term Emission Trends, 2003–2005	623

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 UNFCCC reporting guidelines. The year 2007 marks the production of Canada's 13th National Inventory Report (NIR). It is also the third 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 (NIR) and Common Reporting Format (CRF) 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.

Guidelines under the UNFCCC have a number of implications on 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 now requires that countries identify, quantify, and reduce uncertainty of estimates as far as practicable. This will result 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. This requires that a number of key inventory planning, preparation, and management functions be performed. The current report provides a short discussion (in Chapter 1) on the system that Canada has developed. A full description of the national system in accordance with guidelines under Article 5.1 of the Protocol has been included, among other things, in Canada's initial report, submitted to the UNFCCC earlier this year. In that report, Canada also provided a calculation of its assigned amount (emissions target) under Article 7.4. The initial report, along with the inventory submitted in 2006 will be subjected to a full review by the UNFCCC in the fall of 2007.

This year's GHG inventory incorporates further improvements in the estimation methodologies, including the results of a study on fugitive emissions from the non-conventional oil extraction industry. New vehicle data and emission factors have been

incorporated into the transportation model and revised estimation methods have been utilized in the Waste sector. In developing the estimates, quality assurance/quality control (QA/QC) procedures continue to be used to formally ensure and document the quality of the estimates. A new Quality Management group has been established and a full quality control plan has been developed, as well as improved archiving and documenting procedures.

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, provincial and territorial emissions for the period 1990–2005. Chapter 1, the Introduction, provides an overview of the most recent 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 QA/QC procedures, and explanations of major changes to this year's inventory 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 emissions and removals category according to UNFCCC CRF requirements. Chapter 9 presents a summary of recalculations and planned improvements. Annexes 1–7 provide a key category analysis, detailed explanations of estimation methodologies, a comparison of the sectoral and reference approaches, a more complete description of QA/QC 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 annually Canada's GHG inventory. The GHGs for which emissions and removals have been estimated in the national inventory are:

- carbon dioxide (CO₂);
- methane (CH₄);
- nitrous oxide (N₂O);
- sulphur hexafluoride (SF₆);
- 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) (see above). 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 category and subsector divisions.¹ 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_x), carbon monoxide (CO), and non-methane volatile organic compounds (NMVOCs), as well as on sulphur dioxide (SO₂).

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

In 2005, Canadians contributed about 747 megatonnes of CO₂ equivalent (Mt CO₂ eq)² of GHGs to the atmosphere (Figure S-1),³ a decrease of 0.1% over the 747 Mt recorded for the year 2004. This small decline in emissions follows a year of relatively modest growth in emissions such that the overall trend from 2003 is flat. Canada's economic GHG intensity — the amount of GHGs emitted per unit of economic activity — was 5.8% lower in 2005 than in 2004. Since 1990, emissions have increased by about 25%.

¹ Minor differences exist between the UNFCCC and Canada's national inventory sector designations. These are explained in footnotes throughout this report. More details can be found in Chapters 3–8, 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 (GWP) has been introduced to equate this climate forcing for different GHGs to that of CO₂. 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 CO₂ equivalent.

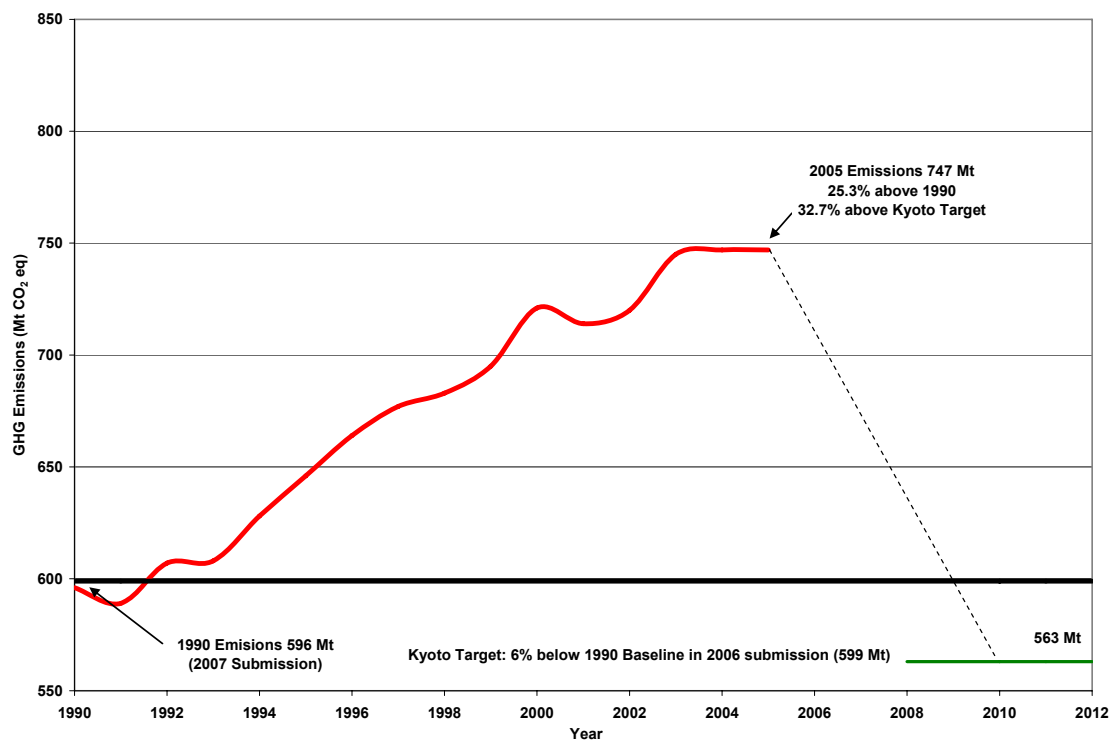


Figure S-1: Canadian GHG Emission Trend and Kyoto Target

Table S-1 depicts Canada's total GHG emissions from 1990 to 2005, 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 25% increase in GHG emissions during the 15-year period outpaced increases in population (which totalled 16.5%) and approximately equalled the increase in energy use (which was 23%). However, the growth in total emissions was well short of the 53% growth in GDP between 1990 and 2005 (Informetrica-2006: Industrial Sector Real Gross Domestic Product - millions of 1997 dollars).

The result is that economic GHG intensity has decreased by a total of 18% over the period, an average of 1.2% 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. This is to some extent related to energy efficiency improvements that have taken place in the Canadian economy since 1990 (NRCan, 2005).

Another trend worth noting is the much larger growth in energy *production* than 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.)

Table S-1: Canada's GHG Emissions and Accompanying Variables, 1990–2005

Year	1990	1995	2000	2001	2002	2003	2004	2005
Total GHG (Mt)	596	646	721	714	720	745	747	747
<i>Growth Since 1990</i>	<i>N/A</i>	<i>8.3%</i>	<i>21.0%</i>	<i>19.8%</i>	<i>20.9%</i>	<i>25.0%</i>	<i>25.4%</i>	<i>25.3%</i>
<i>Annual Change</i>	<i>N/A</i>	<i>2.8%</i>	<i>3.7%</i>	<i>-0.9%</i>	<i>0.9%</i>	<i>3.4%</i>	<i>0.3%</i>	<i>-0.1%</i>
<i>Average Annual Change</i>	<i>N/A</i>	<i>1.7%</i>	<i>2.1%</i>	<i>1.8%</i>	<i>1.7%</i>	<i>1.9%</i>	<i>1.8%</i>	<i>1.7%</i>
GDP - Expense¹	707 669	772 842	946 025	960 657	989 337	1 012 785	1 045 795	1 078 922
<i>Growth Since 1990</i>	<i>N/A</i>	<i>9.2%</i>	<i>33.7%</i>	<i>35.7%</i>	<i>39.8%</i>	<i>43.1%</i>	<i>47.8%</i>	<i>52.5%</i>
<i>Annual Change</i>	<i>N/A</i>	<i>2.6%</i>	<i>5.5%</i>	<i>1.5%</i>	<i>3.0%</i>	<i>2.4%</i>	<i>3.3%</i>	<i>3.2%</i>
<i>Average Annual Change</i>	<i>N/A</i>	<i>1.8%</i>	<i>3.4%</i>	<i>3.2%</i>	<i>3.3%</i>	<i>3.3%</i>	<i>3.4%</i>	<i>3.5%</i>
GHG Intensity (Mt/\$B GDP)	0.84	0.84	0.76	0.74	0.728	0.736	0.715	0.692
<i>Growth Since 1990</i>	<i>N/A</i>	<i>-0.8%</i>	<i>-9.5%</i>	<i>-11.7%</i>	<i>-13.5%</i>	<i>-12.7%</i>	<i>-15.1%</i>	<i>-17.8%</i>
<i>Annual Change</i>	<i>N/A</i>	<i>0.2%</i>	<i>-1.7%</i>	<i>-2.4%</i>	<i>-2.1%</i>	<i>1.0%</i>	<i>-2.8%</i>	<i>-3.1%</i>
<i>Average Annual Change</i>	<i>N/A</i>	<i>-0.2%</i>	<i>-1.0%</i>	<i>-1.1%</i>	<i>-1.1%</i>	<i>-1.0%</i>	<i>-1.1%</i>	<i>-1.2%</i>
GHG Efficiency (\$GDP/Kt GHG)	1.19	1.20	1.31	1.35	1.373	1.360	1.399	1.445
<i>Growth Since 1990</i>	<i>N/A</i>	<i>0.8%</i>	<i>10.5%</i>	<i>13.3%</i>	<i>15.6%</i>	<i>14.5%</i>	<i>17.8%</i>	<i>21.7%</i>
<i>Annual Change</i>	<i>N/A</i>	<i>-0.2%</i>	<i>1.7%</i>	<i>2.5%</i>	<i>2.1%</i>	<i>-1.0%</i>	<i>2.9%</i>	<i>3.2%</i>
<i>Average Annual Change</i>	<i>N/A</i>	<i>0.2%</i>	<i>1.1%</i>	<i>1.2%</i>	<i>1.3%</i>	<i>1.1%</i>	<i>1.3%</i>	<i>1.4%</i>
Population (000s)²	27 698	29 302	30 689	31 021	31 373	31 669	31 974	32 271
<i>Growth Since 1990</i>	<i>N/A</i>	<i>5.8%</i>	<i>10.8%</i>	<i>12.0%</i>	<i>13.3%</i>	<i>14.3%</i>	<i>15.4%</i>	<i>16.5%</i>
<i>Annual Change</i>	<i>N/A</i>	<i>1.0%</i>	<i>0.9%</i>	<i>1.1%</i>	<i>1.1%</i>	<i>0.9%</i>	<i>1.0%</i>	<i>0.9%</i>
<i>Average Annual Change</i>	<i>N/A</i>	<i>1.2%</i>	<i>1.1%</i>	<i>1.1%</i>	<i>1.1%</i>	<i>1.1%</i>	<i>1.1%</i>	<i>1.1%</i>
GHG Per Capita (tonnes/person)	21.5	22.0	23.5	23.0	22.96	23.52	23.37	23.14
<i>Growth Since 1990</i>	<i>N/A</i>	<i>2.4%</i>	<i>9.2%</i>	<i>7.0%</i>	<i>6.7%</i>	<i>9.3%</i>	<i>8.6%</i>	<i>7.6%</i>
<i>Annual Change</i>	<i>N/A</i>	<i>1.8%</i>	<i>2.7%</i>	<i>-2.0%</i>	<i>-0.3%</i>	<i>2.4%</i>	<i>-0.6%</i>	<i>-1.0%</i>
<i>Average Annual Change</i>	<i>N/A</i>	<i>0.5%</i>	<i>0.9%</i>	<i>0.6%</i>	<i>0.6%</i>	<i>0.7%</i>	<i>0.6%</i>	<i>0.5%</i>
Energy Use (PJ)³	9 230	9 695	10 830	10 950	11 076	11 363	11 528	11 310
<i>Growth Since 1990</i>	<i>N/A</i>	<i>5.0%</i>	<i>17.3%</i>	<i>18.6%</i>	<i>20.0%</i>	<i>23.1%</i>	<i>24.9%</i>	<i>22.5%</i>
<i>Annual Change</i>	<i>N/A</i>	<i>1.4%</i>	<i>3.0%</i>	<i>1.1%</i>	<i>1.2%</i>	<i>2.6%</i>	<i>1.5%</i>	<i>-1.9%</i>
<i>Average Annual Change</i>	<i>N/A</i>	<i>1.0%</i>	<i>1.7%</i>	<i>1.7%</i>	<i>1.7%</i>	<i>1.8%</i>	<i>1.8%</i>	<i>1.5%</i>
Energy Produced (PJ)⁵	7 746	10 299	11 729	11 949	12 336	12 491	12 744	12 798
<i>Growth Since 1990</i>	<i>N/A</i>	<i>33.0%</i>	<i>51.4%</i>	<i>54.3%</i>	<i>59.3%</i>	<i>61.3%</i>	<i>64.5%</i>	<i>65.2%</i>
<i>Annual Change</i>	<i>N/A</i>	<i>4.6%</i>	<i>3.8%</i>	<i>1.9%</i>	<i>3.2%</i>	<i>1.3%</i>	<i>2.0%</i>	<i>0.4%</i>
<i>Average Annual Change</i>	<i>N/A</i>	<i>6.6%</i>	<i>5.1%</i>	<i>4.9%</i>	<i>4.9%</i>	<i>4.7%</i>	<i>4.6%</i>	<i>4.3%</i>
Energy Exported (PJ)⁴	3 040	5 447	7 069	7 317	7 504	7 482	7 833	7 789
<i>Growth Since 1990</i>	<i>N/A</i>	<i>79.2%</i>	<i>132.5%</i>	<i>140.7%</i>	<i>146.8%</i>	<i>146.1%</i>	<i>157.6%</i>	<i>156.2%</i>
<i>Annual Change</i>	<i>N/A</i>	<i>8.7%</i>	<i>8.2%</i>	<i>3.5%</i>	<i>2.5%</i>	<i>-0.3%</i>	<i>4.7%</i>	<i>-0.6%</i>
<i>Average Annual Change</i>	<i>N/A</i>	<i>15.8%</i>	<i>13.2%</i>	<i>12.8%</i>	<i>12.2%</i>	<i>11.2%</i>	<i>11.3%</i>	<i>10.4%</i>
Emissions Associated with Exports (Mt)⁴	27.8	51.0	65.4	67.4	69.5	69.9	73.4	72.8
<i>Growth Since 1990</i>	<i>N/A</i>	<i>83.5%</i>	<i>135.4%</i>	<i>142.6%</i>	<i>150.2%</i>	<i>151.5%</i>	<i>164.1%</i>	<i>161.9%</i>
<i>Annual Change</i>	<i>N/A</i>	<i>12.1%</i>	<i>8.8%</i>	<i>3.1%</i>	<i>3.1%</i>	<i>0.5%</i>	<i>5.0%</i>	<i>-0.8%</i>
<i>Average Annual Change</i>	<i>N/A</i>	<i>16.7%</i>	<i>13.5%</i>	<i>13.0%</i>	<i>12.5%</i>	<i>11.7%</i>	<i>11.7%</i>	<i>10.8%</i>

Notes:

1 GDP: Industrial Sector Real Gross Domestic Product by NAIC Code - Millions 1997 dollars - Informetrica, 2006.

2 Source: Statistics Canada, *Annual Demographic Statistics*, 2006.

3 Statistics Canada's *Report on Energy Supply-Demand in Canada 2005 (57-003)*, Table S, Line 2.

4 Natural Gas and Crude Oil only.

PJ = petajoule. A petajoule is a measure of the energy content of fuels.

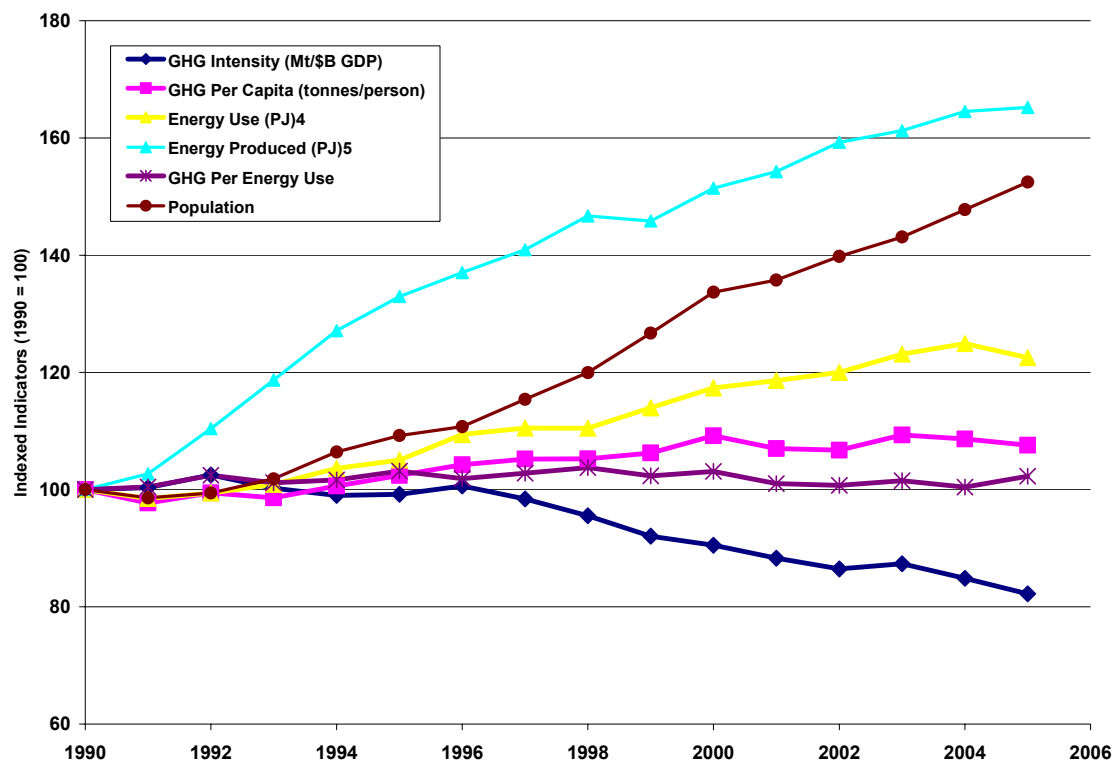


Figure S-2: Trends in GHG Emissions per Capita and per Unit GDP, 1990–2005

Changes from the Previous NIR

As a result of changes and improvements to the inventory, Canada's 1990–2004 GHG estimates have been revised since last year's report. A new study on emissions from the non-conventional oil extraction industry and updates to the transportation emission model have both affected the Energy Sector's GHG estimates. In addition, Statistics Canada's underlying energy data for 2004 were updated, primarily affecting the estimates for electricity emissions. New survey data on the amount of waste land filled and updated parameters have been incorporated into the estimation model for emissions from landfills, leading to revised GHG estimates for the Waste Sector. Finally, refinements have been incorporated into the agricultural emission estimates. Taken together, these changes are the primary contributors to the revised national GHG estimates.

As a result, total GHG emissions (without LULUCF) previously reported for 1990 have been revised downward from 599 to 596 Mt while those for 2004 have been revised downward from 758 Mt to 747 Mt. The overall impact of these changes is that emission growth over the period 1990–2004, previously reported to be 26.6%, is now estimated to be 25.4%.

ES.3 Emissions and Removals Estimates and Trends

ES.3.1 2005 Emissions and Removals

Table S-2 details Canada's emissions and removals for 2005. On an individual GHG basis, CO₂ contributed 78% of the total emissions, while CH₄ accounted for 15%. N₂O accounted for 6% of the emissions, while PFCs, SF₆, and HFCs constituted the remainder.

Approximately 73% of total GHG emissions in 2005 resulted from the combustion of fossil fuels. Another 9% were from fugitive sources, with the result that almost 82% of emissions were from the Energy Sector. A sectoral breakdown of Canada's total emissions for 2005 is shown in Figure S-3.

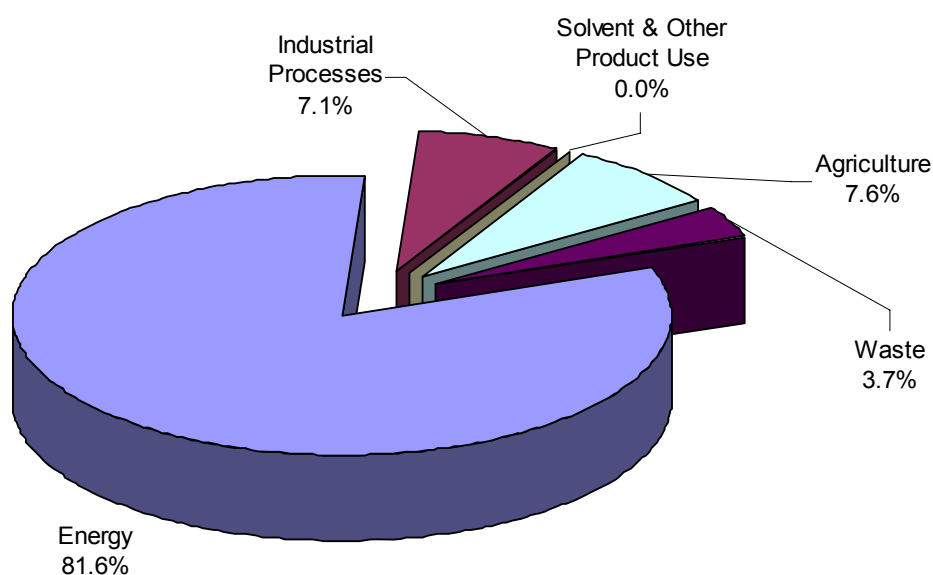


Figure S-3: Sectoral Breakdown of Canada's GHG Emissions, 2005

As per reporting requirements, the LULUCF Sector estimates are not included in the national totals. This sector displays net overall removals of 17 Mt for 2005. This would, if included, reduce the total Canadian GHG emissions by 2%.

Table S-2: Canada's GHG Emissions by Gas and Sector, 2005

Greenhouse Gas Categories		Greenhouse Gases								TOTAL
Global Warming Potential	Unit	CO ₂	CH ₄	CH ₄	N ₂ O	N ₂ O	HFCs	PFCs	SF ₆	
				21		310				
		kt	kt	kt CO ₂ eq	kt	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	
TOTAL¹		583 000	5 200	110 000	140	44 000	4 800	3 100	2 500	747 000
ENERGY		544 000	2 600	54 000	30	10 000	—	—	—	609 000
a. Stationary Combustion Sources		338 000	200	5 000	8	3 000	—	—	—	346 000
Electricity and Heat Generation		128 000	5.1	110	2	700	—	—	—	129 000
Fossil Fuel Industries		70 400	100	3 000	2	500	—	—	—	73 000
Petroleum Refining and Upgrading		18 000	—	—	0.4	100	—	—	—	18 000
Fossil Fuel Production		52 000	100	3 000	1	400	—	—	—	55 000
Mining & Oil and Gas Extraction		15 500	0.3	6	0.4	100	—	—	—	15 600
Manufacturing Industries		45 400	3	60	2	500	—	—	—	45 900
Iron and Steel		6 460	0.2	5	0.2	60	—	—	—	6 520
Non Ferrous Metals		3 170	0.07	2	0.05	20	—	—	—	3 190
Chemical		5 320	0.11	2.3	0.09	30	—	—	—	5 350
Pulp and Paper		7 040	2	40	0.8	300	—	—	—	7 340
Cement		4 570	0.1	2	0.04	10	—	—	—	4 580
Other Manufacturing		18 800	0.4	8	0.4	100	—	—	—	18 900
Construction		1 300	0.02	0.5	0.03	10	—	—	—	1 310
Commercial & Institutional		36 600	0.6	10	0.7	200	—	—	—	36 800
Residential		39 500	90	2 000	2	500	—	—	—	42 000
Agriculture & Forestry		1 930	0.03	0.7	0.06	20	—	—	—	1 950
b. Transportation²		190 000	30	600	20	8 000	—	—	—	200 000
Domestic Aviation		8 420	0.5	9	0.8	200	—	—	—	8 700
Road Transportation		131 000	9.4	200	11	3 500	—	—	—	135 000
Light Duty Gasoline Vehicles		39 800	3.2	66	4.1	1 300	—	—	—	41 200
Light Duty Gasoline Trucks		42 800	3.2	67	5.3	1 600	—	—	—	44 500
Heavy Duty Gasoline Vehicles		6 370	0.38	8.0	0.43	130	—	—	—	6 510
Motorcycles		255	0.16	3.5	0.01	1.5	—	—	—	260
Light Duty Diesel Vehicles		432	0.01	0.2	0.03	10	—	—	—	443
Light Duty Diesel Trucks		2 150	0.05	1	0.2	50	—	—	—	2 200
Heavy Duty Diesel Vehicles		38 600	2	40	1	400	—	—	—	39 000
Propane & Natural Gas Vehicles		706	0.7	10	0.01	4	—	—	—	720
Railways		5 620	0.3	6	2	700	—	—	—	6 000
Domestic Marine		6 070	0.4	9	1	400	—	—	—	6 500
Others		38 000	20	400	9	3 000	—	—	—	40 000
Off Road Gasoline		7 000	8	200	0.2	50	—	—	—	7 000
Off Road Diesel		21 000	1	20	9	3 000	—	—	—	20 000
Pipelines		9 850	9.8	210	0.3	80	—	—	—	10 100
c. Fugitive Sources		16 000	2 300	49 000	0.1	40	—	—	—	65 700
Coal Mining		—	30	700	—	—	—	—	—	700
Oil and Natural Gas		16 500	2 310	48 500	0.1	40	—	—	—	65 000
Oil		170	260	5 460	0.1	30	—	—	—	5 660
Natural Gas		61.0	989	20 800	—	—	—	—	—	20 800
Venting		10 800	1 050	22 100	0.01	4.56	—	—	—	33 000
Flaring		5 400	3.7	78	0.01	2	—	—	—	5 500
INDUSTRIAL PROCESSES		39 000	—	—	12.6	3 910	4 800	3 100	2 500	53 300
a. Mineral Products		9 500	—	—	—	—	—	—	—	9 500
Cement Production		7 200	—	—	—	—	—	—	—	7 200
Lime Production		1 700	—	—	—	—	—	—	—	1 700
Mineral Product Use ³		599	—	—	—	—	—	—	—	599
b. Chemical Industry		5 000	—	—	12.6	3 910	—	—	—	8 900
Ammonia Production		5 000	—	—	—	—	—	—	—	5 000
Nitric Acid Production		—	—	—	4.08	1 260	—	—	—	1 260
Adipic Acid Production		—	—	—	8.5	2 600	—	—	—	2 600
c. Metal Production		11 900	—	—	—	—	—	3 000	1 320	16 200
Iron and Steel Production		7 010	—	—	—	—	—	—	—	7 010
Aluminum Production		4 800	—	—	—	—	—	3 000	17.6	7 900
SF ₆ Used in Magnesium Smelters and Casters		—	—	—	—	—	—	—	1 300	1 300
d. Consumption of Halocarbons and SF₆		—	—	—	—	—	4 800	30	1 200	6 100
e. Other & Undifferentiated Production		13 000	—	—	—	—	—	—	—	13 000
SOLVENT & OTHER PRODUCT USE		—	—	—	0.57	180	—	—	—	180
AGRICULTURE		—	1 300	28 000	93	29 000	—	—	—	57 000
a. Enteric Fermentation		—	1 200	25 000	—	—	—	—	—	25 000
b. Manure Management		—	150	3 200	17	5 400	—	—	—	8 600
c. Agriculture Soils		—	—	—	76	23 000	—	—	—	23 000
Direct Sources		—	—	—	41	13 000	—	—	—	13 000
Pasture, Range and Paddock Manure		—	—	—	14	4 400	—	—	—	4 400
Indirect Sources		—	—	—	20	6 000	—	—	—	6 000
WASTE		190	1 300	27 000	2	700	—	—	—	28 000
a. Solid Waste Disposal on Land		—	1 300	27 000	—	—	—	—	—	27 000
b. Wastewater Handling		—	12	250	2	700	—	—	—	930
c. Waste Incineration		190	0.06	1	0.2	50	—	—	—	240
Land Use, Land-use Change and Forestry		-26 000	260	5 400	11	3 400	—	—	—	-17 000
a. Forest Land		-35 000	240	5 100	10	3 100	—	—	—	-27 000
b. Cropland		180	9	200	0.5	200	—	—	—	520
c. Grassland		—	—	—	—	—	—	—	—	—
d. Wetlands		1 000	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 CO₂ emissions coming from the use of limestone & dolomite, soda ash, and magnesite.

Totals may not add up due to rounding.

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 2005. As indicated above, emissions in both 2004 and 2005 are estimated at about 747 Mt CO₂e, which represents a slight increase from 2003 levels. Overall, the long term trend indicates emissions in 2005 were 25.3 % above the revised 1990 total of 596Mt.

Previous Two Years

Since 2003, growth in GHG emissions has been quite minor (about 2 Mt, or only 0.3%). Though there were some large increases in certain areas (notably Transportation and, to a smaller extent, the Agriculture Sector) these were offset by a significant decline in Electricity and Heat Generation. In addition, there was an uncharacteristically small emission increase from the fossil fuel industries and a decline in the Residential and Commercial/Institutional subsectors.

Between 2003 and 2005, despite increasing electricity demand, greenhouse gas emissions from Electricity and Heat Generation decreased by over 6 Mt. due to a reduction in emissions from coal-fired generation, brought on by an increase in nuclear and hydro electricity production. The return to service of a number of nuclear units in Ontario had the greatest impact on reducing the use of coal generation during this period. The decrease in GHG emissions from coal was further enhanced by fuel switching in a number of regions, which resulted in natural gas-based generation offsetting other fossil fuels with higher emission intensity.

The fossil fuel industries⁴, consisting of oil, gas and coal production, refining and transmission showed a rather small (0.5% or 3/4 Mt) growth between 2003 and 2005. During the period, average oil and gas production increased by only 1.2% annually. The slowing of natural gas production has primarily been due to declines in production in the Athabasca basin in Alberta, the largest gas producing area in Canada (J. Nyboer and Tu, K., 2007). The decline in crude oil production can be linked to incidents which occurred in the oil sands industry. Between 2004 and 2005, several planned and unplanned plant outages at major oil sands production facilities (including one due to a fire) lowered synthetic crude output.

On average, Canadian homes and businesses required lower energy quantities for space heating in the winters of 2005 and 2004 compared to the winter of 2003 due to milder temperatures. In 2005, Heating Degree Days (HDD), an indicator of the necessity for space heating due to the severity of cold weather, were down 5 percent compared to 2003

⁴ Sum of Petroleum Refining, Fossil Fuel Production, Pipelines (Transportation) and Fugitives.

and 2.2 percent compared to 2004, both on a National basis. This fact likely had an impact on fossil fuel consumption, specifically in the Residential and Commercial/Institutional subsectors where emissions declined by a total of 4.4 Mt in the two year period.

Year-Over-Year Changes

While there were very small increases in most sectors between 2004 and 2005 (Energy, Waste and Agriculture), the overall change was close to zero owing mainly to reduced emissions from both the Chemical Industries and Metal Production subsectors of Industrial Processes.

Energy Sector emissions showed a minimal increase (of about 1 Mt). Electricity and Heat Generation showed a minimal increase, which is partially the result of ongoing efforts in Ontario to close that province's coal generation plants (Nyboer *et al.*, 2006).

In the Transportation subsector, emissions from heavy duty diesel vehicles (HDDVs, large transport trucks) increased approximately 1.6 Mt since 2004, continuing the long term trend which has been occurring since 1990.

On average, Canadian homes and businesses required lower energy quantities for space heating in the winter of 2005 compared with the winter of 2004 due to milder temperatures. In 2005, the number of heating degree-days (HDDs) was down 2.8% on a national basis compared with 2004. This affected the residential category, where emissions declined by 1 Mt from 2004.

GHG emissions from the Industrial Process Sector decreased by over 2 Mt between 2004 and 2005. Reductions were observed primarily in Chemical Industries and Iron and Steel production. Varying drivers for these decreases were noted including reduced output due to maintenance and workforce issues. The fall in Chemical Industry emissions includes a 0.5 Mt reduction from Canada's only adipic acid producer, due to the improved utilization of its N₂O abatement system.

Emissions from the Agriculture Sector grew by 1/3 Mt (0.6%) between 2004 and 2005 as a result of an increase in beef cattle population (2.4%) being offset by a decrease in synthetic nitrogen fertilizer consumption (6.7%).

ES.3.2.2 Long-Term Trends

Although the long-term (1990–2005) sectoral emission trends showed both declines and increases, the increases were well ahead of the declines, for a net growth of 151 Mt, or 25%. 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 & 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)⁵. The fossil fuel industries registered a net increase of about 48 Mt of GHG emissions from 1990 to 2005 (48% growth). These emissions are related to coal mining and the production, transmission, processing, refining, and distribution of all oil and gas products.

By 2005, total production of crude oil and natural gas showed a 65% increase over 1990 levels (see Section ES.4.1). Elevated demand in both Canada and the United States drove these trends, with the export market growing by far the most rapidly (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.

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, 2006). At the same time, highly energy- and GHG-intensive⁶ synthetic oil production (i.e., from oil sands) has become increasingly competitive with conventional oil extraction. These trends then also contribute significantly to the rapidly rising emission increases in the oil and gas industry over the 1990–2005 period.

⁵ 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.

⁶ Nyboer and Tu (2006) estimate 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.

Table S-3: Canada's GHG Emissions by Sector, 1990–2005

Greenhouse Gas Categories	1990	1995	2000	2004	2005
	<i>kt CO₂ eq</i>				
TOTAL	596 000	646 000	721 000	747 000	747 000
ENERGY	473 000	514 000	592 000	608 000	609 000
a. Stationary Combustion Sources	282 000	294 000	344 000	349 000	346 000
Electricity and Heat Generation	95 300	101 000	132 000	127 000	129 000
Fossil Fuel Industries	52 000	54 000	67 000	72 000	73 000
Petroleum Refining and Upgrading	16 000	14 000	14 000	18 000	18 000
Fossil Fuel Production	36 000	40 000	53 000	54 000	55 000
Mining	6 180	7 850	10 400	14 800	15 600
Manufacturing Industries	54 700	52 900	53 000	50 900	45 900
Iron and Steel	6 490	7 040	7 190	6 480	6 520
Non-Ferrous Metals	3 180	3 090	3 190	3 230	3 190
Chemical	7 090	8 450	7 850	6 760	5 350
Pulp and Paper	13 600	11 700	11 000	9 310	7 340
Cement	3 690	3 670	3 890	4 210	4 580
Other Manufacturing	20 600	19 000	19 900	20 900	18 900
Construction	1 880	1 180	1 080	1 350	1 310
Commercial & Institutional	25 800	29 000	33 200	37 900	36 800
Residential	44 000	45 000	45 000	43 000	42 000
Agriculture & Forestry	2 420	2 790	2 570	2 100	1 950
b. Transportation²	150 000	160 000	180 000	190 000	200 000
Domestic Aviation	6 400	5 900	6 600	7 900	8 700
Road Transportation	101 000	112 000	122 000	133 000	135 000
Light-Duty Gasoline Vehicles	47 200	45 700	43 300	42 400	41 200
Light-Duty Gasoline Trucks	21 300	28 700	37 900	43 300	44 500
Heavy-Duty Gasoline Vehicles	8 050	6 270	5 450	6 600	6 510
Motorcycles	151	125	163	252	260
Light-Duty Diesel Vehicles	363	335	362	441	443
Light-Duty Diesel Trucks	724	1 360	1 730	2 040	2 200
Heavy-Duty Diesel Vehicles	21 200	27 100	32 100	37 400	39 000
Propane & Natural Gas Vehicles	2 200	2 100	1 100	860	720
Railways	7 000	6 000	7 000	6 000	6 000
Domestic Marine	5 100	4 400	5 100	6 700	6 500
Others	30 000	30 000	40 000	40 000	40 000
Off-Road Gasoline	7 000	7 000	8 000	8 000	7 000
Off-Road Diesel	20 000	20 000	20 000	20 000	20 000
Pipelines	6 900	12 000	11 300	8 520	10 100
c. Fugitive Sources	42 700	57 000	64 700	66 200	65 700
Coal Mining	2 000	2 000	900	700	700
Oil and Natural Gas	40 700	55 300	63 700	65 500	65 000
Oil	4 180	5 150	5 430	5 940	5 660
Natural Gas	12 900	16 500	19 400	20 400	20 800
Venting	19 300	28 600	33 500	33 700	33 000
Flaring	4 400	5 100	5 400	5 400	5 500
INDUSTRIAL PROCESSES	53 500	55 700	50 200	55 400	53 300
a. Mineral Products	8 300	8 800	9 600	9 500	9 500
Cement Production	5 400	6 100	6 700	7 100	7 200
Lime Production	1 700	1 800	1 900	1 800	1 700
Mineral Product Use ³	1 090	878	1 020	590	599
b. Chemical Industry	16 000	17 000	7 400	9 800	8 900
Ammonia Production	3 900	5 300	5 300	5 500	5 000
Nitric Acid Production	1 010	1 000	1 230	1 230	1 260
Adipic Acid Production	11 000	11 000	900	3 100	2 600
c. Metal Production	19 500	19 200	18 900	17 600	16 200
Iron and Steel Production	7 060	7 880	7 900	8 160	7 010
Aluminium Production	9 300	9 200	8 200	7 300	7 900
SF ₆ Used in Magnesium Smelters and Casters	3 110	2 110	2 780	2 190	1 300
d. Consumption of Halocarbons and SF₆	1 800	2 000	4 500	5 500	6 100
e. Other & Undifferentiated Production	8 300	8 700	9 700	13 000	13 000
SOLVENT & OTHER PRODUCT USE	170	210	240	210	180
AGRICULTURE	46 000	50 000	53 000	56 000	57 000
a. Enteric Fermentation	18 000	21 000	22 000	24 000	25 000
b. Manure Management	6 700	7 400	7 800	8 400	8 600
c. Agricultural Soils	21 000	22 000	23 000	24 000	23 000
Direct Sources	12 000	12 000	13 000	13 000	13 000
Pasture, Range, and Paddock Manure	3 200	3 700	3 900	4 300	4 400
Indirect Sources	5 000	6 000	6 000	6 000	6 000
WASTE	23 000	25 000	26 000	28 000	28 000
a. Solid Waste Disposal on Land	22 000	24 000	25 000	26 000	27 000
b. Wastewater Handling	780	810	880	930	930
c. Waste Incineration	400	350	250	230	240
LAND USE, LAND-USE CHANGE AND FORESTRY	-120 000	150 000	-110 000	81 000	-17 000
a. Forest Land	-150 000	140 000	-120 000	70 000	-27 000
b. Cropland	14 000	7 300	3 700	1 200	520
c. Grassland	-	-	-	-	-
d. Wetlands	5 000	3 000	2 000	2 000	2 000
e. Settlements	9 000	9 000	8 000	8 000	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 subcategories.

3 The category mineral product use includes CO₂ emissions from the use of limestone & dolomite, soda ash, and magnesite.

Totals may not add up due to rounding.

Electricity and Heat Generation, representing the other portion of the Energy Industries, also saw large increases in emissions. Rising demand for electricity, exacerbated by the increasing use of fossil fuels in the generation mix, drove GHG emissions up 33 Mt between 1990 and 2005. Comparatively, in 2005 electricity demand was approximately 128 terawatt-hours (TWh) above the 1990 level. Although this increased demand was supplied in part by greater hydroelectricity and nuclear generation, fossil fuel generation rose even more. By 2005, hydropower's share of the generation mix had fallen from 63% to 60%, while fossil fuels' had risen from 22% to 25%, worsening the average GHG intensity of production. The end result was that from 1990 to 2005, generation rose 28% while GHG emissions increased 35%, about 1.25 times the generation increase.

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 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 generation in Ontario, as well as fuel switching to natural gas in a number of regions of the country. Increases in interprovincial and international trade have also played a role. Though having minimal effect in the pre-2005 period, non-hydro renewable energy sources are predicted to have an impact on emission reductions post-2005. The reason for this is that the installed capacity of wind power in Canada is noted to have begun rising 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 37 Mt (33%) between 1990 and 2005. Of particular interest in this subsector is a 23 Mt increase in emissions from Light Duty Gasoline Trucks (LDGTs). This was partially offset by 6 and 1.5 Mt emission reductions from gasoline-fuelled cars (LDGVs) and alternatively fuelled cars (Propane & Natural Gas Vehicles).

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 SUVs and pickups worsened the emission impact of increasing numbers of people driving further.

Research suggests⁷ that, over the period, about 10% of the emission increase from automobiles and light trucks can 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, which has negated the rather substantial efficiency improvements made in power plants for all classes of passenger vehicles.

⁷ Adapted from NRCan (2005).

Emissions from HDDVs (large freight trucks) rose by about 18 Mt between 1990 and 2005, an 84% 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 11 Mt (43%) increase in GHG emissions between 1990 and 2005. Driving this trend was a 25.5% increase in the floor space of commercial and institutional buildings between 1990 and 2005 (e.g., offices, schools, stores, and government edifices), a result of Canada's growing economy over the period (Informetrica, 2006). Energy demand in commercial buildings is also influenced by weather. In terms of HDDs, 2005 was 5% colder than 1990, so this contributed to the emission growth; however, its impact was considerably less than that of increased floor space.

Mining showed a large increase in emissions between 1990 and 2005 — 9.4 Mt (about 151%).

Another sector that contributed, although to a lesser extent than Energy, to the longer-term growth in GHG emissions is Agriculture. This sector showed an 11 Mt increase (24%) between 1990 and 2005, resulting primarily from the expansion of the beef cattle, swine, and poultry industries, as well as an increase in synthetic nitrogen fertilizer consumption.

In addition to the already-mentioned reduction in emissions from automobiles, three subsectors, all within the Industrial Processes Sector, contributed towards counteracting 1990–2005 emission growth — Adipic Acid Production (Chemical Industry), Aluminium Production and the Use of SF₆ in Magnesium Smelters and Casters (both constituents of Metal Production)

While output increased at the sole adipic acid production plant in Canada, the installation of an emission abatement system in 1997 resulted in significant reductions of N₂O emissions. Despite being temporarily off-line in 2004, this system reduced GHG emissions by 8 Mt (75%) over the 1990–2005 period.

In the aluminium industry (which emits both CO₂ 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 2005, total GHG process emissions from the aluminium industry decreased by 1.4 Mt (15%), while primary aluminium production increased by more than 80%⁸.

⁸ Source: Aluminum Association of Canada. Data provided to Greenhouse Gas Division, Environment Canada.

Although it does not contribute to national totals, it is of interest to consider the trends in the LULUCF Sector. The net flux, calculated as the sum of CO₂ emissions and removals and non-CO₂ emissions, displays high interannual variability over the reporting period. In fact, there is no discernible trend, with the flux ranging from net emissions of 155 Mt (in 1995) to net removals of 151 Mt (in 1992). The Sector registered a net removal of 123 Mt in 1990 and 17 Mt in 2005. The interannual swings are primarily a consequence of the large and variable impact of emissions from wildfires in the managed forests, which are inventoried under the LULUCF 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.

Growth in oil and gas exports, almost all to the United States, contributed significantly to emissions growth⁹ between 1990 and 2005. In this period, oil exports grew by 148% to 3,723 petajoules (PJ)¹⁰ (almost 3 times the rate of growth of oil production) (Table S-4), while exports of natural gas increased 165% to 4,066 PJ (almost twice the rate of growth of natural gas production) (Table S-5). Over the period, the sum total of oil and gas energy exports increased by 156% (Table S-6).

The total emissions associated with the production, processing and transmission of all oil and gas destined for export was about 73 Mt in 2005, up 162% from 1990

Although Canadian fuel exports have risen dramatically, it is also interesting to note that imports, too, have risen rapidly. For instance, 73% more oil was imported in 2005 than in 2004. Clearly, the market has developed so that a considerable portion of the growth in exports has been offset by a growth in imports. Increases in the Canadian use of fuels are balanced between these large changes in exports, imports and production, such that the growth in the domestic consumption of oil and gas between 1990 and 2005 has been a more moderate 26% (Fig S-6). It is therefore logical to assume that, should exports be reduced, imports would fall as well, to maintain sufficient domestic market for production.

Since the export of oil and gas results in significant emissions, but very few Canadian GHGs are released upon the import of fuels, it is clear that any emission reduction from a

⁹ The source for all export and energy production data is Statistics Canada, #57-003. The 1990–1995 GHG emissions associated with net exports are taken from a report prepared for Environment Canada (McCann, 1997), while the 1996–2005 estimates were extrapolated from this report.

¹⁰ A petajoule (PJ) is a measure of the energy content of fuels.

lowering of exports would be tempered by an accompanying decrease in the amount of fuel being imported. The concept of net export emissions approximates this effect.¹¹

The portion of emissions from all oil and gas production, processing, and transmission activities that is attributable to net exports rose from about 22 Mt in 1990 to 49 Mt in 2005 (a 128% increase; Table S-6).¹² This 27 Mt increase is well over half of the total growth in emissions from the oil and gas industry, which is in turn almost one-third of the 151 Mt national emission growth over the period.

It should be noted that natural gas exports have not shown much increase since 2000. It has been forecasted that since the reserves in Canada's largest natural gas reservoir (the Western Sedimentary Basin) are reaching their limit, the country's natural gas production will not increase significantly in the future (Nyboer and Tu, 2006). As a result, gas exports may show very little growth from this point on.

Table S-4: Crude Oil: Production, Export, and GHG Emission Trends, 1990–2005

Crude Oil	1990	1995	2000	2003	2004	2005
Domestic Production (PJ)	3 562	4 170	4 669	5 427	5 648	5 548
<i>Growth Since 1990</i>	<i>N/A</i>	<i>17%</i>	<i>31%</i>	<i>52%</i>	<i>59%</i>	<i>56%</i>
Energy Imported (PJ)	1 200	1 319	2 042	2 028	2 090	2 072
<i>Growth Since 1990</i>	<i>N/A</i>	<i>9.9%</i>	<i>70.2%</i>	<i>68.9%</i>	<i>74.1%</i>	<i>72.6%</i>
Energy Exported (PJ)	1 503	2 436	3 222	3 605	3 810	3 723
<i>Growth Since 1990</i>	<i>N/A</i>	<i>62%</i>	<i>114%</i>	<i>140%</i>	<i>153%</i>	<i>148%</i>
Apparent Domestic Consumption (PJ)	3 259	3 053	3 489	3 850	3 928	3 897
<i>Growth Since 1990</i>	<i>N/A</i>	<i>-6.3%</i>	<i>7.0%</i>	<i>18.1%</i>	<i>20.5%</i>	<i>19.6%</i>
Emissions Associated with Gross Exports (Mt CO₂ eq.)	13.9	24.5	32.3	36.6	38.8	37.9
<i>Growth Since 1990</i>	<i>N/A</i>	<i>76.3%</i>	<i>132.6%</i>	<i>163.1%</i>	<i>179.4%</i>	<i>172.4%</i>
Emissions Associated with Net¹ Exports (Mt CO₂ eq.)	8.8	17.8	16.8	21.3	22.8	22.0
<i>Growth Since 1990</i>	<i>N/A</i>	<i>102%</i>	<i>91%</i>	<i>142%</i>	<i>159%</i>	<i>150%</i>

Note:

- 1 Net exports recognizes that a country producing fossil fuels for export to Canada has emissions associated with that production and offsets those emissions in Canada associated with our production for export.

¹¹ Net export emissions are the Canadian emissions associated with extracting, processing, and transporting exported fuel minus the foreign emissions associated with extracting, transporting and processing imported fuels. The emissions associated with net exports approximate the quantity of greenhouse gases that Canada would not emit should these exports be eliminated.

¹² Absolute emissions attributable to net exports are rough approximations. The long-term trends are considered to be more accurate.

Table S-5: Natural Gas: Production, Export, and GHG Emission Trends, 1990–2005

Natural Gas	1990	1995	2000	2003	2004	2005
Domestic Production (PJ)	4 184	6 129	7 060	7 064	7 096	7 250
<i>Growth Since 1990</i>	<i>N/A</i>	<i>46.5%</i>	<i>68.8%</i>	<i>68.8%</i>	<i>69.6%</i>	<i>73.3%</i>
Energy Imported (PJ)	24	26	62	370	415	375
<i>Growth Since 1990</i>	<i>N/A</i>	<i>6.0%</i>	<i>155.2%</i>	<i>1426.8%</i>	<i>1613.3%</i>	<i>1448.7%</i>
Energy Exported (PJ)	1 537	3 011	3 846	3 876	4 022	4 066
<i>Growth Since 1990</i>	<i>N/A</i>	<i>95.9%</i>	<i>150.2%</i>	<i>152.2%</i>	<i>161.6%</i>	<i>164.5%</i>
Apparent Domestic Consumption (PJ)	2 671	3 144	3 276	3 557	3 489	3 558
<i>Growth Since 1990</i>	<i>N/A</i>	<i>17.7%</i>	<i>22.7%</i>	<i>33.2%</i>	<i>30.6%</i>	<i>33.2%</i>
Emissions Associated with Gross Exports (Mt CO₂ eq.)	13.9	26.5	33.1	33.4	34.6	34.9
<i>Growth Since 1990</i>	<i>N/A</i>	<i>74.8%</i>	<i>122.3%</i>	<i>124.1%</i>	<i>132.9%</i>	<i>135.6%</i>
Emissions Associated with Net¹ Exports (Mt CO₂ eq.)	12.7	25.1	31.1	25.6	25.9	27.0
<i>Growth Since 1990</i>	<i>N/A</i>	<i>97.6%</i>	<i>144.5%</i>	<i>101.2%</i>	<i>104.1%</i>	<i>112.9%</i>

Note:

- 1 Net exports recognizes that a country producing fossil fuels for export to Canada has emissions associated with that production and offsets those emissions in Canada associated with our production for export.

Table S-6: Combined Crude Oil and Natural Gas: Production, Export, and GHG Emission Trends, 1990–2005

Crude Oil & Natural Gas	1990	1995	2000	2003	2004	2005
Domestic Production (PJ)	7 746	10 299	11 729	12 491	12 744	12 798
<i>Growth Since 1990</i>	<i>N/A</i>	<i>33.0%</i>	<i>51.4%</i>	<i>61.3%</i>	<i>64.5%</i>	<i>65.2%</i>
Energy Imported (PJ)	1 224	1 345	2 104	2 397	2 505	2 447
<i>Growth Since 1990</i>	<i>N/A</i>	<i>9.9%</i>	<i>71.9%</i>	<i>95.8%</i>	<i>104.6%</i>	<i>99.8%</i>
Energy Exported (PJ)	3 040	5 447	7 069	7 482	7 833	7 789
<i>Growth Since 1990</i>	<i>N/A</i>	<i>79.2%</i>	<i>132.5%</i>	<i>146.1%</i>	<i>157.6%</i>	<i>156.2%</i>
Apparent Domestic Consumption (PJ)	5 930	6 197	6 765	7 407	7 416	7 456
<i>Growth Since 1990</i>	<i>N/A</i>	<i>4.5%</i>	<i>14.1%</i>	<i>24.9%</i>	<i>25.1%</i>	<i>25.7%</i>
Emissions Associated with Gross Exports (Mt CO₂ eq.)	27.8	51.0	65.4	69.9	73.4	72.8
<i>Growth Since 1990</i>	<i>N/A</i>	<i>83.5%</i>	<i>135.4%</i>	<i>151.5%</i>	<i>164.1%</i>	<i>161.9%</i>
Emissions Associated with Net¹ Exports (Mt CO₂ eq.)	21.5	42.9	47.9	46.8	48.7	49.1
<i>Growth Since 1990</i>	<i>N/A</i>	<i>99.5%</i>	<i>122.8%</i>	<i>117.7%</i>	<i>126.5%</i>	<i>128.2%</i>

Note:

- 1 Net exports recognizes that a country producing fossil fuels for export to Canada has emissions associated with that production and offsets those emissions in Canada associated with our production for export.

ES.4.2 Provincial/Territorial Greenhouse Gas 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, particular 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 2005.

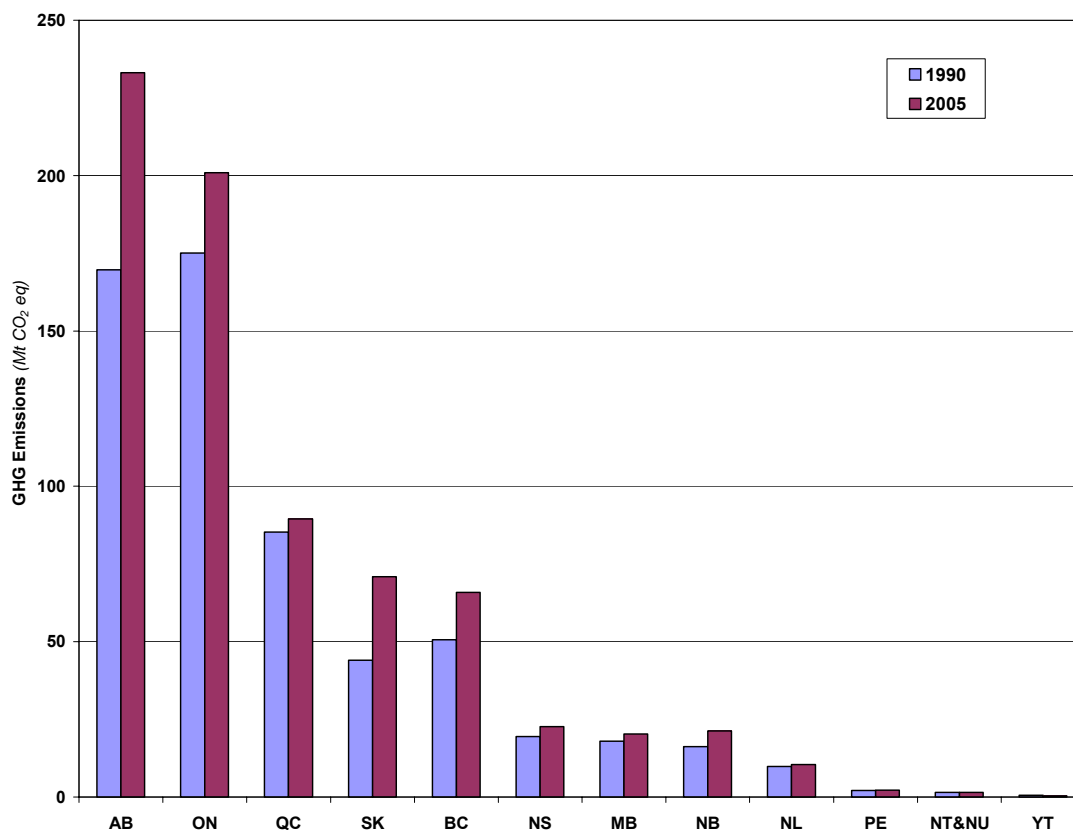


Figure S-4: Total Provincial/Territorial GHG Emissions, 1990 and 2005

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 23 t of GHGs per capita, which represents 8% growth since 1990 (see Table S-1).

In terms of total anthropogenic GHG emissions, Canada is among the eight Annex I Parties whose emissions increased more than 20% over the 1990–2004 period¹³, ranking first among the G8 nations. Canada's +25% growth (–6% Kyoto target) compares with Spain's +49% growth (–8% target¹⁴), Greece's +27% rise (–8% target¹⁴), and Japan's +6.5% increase (–6% target¹⁴). Parties whose emissions decreased by 2004 include the European Union, by –1% (–8% target), the United Kingdom, by –14% (–8% target¹⁴), and Germany, by –17% (–8% target¹⁴).

¹³ These aggregate estimates are based on data from 39 Parties that submitted inventories to the UNFCCC in 2006 (Table 4 in UNFCCC, 2006).

¹⁴ Though this -8% target was agreed to by all 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, 2007), 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 the 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 1.2°C over the period 1948–2005 (Figure 1-1).

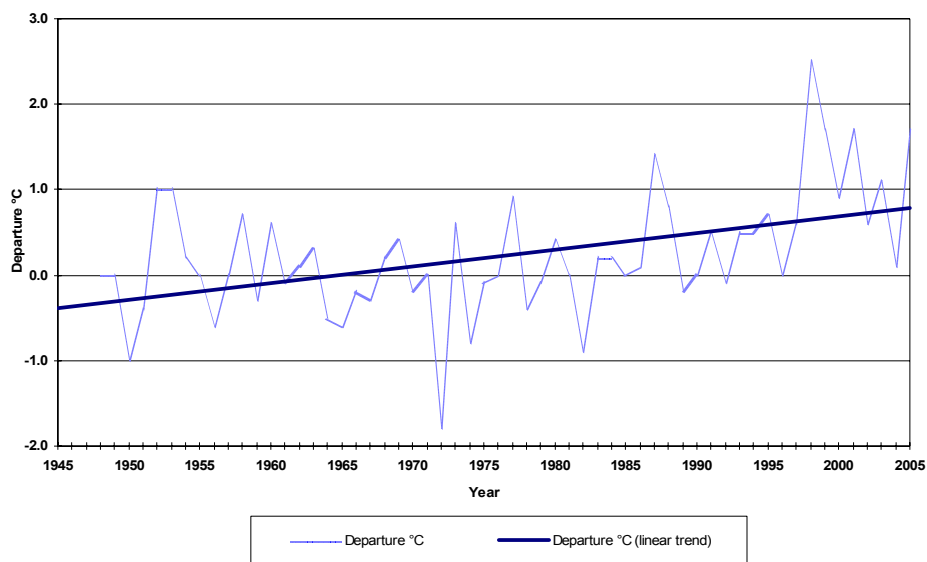


Figure 1-1: Annual Canadian Temperature Departures and Long-Term Trend, 1948–2005

Source: Environment Canada 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 (Figure 1-2). The concentration of CO₂ has increased by 35% since 1750, the concentration of CH₄ has increased by 155%, and the concentration of N₂O has increased by 18% (WMO, 2006). These trends can be largely attributed to human activities — mostly fossil fuel use and permanent loss of forest cover.

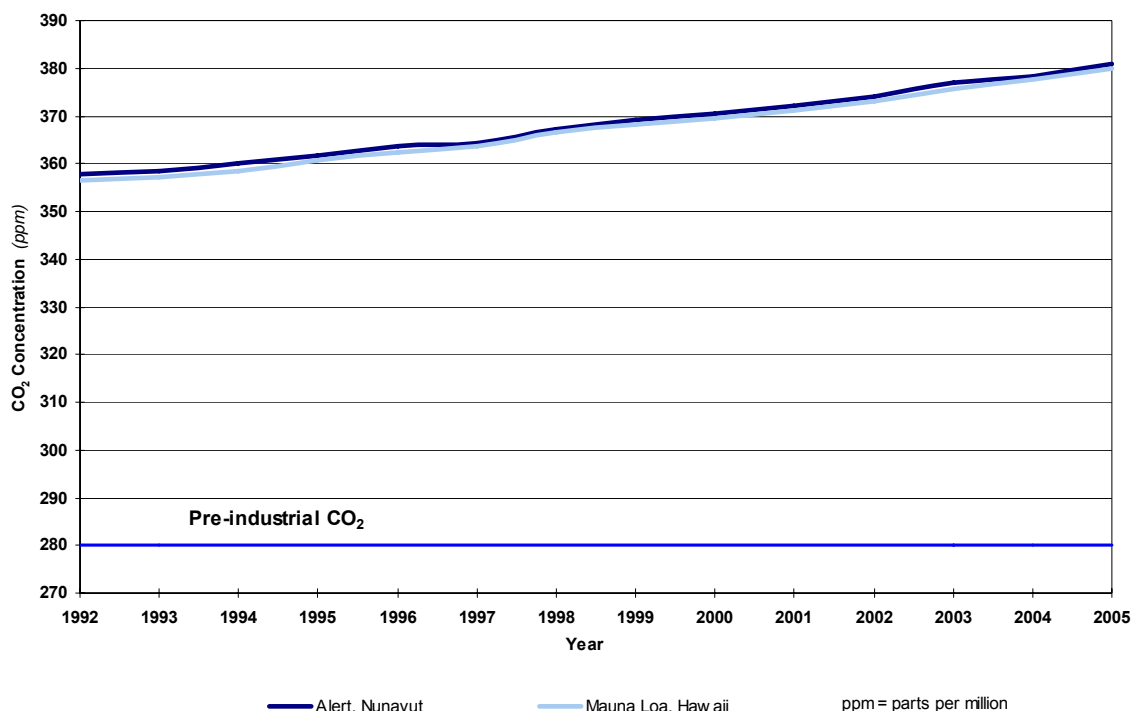


Figure 1-2: Global Atmospheric Concentrations of CO₂, 1992–2005

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

The ultimate objective of the 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,¹⁵ publish, and make available to the Conference of the Parties national inventories of anthropogenic¹⁶ 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: CO₂, CH₄, N₂O, SF₆, PFCs, and HFCs. In addition, and in keeping with the UNFCCC reporting guidelines for Annex I Parties, this report contains estimates of the ozone

¹⁵ Annex I Parties or Developed Countries are required to annually submit a national inventory by April 15.

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

precursors NO_x, CO, and NMVOCs, as well as SO₂.

1.1.1 CO₂

On a worldwide basis, CO₂ emissions generated from anthropogenic activities are known to be small. In comparison with the gross fluxes of carbon (C) from natural systems, they represent only a fraction (~2%) of total global emissions. However, evidence suggests that they account for most of the observed accumulated CO₂ in the atmosphere (Sullivan, 1990; Edmonds, 1992). On the basis of global emissions information, the primary sources of CO₂ generated from anthropogenic activities are fossil fuel combustion (including both stationary and mobile sources), deforestation (resulting in permanent loss of forest cover), and industrial processes, such as cement production.

Since the mid 1970s, over 150 billion tonnes of carbon have been released to the atmosphere from the consumption of fossil fuels and cement production. In 2003, global CO₂ emissions reached 7303 million tonnes, a 4.5% increase from 2002 (Marland, 2006). Deforestation, land-use practices, and ensuing soil oxidation have been estimated to account for about 23% of anthropogenic CO₂ emissions. The primary natural sources of CO₂ 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 CO₂ from the atmosphere. However, the absorption capacity of these natural sinks appears to be exceeded, as atmospheric concentrations of CO₂ and other GHGs are increasing.

1.1.2 CH₄

Global CH₄ emissions resulting from anthropogenic activities are considered to have caused an increase of about 155% in atmospheric concentrations of CH₄ since the mid-1700s (WMO, 2006). Recent atmospheric measurements of CH₄ concentrations are shown in Figure 1-3. Methane growth has slowed during the last decade, averaging approximately 3ppb per year over this period.

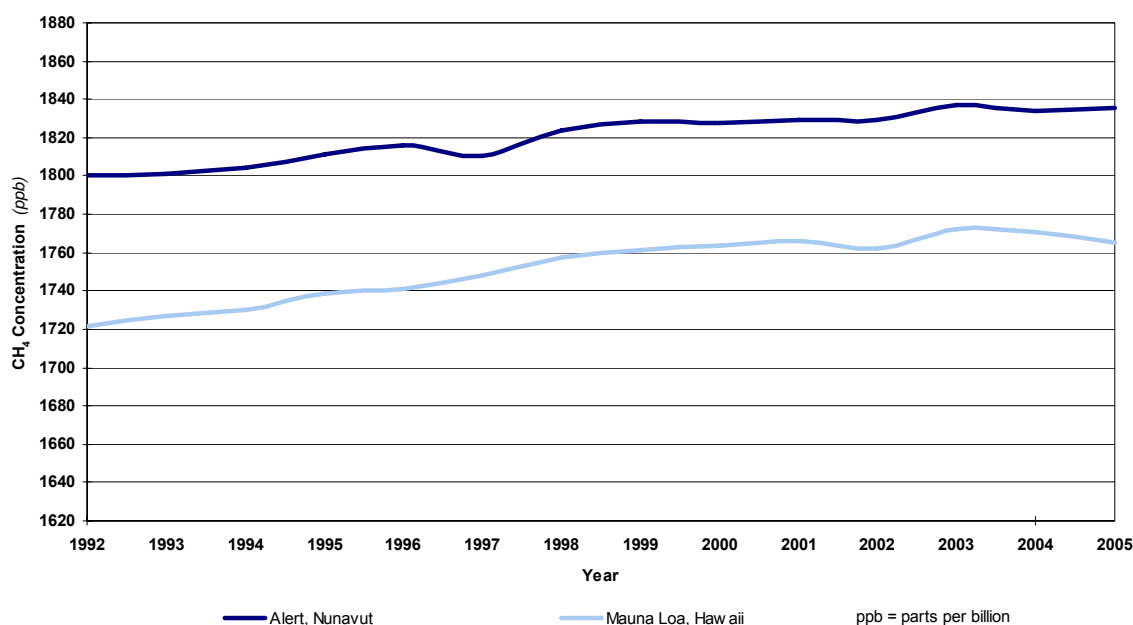


Figure 1-3: Global Atmospheric Concentrations of CH₄, 1992–2005

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

The current annual rate of accumulation of CH₄ is estimated to range between 40 and 60 Mt (~14–21 parts per billion by volume, or ppbv), or approximately 10% of total worldwide CH₄ emissions (Thompson *et al.*, 1992). Methane emissions generated from human activities, amounting to ~360 Mt, are primarily the result of activities such as livestock and rice cultivation, biomass burning, natural gas delivery systems, landfills, and coal mining (EPA, 1981). Although several uncertainties exist in the actual contributions and relative importance of these sources, emission reductions of about 8% are thought to be required to stabilize CH₄ concentrations at current levels (IPCC, 1996a).

1.1.3 N₂O

It is estimated that approximately one-third of global atmospheric N₂O is of human origin, resulting primarily from the application of nitrogen fertilizers, soil cultivation, and the combustion of fossil fuels and wood. Atmospheric concentrations of N₂O have grown by about 18% since the mid-1700s (WMO, 2006). Total annual emissions from all sources are estimated to be within the range of 10–17.5 Mt N₂O, expressed as nitrogen (N) (IPCC, 1996b). Figure 1-4 shows global atmospheric N₂O concentrations from 1993 to 2005. The other two-thirds of global atmospheric N₂O comes from soil and water denitrification under anaerobic conditions.

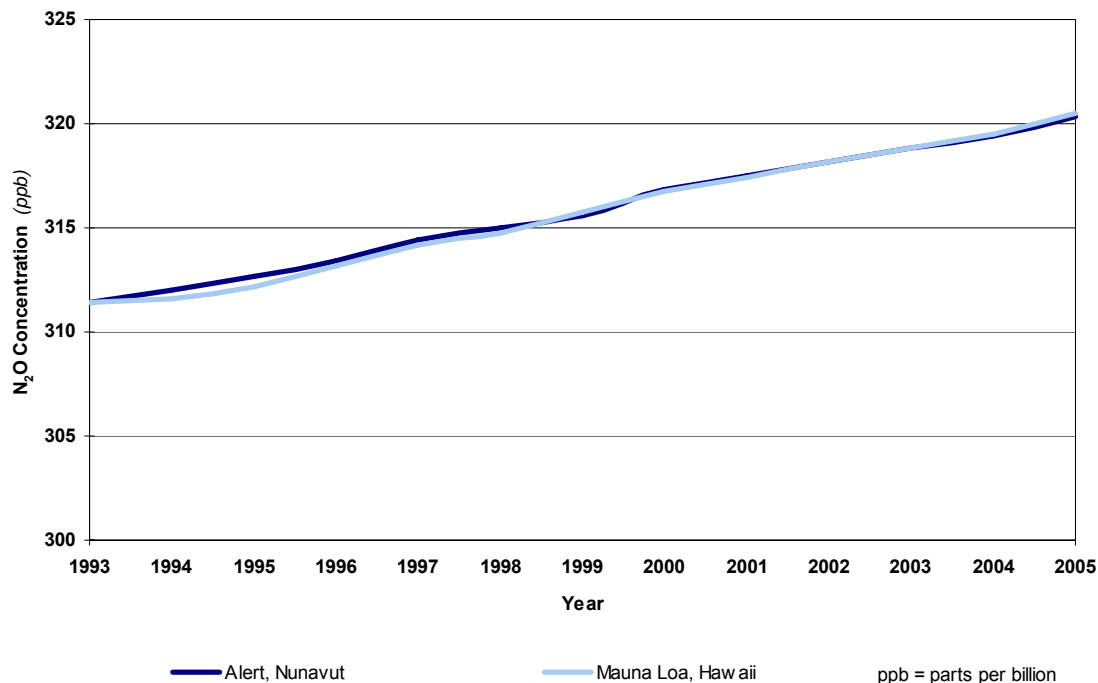


Figure 1-4: Global Atmospheric Concentrations of N₂O, 1993–2005

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

1.1.4 HFCs, PFCs, and SF₆

The final group of GHGs included in this report is the synthetic (not naturally occurring) fluorinated gases HFCs, PFCs, and SF₆. 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 understand the emission data presented in this report, it is important to understand that the radiative forcing¹⁷ 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

¹⁷ 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).

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 policymakers 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 CO₂. 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 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

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

Sources:

GWP: IPCC (1996a).

Atmospheric Lifetime: IPCC (1995), Table 2.9, p. 121.

Note:

The CH₄ 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 CO₂.

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 21.5 t of GHGs per capita. By 2005, this had increased to 23.1 t of GHGs per capita (Figure 1-5).

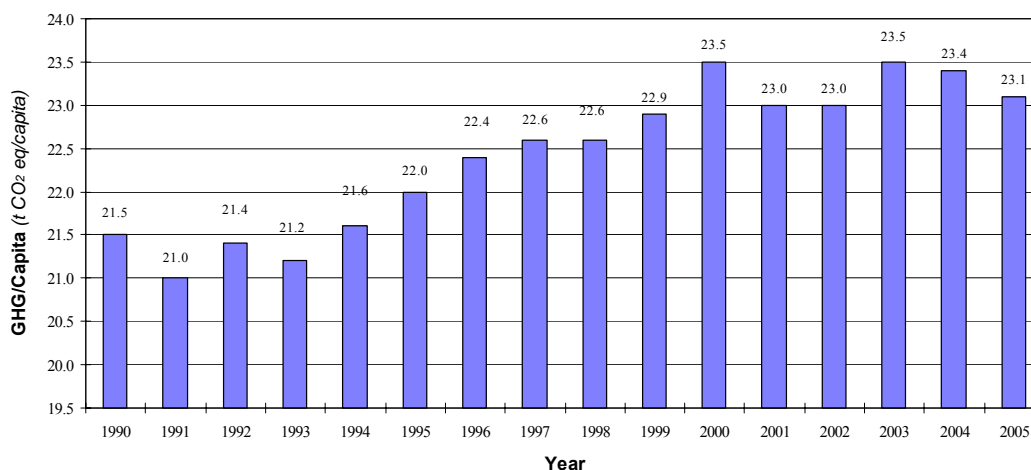


Figure 1-5: Per Capita GHG Emission Trend for Canada, 1990–2005

In terms of growth in total anthropogenic GHG emissions without LULUCF, Canada ranks fourth among the eight Annex I Parties whose emissions increased more than 20% over the 1990–2004 period (Figure 1-6), and first among the G8 countries.

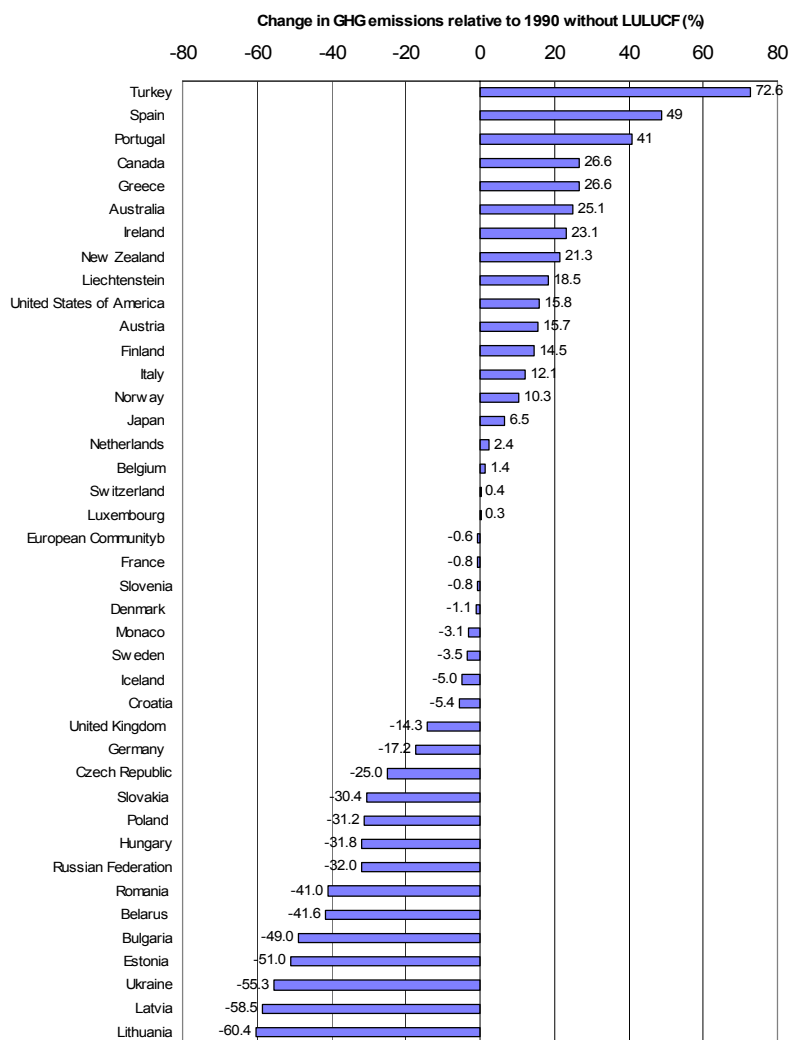


Figure 1-6: Change in Aggregate GHG Emissions for Annex I Parties, 1990–2004

Source: UNFCCC (2006), Table 4.

1.2 Institutional Arrangements for Inventory Preparation

1.2.1 The National Inventory System

Under Article 5, paragraph 1 of the Kyoto Protocol, each Party to the Kyoto Protocol included in Annex I shall have in place, no later than January 1st, 2007, a National System for the estimation of anthropogenic emissions from sources and removals by sinks of all greenhouse gases 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 roles and responsibilities of the various agencies and players in the implementation of the National 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. Recognizing the need to draw on the best available technical and scientific expertise and information in accordance with good practice and the international quality standards, the GHG 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 GHG 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 tables. The GHG Division also manages the quality and the archiving systems, performs trends analysis, publishes fact sheets and acts as a clearinghouse for GHG information and technical guidance on GHG quantification. Moreover, the GHG Division manages the mandatory GHG Reporting Program (GHGRP) from facilities emitting over 100 kt CO₂ equivalent annually as described in section 1.4.1.

Groups at Environment Canada other than the GHG Division also contribute data on waste and waste management, residential fuel use of biomass, and emissions of sulphur hexafluoride, ozone and aerosol precursors.

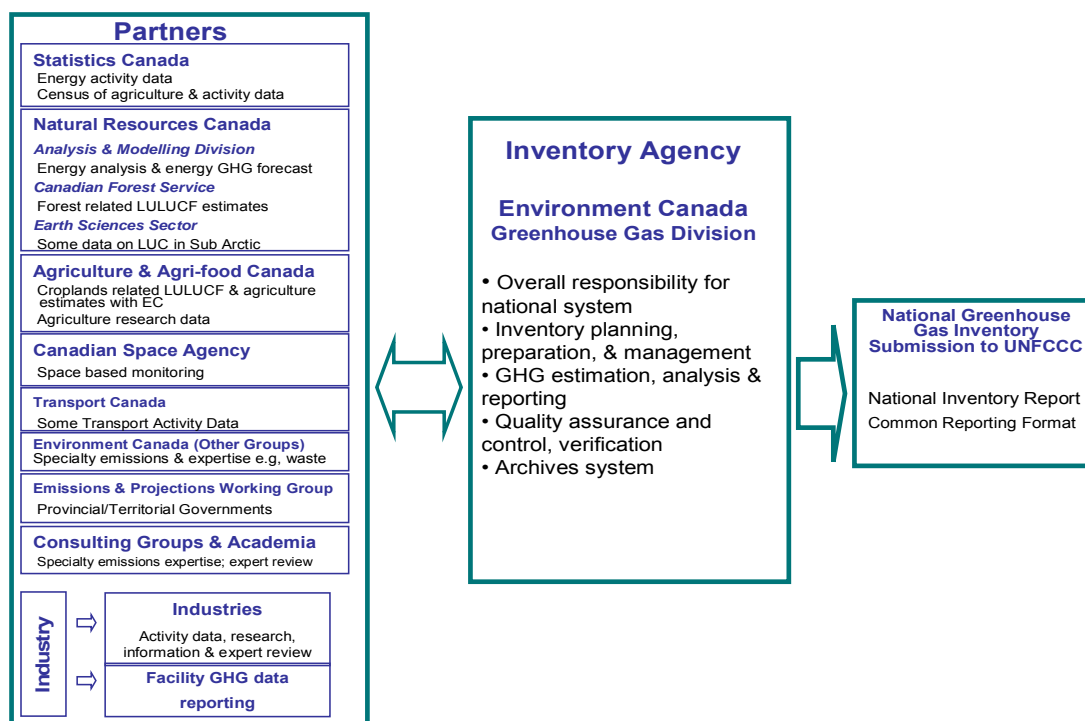


Figure 1-7: Partners of the National Inventory System

Because sources and sinks of greenhouse gas originate from a tremendous range of economic sectors and activities, the GHG 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 greenhouse gas 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*'. The energy balance is transmitted annually to Environment Canada according to the terms of a Memorandum of Understanding as established between the two departments.

Energy and fossil fuel data are collected based on a mix of annual and monthly census and surveys from industries, federal agencies (such as the Alberta Energy Utilities Board), from provincial energy departments and from the *Canadian Industrial Energy End Use Data and Analysis Centre*. MCED also conducts an annual survey of the *Industrial Consumption of Energy*, a bottom-up approach which 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. Due the complexity of energy data, a *Working Group on Energy Statistics* consisting of members from Statistics Canada, Environment Canada and Natural Resources Canada 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 agriculture activity data through the Agriculture Census and provides other activity data such as solid waste land disposal and population data.

Natural Resources Canada (NRCan) is a key partner of Environment Canada who 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 residue. The Analysis and Modelling Division of NRCan is responsible for preparing GHG emission forecasts for the Energy Sector. Fleet fuel efficiency data is provided by the federal Transport department.

Since 2004, Environment Canada has officially designated responsibilities to the Canadian Forest Service of Natural Resources Canada (NRCan-CFS) 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 EC and with representatives from the Research Branch of AAFC and from NRCan-CFS. Three technical Working Groups address the sub-sectors 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 1st annually, estimates must be accompanied by complete and transparent documentation, including uncertainty analysis and quality control. NRCan-CFS has developed the National Forest Carbon Monitoring Accounting and Reporting System (NFC-MARS), and AAFC the Canadian Agricultural Greenhouse Gas – Monitoring, Accounting, and Reporting System (CanAg-MARS), both of which contributed major improvements to the LULUCF Sector. EC develops estimates for other LULUCF categories, undertakes quality assurance and plays an integrating role, ensuring consistency in the land representation system. In addition to its responsibility in the LULUCF MARS, AAFC also plays a major role in the Agriculture Sector inventory preparation in concert with EC.

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

The GHG 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 resource permitting, contracts are established with consulting firms and universities to conduct in-depth studies, for example on updating emissions factors. The industry sector is a key partner in all Sectors of the inventory providing technical hands-on expertise on emission factors, activity data or GHG estimates. A bilateral agreement with the Aluminium Association of Canada has been signed by which process-related emissions estimates for CO₂, PFC and SF₆ are to be provided annually to Environment Canada. A similar agreement has been negotiated with the Canadian Electricity Association for provision of SF₆ emissions and supplementary data relating to power transmission systems.

1.3 Process for Inventory Preparation

Continuous data collection and improvements are an integral part 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 ups; the UNFCCC review report; and the improvement plan. 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 reviewed 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. However, the development of the 2007 inventory submission has been highly atypical with significant delays in the receipt of activity data. Risk mitigation and contingency planning for such events will be a key focus of QA/QC activities in the preparation of the 2008 submission.

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 emissions expert working group 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.

In April and May each year, review meetings are held both internally and with partners in order to capture lessons-learned during the previous inventory cycle. These results, as well as the annual UNFCCC expert review and the external domestic review feed into improvement plans for the following year's inventory and help to identify priorities and areas for improvement.

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:

- CO₂;
- CH₄;
- N₂O;
- HFCs;
- PFCs; and
- SF₆.

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

- sulphur oxides (SO_x);
- NO_x;
- 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 (UNECE).¹⁸ 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

¹⁸ See website: <http://webdab.emep.int/>

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:

- *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, CO₂ 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:* Where 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.

For the 2007 submission, a number of changes and improvements have been

implemented resulting in the recalculation of Canada's 1990–2004 GHG estimates. A new study on emissions from the non-conventional oil extraction industry and updates to the transportation emission model have both affected the Energy Sector's GHG estimates. In addition, Statistics Canada's underlying energy data for 2004 were updated, primarily affecting the estimates for electricity emissions. New survey data on the amount of waste landfilled and updated parameters have been incorporated into the estimation model for emissions from landfills, leading to revised GHG estimates for the Waste Sector. Finally, refinements have been incorporated into the agricultural emission estimates. For further information, refer to specific sectoral chapters as well as Chapter 9.

1.4.1 Mandatory Reporting System for GHGs

In March 2004, the Government of Canada established the Greenhouse Gas Emissions Reporting Program (GHGRP) under Section 46(1) of *CEPA 1999*. Unlike the National GHG Inventory which compiles GHG data at a national level, primarily using a top-down approach, the GHGRP applies only to the largest industrial GHG emitters in Canada. Collection of facility level GHG emissions data will enhance the level of detail in the National GHG Inventory, while at the same time provide Canadians with timely information on GHG emissions and help meet provincial and territorial requirements for GHG emissions reporting.

The GHGRP specifically targets only the largest GHG emitters and sets out basic reporting requirements which are published annually in the *Canada Gazette*. Facilities that emit 100,000 tonnes of CO₂ equivalent (100 kt CO₂ eq) or more annually are required to submit a GHG emissions report by June 1st of the following year. Voluntary submissions from facilities with GHG emissions below the reporting threshold are encouraged.

The major industrial sources of greenhouse gas emissions include power generation facilities 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. There are several methodologies for estimating GHG emissions at a facility. These include monitoring and direct measurement; mass balance; emission factors; and engineering estimates. Specific estimation methods are not prescribed and reporters can choose the quantification methodologies most appropriate for their own particular industry or application. However, 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.

The GHG dissemination website (<http://www.ec.gc.ca/ghg>) provides public access to the reported GHG emissions information (GHG totals by gas and by facility). The GHG data is 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 2005 Facility GHG Emissions*

A total of 336 facilities reported GHG emissions for the 2005 calendar year, collectively emitting a total of 280 Mt of GHGs (CO_2 eq)¹⁹. The reported facility emissions represent just over one-third (~37%) of Canada's total 2005 GHG emissions of 747 Mt.

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_2 eq.

Information on the direct releases of six greenhouse gases must be reported annually if the facility meets or exceeds the reporting threshold. Of these gases, CO_2 represents the majority of total reported emissions at approximately 93%, while CH_4 accounts for 3%, and N_2O represents just over 2%. HFCs and PFCs (reported by species) and SF_6 originating primarily from the manufacturing sector, account for the remaining 2% (see Table 1-2).

Table 1-2: Facility Reported 2005 GHG Emissions by Gas

GHG	Total Emissions (kt CO_2 eq)	% of Total
CO_2	260 739	93
CH_4	8 506	3
N_2O	6 347	2
HFCs	53	0
PFCs	3 065	1
SF_6	1 132	0.4
Total	278 890	100

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 2005 GHG emissions with approximately 39% of the total, followed by those in Ontario, which accounted for about 28%. Saskatchewan and Quebec were the next largest contributors, both at about 8% of reported emissions, although there were 53 reporting facilities in Quebec compared to 22 facilities in Saskatchewan (see Table 1-3).

¹⁹ Data presented are current as of November 30, 2006.

Table 1-3: Facility Reported 2005 GHG Emissions by Province/Territory

Province/Territory	Number of Reporting Facilities	Total Reported Emissions (kt CO ₂ eq)	% of Total
Alberta	101	109 323	39
Ontario	85	78 400	28
Quebec	53	22 101	8
Saskatchewan	22	22 870	8
British Columbia	37	13 902	5
New Brunswick	12	12 611	5
Nova Scotia	9	12 015	4
Newfoundland and Labrador	7	5 216	2
Manitoba	7	2 941	1
Northwest Territories	2	359	0
Prince Edward Island	1	104	0
Nunavut	0	n/a	
Yukon	0	n/a	
Total	336	279 842	100

Note:

Totals may not add up due to rounding.

1.4.1.2 Reported 2005 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).

Table 1-4: Total Facility Reported 2005 GHG Emissions Contribution by Sector

NAICS ¹	Sector	GHG Emissions (kt CO ₂ eq)	% of Total
21	Mining and Oil and Gas Extraction	50 335	18
22	Utilities	124 439	44
31–33	Manufacturing	90 608	32
Other ²	Other	14 460	5
Total		279 842	100

Note:

1 North American Industrial Classification System.

2 Includes a number of smaller sectors (e.g., pipeline transportation of natural gas and waste treatment and disposal, etc.).

Totals may not add due to rounding.

Emissions from the utilities sector accounted for 44% of the total reported 2005 GHG emissions, with slightly over 99% of the GHG emissions produced by electric power generation, transmission, and distribution. The manufacturing sector accounted for 32% of the 2005 GHG emissions while GHG emissions from the mining and oil and gas extraction sector accounted for 18% of the total. 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. Breakdown of the reported GHG

emissions information into subsectors, from the manufacturing and mining and oil and gas extraction sectors, are provided in Figures 1-8 and 1-9.

1.4.1.3 Comparison Between 2005 and 2004 Reported GHG Emissions

The number of facilities reporting GHG emissions data rose slightly from 326 reporting facilities in 2004 to 336 in 2005. However, when comparing the reported GHG emissions data for 2004 and 2005, it should be noted that 19 facilities that reported 2004 emissions did not submit a GHG report for 2005.²⁰ Therefore, only 307 facilities that reported GHG emissions in both years can be considered "comparable facilities".

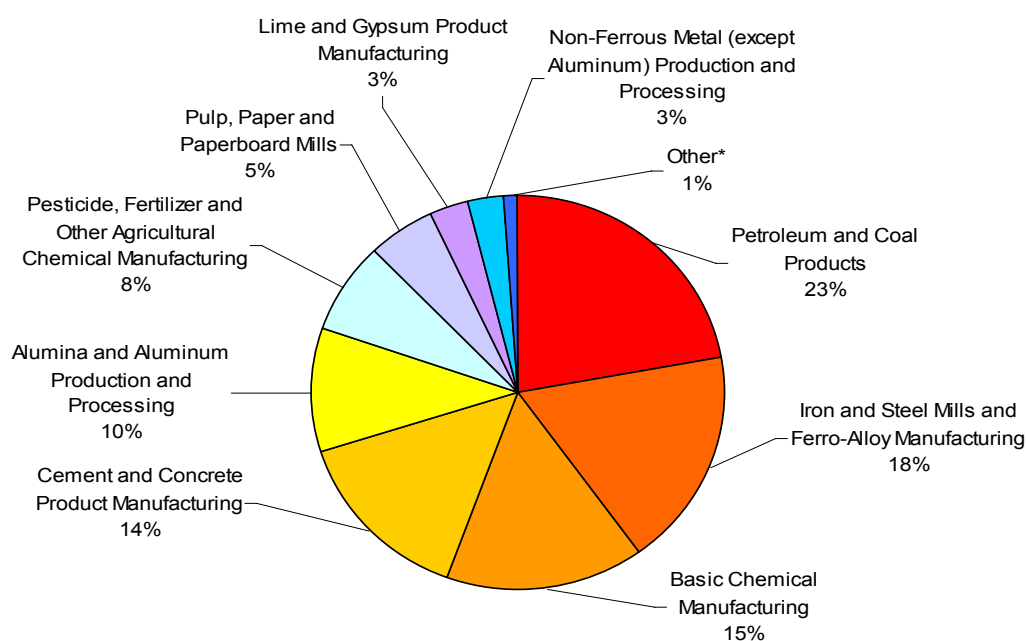


Figure 1-8: Reported GHG Emissions for Subsectors of Manufacturing (NAICS 31-33)²¹

Note: This pie represents 90 608 kt $CO_2 eq$, or 32% of the total reported emissions

²⁰ Of these, 6 facilities were identified as being below the reporting threshold in 2004 and may have elected not to again voluntarily report emissions for 2005 while the remaining 13 facilities either no longer met the reporting threshold due to a reduction in emissions or a cessation of operations, or the facilities simply failed to report.

²¹ The "Other" category includes the Manufacturing of: Motor Vehicles and Motor Vehicle Parts, Glass and Glass Product, Grain and Oilseed Milling, Other Fabricated Metal Products, Beverage, Fruit and Vegetable Preserving and Specialty Food Resin, Synthetic Rubber, and Artificial and Synthetic Fibres and Filaments, Aerospace Product and Parts, and Rubber Product.

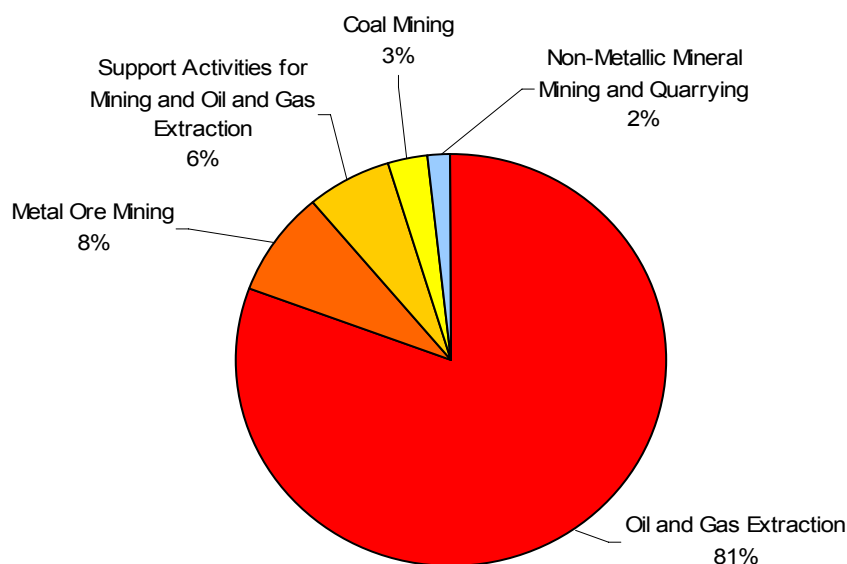


Figure 1-9: Reported GHG Emissions for Subsectors of Mining and Oil & Gas Extraction (NAICS 21)

Note: This pie represents 50 335 kt CO_2eq , or 18% of the total reported emissions

The reported emissions data show almost no change (less than half a percentage point) in reported emissions from year to year on either basis: all facilities or comparable facilities (see Tables 1-5 and 1-6).

Table 1-5: Total Facility Reported GHG Emissions, 2004 and 2005

Year	Total Number of Reporting Facilities	GHG Emissions (kt CO_2eq)
2004	326	279989
2005	336	279842
Annual Change (%)		-0.05 %

Table 1-6: Comparable Facilities Reported GHG Emissions, 2004 and 2005

Year	Number of "Comparable" Reporting Facilities	GHG Emissions (kt CO_2eq)
2004	307	277 820
2005	307	276 474
Annual Change (%)		-0.48 %

1.4.1.4 The National Inventory Context

Data from the GHG Emissions Reporting Program is used to improve and confirm emission estimates in the National Inventory Report, developed from national and provincial statistics. The extent to which the reported GHG emissions 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.

1.5 Key Categories

The IPCC Good Practice Guidance (IPCC, 2000) defines procedures (in the form of decision trees) for the choice of estimation methods within the context of 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, inventory uncertainty is lower when emissions are estimated using the most rigorous methods; due to finite resources, however, this might not be feasible for every emission and removal category. Therefore, it is good practice to identify those categories (key categories) that have the greatest contribution to overall inventory uncertainty 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 GHGs in terms of the absolute level of emissions (level assessment) and/or the trend in emissions (trend assessment). As far as possible, key categories should receive special consideration in terms of two important inventory aspects:

1. The use of category-specific good practice methods is preferred.
2. The key categories should receive additional attention with respect to QA and QC.

Good Practice Guidance indicates that 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. In the absence of quantitative data on uncertainties, this method of identifying key categories provides a good approximation of those areas to which priority should be given to reduce uncertainties in the inventory.

For the 1990–2005 GHG inventory, level, trends, and qualitative key category assessments were performed on the inventory according to the Tier 1 approach, as presented in the IPCC (2000) and IPCC (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 Constructions), Adipic acid production 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 GHG Division annually conducts detailed QA/QC activities during and after the development of the inventory and is systematically implementing formal procedures according to a plan consistent with international standards.

In 2006 calendar year, QA/QC co-ordinator role was staffed in line with the strategic priority of the GHG Division to review and redesign the quality framework. This review has had several key outcomes including the development and implementation of an enhanced QA/QC plan and procedures.

Elements of the QA/QC plan and procedures include:

- Embedding documentation of QC procedures into the inventory development process to ensure real-time recording of QC activities;
- Establishment of the Prioritization and Planning Committee to centralize inventory decision making particularly on approaches to QA and Planned Improvements;
- Development and implementation of a more efficient electronic archiving structure and electronic records management system; and
- Development and implementation of a rolling 5 year schedule to ensure complete coverage of all inventory categories with Tier 1 QC, Tier 2 QC and QA.

Full implementation of this plan is envisaged to span several years, encompassing both Tier 1 and Tier 2 QC procedures, as well as QA, reviews, and audits

Each year, an independent UN (United Nations) ERT (Expert Review Team) reviews the inventory in detail and assesses its accuracy and consistency with international standards. The UNFCCC also conducts a synthesis and assessment of Annex I Parties' inventories and publishes the results each year. Canada's inventory, while not perfect, is relatively good by international standards. As with all inventories, there remains room for improvement.

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 GHG 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 revision of GHG estimates for the entire times series from the 1990 base year to the most recent year available.

For the 2007 submission, Tier 1 QC procedures were implemented and the results documented for 56 key categories and 3 non-key categories, by the experts who prepared these category estimates. Cross-cutting checks on the NIR and CRF were also performed prior to submission. 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. Uncertainties²² in the inventory estimates may be caused by systematic model uncertainty or (more likely) may be 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. The guidelines also require that uncertainty in the data used for all source and sink categories must be qualitatively discussed in a transparent manner in the NIR, in particular for those categories identified as key.

In Canada's 2005 NIR, the results of a Tier 2 quantitative study of uncertainty were provided (as performed on key and non-key source categories — except LULUCF — and on the inventory as a whole, as applied to the 2003 NIR). In this, the 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.

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, without consideration of the uncertainty within the GWPs. With GWP uncertainty considered, the overall uncertainty falls within a range of –5% to +10% (ICF, 2005). N₂O 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, CO₂, exhibits an uncertainty of –4% to 0% (ICF, 2005). For uncertainty information on other gases, reference should be made to Annex 7. The Canadian

²² 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).

inventory's 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. Annex 7 provides details of uncertainty estimates for all sectors except LULUCF. 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 since the Quantitative Assessment of Uncertainty in Canada's National GHG Inventory Estimates for 2001, Supplementary Analysis (ICF, 2005) study was completed, as affecting various source categories (in particular, the Agriculture Sector). Further improvements and updates to the uncertainty values are planned; see Chapter 9 for more details.

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 relate to the unavailability of comprehensive activity data for certain sub-categories of a source which 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 SF₆ emissions from semi-conductor manufacturing. These improved the completeness of the inventory in preparation for Canada's Initial Report due in 2007.

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 further research may provide better information as to the CH₄ emissions from manufacturing processes. In the LULUCF Sector, significant improvements have been implemented starting in 2006, but completeness has not yet been fully met due to data limitations.

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, 1990–2005

2.1 Summary of Emission Trends

In 2005, Canada's GHG emissions (excluding Land Use, Land-Use Change and Forestry - LULUCF) were 747 Mt,²³ which is a 25.3% increase over 1990 emissions. Between 2004 and 2005, emissions decreased by 0.1%.

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 SF₆, Enteric Fermentation, and Waste. There have been overall decreases in Manufacturing Industries and Construction, the Chemical Industry, and Metal Production.

2.2 Emission Trends by Gas

CO₂ is the largest contributor to Canada's GHG emissions. Figure 2-1 shows how the percent contributions of the six GHGs have changed between 1990 and 2005. CO₂ has changed only slightly in proportion, from 77% of emissions in 1990 to 78% in 2005.

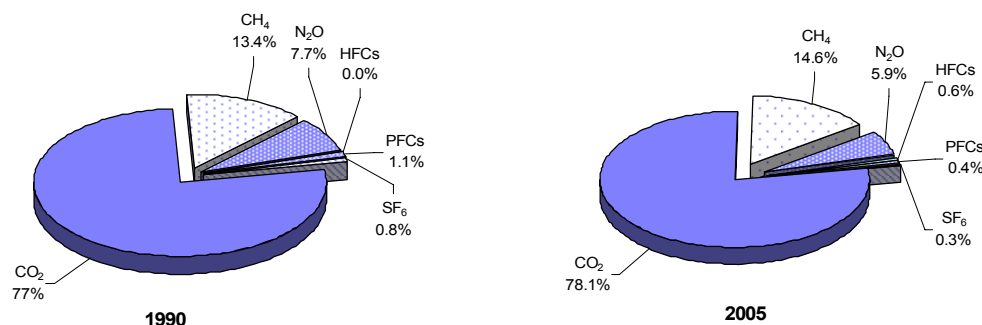


Figure 2-1: Canada's GHG Emissions by Gas, 1990 and 2005 (excluding LULUCF)

²³ Unless explicitly stated otherwise, all emission estimates given in Mt represent emissions of GHGs in Mt CO₂ equivalent.

the Energy Industries accounted for 202 Mt in 2005, while fugitive emissions were responsible for 65.7 Mt. In terms of relative growth, fugitive emissions from Oil and Natural Gas (including production, processing, transmission, and distribution activities) have increased faster than any other category in the Energy Sector. Between 1990 and 2005, these emissions rose by 59%.

2.3.1.1 Emissions from Fuel Combustion (2005 GHG emissions, 543 Mt)

GHG emissions from fuel combustion rose from 431 Mt in 1990 to 543 Mt in 2005, a 26% 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 (2005 GHG emissions, 202 Mt)

The Energy Industries subsector accounts for the largest portion of Canada's fuel combustion emissions (37% 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 2005, combustion emissions from the Energy Industries category totalled 202 Mt, an increase of 37 % from the 1990 level of 147 Mt.

Public Electricity and Heat Production²⁴ (2005 GHG emissions, 129 Mt)

This category accounted for 17% (129 Mt) of Canada's 2005 GHG emissions and was responsible for 22% of the total emissions growth between 1990 and 2005. Overall emissions from this category increased 35%, (33 Mt), since 1990.

Electricity and Heat Generation, a constituent of the Energy Industries subsector, saw large increases in emissions. Rising demand for electricity, exacerbated by the increasing use of fossil fuels in the generation mix, drove GHG emissions up 33 Mt between 1990 and 2005. Comparatively, in 2005 electricity demand was approximately 128 terawatt-hours (TWh) above the 1990 level. Although this increased demand was supplied in part by greater hydroelectricity and nuclear generation, fossil fuel generation rose even more. The result was that by 2005, hydropower's share of the generation mix had fallen from 63% to 60%, while fossil fuels' had risen from 22% to 25%, worsening the average GHG intensity of production. The end result was that from 1990 to 2005, generation rose 28% while GHG emissions increased 35%, about 1.25 times the generation increase.

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

²⁴ The Public Electricity and Heat Production category includes emissions from utilities and industrial generation.

peaking in 2003. Part of the decrease is due to overall fuel switching and usage of less GHG intense coal, while increases in interprovincial and international trade have also played a role. However, fuel costs, market fundamentals, 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 capacity in Canada increased dramatically in 2005.

The growth in emissions from 1990 to 2005 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 emissions growth, the shift away from non-GHG-emitting sources (nuclear and hydro) in the latter part of the decade has resulted in large absolute increases.

Petroleum Refining and Manufacture of Solid Fuels and Other Energy Industries²⁵
(2005 GHG emissions, 73 Mt)

The Petroleum Refining category includes mainly emissions from the combustion of fossil fuels during the production of refined petroleum products while the Manufacture of Solid Fuels and Other Energy Industries category encompasses fuel combustion emissions associated with the upstream oil and gas 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. As shown in Table 2-3, between 1990 and 2005, emissions from these two categories increased by about 22 Mt, or 42%. This growth is due to increases in oil and natural gas production, largely for export.

Table 2-2: GHG Emissions from Petroleum Refining and Manufacture of Solid Fuels and Other Energy Industries, 1990–2005

GHG Source Category	GHG Emissions					% Increase 1990–2005
	1990	1995	2000	2004	2005	
			(Mt CO ₂ eq)			
Petroleum Refining	16	14	14	18	16	18
Manufacture of Solid Fuels and Other Energy Industries	36	40	53	54	55	53
Total	52	54	67	72	73	42

Note:

Totals may not add up due to rounding.

Manufacturing Industries and Construction (2005 GHG emissions, 63 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,

²⁵ In the NIR, the Fossil Fuel Industries category encompasses both the *petroleum refining* and *fossil fuel production* (also known as *manufacture of solid fuels and other energy industries*) subsectors.

pulp, paper and print, construction, mining, and all other manufacturing industries²⁶. In 2005, GHG emissions were 63 Mt. Overall, this subsector was responsible for 8.4% of Canada's total GHG emissions for 2005.

Table 2-3: GHG Emissions from Manufacturing, Mining, and Construction, 1990–2005

GHG Source Category	GHG Emissions					% Increase 1990–2005
	1990	1995	2000 (Mt CO ₂ eq)	2004	2005	
Iron and Steel	6.49	7.04	7.19	6.48	6.52	1%
Non-Ferrous Metals	3.18	3.09	3.19	3.23	3.19	0%
Chemicals	7.09	8.45	7.85	6.76	5.35	-25%
Cement	3.69	3.67	3.89	4.21	4.58	24%
Construction	1.88	1.18	1.08	1.35	1.31	-31%
Mining	6.18	7.85	10.40	14.80	15.60	152%
Pulp, Paper and Print	13.6	11.7	11.0	9.3	7.3	-46%
Other Manufacturing	20.6	19.0	19.9	20.9	18.9	-8%
Total	62.8	62.0	64.5	67.0	62.8	0%

Note:

Totals may not add up due to rounding.

Between 1990 and 2005, there have been changes in both directions in the emissions produced by the various categories within the Manufacturing Industries and Construction subsector. This can be attributed to product demands, fuel switching, and changes in manufacturing operations. The majority of the overall increase can be attributed to the mining category, which has seen a 152% growth since 1990. From 2004 to 2005, the construction industry experienced a 3% decrease in emissions.

Transport (2005 GHG emissions, 200 Mt)

Transport is a large and diverse subsector, accounting for 26% of Canada's GHG emissions in 2005. This subsector includes emissions from fuel combustion for the transport of passengers and freight in five distinct subcategories:

- Road transportation;
- Civil aviation;
- Navigation (Marine);
- Railways; and
- Other transportation (off-road and pipelines).

From 1990 to 2005, GHG emissions from transport, driven primarily by energy used for personal transportation, rose 33%, or 49 Mt. Overall, transport was the second largest emissions producing category in 2005, contributing 200 Mt and accounting for 32% of Canada's emissions growth from 1990 to 2005.

²⁶ The NIR categories that constitute this UNFCCC sector are *manufacturing*, *construction*, and *mining* (refer to Tables S-1 and S-2).

Emissions from light-duty gasoline trucks (LDGT) the subcategory that includes SUVs, pickups, and vans, increased 109% between 1990 and 2005 (from 21.3 Mt in 1990 to 44.5 Mt in 2005), while emissions from cars (light-duty gasoline vehicles - LDGVs) decreased 13% (from 47.2 Mt in 1990 to 41.2 Mt in 2005) (Table 2-4).

Table 2-4: GHG Emissions from Transport, 1990–2005

GHG Source Category	GHG Emissions		
	1990	2004	2005
	<i>(Mt CO₂ eq)</i>		
Transport (Total)	150	190	200
Civil Aviation	6.4	7.9	8.7
Light-Duty Gasoline Vehicles	47.2	42.4	41.2
Light-Duty Gasoline Trucks	21.3	43.3	44.5
Heavy-Duty Gasoline Vehicles	8.05	6.60	6.51
Motorcycles	0.151	0.252	0.260
Light-Duty Diesel Vehicles	0.363	0.441	0.443
Light-Duty Diesel Trucks	0.724	2.04	2.20
Heavy-Duty Diesel Vehicles	21.2	37.4	39.0
Propane & Natural Gas Vehicles	2.2	0.9	0.7
Railways	7	6	6
Navigation (Marine)	5.1	6.7	6.5
Off-Road Gasoline	7	8	7
Off-Road Diesel	20	20	20
Pipelines	6.90	8.52	10.10

Note:

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

As shown in Table 2-4, the growth in road transport emissions is due not only to the 34% 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 1990–2005, the increase of 23 Mt and 18 Mt for LDGTs and heavy-duty diesel vehicles (HDDVs), respectively, reflects the trend towards increasing use of SUVs, vans, and pickups for personal transportation and heavy-duty trucks for freight transport (Table 2-4).

Table 2-5: Trends in Vehicle Populations for Canada, 1990–2005

Number of vehicles (000s)								
Year	LDGV	LDGT	HDGV	MC	LDDV	LDDT	HDDV	Total
1990	10646	3308	518	261	109	112	402	15356
1991	10677	3496	463	255	110	117	394	15512
1992	10674	3712	432	248	109	126	397	15698
1993	10761	4019	425	247	111	145	442	16149
1994	10694	4305	428	234	108	165	487	16421
1995	10590	4395	387	226	104	183	513	16398
1996	10273	4517	383	213	99	174	498	16157
1997	10420	4939	388	225	101	188	537	16797
1998	10250	5347	395	263	107	204	629	17195
1999	10696	5787	349	257	114	205	616	18024
2000	10863	6065	376	288	123	224	649	18587
2001	10969	6266	407	327	131	231	713	19045
2002	10929	6421	394	359	138	234	724	19200
2003	10940	6688	410	390	142	243	742	19554
2004	10931	6959	429	417	153	254	801	19944
2005	10961	7386	435	437	159	277	856	20510
LDGV: Light-Duty Gasoline Vehicles					LDDV: Light-Duty Diesel Vehicles			
LDGT: Light-Duty Gasoline Trucks					LDDT: Light-Duty Diesel Trucks			
HDGV: Heavy-Duty Gasoline Vehicles					HDDV: Heavy-Duty Diesel Vehicles			
MC: Motorcycles								

In 2005, emissions from HDDVs contributed 39 Mt to Canada's total GHG emissions (an increase of 84% from 1990 emissions). Emissions from heavy-duty gasoline vehicles (HDGVs) were substantially lower, at 6.5 Mt for 2005, this figure represents a decrease of 19% 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 emissions²⁷ in the Other transportation subsector increased by 42 % between 1990 and 2005.

The pipeline emissions included in the Other transportation subsector are combustion emissions primarily from natural gas transport. Due to increasing activity in the Energy Sector, these emissions rose 47%, from 6.9 Mt in 1990 to 10.1 Mt in 2005.

Other Sectors (2005 GHG emissions, 80.8 Mt)

The Other Sectors subsector comprises fuel combustion emissions from the residential and commercial categories, as well as stationary fuel combustion emissions from the

²⁷ 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.

agriculture and forestry category.²⁸ Overall, this subsector exhibited increases in GHG emissions of 12% from 1990 to 2005, 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 categories²⁹ accounted for 5.6% (42Mt) and 4.9% (37 Mt), respectively, of all GHG emissions in 2005.

As shown in Figure 2-2, residential emissions have remained fairly constant between 1990 and 2005, decreasing 2 Mt or 4.5% over this period. In the short term, emissions decreased by 1.2 Mt or 2.7% between 2004 and 2005. Commercial/institutional emissions increased 11 Mt or 43% between 1990 and 2005. The combined effect between 1990 and 2005 for the two categories was an increase of 9 Mt, or 13%. GHG emissions, particularly in the residential sector, track Heating Degree Days (HDDs)³⁰ closely (as shown in Figure 2-2). This close tracking indicates the important influence of weather on space heating requirements and therefore on the demands for natural gas, home heating oil, and biomass fuels.

²⁸ The UNFCCC Other Sectors category comprises the following NIR sectors: *residential*, *commercial* and *institutional*, and *other* (listed under energy, fuel combustion in Annex 8).

²⁹ Commercial sector emissions are based on fuel use as reported in the *Report on Energy Supply–Demand in Canada* (RES-D; Statistics Canada, 2005) 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.

³⁰ 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.

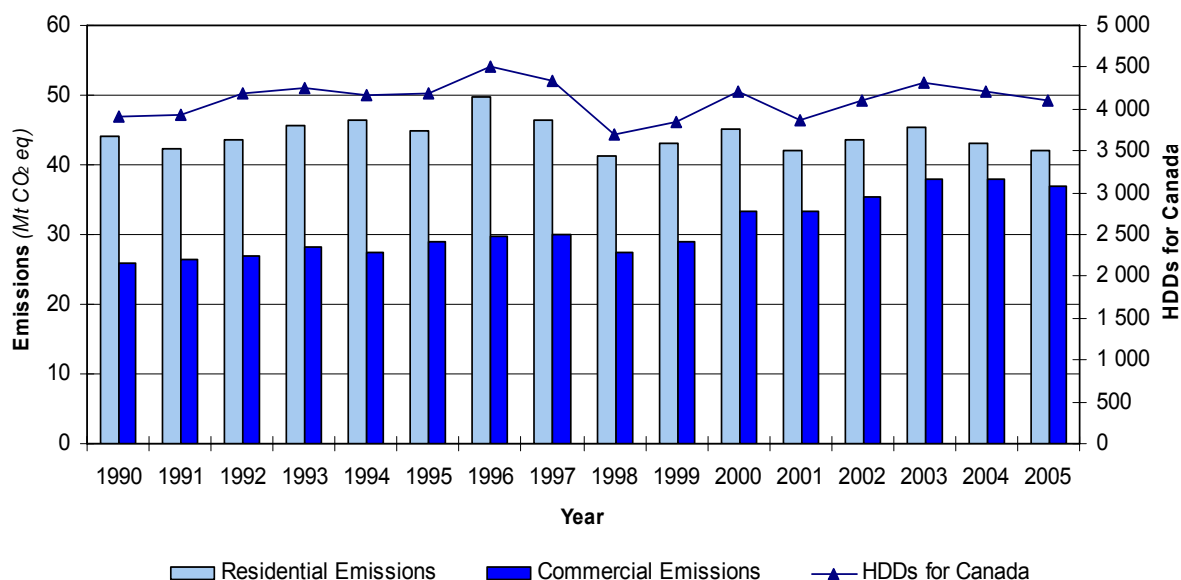


Figure 2-2: GHG Emissions from the Residential and Commercial Sectors Relative to HDDs, 1990–2005

Floor space in both the residential and commercial categories increased significantly and consistently in 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 led to an increased demand for space cooling and heating. There has also been 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 the following influences: fuel substitution away from petroleum products, improvements in end-use efficiency, and improvements in the thermal envelope of houses.

Agriculture and Forestry

Stationary fuel combustion–related emissions from the agriculture and forestry category amounted to 1.9 Mt in 2005, a decrease of 20% since 1990.

2.3.1.2 Fugitive Emissions from Fuels (2005 GHG emissions, 65.7 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 8.8% of Canada’s total GHG

emissions for 2005 and contributed 15% to the growth in emissions between 1990 and 2005.

Table 2-1 summarizes the changes in fugitive emissions from the solid fuel and from the oil and natural gas category. In total, fugitive emissions grew by about 54% between 1990 and 2005, from 42.7 Mt to 65.7 Mt, with emissions from the oil and natural gas category contributing 99% of the total fugitive emissions in 2005, far overshadowing the 1% contribution from coal mining. Although fugitive releases from the solid fuels category (i.e., coal mining) decreased by over 1 Mt (62%) between 1990 and 2005 due to 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 194% increase in the net energy exported from Canada, accompanied by a 128% increase in GHG emissions associated with those net energy exports.

2.3.2 Industrial Processes Sector (2005 GHG emissions, 53.3 Mt)

The Industrial Processes Sector includes GHG emissions that are direct by-products of processes, including Mineral Production, Chemical Industry, Metal Production, Consumption of Halocarbons and SF₆, and Other and Undifferentiated Production. GHG emissions from the Industrial Processes Sector contributed 53.3 Mt to the 2005 national GHG inventory, compared with 53.5 Mt in 1990. Figure 2-3 illustrates the changes in each of the categories over the period 1990–2005, and Table 2-6 provides an emission breakdown by category for selected years.

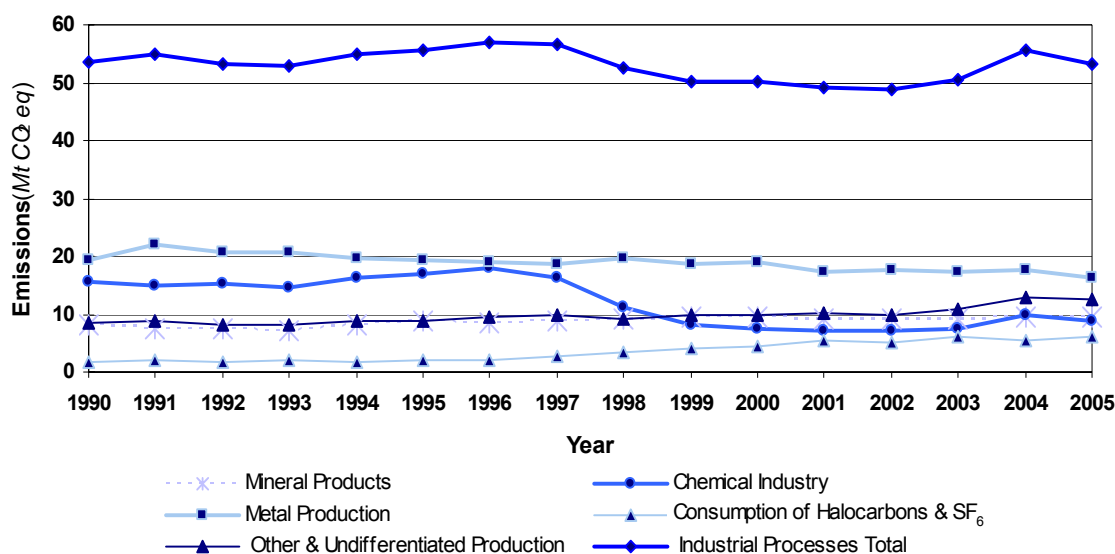


Figure 2-3: GHG Emissions from Industrial Processes by Category, 1990–2005

Table 2-6: GHG Emissions from Industrial Processes by Category, Selected Years

GHG Source Category	GHG Emissions				
	1990	1995	2000	2004	2005
	<i>(Mt CO₂ eq)</i>				
Industrial Processes (Total)	53.5	55.7	50.2	55.4	53.3
Mineral Products	8.3	8.8	9.6	9.5	9.5
Cement Production	5.4	6.1	6.7	7.1	7.2
Lime Production	1.7	1.8	1.9	1.8	1.7
Limestone and Dolomite Use	0.7	0.5	0.6	0.3	0.2
Soda Ash Use	0.2	0.2	0.2	0.1	0.2
Magnesite Use	0.1	0.1	0.2	0.2	0.2
Chemical Industry	15.7	17.0	7.4	9.8	8.9
Ammonia Production	3.9	5.3	5.3	5.5	5.0
Nitric Acid Production	1.0	1.0	1.2	1.2	1.3
Adipic Acid Production	10.7	10.7	0.9	3.1	2.6
Metal Production	19.5	19.2	18.9	17.6	16.2
Iron and Steel Production	7.1	7.9	7.9	8.2	7.0
Aluminium Production	9.3	9.1	8.2	7.3	7.9
Magnesium Production	2.9	1.9	2.3	2.0	1.1
Magnesium Casting	0.2	0.2	0.5	0.2	0.2
Consumption of Halocarbons	0.0	0.5	3.0	4.7	4.9
SF₆ Use in Electric Utilities and Semiconductors	1.8	1.5	1.5	0.8	1.2
Other & Undifferentiated Production	8.3	8.7	9.7	13.0	12.6

Note:

Totals may not add up due to rounding.

Between 1990 and 2005, the overall sector emissions decreased by approximately 0.2 Mt (0.4%). This minor change could be explained by emission reductions in adipic acid production and some metal industries, which were offset by emission growth in the categories of cement production, consumption of HFCs, and other and undifferentiated production (an emission category comprised mainly of petrochemical production that uses hydrocarbons as feedstocks). For instance, the emission levels for adipic acid production, aluminium production and magnesium smelting dropped by 8.1 Mt (75%), 1.4 Mt (15%), and 1.8 Mt (62%), respectively, as compared with the 1990 levels. The installation of an emission abatement system at Canada's only adipic acid facility in 1997, incorporation of automated emission controls in aluminium production, and progressive replacement of SF₆ with alternatives used as cover gas in magnesium production contributed to the downward emission trend in these categories. Also to be noted was the emission drop of 66% for the category of limestone and dolomite use, which was partially due to a decreasing trend of limestone used in the pulp and paper industry.

Cement production, HFC consumption, and other and undifferentiated production have showed increases of 32%, 235% and 52%, respectively, between 1990 and 2005. An increase in cement production associated with growing construction activities in Canada

and parts of the United States contributed to the upward GHG emission trend. The Consumption of Halocarbons category continues to show growth, as more ozone-depleting substances (ODSs) were replaced by the HFCs within the refrigeration and air conditioning (AC) markets. The non-energy (i.e. feedstock) use of fuels in the petrochemical industry has also noticeably increased over the years, causing an important emission growth for the category of other and undifferentiated production.

From 2004 to 2005, the overall diminution of 2.1 Mt (4%) was mainly driven by emission reductions in the chemical and metal industries. Due to lower demand for ammonia in 2005, the emissions associated with its production reduced by 0.45 Mt (8.7%). A strike at Canada's only adipic acid plant, in 2005, caused lower production levels and N₂O emissions. The decrease in international demand for the Canadian steel between 2004 and 2005 accounted for reductions in steel production, and in emissions of 1.15 Mt (14.1%). Finally, one of the two major magnesium producers in Canada significantly reduced its SF₆ use and emissions, because of production reduction in anticipation of potential closure.

2.3.3 Solvent and Other Product Use Sector (2005 GHG emissions, 0.18 Mt)

The Solvent and Other Product Use Sector accounts for emissions related to the use of N₂O as an anaesthetic in medical applications and as a propellant in aerosol products. It contributed 178 kt CO₂ eq to the 2005 national GHG inventory, as compared with 175 kt CO₂ eq in 1990. The emission trends, either long-term (between 1990 and 2005) or short-term (between 2004 and 2005), were driven by the domestic demand for N₂O for anaesthetic or propellant purposes. According to a recent study prepared for Environment Canada, demand for N₂O for medical use has been slowly decreasing over the last few years. For example, it was suggested that dentists have been using less N₂O, in part due to liability concerns, and in part due to changes in their operational practice (Cheminfo, 2006).

2.3.4 Agriculture Sector (2005 GHG emissions, 57 Mt)

Canada's Agriculture Sector is composed of approximately 250 000 farms, 98% of which are family owned. Agricultural emissions accounted for 57 Mt or 7.6% of total 2005 GHG emissions for Canada, an increase of 11 Mt since 1990. All these emissions are from non-energy sources, with N₂O accounting for about 51% of sectoral 2005 emissions and CH₄ for about 49%.

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 (direct and indirect soil emissions and animal manure on pasture) (Figure 2-4).

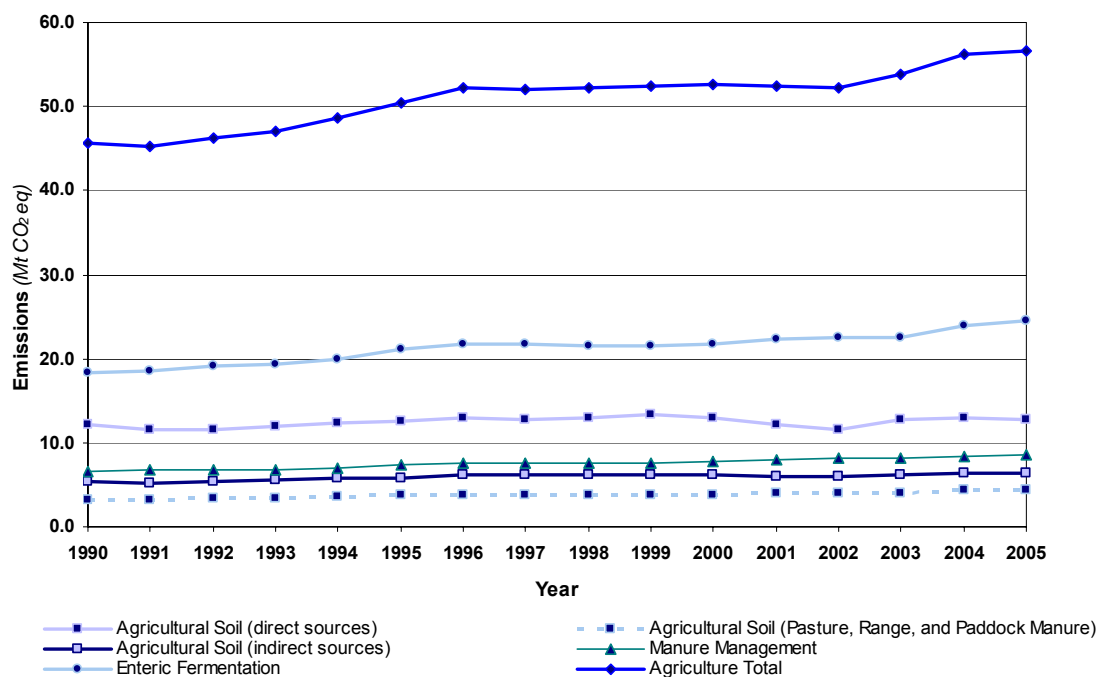


Figure 2-4: GHG Emissions from Agriculture, 1990–2005

Livestock emissions consist of enteric fermentation from domestic animals (i.e., digestive processes that release CH_4) and manure management (which releases CH_4 and N_2O). These emissions accounted for 59% of the Agriculture Sector's total GHG emissions in 2005.

Agricultural soil emissions consist of direct N_2O emissions from synthetic nitrogen fertilizers, animal manure applied to cropland, crop residue decomposition, summerfallow, tillage practices, irrigation and cultivation of organic soils; indirect N_2O emissions from volatilization and leaching of fertilizer, manure, and crop residue nitrogen; and N_2O emissions from manure on pasture, range, and paddock. These sources accounted for about 41% of the Agriculture Sector's total GHG emissions in 2005.

In the period from 1990 to 2005, enteric emissions increased by 33%, emissions from manure management systems by almost 29%, and soil N_2O emissions by over 13%. These increases result mainly from the expansion of the beef cattle, swine, and poultry industry, as well as the increase in consumption of synthetic nitrogen fertilizer.

Between 2004 and 2005, there was an increase in agricultural emissions, amounting to 0.4 Mt. Most of this increase resulted from enteric fermentation (0.5 Mt), manure on pasture (0.1 Mt), and manure management (0.1 Mt), primarily because of a significant increase in beef cattle population (about 2.4% increase between 2004 and 2005). This

increase in animal emissions was partially offset by a decrease in N₂O emissions from synthetic nitrogen fertilizer consumption (-0.4 Mt).

2.3.5 Land Use, Land-Use Change and Forestry Sector (2005 net GHG removals, 17 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 CO₂ emissions and removals and non-CO₂ emissions, displays high inter-annual variability over the reporting period. In 2005, this net flux amounted to removals of 17 Mt (Figure 2-5).

All emissions and removals in the LULUCF Sector are excluded from the national totals. In 2005, the estimated 17 Mt would, if included, decrease the total Canadian GHG emissions by about 2%.

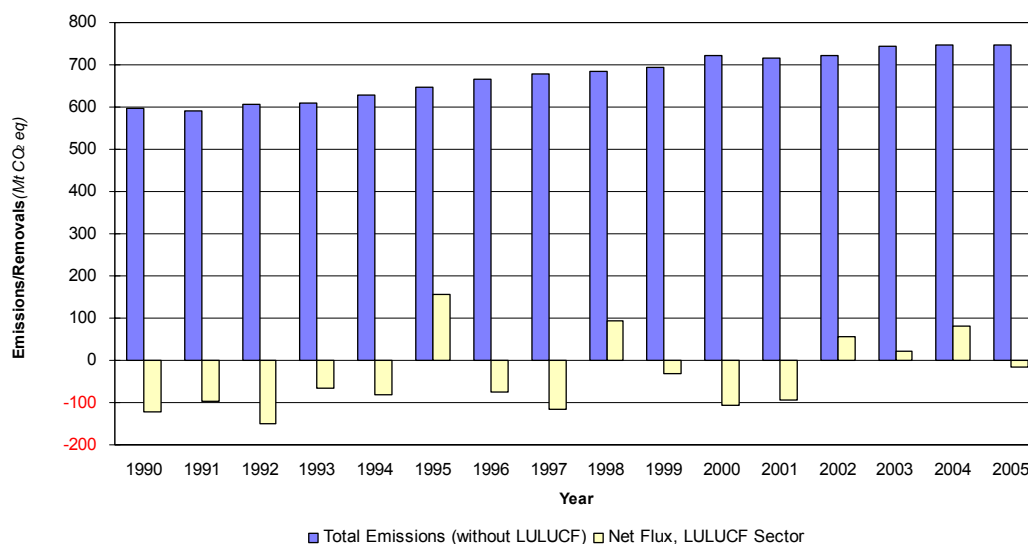


Figure 2-5: GHG Emissions from LULUCF Relative to Total Canadian Emissions, 1990–2005

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 to and removals from Canada's managed forests and modest CO₂ removals from forest plantations. Managed forests display the highest inter-annual 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 291 Mt over the period from 1990 to 2005 (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 inter-annual 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 (respectively -3024 and 2124 Mt CO₂ in 2005). Forest management activities, namely harvesting, account for annual average emissions of 151 Mt with the current default approach which ignores carbon storage in wood products.

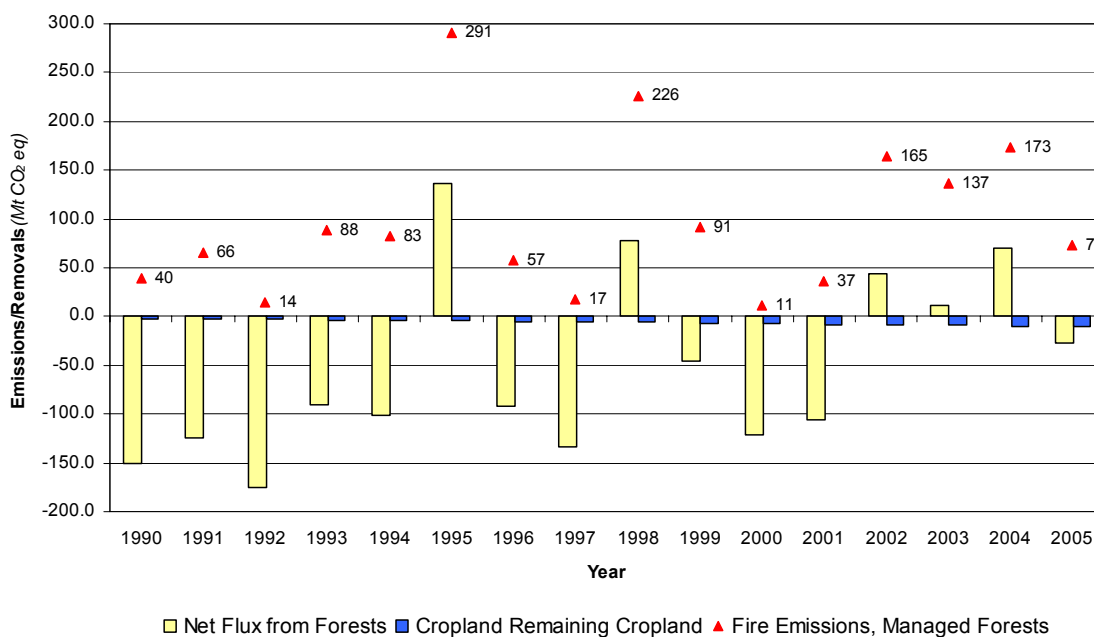


Figure 2-6: Selected GHG Emissions and Removals in LULUCF, 1990–2005

The Cropland subcategory includes the effect of agricultural practices on CO₂ emissions and removals from arable soils and the GHG impact associated with forest and grassland conversion to cropland. In 2005, the net GHG balance of the Cropland category amounted to emissions of 0.5 Mt. The continued adoption of no-till and reduced tillage practices and the reduction of summerfallow have resulted in a steady trend of increasing removals in cultivated soils which almost offset in 2005 the emissions due to land conversion to agriculture.

CO₂ emissions from peatlands managed for peat extraction and from flooding are reported under the Wetlands category. Managed peatlands contribute 0.6 Mt of emissions to the LULUCF Sector total. Land conversion to Flooded lands (reservoirs) emitted 5 Mt in 1990, decreasing to 1 Mt in 2005. 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 2005) 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 amount to emissions of about 21 Mt in 2005, down from 29 Mt in 1990. This reduction is accounted for by declines of more than 4 Mt in emissions from forests converted to cropland, of 3 Mt in forests converted to wetlands (flooded lands), and also a reduction of 1 Mt in emissions from forest conversion to settlements. The reader is referred to additional information in Chapter 7 and Section A3.5 of Annex 3 of the present report.

2.3.6 Waste Sector (2005 GHG emissions, 28 Mt)

From 1990 to 2005, GHG emissions from the Waste Sector increased 21%, only slightly greater than the population growth of 17%, while over the same period the total national GHG emissions grew by 25% (Figure 2-7). In 2005, these emissions represented 3.7% of the total national GHG emissions, compared with a 3.9% contribution in 1990. Of the 28 Mt total emissions from this sector in 2005, solid waste disposal on land, which includes municipal solid waste (MSW) landfills and wood waste landfills, accounted for 27 Mt. CH₄ emissions produced by the decomposition of biomass in MSW were responsible for 96% 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 2-7). Figure 2-7 presents the emission trends for each of the three subsectors as compared with the total emissions for the Waste Sector between 1990 and 2005. The tables in Annex 8 summarize this information nationally by CO₂ equivalent and by category (i.e., individual gas and source).

Table 2-7: GHG Emissions from Waste, Selected Years

GHG Source Category		GHG Emissions				
		1990	1995	2000	2004	2005
		<i>(Mt CO₂ eq)</i>				
Total Waste Sector		23	25	26	28	28
a.	Solid Waste Disposal on Land	22	24	25	26	27
b.	Wastewater Handling	0.78	0.81	0.88	0.93	0.93
c.	Waste Incineration	0.40	0.35	0.25	0.23	0.24

Note:

Totals may not add up due to rounding.

CH₄ emissions from MSW landfills increased by 24% between 1990 and 2005, despite an increase in landfill gas capture and combustion of 50% over the same period.

Approximately 314 kt of CH₄ (or 6594 kt CO₂ eq) were captured by the 52 landfill gas

collection systems operating in Canada (Environment Canada, 2007)³¹. Of the total amount of CH₄ collected, 51% (159 kt) was utilized for various energy purposes and 49% (155 kt) was flared. There were 8 sites that utilized the captured methane, 31 sites that flared the captured methane and 13 sites that utilized and flared the captured methane.

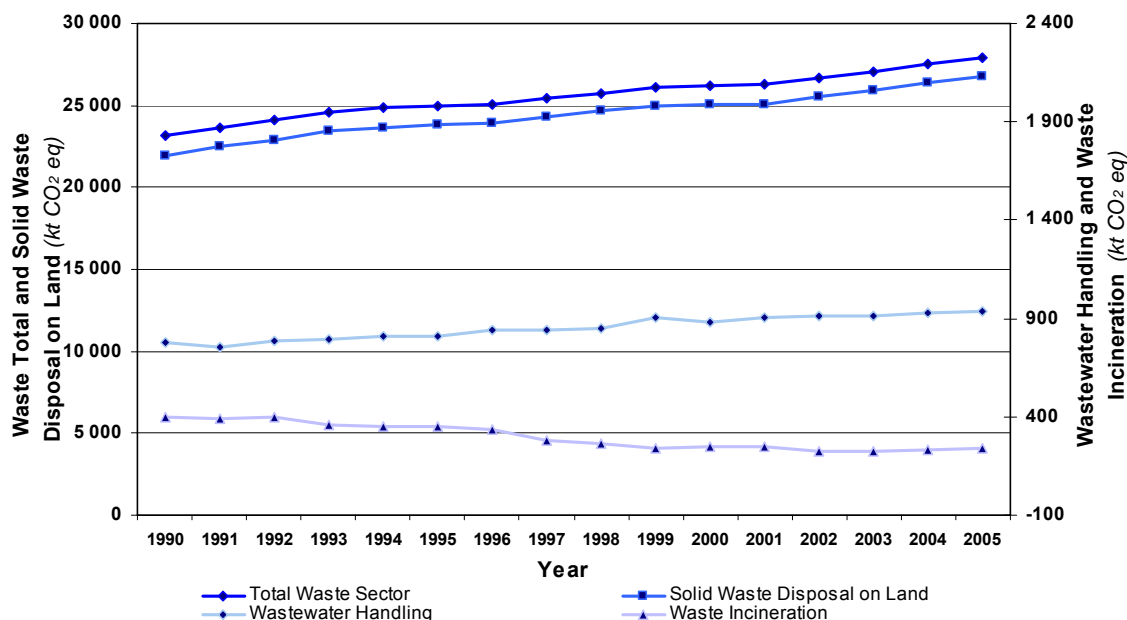


Figure 2-7: GHG Emissions from Waste, 1990–2005

GHG emissions from landfills were estimated for two solid waste types: MSW and wood waste landfills, both of which produce CH₄ anaerobically³². The CH₄ 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.

CH₄ capture and waste diversion programs at landfills have made significant contributions to reductions in emissions during this period. The quantity of CH₄ captured at MSW landfills for flaring, or combusted for energy recovery purposes in 2005 amounted to 22% of the total generated emissions from this source. Per capita emissions

³¹ Five landfill gas (LFG) capture facilities did not provide data for the 2005 LFG inventory by February, 2007. Thus, for the purposes of the NIR 1990-2005, these facilities were included in the total number of active facilities collecting LFG and it was assumed that the data provided by these facilities for the 2003 LFG inventory were constant for 2004 and 2005.

³² When waste consists of biomass, the CO₂ produced from burning or aerobic decomposition is not accounted for in the Waste Sector. This because, in the case of agricultural biomass, it is deemed to be a sustainable cycle (carbon in CO₂ will be sequestered when the biomass regenerates in crop re-production). In the case of biomass from forest products the emissions of CO₂ are accounted for as part of the LULUCF Sector (forest harvests). However, waste that decomposes anaerobically produces CH₄, which is not used photosynthetically and therefore does not sequester carbon in biomass regeneration, or accounted for in forest harvest estimates. The production and release of unburned CH₄ from waste are therefore accounted for in GHG inventories.

from the Waste Sector increased 3.6% from 1990 to 2005 due primarily to the increasing emissions from landfills (Figure 2-8). The amount of CH₄ captured increased by 50% between 1990 and 2005, and the amount of waste diverted increased by 17.5% from 1998 when diversion programs were initiated to 2004. Although the quantity of waste placed in MSW landfills increased by 22% from 1990 to 2005, the landfilled quantity per capita increased by only 4.9% (Statistics Canada, 2000, 2003, 2004, 2007). The amounts of waste exported from Canada to the United States for the years 1998 and 2004 were 560 kt and 2590 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 due to restrictions on the exportation of solid waste. The main contributors to the export of waste outside of Canada have committed to eventually eliminate the shipment of waste to the United States by the end of 2010. Within this timeframe there will be a 20 percent reduction by 2007 and a further 20 percent reduction by the end of 2008 (Ontario Ministry of the Environment, 2006).

Emission trend growth slightly exceeds that of population, partially due to the delayed effect on emissions caused by material landfilled in past decades that is still contributing to CH₄ production. The decline in the growth of emissions per capita observed in the mid-1990s, shown in Figure 2-8, is directly attributable to CH₄ capture at landfills and waste diversion programs. However, from 1997 to 2000, 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 as compared with 1990 emissions per capita for the other waste subsectors, GHG emissions from wastewater handling have remained fairly constant, while waste incineration has shown a significant decrease in GHG emissions over the 1990–2005 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.

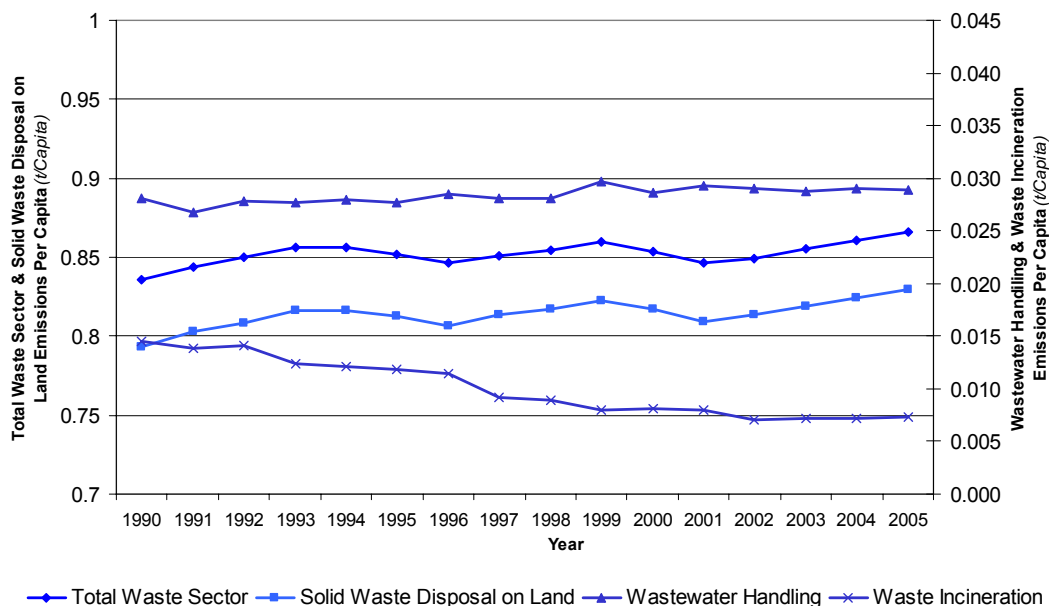


Figure 2-8: Per Capita GHG Emission Trend for Waste, 1990–2005

2.4 Emission Trends for Ozone and Aerosol Precursors

In summary, over the 1990–2005 period, emissions of ozone and aerosol precursors fell. CO fell by 38.2%, NO_x was down 0.5%, NMVOCs declined 19.7%, and SO_x was reduced by 34.3% (see Annex 14 for data tables).

3 Energy (CRF Sector 1)

3.1 Overview

Overall, the Energy Sector contributed about 82% (or 609 Mt CO₂ eq) of Canada's total GHG emissions in 2005 (Table 3-1). The Energy Sector accounts for all GHG (CO₂, CH₄, and N₂O) 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 (i.e., accidental) 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 CH₄ and N₂O 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, while CO₂ 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, road transportation, railways, navigation (marine), and other transportation (off-road and pipelines), are included in the Transport subsector. Usage of transport fuels (such as gasoline and diesel) by all mining industry, by the oil and gas extraction industry, and by agriculture and forestry industry is also included in the Transport – Other subsector. 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	1990	2004	2005
	<i>kt CO₂ eq</i>		
Energy Sector	473 000	608 000	609 000
Fuel Combustion (1.A)	431 000	542 000	543 000
Energy Industries (1.A.1)	147 000	199 000	202 000
Manufacturing Industries and Construction (1.A.2)	62 800	67 000	62 800
Transport (1.A.3)	150 000	190 000	200 000
Other Sectors (1.A.4)	72 200	83 200	80 800
Fugitive Emissions from Fuels (1.B)	42 700	66 200	65 700

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: Detailed discussion of 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 2005, about 543 Mt (or 73%) of Canada's GHG emissions were from the combustion of fossil fuels (Table 3-1). The overall GHG emissions from fuel combustion activities increased by 26% since 1990 and increased by 0.3% since 2004. Between 1990 and 2005, combustion related emissions from the Energy Industries and from the Transport category increased by about 38% and 33%, respectively (Figure 3-1).

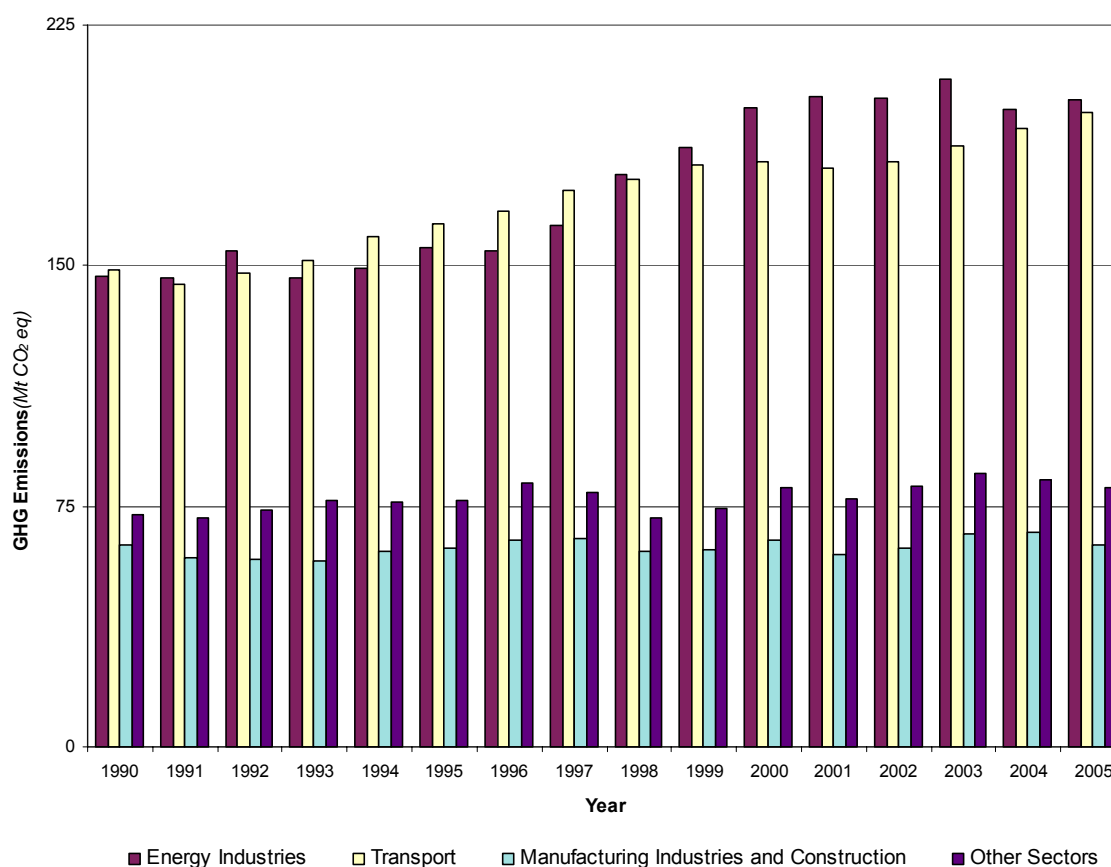


Figure 3-1: GHG Emissions from Fuel Combustion, 1990–2005

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

3.2.1.1 Source Category Description

In 2005, the Energy Industries subsector accounted for 202 Mt (or about 27%) of Canada's total GHG emissions, with an overall increase of about 38% since 1990. Almost 64% (or 129 Mt) of the subsector's GHG emissions are from Public Electricity and Heat Production, while Petroleum Refining and the Manufacture of Solid Fuels and Other Energy Industries contributed 9% (18 Mt) and 27% (55 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). The marked differences in GHG contributions from the fossil fuel industries, as compared to the 1990-2004 NIR, are due to updated information and revisions to the stationary combustion model. These are discussed in greater depth in Chapter 9 – Recalculations and Improvements.

Table 3-2: Energy Industries GHG Contribution

GHG Source Category	GHG Emissions		
	1990	2004	2005
	<i>(kt CO₂ eq)</i>		
Energy Industries TOTAL (1.A.1)	147 000	199 000	202 000
Public Electricity and Heat Production	95 300	127 000	129 000
<i>Electricity Generation — Utilities</i>	92 400	119 000	122 000
<i>Electricity Generation— Industry</i>	2 200	5 400	4 600
<i>Heat/Steam Generation</i>	700	2 000	1 700
Petroleum Refining	16 000	18 000	18 000
Manufacture of Solid Fuels and Other Energy Industries	36 000	54 000	55 000

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 Manufacturing of Solid Fuels and Other Energy Industries have been allocated to the Manufacturing Industries and Construction – Mining and the Transport – Other subsector because fuel consumption data at lower level of disaggregation is not available. Combustion emissions associated with the pipeline transmission of oil and natural gas is included in the Transport – Other subsector according to the Revised 1996, IPCC Guideline.

The Energy Industries subsector is divided into the following three (3) 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).

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 when compared to Canada's significant hydro and nuclear installations. Nuclear, hydro, wind, solar, and tidal electricity generators are not direct emitters of GHGs and 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 refined petroleum products (like light fuel oil or diesel fuel). Reciprocating engines can use natural gas and/or a combination of refined petroleum products while gas turbines are also fired with natural gas or refined petroleum products.

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

The Petroleum Refining category includes direct emissions from the production of liquid petroleum fuels from a raw feedstock. Conventional 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). CO₂ generated as a by-product during the production of hydrogen in the steam reforming of natural gas are reported in the fugitive category (Section 3.3).

The Petroleum Refining category also includes a small portion of combustion emissions that results from the upgrading of heavy oil from oilsands mining and in-situ extraction to produce synthetic crude oil and/or other refined products such as diesel oil for sale. Also, due to the level of aggregation of the fuel consumption data and the assumption 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 CH₄) are included in the Manufacturing of Solid Fuels and Other Energy Industries (and vice versa for a portion of

the emissions associated with bitumen upgrading in the oilsands 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, the oilsands mining, the bitumen extraction and upgrading and the coal mining industry. 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, while emissions associated with pipeline transmission and with the use of transport fuels (such as gasoline and diesel oil) in the coal mining and the oil and gas mining and extraction industry are reported under Transportation – Others since the fuel data cannot be further disaggregated.

Upgrading facilities are responsible for producing synthetic crude oil based on a feedstock of bitumen produced by oil sands mining and *in situ* recovery activities (such as 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 refined petroleum products 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 *Report on Energy Supply–Demand in Canada* (RESO) (Statistics Canada, #57-003). 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)

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 category 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 RESO 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 sectors' emissions in 1990 and increased to 3.6% in 2005.

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 includes all petroleum products (including still gas, petroleum coke, diesel, etc.) 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 is 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, 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 is 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_2 alone. Refer to the Uncertainty annex (Annex 7) for additional discussion on the ICF (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, while there is greater uncertainty surrounding both the reported quantities and properties of non-marketable fuels (such as *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_2 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_2 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 due to lack of disaggregated information.

Over 86% of the 2005 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 CO₂ emission factors ($\pm 6\%$) and CH₄ 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 CH₄ (1% to 230%) and N₂O (-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 CH₄ and N₂O uncertainty estimates for some of the emission factor uncertainty ranges and probability density functions developed by ICF (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*

Tier 1 QC checks were completed on the entire stationary combustion GHG estimation model which included checks of emission factors, activity data and CO₂, CH₄ and N₂O estimates for the entire time series. The Tier 1 QC checks were completed during the upgrade of the estimation model to a relational database and also during the estimation process.

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 were identified during the review, and primarily involved historical data. Emission factors entry error and the un-substantiated application of emission factors were also identified and corrected. No mathematical or reference errors were found during the QC checks, while only minor labelling issues were revealed. A small amount of fugitive emissions associated with the fossil fuel industries were found to have been double counted in the past and have 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*

A complete set of historical data from Statistics Canada were obtained during the upgrade of the estimation model. The data set contained values with higher precision than previously used and on rare occasions identified small differences due to rounding.

Emission factors were also reviewed during the upgrade process and in some cases the underlying assumptions for their use were either un-substantiated or were incorrectly applied. In these cases the appropriate country specific emission factor was added or the IPCC default emission factor (IPCC 2006) was applied using country-specific energy data. New emission factors for still gas and petroleum coke were also incorporated into the estimation model. These new emission factors were applicable to different end users and resulted in a split of activity data between the end users (refineries and heavy oil upgraders) as provided in the RESD. The combination of these factors contributed significantly to the recalculation of GHG estimates back to 1990. In addition, the underlying 2004 fuel-use data were revised by Statistics Canada, and estimates were recalculated accordingly.

3.2.1.6 Planned Improvements

The use of landfill gas for heat and power in Canada is poorly understood and the quality of reported data and system performance is inadequate for the purposes of the inventory. Though such systems so far are of minimal impact on the GHG Inventory, it is of interest to model them more accurately. Data collection is being enhanced and a study of systems in place in Canada is planned in order to understand the performance of these systems.

Increasing globalization has resulted in the potential for significant volumes of lower cost foreign bituminous coal to be used in Canada. It has been assumed that the majority of imported bituminous coal is supplied by the United States, but increasing global trade of this commodity will be studied to confirm this assumption and revise it if necessary.

Statistics Canada (the national energy statistics agency) is continuously working on improving the data quality and increasing the detail of the reporting categories of the national energy balance for use by Environment Canada and NRCan.

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 2005, the Manufacturing Industries and Construction subsector accounted for 62.8 Mt (or 8%) of Canada's total GHG emissions, with no significant change in emissions since 1990 (refer to Table 3-3 for more details). Within the Manufacturing Industries and Construction subsector, more than 40 Mt (or 64%) of the GHG emissions are from the Others category, followed by (in order of decreasing contributions) the Pulp, Paper and

Print, Iron and Steel, Chemicals and Non-Ferrous Metals categories, at 7.3 Mt (or 12%), 6.5 Mt (or 10%), 5.4 Mt (or 8.5%), and 3.2 Mt (or 5.1%), 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 have increased by almost 152% between 1990 and 2005.

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 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		
	1990	2004	2005
	<i>(kt CO₂ eq)</i>		
Manufacturing Industries and Construction TOTAL (1.A.2)	62 800	67 000	62 800
Iron and Steel	6 490	6 480	6 520
Non-Ferrous Metals	3 180	3 230	3 190
Chemicals	7 090	6 760	5 350
Pulp, Paper and Print	13 600	9 310	7 340
Food Processing, Beverages and Tobacco¹	IE	IE	IE
Others	32 400	41 200	40 400
<i>Cement</i>	3 690	4 210	4 580
<i>Mining</i>	6 180	14 800	15 600
<i>Construction</i>	1 880	1 350	1 310
<i>Other Manufacturing</i>	20 600	20 900	18 900

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.

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 CH₄ and N₂O from the combustion of biomass are included in the pulp and paper industrial category. CO₂ 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. The mining data also include off road fuels (i.e., diesel) used in the oil and gas mining and extraction industry that cannot be reported separately with accuracy or certainty and emissions associated with off road fuels from all mining activities have been allocated to the Transport – Other 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 CO₂. 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 CO₂ 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 CH₄ and N₂O 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, due to the 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 CO₂, CH₄ and N₂O estimates for the entire time series. The Tier 1 QC checks were completed during the upgrade of the estimation model to a relational database and also during the estimation process.

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 were identified during the review, and primarily involved historical data. Emission factors entry error and the un-substantiated application of emission factors were also identified and corrected. No mathematical or reference errors were found during the QC checks, while 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*

A complete dataset of higher precision historical data was obtained from Statistics Canada during the upgrade of the estimation model which resulted in recalculation of estimates for the entire sector.

Emission factors were also reviewed during the upgrade process and in some cases the underlying assumptions for their use were either un-substantiated (meaning no documented evidence supported their use), or were incorrectly applied. In these cases the validation of the assumption(s) was pursued, the appropriate country specific emission factor was added or the IPCC default emission factor (IPCC 2006) was applied using country-specific energy data. These corrections were primarily applied to N₂O emission factors. The combination of these factors contributed significantly to the recalculation of GHG estimates back to 1990.

In addition, the underlying 2004 fuel-use data were revised by Statistics Canada, and estimates were recalculated accordingly.

3.2.2.6 *Planned Improvements*

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 over 26% of Canada's total GHG emissions. The greatest emission growth since 1990 has been observed in light-duty gasoline trucks (LDGTs) and heavy-duty diesel vehicles (HDDVs); this growth amounts to 109% (23.2 Mt) for LDGTs and 84% (17.8 Mt) for HDDVs. A long-term decrease in some transport subsectors has also been registered: specifically, reductions in emissions from light-duty gasoline vehicles (LDGVs - cars), propane and natural gas vehicles, and heavy-duty gasoline vehicles, for a combined decrease of 9.1 Mt since 1990. Generally, the Transport subsector has increased 33% and has contributed the equivalent to 32% of the total overall growth observed in Canada (see Table 3-4).

Table 3-4: Transport GHG Contribution

GHG Source Category	GHG Emissions		
	1990	2004 (<i>kt CO₂ eq</i>)	2005
Transport TOTAL (1.A.3.)	150,000	190,000	200,000
Civil Aviation	6,400	7,900	8,700
Road Transportation	101,000	133,000	135,000
<i>Light-Duty Gasoline Vehicles</i>	47,200	42,400	41,200
<i>Light-Duty Gasoline Trucks</i>	21,300	43,300	44,500
<i>Heavy-Duty Gasoline Vehicles</i>	8,050	6,600	6,510
<i>Motorcycles</i>	151	252	260
<i>Light-Duty Diesel Vehicles</i>	363	441	443
<i>Light-Duty Diesel Trucks</i>	724	2,040	2,200
<i>Heavy-Duty Diesel Vehicles</i>	21,200	37,400	39,000
<i>Propane & Natural Gas Vehicles</i>	2,200	860	720
Railways	7,000	6,000	6,000
Navigation (Marine)	5,100	6,700	6,500
Other Transportation	30,000	40,000	40,000
<i>Off-Road Diesel</i>	20,000	20,000	20,000
<i>Off-Road Gasoline</i>	7,000	8,000	7,000
<i>Pipelines</i>	6,900	8,520	10,100

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;
- Road Transportation;
- Railways;
- Navigation (Marine); and
- Other Transportation.

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 (MGEM07). 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) and aviation.

Civil Aviation (CRF Category 1.A.3.a)

This category includes all GHG emissions from domestic air transport (commercial, private, military, agricultural, etc.). Although the IPCC Guidelines (IPCC/OECD/IEA, 1997) call for military air transportation emissions to be reported in the Other subsector (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 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 natural gas and propane vehicles which follow a modified IPCC Tier 1 method), as outlined in IPCC/OECD/IEA (1997). MGEM07 disaggregates vehicle data and calculates emissions of CO₂, CH₄, and N₂O from all mobile sources except aviation and 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 MGEM07. Fuel consumption data from the RESD (Statistics Canada, #57-003), reported as railways, are multiplied by fuel-specific emission factors (refer to Annex 2 for a description of the methodology).

Navigation (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 calculations methodology is considered to be modified IPCC Tier 1 approach (IPCC/OECD/IEA, 1997), and emission estimates are performed within MGEM07. 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 transport³³ (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.

³³ Referred to as non-road or off-road vehicles. The terms “non-road” and “off-road” are used interchangeably.

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

Pipelines³⁴ 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, 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 i) the mobile sources of transport, including on-road and off-road vehicles, railways, civil aviation, and navigation, and ii) pipeline transport. The uncertainty in the 2001 estimates for CO₂ emissions from fossil fuel combustion in mobile sources was estimated at -4% to 0%, indicating that the inventory GHG values are likely overestimates.

Similar to the stationary fuel combustion sources, the uncertainty ranges of approximately a factor of four or more for the 2003 submission (2001 inventory year) for the CH₄ and N₂O emissions from Transport subsector fossil fuel combustion were attributable to the large uncertainty ranges for several CH₄ and N₂O 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 CO₂ in the total GHG emissions from the mobile sources of transport and its relatively low uncertainty estimate.

³⁴ Consisting of both oil and gas types.

CO₂ Emissions from Civil Aviation

The uncertainty associated with the CO₂ emission estimates from civil aviation reported in ICF (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 CO₂ emission factor and the fuel consumption estimate for aviation turbo fuel, which accounted for nearly 98% of the total CO₂ emissions from civil aviation in 2005. There is a rationale to suggest 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.

CO₂ Emissions from Road Transportation

The uncertainty associated with CO₂ 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 i) the amount of fuel consumed by motor gasoline and diesel on-road vehicles and ii) the CO₂ emission factors for motor gasoline. The 95% confidence interval uncertainty range for the CO₂ motor gasoline emission factor was estimated to be -3% to -1% by McCann (2000). For the 2007 submission, MGEM07 employed a higher disaggregation of activity data which resulted in an increased confidence in the on-road portion of the model prompting a modification of the fuel balance algorithm thereby transferring fuel from on-road to off-road category. With this improvement, the uncertainties for both on-road and off-road should be lower than when they were evaluated for the 2003 submission.

CO₂ Emissions from Railways

The uncertainty associated with CO₂ 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 CO₂ emission factor for diesel (with an uncertainty range of -4% to +2%) were equally responsible.

CO₂ 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 CO₂ emissions from this source category. The CO₂ emissions from off-road diesel vehicles accounted for nearly 77% of the total CO₂ emissions from the off-road category in 2005. The main sources of uncertainty for this

source category are the uncertainty associated with the 2005 inventory year values of 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 “CO₂ Emissions from Road Transport” above for a complete explanation.

Summary

Generally, for the Transport subsector, the ICF (2004) study merely incorporated previous studies’ reported values for the estimated uncertainty surrounding the CO₂, CH₄, and N₂O emission factors (McCann, 2000; SGA, 2000). ICF (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, however, minor issues with labelling and references were found and corrected. 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 MGEM07 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 data but also knowledge of vehicle population data, fuel consumption ratios (FCR’s) and vehicle kilometres travelled (Vkt’s). This increased perspective fosters a better understanding of actual vehicle use and subsequently should promote better modelling and emissions estimating. With support from Transport Canada, Statistics Canada

publishes the Canadian Vehicle Survey (CVS), a quarterly report that provides both vehicle population and Vkt's 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 emissions modelling is unavailable from the CVS, and therefore it cannot replace the annually purchased data sets.

3.2.3.5 *Recalculations*

Transport estimates were revised for the 1990-2004 period due to the following factors:

- Statistics Canada fuel consumption data. Two changes are noted that contribute 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 MGEM07 model. Vehicle populations in MGEM07 are now disaggregated by class and model year for all provinces and territories. Other data improvements in MGEM07 included refined technology penetration assumptions, fuel consumption ratio, and vehicle kilometres travelled. 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 CH₄ and N₂O emission factors was carried out to ensure the most appropriate emission factor was being used. As part of the technical review the applicability of separate N₂O emission factors for new and aged (over 20,000km) Tier 0 vehicles was reviewed. It was concluded that age alone does not affect the N₂O removal efficiency of Tier 0 catalysts. An average N₂O emission factor based on aged Tier 0 vehicles is used for all Tier 0 vehicles in the 1990-2005 estimates. Minor adjustments resulted for all years.
- Modification of the on and off-road fuel allocation methodology. Due to an improved understanding of the vehicle fleet, the amount of fuel allocated by MGEM07 to road transportation is now estimated to have higher certainty. The fuel normalization routine used by MGEM07 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 re-allocated fuel to off-road applications from on-road transportation for all years.

3.2.3.6 *Planned Improvements*

The transportation model was upgraded in 2006/2007 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:

- Investigating the possibility of applying off-road emission factors based on a modified version of USEPA's NONROAD model, which employs time dependant device populations, fuel consumption ratios and duty cycles representative of Canada's regions.
- Developing a Tier 2 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 and aviation bunkers.
- Developing region and time specific fuel carbon characteristics.
- 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).

Biomass³⁵ combustion is a significant source of emissions in the residential sector and CH₄ and N₂O emissions are included in the subsector estimates. However, CO₂ 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 2005, the Other Sectors subsector contributed about 80.8 Mt (or 11%) of Canada's total GHG emissions, with an overall growth of about 12% since 1990. Within the Other Sectors category, residential emissions contributed about 42.0 Mt (or 52%), followed by a 36.8 Mt (or 46%) contribution from the commercial and 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 43% for the

³⁵ Typically firewood.

commercial/institutional sector. 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).

Table 3-5: Other Sectors GHG Contribution

GHG Source Category	GHG Emissions		
	1990	2004	2005
	<i>(kt CO₂ eq)</i>		
Other Sectors TOTAL (1.A.4)	72 200	83 200	80 800
Commercial/Institutional	25 800	37 900	36 800
<i>Commercial and Other Institutional</i>	23 800	35 900	34 800
<i>Public Administration</i>	2 000	2 070	2 060
Residential	44 000	43 000	42 000
Agriculture/Forestry/Fisheries	2 420	2 100	1 950
<i>Forestry</i>	55	127	75
<i>Agriculture</i>	2 370	1 980	1 870

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 as 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 (such as 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.

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

Emissions are based on fuel-use data reported as residential in the RESD. The methodology for biomass combustion from residential firewood is detailed in the CO₂ Emissions from Biomass section (Section 3.4.2); although CO₂ emissions are not accounted for in the national residential GHG total, the CH₄ and N₂O 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_2 . Refer to the Uncertainty annex (Annex 7) for a detailed discussion on the ICF (2004) uncertainty study and additional uncertainty values for the Other Sectors subsector.

The underlying fuel quantities and CO_2 emission factors have low uncertainties, since they are predominantly commercial fuels, which have consistent properties and accurate tracking. Although the non- CO_2 emissions from biomass combustion contributed only 5% to the total Residential category, its CH_4 (-90% to $+1500\%$) and N_2O (-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_4 and N_2O uncertainty estimates for some of the emission factor uncertainty ranges and probability density functions developed by the ICF (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 was identified as a key category for both CH_4 and CO_2 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 while only minor labelling issues were revealed. Activity data errors involving historical values were identified during the review and corrected. Small errors in emission factors and the un-substantiated application of emission factors were also identified 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*

A complete dataset of higher precision historical data was obtained from Statistics Canada during the upgrade of the estimation model which resulted in recalculation of estimates for the entire sector.

Emission factors were also reviewed during the upgrade process and in some cases the underlying assumptions for their use were either un-substantiated (meaning no documented evidence supported their use), or were incorrectly applied. In these cases the validation of the assumption(s) was pursued, the appropriate country specific emission factor was added or the IPCC default emission factor (IPCC 2006) was applied using

country-specific energy data. These corrections were primarily applied to N₂O emission factors. The combination of these factors contributed significantly to the recalculation of GHG estimates back to 1990.

In addition, the underlying 2004 fuel-use data were revised by Statistics Canada, and estimates were recalculated accordingly.

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 2005, the Fugitives category accounted for about 65.7 Mt (or 8.8%) of Canada's total GHG emissions, with over a 54% growth in emissions since 1990. Between 1990 and 2005, fugitive emissions from oil and natural gas increased 59% to 65 Mt and those from coal decreased 62% from 1.9Mt in 1990. The oil and gas production, processing, transmission, and distribution activities contributed 98.9% of the fugitive emissions and the remaining 1.1% originates from coal mining. Refer to Table 3-6 for more detail.

Table 3-6: Fugitive GHG Contribution

GHG Source Category	GHG Emissions		
	1990	2004	2005
	<i>(kt CO₂ eq)</i>		
Fugitives TOTAL (1.B)	42,700	66,200	65,700
Solid Fuels — Coal Mining	2,000	700	700
Oil and Natural Gas	40,700	65,500	65,000
<i>Oil</i> ¹	4,180	5,940	5,660
<i>Natural Gas</i> ¹	12,900	20,400	20,800
Venting and Flaring	23,700	39,100	38,500
<i>Venting</i> ²	19,300	33,700	33,000
<i>Flaring</i> ²	4,400	5,400	5,500

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 CH₄. In coal deposits, CH₄ is either trapped under pressure in porous void spaces within the coal formation or adsorbed to the coal. The pressure and amount of CH₄ 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 geologic formations are disturbed, and pathways are created that release the pressurized CH₄ to the atmosphere. As the pressure on the coal is lowered, the adsorbed CH₄ is released until the CH₄ 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 CH₄ from within the deposit. Post-mining activities such as preparation, transportation, storage, or final processing prior to combustion also release CH₄.

Fugitive emissions from solid fuel transformation (such as fugitive losses from the opening of metallurgical coking oven doors) are not estimated due to 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 emissions 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 CH₄ 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 CH₄ 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*

The coal mining emissions for 2002, 2003, and 2004 were recalculated due to updated activity data. Statistics Canada released the surface and underground coal mining production statistics for these years. Prior to this, the 2001 mining activity data was used to estimate the GHG emissions for this industry.

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 fugitive subsector includes emissions from oil and gas production, processing, oil sands mining, bitumen extraction, heavy/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 (which includes the petroleum refining industry), 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 section. Venting results from conventional service work, such as the release of solution gas from mud tanks and blowdown 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 kg/m^3 . This viscous liquid requires a special infrastructure to produce. 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 from 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 due to 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

upstream oil and gas 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 due 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 stream (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/bitumen oil upgrading to produce bitumen, synthetic crude oil and other derived products for sale. The fugitive emissions are primarily from: hydrogen production, flue gas desulphurization; venting and flaring activities; storage and handling losses; fugitive equipment leaks; and CH₄ 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 sources are 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 industry are based on Canadian Association of Petroleum Producers' Upstream Oil and Gas study of the industry; *A National Inventory of Greenhouse Gas (GHG), Criteria Air Contaminant (CAC) and Hydrogen Sulphide (H₂S) Emissions by the Upstream Oil and Gas Industry* (CAPP, 2005). 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 over 209 000 facilities and approximately 370 000 primary sources from flaring, venting, equipment leaks, formation CO₂ venting, storage losses, loading/unloading losses, and accidental releases. Natural gas system, 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 was collected and used in the study. This 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 Upstream Oil and Gas report.

The 1990–1999 and 2001–2005 fugitive emissions were extrapolated using annual industry activity data from conventional upstream oil and gas production and the 2000 emission results. The 1990–1999 estimates and method is presented in Volume 1 of the Upstream Oil and Gas 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 Upstream Oil and Gas and the extrapolation report (CAPP, 2005).

- ***Natural Gas Transmission***

1990 to 1996 fugitive emissions from natural gas transmission are from the conventional upstream oil and gas industry study, *CH₄ 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 Gertz Inc. in association with Levelton Consultants Ltd. (CPPI, 2004). Refer to the CPPI report for full details on the study. Levelton used historical fuel, energy, and emission data gathered by the Canadian Industrial Energy End-Use Data Analysis Centre (CIEEDAC) and data collected directly from the refineries for the years 1990 and 1994–2002. Fugitive, venting, and flaring emissions for the years 1991–1993 were interpolated, while the emissions for 2003 to 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 upgrading operations; heavy oil upgraders; and integrated co-generation facilities. Fugitive emissions for the oil sands mining and heavy oil upgrading industries are from the bitumen study; *An Inventory of GHGs, CACs, and H₂S Emissions by the Canadian Bitumen Industry: 1990 to 2003* prepared for CAPP by Clearstone Engineering (CAPP, 2006). The bitumen study is a compilation of GHG emissions from the following companies: Suncor Energy Inc; Syncrude Canada Limited; Shell Canada Limited; and Husky Energy Inc. While methods used to estimate fugitive emissions from in-situ oilsands extraction to produce heavy oil/bitumen for sale and for upgrading to synthetic oil and other products are from the CAPP's Upstream Oil and Gas study (CAPP, 2005).

Facilities' inventories were reviewed by Clearstone Engineering 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. 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 were provided to each operator for their review. QA/QC and an uncertainty analysis following the IPCC GPG were also included in the study.

An extrapolation model was developed to allow annual update of fugitive emissions from oilsands 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: Alberta Energy and Utilities Board (EUB) ST-43; and National Energy Board (NEB) Production of Crude Oil and Equivalent. This data is updated annually for use in estimating GHG emissions. Refer to both the bitumen study and the extrapolation report for a detailed description of the methodology.

Natural Gas Distribution

The emission estimates were derived from a study for the Canadian Gas Association (Radian International, 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 (Radian International, 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 upstream oil and gas fugitive emissions for 2000 are taken directly from the CAPP's Upstream Oil and Gas study. The emissions from 1990 to 1999 and from 2001 to 2004 have been extrapolated using the 2000 data along with other factors discussed above. The uncertainty for the overall 2000 emissions (in CO₂ eq) is $\pm 1.5\%$. The uncertainties for the 2000 emissions (in CO₂ eq) for the oil and the natural gas industry are listed in Table 3-7 and Table 3-8, respectively. The detailed uncertainties for each gas can be found in the Upstream Oil and Gas report.

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

GHG Source Category	Uncertainty		
	Oil Exploration	Oil Production (%)	Oil Transportation
Flaring	±4.2	±2.3	±24.0
Fugitive	-8.9 to +8.3	±7.4	-20.9 to +21.0
Venting	-38.4 to +30.4	-3.7 to +3.4	
Total	-2.3 to +2.1	± 3.1	-16.7 to +16.8

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	±1.7
Venting	-4.0 to +3.5
Total	±0.7

Source: CAPP (2005).

The uncertainties were determined using the Tier 1 uncertainty approach presented in the IPCC GPG (IPCC, 2000). According to the IPCC GPG, there are three sources for uncertainties: definitions, natural variability of the process that produces the emissions, and the assessment of the process or quantity (IPCC, 2000). Only the last two sources of uncertainty were considered in the analysis, as 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 upstream oil and gas 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, 2003, and 2004 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. Levelton completed a Tier 1 and Tier 2 analysis, for comparison purposes, on the uncertainty of the emission factors and activity data, for an overall uncertainty for CO₂ in 2002 (CPPI, 2004).

The results of these analyses are as follows: For the Tier 1 analysis, the overall uncertainty was ±8.3%. The Tier 2 analysis determined that the overall uncertainty was ±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	± 8.3	± 4.3	± 8.3	± 8.3
Tier 2	± 14	± 5	± 14	± 14

Unconventional Oil Production

Only facility level uncertainty estimates are presently available from the bitumen study and from the extrapolation model. Clearstone Engineering conducted an IPCC GPG Tier 1 uncertainty assessment for each facility and full details of the assessment can be found in the Bitumen Study and the OS/HOU emissions extrapolations model. 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 Upstream Oil and Gas study (CAPP, 2005), Clearstone Engineering 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.

A Tier 1 QC checks consistent with IPCC Good Practice Guidance (IPCC, 2000) were performed on the CO₂ and CH₄ 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*

Recalculations to the oil and natural gas fugitive emissions were due to the following changes: 1) updates from the final bitumen study and extrapolation model; 2) reallocation of emissions from Oil and Natural Gas Production category to venting and vice versa; 3) revised fuel consumption data for the petroleum refining industry; and 4) revised activity data of the length of natural gas transmission pipeline and distribution.

A complete time series recalculation of emissions from 1990 to 2004 for the oilsands mining and heavy oil upgrading industry was implemented based on updates from the finalized bitumen study and the oilsands mining and heavy oil upgrading extrapolation model. This has resulted in recalculations for 1990 to 2004 in emission estimates in the following categories: 1.B.2.a.ii. Oil Production; 1B.2.c.i. Venting – Oil; and 1B.2.c.i Flaring – Oil.

To ensure consistent reporting, intentional and unintentional fugitive emissions were reallocated, for example emissions from the Oil Refining/Storage and the Natural Gas Production and Processing category were reallocated to the Venting – Oil and the Venting – Natural Gas category and vice versa resulting in a complete time series reporting of emissions for these categories, without any changes to the emission estimates, methodology, activity data or emission factors.

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 to 1993 and to extrapolate from 2003 onwards is 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 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 to 1993 and for 2003 onwards.

For natural gas transmission and distribution, fugitive emissions were recalculation for the years 2002 to 2004 based on new natural gas pipeline and distribution distances as published by Statistics Canada.

3.3.2.6 *Planned Improvements*

Environment Canada plans to conduct a review and an assessment of improvements of 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.C.1)

According to the 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.C.1.A)

Emissions have been calculated using the same methods listed in the section Civil 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 desegregation 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 due 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 , 1990-2005 (Mt CO₂ eq)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Aviation Bunkers (International)	7.1	6.4	6.9	6.7	7.1	7.6	8.9	9.1	9.4	10.1	10.2	9.2	9.2	8.6	9.6	9.5
Civil Aviation (Domestic)	6.4	5.7	5.5	5.3	5.4	5.9	6.2	6.3	6.5	6.6	6.6	6.2	6.8	7.3	7.9	8.7
Total	13.5	12.1	12.5	11.9	12.6	13.5	15.1	15.5	15.9	16.7	16.8	15.3	16	15.8	17.5	18.2

Note: Totals may not add up due to rounding.

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

Emissions have been calculated using the same methods listed in the section Navigation (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, 1990-2005 (Mt CO₂ eq)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Marine Bunkers (International)	3.1	3.2	3.3	2.9	3.3	3.4	3.2	3.1	3.9	3.5	3.5	3.8	2.9	1.7	2	2
Navigation (Domestic)	5.1	5.3	5.1	4.5	4.7	4.4	4.5	4.5	5.2	5	5.1	5.5	5.5	6.2	6.7	6.5
Total	8.2	8.5	8.4	7.4	8	7.8	7.7	7.7	9	8.5	8.7	9.3	8.4	7.8	8.7	8.4

Note: Totals may not add up due to rounding.

3.4.2 CO₂ Emissions from Biomass

As per the UNFCCC reporting guidelines, CO₂ 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. CH₄ and N₂O 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 CO₂, CH₄, and N₂O 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 CAC Inventory (Environment Canada, 1999). Statistics Canada and NRCan residential fuel-use data 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 N₂O and CH₄ emission factors for different wood-burning appliances are from the U.S. EPA's AP-42, supplement B (EPA, 1996). These emissions are included in the fuel combustion sector of the inventory.

The emission factors for CO₂ are from an Environment Canada study (ORTECH Corporation, 1994).

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 CO₂ and CH₄ emission factors are those assigned by the U.S. EPA to wood fuel/wood waste (EPA, 1996). For CH₄, 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 N₂O emission factors are those assigned to wood fuel/wood waste (Rosland and Steen, 1990; Radke *et al.*, 1991) (see Annex 12).

The emission factor for CO₂ 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 CO₂.

The emission factor (EF) is therefore calculated as follows (Jaques, 1992):

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

Emissions are calculated by applying emission factors to the quantities of biomass combusted. The CH₄ and N₂O emissions are included in the manufacturing sector of the inventory.

3.4.2.3 *Fuel Ethanol*

For the 2007 submission, fuel ethanol used in transportation for 1990–2005 was included. Ethanol properties were developed according to chemistry and resulted in an HHV (GCV) of 24.12 TJ/ML, 52.14% carbon content, and 789.2 kg/m³ density.

Table 3-12: Ethanol Used for Transport in Canada, 1990-2005

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

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 MGEM07. In lieu of reviewed emission factors for CH₄ and N₂O for ethanol, the representative gasoline emission factor was applied as per mode and technology class. CO₂ emission factors used are those based upon true chemical characteristics mentioned previously and a 98.5% oxidation rate.

3.5 Other Issues

3.5.1 Comparison of Sectoral and Reference Approaches

The results from the reference approach (RA) were compared with the sectoral approach (SA) to verify the combustion-related emissions and the fuel/energy consumption data. The check was performed for all years from 1990 to 2005 and is an integral part of reporting to the UNFCCC. Additional details on the reference approach are located in Annex 4.

In the CRF, the RA is directly compared with the sectoral fuel combustion total. This comparison produces a significant discrepancy, since the combustion total of the sectoral approach does not include fossil fuel-derived CO₂ emissions from industrial processes and non-energy use of fuels for activities such as flaring; as shown in Table 3-13. When the RA and SA are directly compared, there is a 3.1% to 10.9% variation in kilotonnes of CO₂ equivalent emissions and a 8.4% to 13.1% variation in petajoules of fuel use, with the RA being consistently larger than the SA. To ensure that energy information is comparable with those from sectoral combustion model, the apparent energy consumption output excluding non-energy use and feedstock (as presented in CRF Table

1.A.(c) Comparison of CO₂ Emissions from Fuel Combustion) should be used when comparing with the RA's energy consumption with the SA.

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 industrial processes, while CO₂ emissions resulting from non-energy use of fossil fuels in the oil and gas industries (e.g., natural gas used for flaring or hydrogen production) are reported in the fugitive oil and gas section of the CRF. Due to these discrepancies, the predefined comparison of emissions used in the CRF Table 1.A.(c) is not appropriate for Canada, since this table is not comparing similar emission sources.

The Canadian reporting procedure follows the IPCC Guidelines (IPCC/OECD/IEA, 1997). 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 -1.7% to +3.0%. If the RA is corrected for emissions in the same way by subtracting the industrial process and fugitive emissions calculated by the SA, the totals match within -3.3% to +4.5%. A reconciliation of the 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
Energy - PJ																
Reference Approach Value	7,378	7,121	7,343	7,339	7,585	7,724	8,002	8,152	8,273	8,479	8,758	8,801	8,866	9,234	9,275	9,226
Sectoral Approach Value	6,523	6,396	6,632	6,638	6,854	7,022	7,209	7,345	7,467	7,722	8,077	7,948	8,116	8,478	8,320	8,337
Difference	13.1%	11.3%	10.7%	10.6%	10.7%	10.0%	11.0%	11.0%	10.8%	9.8%	8.4%	10.7%	9.2%	8.9%	11.5%	10.7%
Adjusted Reference Approach Excluding Non-Energy Use and Feedstocks	6,720	6,458	6,660	6,619	6,857	6,968	7,205	7,318	7,465	7,657	7,986	7,955	7,981	8,347	8,264	8,266
Adjusted Difference	3.0%	1.0%	0.4%	-0.3%	0.0%	-0.8%	-0.1%	-0.4%	0.0%	-0.8%	-1.1%	0.1%	-1.7%	-1.6%	-0.7%	-0.9%
Emissions - kt CO₂eq																
Reference Approach Value	463,422	444,545	455,689	448,561	464,290	468,901	482,192	490,372	497,970	508,294	526,994	529,314	528,115	553,055	548,838	548,916
Sectoral Approach Value	417,796	408,239	421,640	418,587	431,231	442,668	454,008	465,164	472,242	488,301	510,952	505,084	512,400	532,043	526,440	527,752
Difference	10.9%	8.9%	8.1%	7.2%	7.7%	5.9%	6.2%	5.4%	5.4%	4.1%	3.1%	4.8%	3.1%	3.9%	4.3%	4.0%
Non-energy Use and Feedstock Emissions																
Ammonia Production	3,924	3,869	4,154	4,497	4,463	5,300	5,389	5,167	5,237	5,269	5,309	5,011	4,719	5,038	5,477	5,002
Iron and Steel Production	7,060	8,317	8,502	8,184	7,539	7,884	7,747	7,552	7,688	7,893	7,896	7,282	7,116	7,044	8,164	7,010
Aluminium Production	2,715	3,147	3,273	3,908	3,771	3,643	3,863	3,929	3,977	3,949	3,899	4,202	4,419	4,581	4,224	4,842
Other & Undifferentiated Production	8,317	8,728	8,210	8,252	8,969	8,707	9,633	9,972	9,191	9,667	9,697	10,144	9,911	10,903	13,000	12,613
Hydrogen Production from Refineries	526	787	805	800	383	402	744	764	621	355	869	1,006	1,030	1,145	973	1,085
Fugitive Flaring	4,352	4,214	4,309	4,623	4,723	4,988	5,296	5,491	6,994	5,260	5,341	4,926	5,360	5,542	5,366	5,404
Total Non-Energy Use of Fuel and Feedstock	26,894	29,063	29,253	30,266	29,848	30,924	32,672	32,874	33,708	32,394	33,011	32,570	32,555	34,252	37,204	35,955
Adjusted Reference Approach Excluding Non-Energy Use and Feedstocks	436,528	415,482	426,436	418,295	434,442	437,977	449,520	457,498	464,263	475,900	493,982	496,744	495,560	518,803	511,634	512,961
Sectoral Approach Value	417,796	408,239	421,640	418,587	431,231	442,668	454,008	465,164	472,242	488,301	510,952	505,084	512,400	532,043	526,440	527,752
Adjusted Difference	4.5%	1.8%	1.1%	-0.1%	0.7%	-1.1%	-1.0%	-1.6%	-1.7%	-2.3%	-3.3%	-1.7%	-3.3%	-2.5%	-2.8%	-2.8%

Note that in Canada, as in the United States, higher heating value (HHV) is used to record the energy content of fossil fuels and the use of OECD factors to convert from HHV to lower heating value (LHV) for the purpose calculating emission information for the RA and for CRF reporting of energy information for both the RA and SA will also have an impact on the comparison of energy and emission information. For further details on the method of developing HHV conversion factors refer to Annex 4.

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, while emissions from the use of natural gas as a feedstock in the upstream and downstream oil refining or processing industry are included in the fugitive section.

A discussion of the non-energy use of fossil fuels and the methodological issues associated with calculating emissions from this source may be found in Section 4.11.

3.5.3 CO₂ Capture and Storage

CO₂ 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 geologic 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 (imported CO₂ used to enhance oil recovery is also not accounted for). However, current inventory procedures are designed to estimate the net CO₂ actually emitted to the atmosphere from all energy 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 2005, Canada exported over 60% (energy equivalent) of its gross 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.

To update this work, 1996–2005 emission estimates have been calculated using similar energy data from Statistics Canada, while emissions attributable to the exports were extrapolated based on the study. Using the emission results presented in the study, an empirical relationship was established between those 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 1996–2005 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

The Industrial Processes Sector includes emissions of GHGs produced as a direct by-product of non-energy industrial activities. GHG emissions from fuel combustion for supplying of energy to the industrial activities are assigned to the Energy Sector. Emissions associated with the use of natural gas as feedstock in the upstream and downstream oil industries, to produce hydrogen are also 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, production and consumption of SF₆, and other and undifferentiated production.

CO₂ emissions resulting from the use of fossil fuels as feedstock for the production of any chemical products other than ammonia, nitric acid, and adipic acid are reported under other and undifferentiated production (Section 4.11).

Emissions of indirect GHGs and SO₂ from activities including asphalt roofing, road paving with asphalt, pulp and paper production, and production of food and drink have not been estimated.

As shown in Table 4-1, the GHG emissions from the Industrial Processes Sector contributed 53.3 Mt to the 2005 national GHG inventory, as compared with 53.5 Mt in 1990. These emissions represented 7.1% of the total Canadian GHG emissions in 2005. The overall slight change of -0.4% (as compared with the 1990 level) in this Sector could be explained by emission reductions in the mineral product use, chemical and metal industries, which were offset by growths in emissions from cement production, consumption of HFCs, and other and undifferentiated production.

Between 1990 and 2005, emissions from mineral product use, adipic acid production, aluminum production and magnesium smelters and casters dropped by 45%, 75%, 15% and 58%, respectively. The emissions from the mineral product use have decreased from 1090 kt CO₂ eq in 1990 to 599 kt CO₂ eq in 2005. This decrease was primarily due to a decrease in limestone use. Limestone and dolomite use in 2005 has decreased by 66% from the 1990 value. This decrease was partially due to a decreasing trend of limestone used in pulp and paper, due to the increasing reliance on obtaining lime directly from lime manufacturers. As well, soda ash usage in 2005 has decreased by 23% from the 1990 value. The use of an emission abatement system since 1997 by Invista's plant in Maitland, Ontario, explains the considerable N₂O 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 and casting were due to the progressive replacement of SF₆ used as cover gas with alternatives, and reduction of production activity because of plant closures.

In regards to increases in emissions between 1990 and 2005, production of cement and other and undifferentiated production have showed increases of 32% and 52%, respectively. For cement production, the emission increase is explained by an increase in cement production associated with a higher cement demand due to an increase in construction activities in Canada and parts of the United States. The non-energy (feedstock) use of fuels, such as butane and ethane, in the petrochemical industry has also noticeably increased over the years. This has caused an important emission growth for the category of other and undifferentiated production. Since the Montreal Protocol came into effect in 1996, the progressive replacement of chlorofluorocarbons (CFCs) by HFCs has resulted in upward HFC emissions. Between 1995 and 2005, an emission growth of 235% was observed for the category of consumption of HFCs.

Between 2004 and 2005, the total emissions for the Industrial Processes Sector decreased by 4%. This overall diminution was mainly driven by emission reductions in the chemical and metal industries. Due to lower demand for ammonia and other chemical products, the emissions associated with production of ammonia, and other and undifferentiated production, reduced in 2005 by, 0.48 Mt (8.8%) and 0.39 Mt (3%) compared to 2004. A strike at Canada's only adipic acid plant, in 2005, caused lower production levels and N₂O emissions. This reduction was partly offset by a poorer than normal performance of the abatement system. The international demand for Canadian steel decreased between 2004 and 2005. This accounted for reductions in steel production, and in emissions of 1.15 Mt (14.1%) in 2005 for this category. Finally, one of the two major magnesium producers in Canada significantly reduced its SF₆ use, and its emissions, because of the production reduction in anticipation of potential closure.

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

GHG Source Category	GHG Emissions		
	1990	2004 (kt CO ₂ eq)	2005
Industrial Processes TOTAL	53 500	55 400	53 300
a. Mineral Products	8 300	9 500	9 500
<i>Cement Production</i>	5 400	7 100	7 200
<i>Lime Production</i>	1 700	1 800	1 700
<i>Limestone and Dolomite Use</i>	730	250	250
<i>Soda Ash Use</i>	210	150	160
<i>Magnesite Use</i>	147	189	186
b. Chemical Industry	16 000	9 800	8 900
<i>Ammonia Production</i>	3 900	5 500	5 000
<i>Nitric Acid Production</i>	1 010	1 230	1 260
<i>Adipic Acid Production</i>	11 000	3 100	2 600
c. Metal Production	19 500	17 600	16 200
<i>Iron and Steel Production</i>	7 060	8 160	7 010
<i>Aluminium Production</i>	9 300	7 300	7 900
<i>Magnesium Production</i>	2 870	2 000	1 100
<i>Magnesium Casting</i>	236	191	191
d. Consumption of Halocarbons (HFCs & PFCs)	0	4 700	4 900
e. SF₆ Use in Electric Utilities and Semiconductors	1 800	820	1 200
f. Other and Undifferentiated Production	8 300	13 000	13 000

Note: Totals may not add up due to rounding.

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, 2004). Improvements have been made to some categories since the completion of the ICF 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 Mineral Products (CRF Category 2.A)

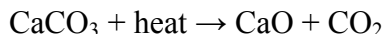
4.2.1 Source Category Description

This subsector accounts for CO₂ emissions related to the production and use of non-metallic minerals, including cement, lime, limestone, dolomite, soda ash, and magnesite. Possible GHG emissions associated with the production and/or use of other mineral products have not been estimated.

4.2.1.1 Cement Production (CRF Category 2.A.1)

CO₂ is generated during the production of clinker, an intermediate product from which cement is made. Calcium carbonate (CaCO₃) 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 CO₂ in a process called calcination or calcining, which occurs in the lower-temperature section of the kiln (800–900°C) and can be represented as follows:



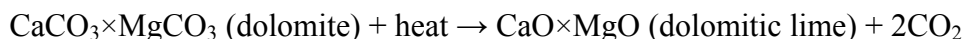
The lime is then combined with silica-containing materials in the higher-temperature section of the kiln (1350–1450°C) to produce clinker (greyish-black pellets about the size of 12-mm-diameter marbles). The clinker is removed from the kiln, cooled, and pulverized, while gypsum is added to produce portland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

CO₂ 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.

4.2.1.2 Lime Production (CRF Category 2.A.2)

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 CO₂. 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 4.2.1.1 on cement production.

Dolomitic limestone, which is a mix of calcite and magnesite (MgCO₃), may also be processed at high temperature to obtain dolomitic lime (and release CO₂) 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 CO₂ is biogenic in origin, it is recorded as a change in forest stock in the LULUCF Sector.

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

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, CO₂ is produced by the same reaction described in Section 4.2.1.1 on cement production.

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

4.2.1.4 Soda Ash Production and Use (CRF Category 2.A.4)

Soda ash (sodium carbonate, Na_2CO_3) 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, flue gas desulphurisation, and waste water treatment (AMEC, 2006). Based on use data supplied in a recent 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 mainly used in the glass products manufacturing industry. CO_2 is emitted as the soda ash decomposes at high temperatures in a glass manufacturing furnace.

CO_2 is also emitted during the Solvay process that is used to produce soda ash. However, as it is a necessary component in the carbonation stage of the production process, it is usually recovered and recycled for use.

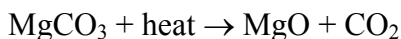
4.2.1.5 Magnesite Use (CRF Category 2.A.7.2)

Magnesite, or magnesium carbonate (MgCO_3), 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_2 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_2 is generated along with magnesia when magnesium carbonate decomposes at high temperatures:



4.2.2 Methodological Issues

4.2.2.1 Cement Production (CRF Category 2.A.1)

To estimate national CO_2 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:

$\text{EF}_{\text{clinker}}$	= emission factor based on clinker production
Clinker Production	= clinker production data
CKD Correction Factor	= factor that corrects for the loss of cement kiln dust (CKD)

The IPCC default $\text{EF}_{\text{clinker}}$ of 0.5071 t CO₂/t clinker produced was applied. This factor was developed based on an average lime percentage of 64.6% and the molecular weight ratio of CO₂ 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 CO₂ calculated for clinker) as the default CKD Correction Factor.

Clinker production data for 1990–1996 were obtained from *Review of Energy Consumption and Related Data: Canadian Cement Manufacturing Industry, 1990 to 2002* (CIEEDAC, 2005). Clinker production data for 1997–2004 were obtained from Statistics Canada (#44-001), and for 2005 from the CANSIM Table 303-0060 (Statistic Canada, 2007). To be noted is that CIEEDAC data on clinker production are obtained from the Portland Cement Association, which is a North American association representing cement companies operating in the United States and Canada.

Applying equation 4.1 above to the clinker production data is considered a Tier 2–type approach.

To estimate CO₂ 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. CO₂ emissions on a provincial/territorial level were estimated by multiplying the percentage attributed to each province/territory by the national emission estimate.

It should be noted that in the most recent 2005 *Canadian Minerals Yearbook* (NRCan), only 2004 capacity data are provided. Therefore, it is assumed that there was no change in clinker production capacity from 2004 to 2005.

4.2.2.2 Lime Production (CRF Category 2.A.2)

CO₂ emissions from lime production were estimated using an emission factor of 750 g CO₂/kg high-calcium lime (or quicklime) and an emission factor of 860 g CO₂/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 CO₂ 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. CO₂ 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.

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

CO₂ 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 CO₂ could be emitted per kg 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 CO₂/kg of limestone used (AMEC, 2006). The purity fraction of 95% came from a report prepared for Limestone Industries of Ontario (1983).

Dolomite consists of both limestone (CaCO₃) and magnesite (MgCO₃). A major Canadian producer of dolomite reported the composition of its dolomite to range from 56% to 58% CaCO₃ and 38% to 41% MgCO₃ (Limestone Industries of Ontario, 1989). An overall emission factor of 468 g CO₂/kg of dolomite used was derived based on the emission factors for pure limestone (440 kg of CO₂ per ton) and magnesite (522 kg of CO₂ per ton), and the assumption that dolomite is composed of 58% of CaCO₃ and 41% of MgCO₃ (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 CO₂ 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 2004; only a national consumption value of stone was available for 2005. The national stone

consumption in 2005 was compared to the national consumption in 2004. The change from 2004 to 2005 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 2004. 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 CO₂ emissions for dolomite and limestone use. A 70/30 split on the consumption of limestone and dolomite was used. Methodological issues for calculating CO₂ emissions from limestone and dolomite use are addressed in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006).

4.2.2.4 Soda Ash Production and Use (CRF Category 2.A.4)

Soda ash in Canada is used in glass manufacturing and for other purposes, such as chemical production, pulp and paper mills and flue gas desulphurization, resulting in CO₂ emissions (AMEC, 2006).

For each mole of soda ash used, 1 mole of CO₂ is emitted. The emission factor (EF) for the mass of CO₂ emitted is estimated from the stoichiometry of the chemical process as follows:

Equation 4-2:

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

National CO₂ emissions were calculated by applying the emission factor of 415 g CO₂/kg to the national data on soda ash consumption. Quantities of soda ash used were estimated based on soda ash import and export data obtained from the Global Trade Information Services (GTIS). It should be noted that since GTIS did not report trade data before 1995, it was assumed that the trade data for years 1990 to 1994 were the same as those for 1995.

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 CO₂ 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. Since 1990, the only soda ash producing plant, which produced soda ash using the Solvay process, closed in 2001. Although most CO₂ that was emitted from this facility was recovered for re-use (as mentioned in section 4.2.1.4), some CO₂ may have been released from vents on

absorbers, scrubbers and distillation units. However, the amount of net CO₂ emissions from soda ash production in Canada is assumed to be minimal (AMEC, 2006).

4.2.2.5 Magnesite use (CRF Category 2.A.7.2)

In calculating the CO₂ emissions in 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). Three facilities in Canada have used magnesite as a raw material in the years 1990 to 2005. In the 5th *Strategic Diversification Newsletter* (SIDEX, 2004), one of these facilities reported the purity fraction of the magnesite they used to be 97%, this magnesite being 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 CO₂/kg was used in estimating CO₂ emissions from magnesite use.

The facility-specific magnesite use data came from the Province of British Columbia's Ministry of Energy (Mines and Petroleum Resources) and Environment Canada (Quebec Region, Environment Protection Branch). Multiplying the consumption data by the above-mentioned emission factor gives the national emission estimates for this sub-sector.

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.

4.2.3 Uncertainties and Time-Series Consistency

4.2.3.1 Cement Production

The uncertainty shown in the ICF (2004) report for the emission estimate for this subsector for the year 2001 is $\pm 35\%$. This may represent a highly conservative uncertainty range for the 2005 estimate, because there has been a methodological improvement since the completion of the ICF (2004) study.

According to the IPCC Good Practice Guidance (IPCC, 2000), estimation via direct clinker production data, as in the case of the 2005 estimate, results in an error of about 10%. It should be recognized that this is an approximate IPCC default uncertainty value. A more complete and updated uncertainty assessment would be necessary to analyze in detail the uncertainty in the current emission estimate of this subsector.

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.

4.2.3.2 *Lime Production*

A new uncertainty estimate of $\pm 20\%$ on activity data has been obtained from NRCan this year (Panagapko, D., 2006). Combining this new uncertainty with the IPCC (2000) default uncertainty for emission factor of $\pm 15\%$, the global new uncertainty for CO₂ emission from lime production is $\pm 25\%$. This is an improvement from the previous uncertainty estimate which was -2% to 110% for the emission estimate for lime production for the year 2001 (ICF, 2004). However, 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.

4.2.3.3 *Limestone and Dolomite Use*

The overall uncertainties associated with CO₂ 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 use 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.

4.2.3.4 *Soda Ash Production and Use*

The uncertainties associated with emissions from soda ash use stem mostly from activity data, and they were higher for the years 1990 to 1994. The soda ash import and export data were only available from the Global Trade Information Services (GTIS) from 1995 onwards. The data for these years were assumed to be the same as those for 1995. The uncertainty associated with import data before 1995 was estimated to be $\pm 23\%$ and $\pm 27\%$ for export data; for 1995 and later, the uncertainty of both the import and export data was estimated to be $\pm 2.0\%$ (AMEC, 2006). The overall uncertainty values associated with CO₂ emissions from soda ash use in the whole time series vary from $\pm 10\%$ to $\pm 14\%$.

4.2.3.5 *Magnesite Use*

The uncertainties associated with CO₂ emissions from magnesite use in the whole time series vary from $\pm 4.86\%$ to $\pm 6.01\%$. 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).

4.2.4 Category-Specific QA/QC and Verification

4.2.4.1 *Cement Production*

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 issues of importance were detected from the Tier 1 QC process.

4.2.4.2 *Lime Production*

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.

4.2.4.3 *Soda Ash Use and Production*

CO₂ from soda ash use is not a key category; however, informal QC checks have been performed. Some of these QC checks include double-checking calculations in the model, comparing emission estimates developed this year to those developed last year, and checking for transcription errors throughout the NIR production steps. No issues of importance were detected from the checks.

4.2.4.4 *Limestone and Dolomite Use*

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). There were no anomalies observed.

4.2.4.5 *Magnesite Use*

CO₂ from magnesite use is not a key category; however, informal QC checks have been performed. Some of these QC checks include double-checking calculations in the model, comparing emission estimates developed this year to those developed last year, and checking for transcription errors throughout the NIR production steps. No issues of importance were detected from the checks.

4.2.5 Category-Specific Recalculations

4.2.5.1 Cement Production (CRF Category 2.A.1)

In the previous NIR, the CO₂ emission from cement production was estimated by using a rounded EF_{Clinker} of 0.507, but in this NIR, the unrounded value of 0.5071 was used (IPCC 2000).

The impact of the recalculations was an increase in national and provincial/territorial CO₂ emission estimates for 1990 to 2004. The differences in emission values calculated using the corrected EF_{Clinker} is +0.02%.

4.2.5.2 Lime Production (CRF Category 2.A.2)

The 2004 CO₂ emissions from lime production at national and provincial/territorial levels were recalculated. This recalculation was due to the update of data on national lime production and national hydrated lime production obtained from the *Canadian Minerals Yearbook* (NRCan). The impact of the recalculation was a decrease of 2.4% of the total 2004 CO₂ emissions from lime production.

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

The 2004 CO₂ emission from limestone and dolomite use were recalculated. The 2004 CO₂ emissions from limestone and dolomite use reported in the previous inventory were based on a national stone use number reported in the *2004 Canadian Mineral Yearbook* (NRCan), as sectoral stone use data in that report were not available. A new national number and sectoral stone use data were subsequently reported in the *2005 Canadian Mineral Yearbook* (NRCan). The 2004 CO₂ emissions were recalculated based on the new sectoral stone use activity data. As well, the CO₂ emissions for rest of the time series, 1990 to 2003, were re-calculated due to using original activity data in one of the sectors instead of the rounded numbers.

4.2.5.4 Soda Ash Production and Use (CRF Category 2.A.4.2)

CO₂ emissions from soda ash use for 2004 have been recalculated based on new soda ash import and export data. This resulted in a 9.5% increase in emissions for that year.

4.2.5.5 Magnesite Use (CRF Category 2.A.4.3)

There have been no recalculations related to magnesite use.

4.2.6 Category-Specific Planned Improvements

4.2.6.1 Cement Production (CRF Category 2.A.1)

QA review will be discussed with the Cement Association of Canada, in order to identify potential improvements in methodology and EFs. New improved uncertainty data for clinker production data is expected to be obtained from national experts.

4.2.6.2 Lime Production (CRF Category 2.A.2)

There are currently no improvements planned specifically for estimating CO₂ emissions from lime production.

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

The emissive portion of the sub-category “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.

4.2.6.4 Soda Ash Production and Use (CRF Category 2.A.4.2)

There are currently no improvements planned specifically for estimating CO₂ emissions from soda ash production and use.

4.2.6.5 Magnesite Use (CRF Category 2.A.4.2)

There are currently no improvements planned specifically for estimating CO₂ emissions from magnesite use.

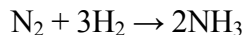
4.3 Ammonia Production (CRF Category 2.B.1)

4.3.1 Source Category Description

Ammonia (NH₃) 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 mainly used in the production of fertilizers, explosives and polymers.

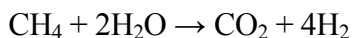
To produce anhydrous ammonia, nitrogen and hydrogen react together in the *Haber-Bosch* process. The reaction (as shown below) happens at high temperature, with the presence of a catalyst:

Ammonia Synthesis Reaction



The nitrogen required is obtained from air. The typical source of hydrogen for ammonia plants is the catalytic steam reforming of methane (and minor amounts of other hydrocarbons) contained in natural gas. Carbon dioxide is also generated, as a by-product gas, during the steam methane reforming (SMR) process:

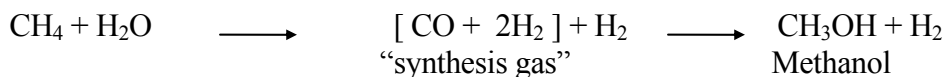
Steam-Methane Reforming for Hydrogen Production



CO₂ is then removed from the process gas by absorption, usually with a solution of monoethanolamine (MEA) or potassium carbonate (K₂CO₃). The primary release of CO₂ occurs during the regeneration (for re-use) of the CO₂-rich absorption solution by steam stripping or boiling. The stripping gas, which contains CO₂ and other impurities, is then vented to the atmosphere. Alternatively, it can be directed to a neighbouring urea plant, where the CO₂ is recovered and utilized as a feedstock gas (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 CO₂ from the ammonia production process. In other words, the hydrogen needed for producing ammonia can also be obtained from other ways that do not involve an on-site steam-methane reforming operation. For instance, at methanol plants, a synthesis gas (or “syn gas”) consisting of one part carbon monoxide and two parts hydrogen (CO + 2H₂) is prepared by using a variation of the steam-methane reforming reaction. The reaction (as depicted below) produces an excess of hydrogen that is more than what is required for methanol production:

Steam-Methane Reforming 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, etc.). This hydrogen stream can be used at the nearby ammonia plants as well (Cheminfo, 2006).

4.3.2 Methodological Issues

Emissions from ammonia production were estimated by multiplying CO₂-related ammonia production by an emission factor of 1.56 t CO₂/t NH₃ produced. The emission factor was developed based on typical energy and material requirements for ammonia production in Canada (Jaques, 1992). Data on CO₂-related production used in the calculation could either be directly collected from ammonia plants or estimated. When plant-specific data were not available, estimation of production that had involved SMR (i.e. releasing CO₂) was done based the reported production and capacity data gathered in a recent study (Cheminfo, 2006), and national ammonia production statistics found in Statistics Canada catalogue # 46-002.

As mentioned above, some CO₂ coming from ammonia production can be used to make urea destined for export, and hence emissions of CO₂ would only occur outside Canada. Therefore, to avoid overestimation, the amount of CO₂ sequestered in exported urea was taken into account in the calculation of net CO₂ emissions from ammonia production. The quantity of CO₂ found in exported urea was determined by multiplying urea export (Statistics Canada, #65-004) by a factor of 0.733 t CO₂ trapped/t urea. The latter factor was developed based on the stoichiometry of the urea manufacturing process:



As shown in the chemical equation above, 1 mole of CO₂ is needed to produce 1 mole of urea. Thus, taking the molar weight ratio of CO₂ (44) to urea (60) gives a factor of 0.733 t CO₂/ t urea.

The estimation technique (emission = production of ammonia x emissions factor) is one of the default methods suggested in the Revised 1996 IPCC Guidelines. However, it should be noted that the emission factor of 1.56 t CO₂/t NH₃ produced is a national average value and plant-specific production data were used, whenever possible. Methodological issues for calculating CO₂ 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 CO₂ emissions from ammonia production were subtracted from the total non-energy fossil fuel use CO₂ emissions.

4.3.3 Uncertainties and Time-Series Consistency

The ICF (2004) report shows an uncertainty range of -23% to +55% for the CO₂ 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 value of ammonia production not involving SMR and the urea export data used for estimating emissions

have been updated for all years. It is expected that the uncertainty associated with this category be lowered as a result of these updates. 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.

4.3.4 Category-Specific QA/QC and Verification

Ammonia 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.

4.3.5 Category-Specific Recalculations

The whole time series has been recalculated because updated data on ammonia production that did not involve SMR and on urea export have been obtained (Cheminfo, 2006). Improvements made to this category have resulted in changes in the 1990-2004 emission estimates, ranging from -3.2% to +3.9%.

4.3.6 Category-Specific Planned Improvements

The emission factor of 1.56 t CO₂/ t NH₃ was derived based on the energy and process requirements for natural gas for producing one tonne of liquefied ammonia. Efforts will be made to disaggregate the estimates of energy and process-related emissions calculated using this emission factor. Also, discussions will be held with Statistics Canada and industry to determine the amounts of natural gas used as feedstock and as fuel during ammonia production over the years.

4.4 Nitric Acid Production (CRF Category 2.B.2)

4.4.1 Source Category Description

Nitric acid (HNO₃) is a highly corrosive and toxic inorganic compound that is mainly used 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 (NH₃) to nitrogen dioxide (NO₂) and then subsequent formation of nitric acid

by addition of water to NO₂. As shown below, the first stage is the reaction of ammonia gas with oxygen (from air) at high temperatures.

Stage 1 (Reaction): $x\text{NH}_3 + y\text{O}_2 \rightarrow \text{NO} + \text{NO}_2 + \text{H}_2\text{O}$ (+ trace N₂O and N₂)

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 (NO), nitrogen dioxide (NO₂) and water vapour with trace amounts of nitrous oxide (N₂O) and nitrogen (N₂) (Cheminfo, 2006). An excess of oxygen may drive the nitric oxide to be converted to nitrogen dioxide. Nitrogen oxidation steps under reducing conditions are sources of N₂O. More specifically, nitric oxide, an intermediate in the production of nitric acid, can readily decompose to N₂O and NO₂ at high pressures and at a temperature range of 30 to 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 nitrogen dioxide and to scrub the gases. As shown below, hydration of cooled nitrogen dioxide with water forms a 60-65% solution of nitric acid, leaving the bottom of the tower. Moreover, to complete the conversion of nitric oxide (NO) to nitrogen dioxide (NO₂), excess air (oxygen) is introduced at the bottom tray of the absorber tower. The NO₂ formed is also absorbed.

Stage 2 (Absorption):
$$\begin{array}{l} 2\text{NO} + \text{O}_2 \longrightarrow 2\text{NO}_2 \\ 3\text{NO}_2 + \text{H}_2\text{O} \longrightarrow 2\text{HNO}_3 + \text{NO} \end{array}$$

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 nitrous oxide (N₂O), nitric oxide (NO), nitrogen dioxide (NO₂) and other nitrogen oxides. The concentration of N₂O in the exhaust gases depends on the type of plant and its emission controls (Cheminfo, 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 (Cheminfo, 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 nitrogen oxides (NO_x). In contrast, “selective” catalytic reduction (SCR) uses ammonia, which selectively reacts with only NO and NO₂ gases, but not N₂O. Dual pressure plants also exist in Canada. They either

operate with extended absorption tower (also referred to as “*absorption Type 1*”) or with double absorption (also referred to as “*absorption Type 2*”).

4.4.2 Methodological Issues

Updated data supporting the estimation of N₂O emissions from nitric acid production were gathered through a recent study conducted for Environment Canada (Cheminfo, 2006). 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 is 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 Fertilizers Institute in the early 1990’s (Collis, 1992). 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, 2006). The table below summarizes the industry typical emission factors by process and control types.

Table 4-2: Nitric Acid Industry Typical Emission Factors.

Type of Production Process Technology	Type of Emission Control Technology	Emission Factor (kg N ₂ O/ t HNO ₃)	Data Source
Dual Pressure	Extended Absorption “Type 1”	9.4	(Collis, 1992)
Dual Pressure	Extended Absorption “Type 2”	12	(Collis, 1992)
High Pressure	NSCR	0.66	(Collis, 1992)
High Pressure	SCR	8.5	(IPCC, 2000)

When production data for some plants were not available, they were estimated based on the national production data from STC catalogue #46-002, the reported production data

and the production capacity data were obtained through the Cheminfo study (Cheminfo, 2006). More specifically, the sum of all production reported by companies was deducted from the national total production (from STC catalogue #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 little 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. For 2005, the data used were reported by companies to the GHG Division on a voluntary basis.

Finally, the estimates of N₂O emissions (by plant) were summed either altogether to yield the national emission estimate or by province to give the provincial emission estimate.

4.4.3 Uncertainties and Time-Series Consistency

It should be noted that the uncertainty range, provided in the ICF study, for this category is no longer applicable, since the emission estimation methodology was revised in the 2006 Cheminfo study (Cheminfo, 2006). The updated data and information collected from the study has helped reduce the uncertainty related to this category. According to the Tier 1 uncertainty assessment that was also performed as part of the study for this category, the uncertainty was +/- 8% for the 1990-1998 estimates and +/- 7% for the 1999-2005 estimates.

The data sources and methodology used are consistent over the time series.

4.4.4 Category-Specific QA/QC and Verification

Due to methodological change, nitric acid 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.

4.4.5 Category-Specific Recalculations

Emissions from nitric acid production for 1990-2004 were recalculated, since plant-specific information on nitric acid production and emission abatement technologies applied were obtained through the Cheminfo Services study in 2006 (Cheminfo, 2006). Improvements made to this category have resulted in changes in the 1990-2004 emission estimates, ranging from +24.9% to +61.5%.

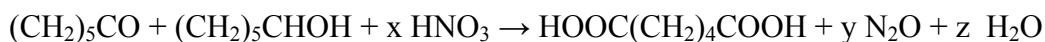
4.4.6 Category-Specific Planned Improvements

There are currently no improvements planned for this category.

4.5 Adipic Acid Production (CRF Category 2.B.3)

4.5.1 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 or cyclohexanone 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. N_2O is generated as a by-product in the second oxidation reaction as shown below:



Emissions of N_2O 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 N_2O generated is generally vented to the atmosphere in a waste gas stream. Adipic acid production also results in emissions of NMVOCs, CO and 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 N_2O emissions since 1997 when a catalytic N_2O abatement system with emission monitoring system was started up.

4.5.2 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 N_2O /kg adipic acid.

As mentioned above, Invista installed in 1997 a N_2O 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:

$$\text{Total emissions (t)} = \text{Abated N}_2\text{O Emissions (t)} + \text{Unabated N}_2\text{O Emissions (t)}$$

The first term accounts for emissions that occur when the abater is operating and the second for emissions that occur when the abater is *NOT* operating.

Abated N₂O Emissions:

Equation 4-5:

$$\text{Abated N}_2\text{O emissions (t)} = \text{Production (t)} \times 0.3 \text{ tN}_2\text{O/ t adipic acid} \times (1 - \text{Destruction Efficiency}) \times \text{Abatement Utilization Ratio}$$

where:

Destruction Efficiency is assumed to be 97%

Abatement Utilization Ratio = hours during which N₂O goes through the abator / total operating time

Unabated N₂O Emissions:

Equation 4-6:

$$\text{Unabated N}_2\text{O Emissions (t)} = \text{Production} \times 0.3 \text{ tN}_2\text{O/ t adipic acid} \times (1 - \text{abatement utilization ratio})$$

It is important to note that the in-line continuous emission monitor is only used to confirm the reasonableness of the assumed 97% destruction factor, but it has never been used to directly monitor net N₂O emissions. This is because the analyzer is limited to accurately measuring relatively low concentrations of N₂O only when the reactor is on-line and abating N₂O gas. The analyzer is not capable of measuring the full range of N₂O concentration that could potentially exist in the stack. The N₂O concentration can vary from a low nominal level of 0.3% when the stream leaves the abater to a high nominal level of 35-39% N₂O in the unabated stream. When the abatement reactor is by-passed, there is no N₂O abatement occurring and the analyzer will not record N₂O stack emissions (Cheminfo, 2006).

The calculation techniques used to estimate emissions for the periods 1990-1997 and 1998-2005 are basically the same as the default methods presented in the IPCC Good Practice Guidance (IPCC, 2000) and the Revised 1996 IPCC Guidelines.

4.5.3 Uncertainties and Time-Series Consistency

According to the ICF (2004) report, the 2001 N₂O emission estimate for adipic acid production had an uncertainty of $\pm 2\%$, reflecting the random component of the uncertainty related to monitoring and reporting of emissions. The results of the ICF Tier 2 uncertainty assessment are applicable to the 2005 estimate of this category. During the 2006 Cheminfo 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.

4.5.4 Category-Specific QA/QC and Verification

Adipic acid 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.

4.5.5 Category-Specific Recalculations

There have been no recalculations of N₂O emissions related to adipic acid production.

4.5.6 Category-Specific Planned Improvements

Information on the abatement technology employed, the N₂O monitoring system, and the accuracies involved, which helps increase the transparency of the estimation methodology, has been obtained. This means that the planned improvements mentioned in the previous inventory have been achieved. There are currently no improvements planned specifically for estimating N₂O emissions from adipic acid production in Canada.

4.6 Iron and Steel Production (CRF Category 2.C.1)

4.6.1 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 CO₂. 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. CO₂ 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 CO₂ given off by limestone flux in the blast furnace is covered under Limestone and Dolomite Use (Section 4.2).

4.6.2 Methodological Issues

To estimate CO₂ 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:

$$\text{Emission}_{\text{pig iron}} = (\text{Emission Factor}_{\text{reductant}} \times \text{mass of reductant}) - (\text{mass of carbon in pig iron} \times 44/12)$$

where:

Emission Factor _{reductant}	=	2.479 tonnes CO ₂ / tonne of coke used (Jaques, 1992). [Note that it was assumed that the reductant used in the process was 100% metallurgical coke].
mass of reductant	=	mass of metallurgical coke used in the process (kt)
mass of carbon in pig iron	=	total pig iron production (kt) × carbon content in pig iron (%)
44/12	=	ratio of the molecular weight of CO ₂ to the molecular weight of carbon

The data source for the use of metallurgical coke was RESD (Statistics Canada, #57-003). Data on total pig iron production in Canada came from Statistics Canada (for 1990-2003: #41-001 and for 2004-2005: #41-019). The IPCC default carbon content in pig iron of 4% was applied.

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:

mass of carbon in pig iron used for crude steel	=	total pig iron charged to steel furnaces (kt) × 4%
mass of carbon in crude steel	=	total steel production (kt) × carbon content in crude steel (%)
44/12	=	ratio of the molecular weight of CO ₂ to the molecular weight of carbon
Emission Factor _{EAF}	=	emission factor for steel produced in EAFs (kg CO ₂ / t steel)
Steel produced in the EAFs	=	the amount of steel produced in EAFs (kt)

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 (#41-001). 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 CO₂/t steel was the default value shown in the IPCC Good Practice Guidance (IPCC, 2000).

Data on metallurgical coke use at provincial/territorial levels from RESD (Statistics Canada, #57-003) were used to derive the percentage of total reductant consumption attributed to each province and territory. CO₂ 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.

Further details with respect to the calculation method used are provided in Annex 3.

4.6.3 Uncertainties and Time-Series Consistency

The uncertainty in the 2001 inventory's CO₂ emission estimate for iron and steel production is ±5% (ICF, 2004). It should be noted that this represents a conservative uncertainty value for the 2005 inventory emission estimates because the methodology for calculating CO₂ emissions has improved since the 1990–2002 inventory. The shift from a Tier 1 to 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.

4.6.4 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.

4.6.5 Category-Specific Recalculations

Changing the emission factor for steel production in EAFs from 4.58 kg CO₂/ t steel to 5 kg CO₂/ t steel resulted in the recalculations of 1990-2004 CO₂ emission estimates for the category of iron and steel production. Slight revisions of the 1990-1998 metallurgical coke use data (i.e. data with higher resolution) also contributed to the recalculations of the 1990-1998 emission estimates for this category. Improvements made to this category

have resulted in changes in the 1990-2004 emission estimates of less than 1%, ranging from +0.02% to +0.08%.

4.6.6 Category-Specific Planned Improvements

Efforts will be made to rectify the assumption made regarding the reducing 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 believed 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 CO₂ emissions coming from non-energy use of fossil fuels, currently reported under the category of *Other and Undifferentiated Production*, may be re-allocated to the category of *Iron and Steel Production*.

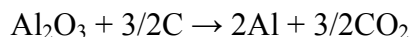
4.7 Aluminium Metal Production (CRF Category 2.C.3)

4.7.1 Source Category Description

Primary aluminium is produced in two steps. First, bauxite ore is ground, purified, and calcined to produce alumina (Al₂O₃). The latter is then electrically reduced to aluminium by smelting in large pots with carbon-based anodes. The pot itself (a shallow steel container) forms the cathode, while the anode consists of one or more carbon blocks suspended within it. Inside the pot, alumina is dissolved in a fluorine bath consisting primarily of cryolite (Na₃AlF₆). Passing a current through the resistance of the cell causes the heating effect, which maintains the contents in a liquid state. Molten aluminium is evolved while the anode is consumed in the reaction. The aluminium forms at the cathode and gathers on the bottom of the pot.

Three GHGs — CO₂, carbon tetrafluoride (CF₄), and carbon hexafluoride (C₂F₆) — are known to be emitted during the reduction process. CF₄ and C₂F₆ are part of a larger class of GHGs known as PFCs. PFCs are considered potent GHGs, as reflected by their high GWPs.

As the anode is consumed, CO₂ is formed in the following reaction, provided that enough alumina is present at the anode surface:



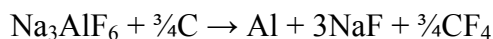
Most of the CO₂ forms from the reaction of the carbon anode with alumina, but some is formed as the anode reacts with other sources of oxygen (especially air). This occurs during cell operation and, in the case of pre-baked electrodes, also during anode production and manufacture.

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 is improved. In some cases, this has meant taking old lines out of production as new ones are installed to meet increasing demand.

Primary aluminium smelting is a major source of PFCs. PFC gases are formed during an occurrence known as the anode effect or anode event, when alumina levels are low. If the concentration of alumina at the anode is below ~2% (by weight), an anode event may begin. 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 occur to produce CO, CF₄, and C₂F₆, in addition to CO₂. The two reactions of interest at this point are:



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).

In addition to CO₂, CF₄, and C₂F₆, a small amount of SF₆ is also emitted from its use in degassing and as cover gas at some aluminium plants. The degassing process involves the removal of unwanted hydrogen from molten aluminium. Hydrogen in dissolved state results from the metal’s exposure to moisture, hydrocarbons, and other process elements. If not taken out, it will get trapped in the metal during the solidification process, leading to porous aluminium with inferior properties. Hydrogen degassing of aluminium is based on the principle that hydrogen gas will move from an area of high pressure (in the melt) to an area of low pressure (in the inert gas). Chlorine was the original gas of choice; due to its hazardous nature, however, most foundries switched to other gases, such as SF₆ (AACCM, 2006).

Although 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. 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.

4.7.2 Methodological Issues

Process-related emission estimates for aluminium production were directly obtained from companies via the Aluminum Association of Canada (AAC). In addition to the smelter-specific emission estimates, information on the methodologies used by the aluminium producers to calculate CO₂, PFC, and SF₆ 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.

Typically, the equations used by smelters to estimate CO₂ emissions from the reaction of the carbon anode with alumina are (AAC, 2002):

Equation 4-9: For Pre-baked Anode Consumption

$$E_{\text{CO}_2}(\text{t}) = [\text{CC} \times \text{MP} \times (100 - \%S_a - \%Ash_a - \%Imp_a)/100] \times 44/12$$

where:

- CC = baked anode consumption per tonne of aluminium (t C/t Al)
- MP = total aluminium production (t)
- S_a = sulphur content in baked anodes (wt %)
- Ash_a = ash content in baked anodes (wt %)
- Imp_a = fluorine and other impurities (wt %)*
- 44/12 = ratio of the molecular weight of CO₂ 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 Søderberg Anode Consumption

$$E_{\text{CO}_2}(\text{t}) = \{(\text{PC} \times \text{MP}) - (\text{BSM} \times \text{MP}/1000) - [\%BC/100 \times \text{PC} \times \text{MP} \times (\%S_p + \%Ash_p + \%H_2/100)] - [(100 - \%BC)/100 \times \text{PC} \times \text{MP} \times (\%S_c + \%Ash_c)/100]\} \times 44/12$$

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_p = sulphur content in pitch (wt %)
- Ash_p = ash content in pitch (wt %)
- H₂ = hydrogen content in pitch (wt %)
- S_c = sulphur content in calcinated coke (wt %)
- Ash_c = ash content in calcinated coke (wt %)
- 44/12 = ratio of the molecular weight of CO₂ to the molecular weight of carbon

The use of the equations above with actual process data to estimate CO₂ emissions is considered Tier 3–type methodology. A Tier 2–type technique involves the application of

some measured data in combination with industrial typical values (as provided by AAC) to these equations.

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. According to a supporting document provided by the AAC (2002), this is 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, 2002):

- Søderberg: EF = 1.7 t CO₂/t Al produced; and
- Pre-baked: EF = 1.6 t CO₂/t Al produced.

CF₄ and C₂F₆ emitted during anode effects can be calculated by smelters using either the Slope or Pechiney Overvoltage Method, depending on the smelter technology (AAC, 2002):

Equation 4-11: Slope Method

$$E_{\text{PFC}} (\text{t CO}_2 \text{ eq}) = \text{slope} \times \text{AEF} \times \text{AED} \times \text{MP} \times \text{GWP} / 1000$$

where:

slope	= slope (for CF ₄ or C ₂ F ₆) 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 ₄ or C ₂ F ₆

Equation 4-12: Pechiney Overvoltage Method

$$E_{\text{PFC}} (\text{t CO}_2 \text{ eq}) = \text{overvoltage coefficient} \times \text{AEO} / \text{CE} \times \text{GWP} \times \text{MP} / 1000$$

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 ₄ or C ₂ F ₆
MP	= total aluminium production (t)

The use of the equations above with actual process data to estimate PFC emissions is considered Tier 3–type methodology. The estimation technique is considered as Tier 2–type when the default coefficients shown in Table 4-3 are used together with smelter-specific operating parameters. Most of these coefficients are found in Table 3-9 of the IPCC Good Practice Guidance (IPCC, 2000). The overvoltage coefficients for C₂F₆, which are not provided by the IPCC Good Practice Guidance, can be estimated as either

A) 10% of that for CF₄ or B) the ratio of the slope coefficient for C₂F₆ to the one for CF₄, depending on the smelter (AAC, 2002).

Table 4-3: Default Slope and Overvoltage Coefficients

Type of Cell	Slope Coefficients		Overvoltage Coefficients		
	CF ₄	C ₂ F ₆	CF ₄	C ₂ F ₆	
				A	B
	([kg PFC/t Al]/[AE-minutes/cell-day])		([kg PFC/t Al]/[mV/cell-day])		
Centre Worked Pre-Baked	0.14	0.018	1.9	0.19	0.13
Side Worked Pre-Baked	0.29	0.029	1.9	0.19	0.10
Vertical Stud Søderberg	0.068	0.003	NA	NA	NA
Horizontal Stud Søderberg	0.18	0.018	NA	NA	NA

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 emission factors shown in Table 4-4 can be used by smelters (AAC, 2002).

Table 4-4: PFC Emission Factors

Type of Cell	Emission Factors					
	1990–1993		1994–1997		1998–2000	
	CF ₄	C ₂ F ₆	CF ₄	C ₂ F ₆	CF ₄	C ₂ F ₆
	(kg PFC/t Al)					
Centre Worked Pre-Baked	0.4	0.068	0.3	0.051	0.2	0.034
Side Worked Pre-Baked	1.4	0.336	1.4	0.336	1.4	0.336
Vertical Stud Søderberg	0.6	0.036	0.5	0.03	0.4	0.024
Horizontal Stud Søderberg	0.7	0.063	0.6	0.054	0.6	0.054

According to the methodology documents supplied by the AAC, SF₆ emissions are equal to consumption in the aluminium industry. This method is consistent with the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA, 1997).

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. The CO₂ 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, to avoid double-counting.

4.7.3 Uncertainties and Time-Series Consistency

The uncertainties in CO₂ and PFC emission estimates for aluminium production provided in the ICF (2004) report are not applicable to the 2005 inventory year estimates due to 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 SF₆ emissions from aluminium production were not included in the 1990–2001 inventory, uncertainties around these were not examined by ICF (2004). An updated uncertainty

analysis would be necessary in order to determine the range of uncertainty around the reported CO₂, PFC, and SF₆ values (also see Section 4.7.6, Category-Specific Planned Improvements).

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.

4.7.4 Category-Specific QA/QC and Verification

CO₂ and PFC emissions from aluminium production are key categories that have 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 issues of importance were detected from the Tier 1 QC process.

4.7.5 Category-Specific Recalculations

Updates in the 1990-2004 SF₆ emission estimates were provided by the aluminum industry. As a result of this data acquisition, the total GHG emissions coming from this Sector were recalculated. Improvements made to this Sector methodology have resulted in changes in the 1990-2004 emission estimates of at most 0.08%.

4.7.6 Category-Specific Planned Improvements

There are currently no improvements planned specifically for estimating CO₂, PFC, and SF₆ emissions from aluminium production in Canada. However, attempts to obtain, through elicitation of experts to be recommended by the AAC, uncertainty values around the emission estimates will be made. 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.

4.8 Magnesium Metal Production and Casting (CRF Categories 2.C.4 & 2.C.5)

4.8.1 Source Category Description

SF₆ 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, SF₆ is an extremely potent GHG, with a 100-year GWP of 23 900. SF₆ is not manufactured in Canada. All SF₆ is imported.

In 2005, there were only two magnesium producers in Canada: Norsk Hydro and Timminco Metals. Another magnesium producer, Métallurgie Magnola, existed between

2000 and 2003, but it 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 SF₆, and eventually eliminating the use of SF₆ as cover gas at its plant (Laperrière, 2004). This research and use of substitute gas mixtures produced significant reductions in the SF₆ emissions in mid- to late 1990's. In 2005, Norsk Hydro's SF₆ emissions were significantly reduced due to production reduction.

There were 11 known magnesium casting facilities in operation during the period 1990–2004 (Cheminfo Services, 2005b). Only a few of them have used SF₆ every year during the entire period. Some casters started using SF₆ towards the mid- or late 1990s, while others have replaced it with an alternative gas, such as SO₂. Two facilities have ceased their casting operations over the last few years. In 2005, only seven facilities still used SF₆.

4.8.2 Methodological Issues

For SF₆ 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 on-line database (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 over the telephone.

Representatives from both Norsk Hydro and Timminco were contacted in 2006, so that the methodology they have applied to estimate SF₆ emissions could be understood. Both companies reported that they used the IPCC default method (Emissions of SF₆ = Consumption of SF₆), as recommended in the IPCC Good Practice Guidance. However, they have used different ways for estimating their SF₆ consumption. Norsk Hydro confirmed that the use of the weight difference method (Laperrière, 2006). 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 SF₆ use (Katan, 2006). In this method, accounting of delivered purchases and inventory changes of SF₆ used are recorded. The purchases must be the actual volumes received in the calendar period and therefore, beginning and end-of-year inventories must be 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 SF₆ emissions from casters, the IPCC Guidelines (IPCC/OECD/IEA, 1997) provide one general equation that assumes that all SF₆ used as a cover gas is emitted to the atmosphere. To apply this equation, attempts have been made to collect 1990–2004 data on SF₆ consumption from casting facilities. A couple of facilities have indicated that they do not hold any historical records of their past SF₆ consumption.

Therefore, to estimate SF₆ use for the entire time series, results of a previous study (Cheminfo Services, 2002) were used in combination with the data received from the 2005 study (Cheminfo Services, 2005b).

For casters that have SF₆ data for only a year, it was assumed that their SF₆ use stayed constant, during the other operating years, at the level of the year for which the actual SF₆ data were obtained. For casters that have data for more than one year, linear interpolation between two data points was applied to estimate SF₆ consumption for the other years.

Consumption data for 2005 were provided by all seven casting facilities. They were used for the calculation of emissions in 2005.

The technique applied to 1990-2004 estimate emissions from magnesium casting 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, the method used is considered as Tier 3-type

4.8.3 Uncertainties and Time-Series Consistency

The uncertainty in the SF₆ emission estimate for magnesium production, provided in the ICF (2004) report, was evaluated at $\pm 1\%$. It is applicable to the 2005 estimate because there has been no change in the data source since the ICF 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, have been reported directly to Environment Canada between 1990 and 1998. Estimates of SF₆ 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 SF₆ emission estimate for magnesium casters has an uncertainty of 4%. This is a weighted average, depending on each company's consumption of SF₆ and the overall data availability. The uncertainty estimate is applicable to the 2005 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 SF₆ as a cover gas by magnesium casters to emissions of SF₆, is applied over the time series with some assumptions for some historical years, as discussed in the methodology section.

4.8.4 Category-Specific QA/QC and Verification

Magnesium production is a key category that 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 issues of importance were detected from the Tier 1 QC process.

For magnesium casting, informal QC measures, such as double-checking calculations and checking activity data and emissions against the ones of previous years, have been taken.

4.8.5 Category-Specific Recalculations

The SF₆ emissions related to magnesium production for 1999-2001 were recalculated due to acquisition of updated data (data with higher resolution). Differences between 1999-2001 estimates included in this submission and that in the previous one were insignificant (less than 0.01%).

Revisions were done to the 1991-2004 SF₆ emission estimates for magnesium casting to correct transcription errors and to include updated data provided by companies. Differences between 1991-2004 estimates included in this submission and that in the previous one were between -2.0% to 7.8%.

4.8.6 Category-Specific Planned Improvements

There are currently no improvements planned specifically for estimating SF₆ emissions from magnesium production and casting in Canada.

4.9 Production and Consumption of Halocarbons (CRF Categories 2.E & 2.F)

4.9.1 Source Category Description

Since HFCs were not widely used before the ban on the production and use of CFCs came into effect in 1996 (as a result of the Montreal Protocol), emissions from HFC consumption were considered negligible for the period 1990–1994. CFCs are GHGs that are not included under the UNFCCC because they are already controlled under the Montreal Protocol. As a result, CFCs are not inventoried herein. Refrigeration and air conditioning equipment represent the primary sources of HFC emissions. Other application areas of HFCs include foam blowing, aerosols, solvents and fire suppression.

Emissions from the consumption of PFCs are minor relative to the by-product emissions of PFCs from aluminium production (discussed in Section 4.7 on Aluminium Production). Emissions are estimated for the following PFC sources: refrigeration, air conditioning, foam blowing, solvents, semi-conductor manufacturing, and other emissive and contained sources.

All HFCs/PFCs consumed in Canada are imported in bulk or in products (e.g., refrigerators). There is no known production of HFCs/PFCs in Canada.

4.9.2 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 (Bovet and Guilbault, 2004-2006). In some cases, one 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. Since HFC data for 2005 were not available, it was assumed that the 2005 HFC consumption stayed at the 2004 levels. However, it should be noted that the assumption of constant HFC use would not mean constancy of HFC emissions, as the Tier 2 method of estimation is used for calculating HFC emissions in 2004. This method considers the HFC stock levels as the basis for emissions (see Section 4.9.2.2 below).

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, 1999–2003 and 2005. The 1999 and 2000 amounts of HFC 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. For 2005, they were assumed to stay at the 2004 level.

Detailed 1995 HFC data were not available, so an IPCC Tier 2 estimate 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 1996–2005 HFC emissions, an IPCC Tier 2 methodology was applied.

The IPCC Tier 2 methodology was used to estimate emissions from the consumption of PFCs for the years 1995–2005. The 1995–2000 activity data were obtained through the 1998 and 2001 PFC surveys conducted by Environment Canada. As 2001–2005 data were unavailable, emission estimates were developed based on the assumption that the use quantities in various applications stayed constant since 2000.

4.9.2.1 1995 HFC Emission Estimates for Refrigeration and Air Conditioning

HFC emission estimates for 1995 used an adapted IPCC Tier 1 method (IPCC/OECD/IEA, 1997). Emission factors for 1995 were developed based on loss rates adapted from the IPCC/OECD/IEA (1997) methodology.

Air Conditioning Original Equipment Manufacture (AC OEM)

Only original charging losses were estimated using the emission factors for this sector. Other losses were accounted for under AC Service. The IPCC Guidelines (IPCC/OECD/IEA, 1997) suggest a 2–5% loss rate. For Canada, a rate of 4% was assumed.

AC Service

It was assumed that most AC-related use of HFCs was due to the replacement of operating losses. A loss rate of 100% was employed.

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 4-13:

$$\text{HFC (refrig)} = \text{Charge} + \text{Operating Loss}$$

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:

$$\text{Emission} = \text{Operating Loss} = 0.17(\text{Charge})$$

Thus,

Equation 4-14:

$$\text{Emission} = 0.17 \{[\text{HFC (refrig)}]/1.17\}$$

4.9.2.2 1995–2005 HFC/PFC Emission Estimates: Emission Factors and Assumptions

To estimate emissions of HFCs and PFCs during assembly, during system operation, and at disposal for 1996 onward, the IPCC Tier 2 methodology presented in the IPCC Guidelines (IPCC/OECD/IEA, 1997) was applied.

System Assembly

To estimate emissions from system assembly, four types of equipment categories were considered: residential refrigeration, commercial refrigeration, stationary AC, and mobile AC. The equation below, found in the IPCC Guidelines (IPCC/OECD/IEA, 1997), was used to estimate emissions during system assembly for each type of equipment:

Equation 4-15:

$$E_{\text{assembly}, t} = E_{\text{charged}, t} \times k$$

where:

$E_{\text{assembly}, t}$	=	emissions during system manufacture and assembly in year t
$E_{\text{charged}, t}$	=	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 IPCC Guidelines (IPCC/OECD/IEA, 1997) (see Table 4-5).

Table 4-5: Equipment Categories and k Values

Equipment Category	k Values (%)
Residential Refrigeration	2.0
Commercial Refrigeration	3.5
Stationary AC	3.5
Mobile AC	4.5

Annual Leakage

The same four categories from system assembly were considered in the calculations of emissions due to leakage. The equation below, given in the IPCC Guidelines (IPCC/OECD/IEA, 1997), was used to calculate HFC and PFC emissions from leakage:

Equation 4-16:

$$E_{\text{operation}, t} = E_{\text{stock}, t} \times x$$

where:

$E_{\text{operation}, t}$	=	quantity of HFCs/PFCs emitted during system operations in year t
$E_{\text{stock}, t}$	=	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 in converted CFC equipment and excludes the amount of HFCs/PFCs in exported equipment. The amount of HFCs used in converted CFC equipment was estimated based on the amount of HFCs used for servicing equipment. It was assumed that no leakage occurred in the year of manufacturing or conversion. The 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 4-6 (IPCC/OECD/IEA, 1997).

Table 4-6: Annual Leakage Rate (x)

Category	x Values (%)
Residential Refrigeration	1.0
Commercial Refrigeration	17.0
Stationary AC	17.0
Mobile AC	15.0

System Disposal

It was assumed that there were no HFC/PFC emissions from system disposal during 1995–2005, since refrigeration and AC systems have a lifetime of 12–15 years and HFC use began only in 1995.

Foam Blowing

HFC emission estimates for 1995 used an adaptation of the IPCC Tier 1 default method (IPCC/OECD/IEA, 1997). For that year, it was assumed that all foams produced were open cell foams. Emission factors for 1995 were developed based on loss rates adapted from the IPCC methodology (IPCC/OECD/IEA, 1997).

The IPCC Tier 2 methodology presented in the IPCC Guidelines (IPCC/OECD/IEA, 1997) was used to estimate HFC and PFC emissions from foam blowing from 1996 onward. 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). At present, there is 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 4-17:

$$E_{\text{foam}, t} = 10\% \times E_{\text{manufacturing}, t} + 4.5\% \times E_{\text{original charge}}$$

where:

$E_{\text{foam}, t}$	=	emissions from closed cell foam in year t
$E_{\text{manufacturing}, t}$	=	quantity of HFCs/PFCs used in manufacturing closed cell foam in year t
$E_{\text{original charge}}$	=	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

HFC emission estimates for 1995 used an adaptation of the IPCC Tier 1 default method (IPCC/OECD/IEA, 1997). Emission factors for 1995 were developed based on loss rates adapted from the IPCC methodology (IPCC/OECD/IEA, 1997).

Two types of fire-extinguishing equipment were considered: portable fire extinguishers and total flooding systems. The IPCC Tier 2 methodology of the IPCC Guidelines (IPCC/OECD/IEA, 1997) was used to calculate HFC emissions from portable fire extinguishers and total flooding systems from 1996 onward. At present, there is no known PFC use in fire-extinguishing equipment.

Portable Fire-Extinguishing Equipment

The IPCC Tier 2 methodology in the 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 IPCC Guidelines (IPCC/OECD/IEA, 1997) estimated emissions from total flooding systems as 35% of the HFCs used in new fire-extinguishing systems installed.

Aerosols/Metered Dose Inhalers

HFC emission estimates for 1995 used an adaptation of the IPCC Tier 1 default method (IPCC/OECD/IEA, 1997). Emission factors for 1995 were developed based on loss rates adapted from the IPCC methodology (IPCC/OECD/IEA, 1997).

The IPCC Tier 2 methodology presented in the 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 PFC 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 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 4-18:

$$E_{SC} = E_{FC} + E_{CF_4}$$

where:

- | | | |
|------------|---|---|
| E_{SC} | = | total PFC emissions from semiconductor |
| E_{FC} | = | emissions resulting from the use of PFCs (see below) |
| E_{CF_4} | = | CF_4 emitted as a by-product during the use of PFCs (see below) |

Equation 4-19

$$E_{FC} = (1-h) \times \sum_p [FC_{i,p} \times (1-C_{i,p}) \times (1-a_{i,p} \times d_{i,p})]$$

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 4-20

$$E_{CF_4} = (1-h) \times \sum_p [B_{i,p} \times FC_{i,p} \times (1-a_{i,p} \times d_{i,p})]$$

where:

- B_{i,p} = fraction of gas i transformed into CF₄ for each process type p

and other terms are as defined above.

Different default values for variables used in equations above are shown in Table 4-7 (IPCC, 2000).

As no information on emission control technologies for these processes is currently available, no emission control factor is applied (IPCC, 2000).

Table 4-7: PFC Emission Rates¹

PROCESS	IPCC Default Emission Fractions			
	CF ₄	C ₂ F ₆	C ₃ F ₈	c-C ₄ F ₈
(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). More specifically, these emissions can come from 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 4-21:

$$E_{\text{contained}, t} = (k \times E_{\text{consumed}, t}) + (x \times E_{\text{stock}, t}) + (d \times E_{\text{consumed}, t})$$

where:

$E_{\text{contained}, t}$	=	emissions from contained sources
$E_{\text{consumed}, t}$	=	quantity of PFC sale for use or manufacturing of contained sources in year t
$E_{\text{stock}, t}$	=	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)

4.9.3 Uncertainties and Time-Series Consistency

The uncertainty in the 2001 HFC emission estimate, provided in the ICF (2004) report, was estimated to be within the range of -21% to +55%. The ICF (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 2005 HFC emissions. Improvements made for estimating “ E_{stock} ” (in Equation 4-16) 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 that these changes have on the uncertainty range, an updated detailed analysis needs to be conducted. Possible sources of uncertainty for this category are i) the IPCC default emission rates, which may not be totally applicable to a Canadian context, and ii) data on HFC quantities found in imported/exported products.

An uncertainty range of –28% to +70% was reported in the ICF (2004) study for the 2001 PFC emission estimate. This uncertainty range is considered to be conservative for the 2004 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. Both surveys conducted by the Chemical Controls Division and the 2005 Cheminfo Services study were data sources for HFC emission estimates.

4.9.4 Category-Specific QA/QC and Verification

Consumption of halocarbons resulting in HFC emissions is 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 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.

Informal QC measures have been taken for the PFC emission estimates.

4.9.5 Category-Specific Recalculations

Data on HFC consumption for 2004 were gathered by Environment Canada's Use Patterns and Controls Implementation Section in 2005. These data were used to revise the 2004 HFC emission estimates, which had been developed in the previous inventory based on the assumption that the quantities of HFCs consumed in 2004 stayed at the 2003 levels. This improvement resulted in a difference of 0.52% between the 2004 estimate in the previous report and that in the current report. The 2003 HFC emission estimate was also revised to correct a transcription error.

There was no recalculation for the PFC emission estimates.

4.9.6 Category-Specific Planned Improvements

Efforts will be made to establish a mechanism that will allow, on a continuous basis, the collection of data on HFC uses and quantities of HFCs contained in imported/exported products.

4.10 Production and Consumption of SF₆ (CRF Categories 2.E & 2.F)

4.10.1 Source Category Description

In addition to magnesium production and casting, electrical equipment in utilities and semi-conductor manufacturing are known sources of SF₆ emissions. In electric utilities, SF₆ 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 SF₆ in Canada; therefore, all Canadian supply of SF₆ is obtained through imports. From 1990 to 1996, more than 95% of total SF₆ imports came from the United States; however, in recent years, this percentage has declined, with an increase in SF₆ imports from Germany (Cheminfo Services, 2002).

4.10.2 Methodological Issues

The method used for estimating SF₆ emissions from electrical equipment in utilities was a top-down approach, assuming that all SF₆ purchased from gas distributors replaces SF₆ lost through leakage.

In a study conducted by Cheminfo Services (2002) to review and assess potential SF₆ emission sources in Canada, several Canadian utilities reported that new equipment is typically delivered with a few cylinders of SF₆ supplied for charging by the original equipment manufacturer (OEM). This implies that the amount of SF₆ purchased from OEMs can be small compared with the quantity bought from gas distributors. Hence, it is assumed that 100% of the SF₆ sales from gas distributors to utilities are used to refill leaking equipment and that SF₆ 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 SF₆ purchased from gas distributors goes to replace SF₆ lost through leakage. It is considered as “modified” because it focuses only on gas distributor SF₆ sales (Cheminfo Services, 2005a).

Gas distributors have been requested by the GHG Division to submit their annual SF₆ sales data by market segment so that this modified Tier 1 method can be applied. However, only sales data for 1995–2000 inclusively were collected. Alternative approaches were applied to estimate SF₆ sales for the other years of the time series. For example, a backcast from 1995 data on global SF₆ sales to the utilities market segment has been done to estimate 1990–1994 sales (Cheminfo Services, 2005a). The 2001–2005 sales estimates were based on data on imports obtained from Statistics Canada and the use of SF₆ in other sectors.

The method applied to estimate SF₆ emissions from semiconductor manufacturing is similar to the one used for calculating PFC emissions. However, as there is no by-product CF₄ created during the use of SF₆ in the process, equation 4-15 is not needed. Hence,

Equation 4-22:

$$\text{SF}_6 \text{ Emissions} = (1 - h) \times [FC \times (1 - C) \times (1 - a \times d)]$$

where:

h	=	fraction of SF ₆ remaining in shipping container (heel) after use (%)
FC	=	quantity of SF ₆ 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 ₆ destroyed in the process by the emission control technologies

The value of h provided and confirmed by two major SF₆ gas distributors, Air Liquide and Praxair, was 12% (Tardif, 2006; Rahal, 2006). 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 zero and one, 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, 2005a), it was assumed that the quantity sold per year in 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 SF₆ sold to semiconductor manufacturers in 2004 and 2005 were estimated based on SF₆ import data purchased from Statistics Canada’s international merchandise trade database (http://www.statcan.ca/trade/scripts/trade_search.cgi) and sales data by market segment provided by three major SF₆ gas distributors.

4.10.3 Uncertainties and Time-Series Consistency

The 2005 Cheminfo Services study provides an uncertainty range of –50% to +19% for the SF₆ emission estimate for electrical equipment. The uncertainty can generally be explained by the drawbacks that the current methodology may have. For example, not all SF₆ purchased from a gas distributor is used in its entirety, and oversupplied SF₆ cylinders could be returned to the distributors (Cheminfo Services, 2005a); however, the methodology assumes that SF₆ emissions in a year are equal to the SF₆ sales in that year. Nevertheless, it is recognized that given the current lack of electricity release data, this approach would be the simplest method for estimating SF₆ emissions until SF₆ emission data reported by utilities, through the Canadian Electricity Association’s (CEA) Environmental Commitment and Responsibilities program, become available to the Greenhouse Gas Division.

Uncertainty in the SF₆ 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.

4.10.4 Category-Specific QA/QC and Verification

Both SF₆ consumption in electrical equipment and SF₆ use in semiconductor manufacturing are key categories that have 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.

4.10.5 Category-Specific Recalculations

The modifications made to the estimation methodology for semi-conductor manufacturing caused recalculations of emission estimates of consumption of SF₆ for 1990–2004.

4.10.6 Category-Specific Planned Improvements

Environment Canada in conjunction with Canadian Electricity Association (CEA) will develop a SF₆ emission estimation protocol that will be used by members of CEA to prepare SF₆ estimates. These estimates, along with supporting calculations, will then be reported to Environment Canada for inclusion in future GHG inventories.

4.11 Other and Undifferentiated Production (CRF Category 2.G)

4.11.1 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 chemicals industry and the use of lubricants. All of them result in varying degrees of oxidation of the fuel, producing CO₂ 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 CO₂ 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.

4.11.2 Methodological Issues

General emission rates for non-energy use of fuels, expressed as grams of CO₂ emitted per unit of fossil fuel used as feedstock or non-energy product, were developed based on the total potential CO₂ emission rates and the IPCC default percentages of carbon stored in products. The potential CO₂ emission rates were derived from the carbon emission factors shown in the McCann (2000) study.

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 CO₂ 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 CO₂ 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 Section A3.2 of Annex 3.

4.11.3 Uncertainties and Time-Series Consistency

An uncertainty range of -40% to +1% reported in the ICF (2004) study for estimates of CO₂ emissions from non-energy use of fuels is generally applicable to the 2005 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 i) the emission factor for petroleum coke and ii) the CO₂ emissions from ammonia production (ICF, 2004).

The data sources and methodology used are consistent over the time series.

4.11.4 Category-Specific QA/QC and Verification

Other and undifferentiated 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.

4.11.5 Category-Specific Recalculations

The Other and Undifferentiated Production category was recalculated for 1990–2004 because of changes made to the ammonia production emission estimates. A minor change in the estimation methodology, which was to subtract the CO₂ already accounted for in the category of iron and steel, also played a part to the recalculations made to this category. Slight revisions of the 1990-1998 activity data and update to the preliminary 2004 data further explained the emission recalculations for these years. Improvements made to this category have resulted in changes in the 1990-2004 emission estimates, ranging from -2.2% to 7.9%.

4.11.6 Category-Specific Planned Improvements

Currently, CO₂ emissions coming from non-energy use of fuels are estimated based on generic fuel-specific emission factors, for instance, 303 g CO₂/ litre of propane used for non-energy purposes. As planned improvements, Statistics Canada is planning to provide disaggregated (by industrial sector) non-energy hydrocarbon values in Statistics Canada catalogue #51-003, starting from the 2006 data year. To utilize these data, the applicability of use-specific emission factors for different types of fuels that were obtained in a recent study will be assessed. The potential application of use-specific data on hydrocarbons and emission factors will be considered as a Tier 2–type methodology.

5 Solvent and Other Product Use (CRF Sector 3)

5.1 Overview

Although the Revised 1996 IPCC Guidelines mention that solvents and related compounds can be significant sources of emissions of non-methane volatile organic compounds (NMVOCs), the Sector of Solvent and Other Product Use only accounts for emissions of direct greenhouse gases. Annexe 14 provides details on emissions of NMVOCs and other indirect GHGs.

This Sector specifically includes emissions that are related to the use of N₂O as 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.

As shown in Table 5-1, the GHG emissions from the Solvent and Other Product Use Sector contributed 180 kt CO₂ eq to the 2005 national GHG inventory, as compared with 170 kt CO₂ eq in 1990. These emissions represented 0.02% of the total Canadian GHG emissions in 2005. The emission trends, either long-term (between 1990 and 2005) or short-term (between 2004 and 2005), were driven by the domestic demand for N₂O for anaesthetic or propellant purposes. According to a recent study prepared for Environment Canada, demand for N₂O for medical use has been slowly decreasing over the last few years. For example, it was suggested that dentists have been using less N₂O, in part due to liability concerns, and in part due to changes in their operational practice (Cheminfo, 2006).

The second major application of N₂O, 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 N₂O in Canada for manufacturing this food product has been relatively stable since 1995 (Cheminfo, 2006).

Table 5-1: Solvent and Other Product Use Sector GHG Emission Summary, Selected Years

GHG Source Category	GHG Emissions		
	1990	2004 (kt CO ₂ eq)	2005
Solvent and Other Product Use TOTAL	170	210	180
<i>Use of N₂O as Anaesthetic</i>	150	180	150
<i>Use of N₂O as Propellant</i>	27	33	28

The emission estimation method and activity data sources have been changed for this Sector for the 2007 submission. Hence, to ensure the correctness of the estimates, this Sector has undergone Tier 1–level QC checks. Further details on QA/QC and uncertainty assessment can be found in sections 5.1.4 and 5.1.3 below.

5.1.1 Source Category Description

Nitrous oxide (N_2O) is a clear, colorless, 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_4NO_3), steam (H_2O) and N_2O are formed. While the steam is condensed out, the “crude” N_2O 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_2O for commercial sale in Canada. It supplies N_2O to two of the three primary N_2O gas distributors that essentially account for the total commercial market in Canada. These companies sell cylinders of N_2O 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_2O in Canada, including dentist offices, clinics, hospitals and laboratories (Cheminfo, 2006).

N_2O is used in a limited number of applications, with anaesthetic use representing the vast majority of consumption in Canada. Use as propellant in food products is the second largest type of end-use in Canada. Other areas where N_2O can be used include production of sodium azide³⁶ (a chemical that was used to inflate automobile airbags); atomic absorption spectrometry; or semiconductor manufacturing. According to the distributors that were surveyed during the recent study, approximately 82% of their N_2O sales volume goes to dentistry/medical applications, 15% to food processing propellant and only 3% to the other uses (Cheminfo, 2006).

It is important to note that amongst all applications in which N_2O can be used, only the two major types are emissive. When used as an anaesthetic, approximately 97.5% of the N_2O is not metabolized and quickly leaves the body in exhaled breath (i.e. emitted) due to its poor solubility in blood and other tissues. In the case of N_2O used as propellant, only emissions coming from N_2O use in whipped cream are estimated because the amounts of N_2O 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_2O gas expands and whips the cream into foam form. As none of the N_2O is reacted during the process, it is all emitted to the atmosphere (Cheminfo, 2006).

5.1.2 Methodological Issues

Estimation of N_2O emissions from this Sector was done based on sales data, following the consumption-based approach presented in the Revised 1996 Guidelines.

An attempt to collect sales data, instead of purchase or consumption data, for all years was made because it was virtually impossible to collect data from all end-users. It was assumed that domestic sales equals to domestic consumption. Canada’s single nitrous

³⁶ N_2O 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.

oxide producer and the three major N₂O gas distributors were surveyed through a recent study (Cheminfo, 2006), so that the sales volumes by end-use type for 1990-2005 could be estimated. Nitrous Oxide of Canada was contacted to obtain its annual production, domestic sales and export information, but it was only able to provide rough estimates of historical data. Also, a questionnaire requesting for sales volumes by market segment was sent to each of the N₂O distributors. However, these companies did not provide the full set of historical data that was requested.

As a complete set of sales data, covering 1990-2005, could not be gathered, the domestic sales of Canadian production data provided by Nitrous Oxide of Canada and N₂O import data purchased from the Statistics Canada's merchandise trade database (http://www.statcan.ca/trade/scripts/trade_search.cgi) were used to estimate the total domestic sales volumes (or consumption) of N₂O for 1990-2005. 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 2005. To calculate the amounts of N₂O 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 national level, the amount of N₂O 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 approximately 97.5% of the N₂O is not metabolized and is emitted in exhaled breath. Note that the same factor is also applied by the U.S. Environmental Protection Agency.

To estimate emissions coming from N₂O use in food products (i.e. whipped cream cans) at 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. Note that the same assumption was also made by the U.S. Environmental Protection Agency.

Summing the emission estimates for anaesthetic and propellant would give the national emission totals for the Sector of Solvent and Other Product Use.

The national emission estimates were divided by the national total population to yield an emission per capita factor. This factor was then multiplied by the population in each province and territory to estimate emissions at provincial/territorial levels. The annual population statistics were obtained from Statistics Canada's publication #91-213.

The IPCC Good Practice Guidance does not provide any recommendations on the estimation of N₂O 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 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 N₂O gas distributors and were estimated, they have an uncertainty range of approximately +/- 30%. For more recent years, the uncertainty related to the total Canadian sales for each application is around +/-10% because more data were gathered from the distributors (Cheminfo, 2006).

The data sources and methodology used are generally consistent over the time series.

5.1.4 QA/QC and Verification

Due to the methodological change, this Sector is considered as key and has undergone for this submission 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.

5.1.5 Recalculations

1990-2004 emission estimates for this sector were recalculated because updated activity data (i.e. N₂O sales data) were obtained during the Cheminfo study in 2006 (Cheminfo, 2006). Improvements made to this category have resulted in downwards revisions in the 1990-2004 emission estimates, ranging from -67.5% to -47.7%.

5.1.6 Planned Improvements

There are currently no improvements planned specifically for this sector.

6 Agriculture (CRF Sector 4)

6.1 Overview

Emission sources from agriculture include CH₄ and N₂O emissions from animal production — namely, enteric fermentation (CH₄) and manure management (N₂O and CH₄) — and N₂O released from agricultural soils. CO₂ emissions from and removals by croplands are reported under the LULUCF Sector under the Cropland Remaining Cropland category (see Chapter 7).

Total GHG emissions from the Canadian Agriculture Sector were 46 Mt in 1990, 56 Mt in 2004, and 57 Mt in 2005 (Table 6-1). This represents an increase of 24% between 1990 and 2005, mainly resulting from the expansion in the beef cattle, swine, and poultry industries as well as an increase in synthetic nitrogen fertilizer consumption.

The slight increase in emissions between 2004 and 2005 was due to a 2.4% increase in beef cattle population, partially offset by a decrease in consumption of synthetic nitrogen fertilizers.

Changes have been introduced this year in the inventory for this sector, notably in the N₂O estimates from agricultural soils further to method and data improvements. A new minor source of emissions was added to the category Direct N₂O from agricultural soils to capture the N₂O emissions associated with the irrigation of croplands. Accounting of conservation tillage impact on direct soil N₂O emissions was limited to the prairie provinces in the 2006 submission, but extended to Eastern Canada in the 2007 submission. The boundary for calculating the EF_{BASE} has been changed for the driest ecodistricts in the country with precipitation/potential evapotranspiration (P/PE) ratios between 0.33 and 0.22. Estimates of crop residue nitrogen have also been changed in the 2007 NIR because of minor updates in estimating crop yields for some crops of relatively minor importance. Finally, some animal population accounts have been updated. All these changes have triggered recalculations resulting in an overall upward change of 1.0 to 1.4 Mt CO₂e or 2 to 3% annually for the Agriculture Sector.

Biological nitrogen (N₂) fixation by the legume–rhizobium association is reported as not occurring. This decision is supported by the conclusion of Rochette and Janzen (2005) (and reflected in the 2006 IPCC Guidelines) that there is no evidence that measurable amounts of N₂O are produced during the nitrogen fixation process. In addition, some minor GHG sources are not included. CH₄ emissions from rice production in Canada are considered to be negligible and are not inventoried. Similarly, neither field burning of agricultural residues nor prescribed burning of savannas is relevant practices in Canada and are therefore not estimated. GHG emissions from on-farm fuel combustion are included in the Energy Sector (Chapter 3).

For each emission source category, a brief introduction and a description of methodological issues, uncertainties and time-series consistency, QA/QC and verification, recalculations, and planned improvements are provided. The detailed inventory methodologies and sources of activity data are described in Section A3.4 of Annex 3.

Table 6-1: Short- and Long-Term Changes in GHG Emissions from the Agriculture Sector

GHG Source Category		GHG Emissions		
		1990	2004 (<i>kt CO₂e</i>)	2005
Agriculture TOTAL		46 000	56 000	57 000
<i>Enteric Fermentation</i>		<i>18 000</i>	<i>24 000</i>	<i>25 000</i>
— CH ₄	Dairy Cattle	3 400	3 000	3 000
	Beef Cattle	14 000	20 000	21 000
	Others	610	1 000	1 000
<i>Manure Management</i>		<i>6 700</i>	<i>8 400</i>	<i>8 600</i>
— CH ₄	Dairy Cattle	740	660	660
	Beef Cattle	670	830	850
	Swine	1 100	1 500	1 600
	Poultry	70	90	90
	Others	20	40	40
— N ₂ O	All Animal Types	4 100	5 300	5 400
<i>Agricultural Soils</i>		<i>21 000</i>	<i>24 000</i>	<i>23 000</i>
Direct Sources (N ₂ O)		12 000	13 000	13 000
	Synthetic Nitrogen Fertilizers	5 100	6 300	5 800
	Manure Applied as Fertilizers	1 900	2 200	2 300
	Crop Residue Decomposition	4 100	4 200	4 300
	Cultivation of Organic Soils	60	60	60
	Conservation Tillage ¹	–180	–550	–580
	Summerfallow	920	570	530
	Irrigation	240	280	280
Pasture, Range, and Paddock Manure (N ₂ O)		3 200	4 300	4 400
Indirect Sources (N ₂ O)		5 400	6 400	6 300

Notes:

1 The negative values reflect a reduced N₂O 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 CH₄ are produced from herbivores through enteric fermentation. During the normal digestive process, microorganisms break down carbohydrates into simple molecules for absorption, where CH₄ is produced as a by-product. This process results in CH₄ in the rumen, which is emitted by eructation and exhalation. Some CH₄ is released later in the digestive process by flatulation. Ruminant animals, such as cattle, generate the most CH₄.

6.2.2 Methodological Issues

CH₄ emissions from enteric fermentation of cattle are estimated using the IPCC Tier 2 methodology. Emission factors for various cattle categories were determined following the guidance provided by IPCC (2000) and based on a study by Boadi *et al.* (2004). The cattle population was characterized by animal type, physiological status, age, gender, weight, rate of gain, level of activity, and production environment. Much of this information was obtained through 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 cattle, reflecting the fact that CH₄ production increases with milk productivity.

Information on animal population characteristics was used to calculate emission factors associated with various cattle categories based on the IPCC Tier 2 equations and in conjunction with Statistics Canada's population data to generate estimates of enteric emissions for each province.

For non-cattle categories, CH₄ 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 from the IPCC Guidelines (IPCC, 2006). CH₄ emissions are calculated for each animal category by multiplying the animal population for that category by the emission factor associated with the specific animal category.

Domestic animal population data are obtained from the Census of Agriculture and other Statistics Canada reports listed in Table 6-2. Semiannual or quarterly data are averaged to obtain annual populations.

Table 6-2: Animal Categories and Sources of Population Data

Category	Sources/Notes
Cattle	
- Dairy Cattle	Dairy cows
- Non-Dairy Cattle	All other cattle
	Data source: Statistics Canada (2005a, #23-012)
Buffaloes	Data for 1991, 1996 and 2001 were obtained from Alternative Livestock on Canadian Farmers [Statistics Canada (2002), #23-502] to derive the 1990–2005 time series.
Sheep and Lambs	Data source: Statistics Canada (2005b, #23-011)
Goats and Horses	Data for 1986, 1991, 1996 and 2001 were obtained from Alternative Livestock on Canadian Farmers [Statistics Canada (2002), #23-502] to derive the 1990–2005 time series.
Camels and Llamas	Considered a negligible source in Canada
Mules and Asses	Considered a negligible source in Canada
Swine	All pigs
	Data source: Statistics Canada (2005c, #23-010)
Poultry	Chicken, layers, and turkey population data are available from the 1986, 1991, 1996, and 2001 farm census (Statistics Canada, #96102, #93350, #93356, and #95F0301).

6.2.3 Uncertainties and Time-Series Consistency

The uncertainty associated with CH₄ emissions from enteric fermentation was determined using the Monte Carlo technique based on the IPCC Tier 2 methodology (IPCC, 2000). 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 and goats. 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-cattle categories were estimated to be $\pm 20\%$ (IPCC/OECD/IEA, 1997). The overall level and trend uncertainty for emission estimates from 1990 to 2005 was 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 study by ICF (2004), as reported in Annex 7.

The same methodology and data sources are used for the entire time series of emission estimates (1990–2005).

6.2.4 QA/QC and Verification

Enteric fermentation, as a key category, has undergone Tier 1–level QC checks as elaborated in QA/QC plan (refer to Annex 6) in a manner consistent with IPCC Good Practice Guidance (IPCC, 2000). In addition, the activity data, methodologies, and changes are documented and archived in both paper and electronic form. 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 CH₄ 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 CH₄ emissions from grazing cattle using SF₆ (McCaughey *et al.*, 1997, 1999; Boadi and Wittenberg, 2002; Boadi *et al.*, 2002a, 2002b; McGinn *et al.*, 2004, 2006; Beauchemin and McGinn, 2005). CH₄ 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

Animal populations have been modified slightly for categories of minor significance. In the 2006 NIR, buffalo population was held constant at the 1996 value for the years of 1990-1995. In the 2007 NIR, buffalo population for 1991 was obtained from Alternative Livestock on Canadian Farms (Statistics Canada, Catalogue no. 23-502) and linearly interpolated between 1991 and 1996, and the 1990 value was held constant at the 1991 population. Furthermore, animal populations for horses, goats and poultry for 1986 were used to linearly interpolate between 1986 and 1991 to obtain the 1990 population instead of holding them constant at the 1991 value as was done for the 2006 NIR. Hog population for 2004 was updated by Statistics Canada. All these changes in animal populations resulted in a small change of emissions (± 0.03 Mt annually) for enteric fermentation with no impact on the long-term trend.

6.2.6 Planned Improvements

In the current methodology, the value for digestible energy 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.

6.3 Manure Management (CRF Category 4.B)

CH₄ and N₂O are emitted during the handling or storage of livestock manure. The magnitude of the emissions depends upon the quantity of manure handled, the manure properties, and the type of manure management system. Typically, poorly aerated manure management systems generate large quantities of CH₄ but smaller amounts of N₂O, whereas well-aerated systems generate little CH₄ but more N₂O.

6.3.1 CH₄ Emissions from Manure Management (CRF Category 4.B (a))

6.3.1.1 Source Category Description

Shortly after manure is excreted, it begins to decompose. If little oxygen is present, the decomposition is mainly anaerobic and thus produces CH₄. The quantity of CH₄

produced depends on the manure characteristics linked to animal types and diets, and on the type of waste management systems, in particular, how well it is aerated.

6.3.1.2 *Methodological Issues*

CH₄ emissions from manure management are estimated using the IPCC Tier 2 methodology (IPCC, 2000). Emission factors were derived from a study by Marinier *et al.* (2004), with modifications and updates following the 2006 IPCC Guidelines (IPCC, 2006). Marinier *et al.* (2004) estimated volatile solids for cattle and non-cattle through expert consultations. Dry matter intake (and therefore volatile solids) for dairy and non-dairy cattle was estimated using the same characterization data as used for the enteric fermentation Tier 2 method by Boadi *et al.* (2004). For dairy cows, the emission factor time series reflects the increase in milk productivity of cows over time. In addition, B₀ (maximal CH₄ producing potential) and methane conversion factors (MCF) have been updated according to the new information in the 2006 IPCC Guidelines (IPCC, 2006). Emissions were calculated for each animal category by multiplying the animal population for that category by the average emission factor associated with the specific animal category. The animal population data are the same as those used for the enteric fermentation emission estimates.

6.3.1.3 *Uncertainties and Time-Series Consistency*

The uncertainty associated with CH₄ emissions from manure management was determined using the Monte Carlo technique based on the IPCC Tier 2 methodology. Uncertainties associated with animal populations are reported in Section 6.2.3. Uncertainties associated with variables and input parameters for estimating dry matter intake for dairy and non-dairy cattle using the IPCC Tier 2 equations were the same as noted under enteric fermentation. Uncertainties or ranges associated with other parameters for estimating emission factors for various animal categories were taken from the IPCC defaults for MCF and B₀ (IPCC, 2006) and Marinier *et al.* (2004) for animal manure distributions. The uncertainties associated with the IPCC Tier 2 emission factors varied from ±26% for beef cows to ±50% for chicken (Marinier *et al.*, 2004). The overall level and trend uncertainty for emission estimates from 1990 to 2005 was estimated to be ±29% and ±23%, respectively (Hutchinson *et al.*, 2007).

The same methodology and data source are used for the entire time series (1990–2005).

6.3.1.4 *QA/QC and Verification*

CH₄ emissions from manure management have undergone Tier 1–level QC checks as elaborated in QA/QC plan (refer to details and references in Annex 6) in a manner consistent with IPCC Good Practice Guidance (IPCC, 2000). The activity data and methodologies are documented and archived in both paper and electronic form. The IPCC Tier 2 CH₄ 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*

Recalculations have been carried out for the entire time series as a result of a revision in animal populations as noted in Enteric Fermentation. Overall, these recalculations resulted in a change of CH₄ emissions from +0.002 to -0.002 Mt annually and had no impact on the emission trend.

6.3.1.6 *Planned Improvements*

In the current methodology, dry matter intake and digestible energy by animal category are 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. Maximal CH₄ producing potentials for various animal manures (Bo) will be determined.

6.3.2 **N₂O Emissions from Manure Management (CRF Category 4.B (b))**

6.3.2.1 *Source Category Description*

The production of N₂O during storage and treatment of animal waste occurs during nitrification and denitrification of nitrogen contained in the manure. Nitrification is the oxidation of ammonium (NH₄⁺) to nitrate (NO₃⁻), and denitrification is the reduction of NO₃⁻ to N₂O or N₂. In general, the amount of N₂O produced increases with greater aeration of the waste.

In Canada, the four major types of animal waste management systems (AWMS) typically used are: liquid systems, solid storage and drylot, pasture and paddock, and other systems such as composters, biodigestors, etc. It is assumed that no manure is burned as fuel.

Table 6-3 presents Canada's breakdown of AWMS. The distribution of manure management systems by animal category is based on a study by Marinier *et al.* (2004). Note that the N₂O emissions from manure on pasture, range, and paddock systems are not

included here but are reported under a separate category (refer to Manure on Pasture, Range, and Paddock, Section 6.4.2).

Table 6-3: Percentage of Manure Nitrogen Handled by Animal Waste Management Systems (AWMS)

Animal Types	Liquid Systems	Solid Storage and Drylot (% of manure nitrogen)	Pasture and Paddock	Other Systems
Non-Dairy Cattle	1	47	48	4
Dairy Cattle	42	40	18	0
Poultry	10	88	2	0
Sheep and Lambs	0	38	62	0
Swine	96	3	0	1
Horses	0	43	57	0
Buffaloes ¹	0	43	57	0
Goats	0	40	60	0

Source:

Marinier *et al.* (2004).

Note:

1 Assuming manure N handled by AWMS the same as horses

6.3.2.2 Methodological Issues

N₂O emissions from manure management are estimated using the IPCC Tier 1 methodology. Emissions are calculated for each animal category by multiplying the animal population for that category by the average nitrogen excretion rate associated with the specific animal category and by the fraction of available nitrogen based on the type of waste management system.

The animal population data are the same as those used for the Enteric Fermentation estimates (Section 6.2) and CH₄ Emissions from Manure Management (Section 6.3.1). The average annual nitrogen excretion rates for domestic animals are taken from the 2006 IPCC Guidelines (IPCC, 2006). The amount of manure nitrogen subject to losses because of leaching and volatilization of NH₃ and NO_x is adjusted by animal types and manure management systems according to the default values provided in the 2006 IPCC Guidelines (IPCC, 2006).

The fraction of nitrogen available for conversion into N₂O is estimated by applying system-specific emission factors to the manure nitrogen handled by each management system. The IPCC default emission factors (IPCC, 2006) for a developed country with a cool climate are used to estimate manure nitrogen emitted as N₂O for each type of AWMS.

6.3.2.3 Uncertainties and Time-Series Consistency

Uncertainties associated with N₂O emission estimates from manure management result from uncertainties associated with estimates of animal populations from the Census of Agriculture, ranging from ±1% to ±15% as noted in the enteric fermentation and manure

management sections. 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 uncertainty associated with this source of emission estimates from 1990 to 2005 was 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 (1990–2005).

6.3.2.4 *QA/QC and Verification*

This category has undergone Tier 1–level QC checks as elaborated in QA/QC plan (refer to details and references in Annex 6) in a manner consistent with IPCC Good Practice Guidance (IPCC, 2000). The activity data, methodology, and changes to methodologies are documented and archived in both paper and electronic form.

6.3.2.5 *Recalculations*

Recalculations have been carried out because of changes in manure management systems for horses, goats and buffaloes as well as updates to animal population accounts as noted in Enteric Fermentation. Overall, these recalculations resulted in changes of ± 0.01 Mt annually, and had no impact on the long-term trend.

6.3.2.6 *Planned Improvements*

Data from direct measurements of N_2O emissions from manure management in Canada are scarce. Recent scientific advances on analytical techniques allow direct measurements of N_2O emissions from point sources, such as lagoons, using a flux tower. However, it will likely take several years before N_2O emissions can be reliably measured and verified from various manure management systems in Canada.

6.4 *N_2O Emissions from Agricultural Soils (CRF Category 4.D)*

Emissions of N_2O from agricultural soils consist of direct and indirect emissions as well as emissions from manure on pasture, range, and paddock. Direct sources are emissions from nitrogen that has entered the soil from synthetic fertilizers, animal manure applied as fertilizer, crop residue decomposition, and modification by tillage practices. Other direct sources include summerfallow, irrigation and cultivation of histosols. Indirect sources are emitted off site through volatilization and leaching of synthetic fertilizer, manure, and crop residue nitrogen.

6.4.1 Direct N₂O Emissions from Soils (CRF Category 4.D.1)

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 N₂O. 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 A3.4 of Annex 3, Canada has developed a country-specific, Tier 2–type methodology to estimate N₂O emissions from synthetic nitrogen fertilizer application on agricultural soils, which takes into account local climate (precipitation and potential evapotranspiration) and topographic conditions. Emissions of N₂O 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 were obtained from the Canadian Fertilizer Institute³⁷. These data include the amount of fertilizer nitrogen sold by retailers on or before June 30 of the inventory year.

Uncertainties and Time-Series Consistency

Uncertainties associated with N₂O emission estimates from synthetic nitrogen fertilizer applications result from uncertainties associated with estimates of nitrogen fertilizer sales ($\pm 20\%$), RF_{THAW} ($\pm 30\%$), and EF_{BASE} ($\pm 25\%$). These terms and emission calculations are explained in the methodological section A3.4 of Annex 3. The overall level and trend uncertainty associated with this source of emission estimates from 1990 to 2005 was 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 (1990–2005).

³⁷ Available online at: http://www.cfi.ca/Publications/Statistical_Documents.asp.

QA/QC and Verification

This category has undergone Tier 1–level QC checks as elaborated in for the QA/QC plan (refer to details and references in 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.

N₂O emissions associated with synthetic fertilizer nitrogen applications on agricultural soils in Canada vary widely, but there is a close agreement between the aggregated, measured emission factor and the IPCC default value in eastern Canada (Gregorich *et al.*, 2005).

Recalculations

Recalculations have been carried out for the full time series for this category. For a more complete representation of the local climatic conditions, EF_{BASE} was increased for the driest ecodistricts in the country (lower boundary of P/PE ratio moved from 0.33 to 0.22). Overall, these recalculations increased the 1990 emissions reported in the 2006 submission by about 0.3 Mt and the 2004 emissions reported in the 2006 submission by 0.5 Mt, and have increased the 1990-2004 trend from about +21% to +24%. Changes to EF_{BASE} also affect all the other N₂O source categories except histosols.

Planned Improvements

There is no immediate plan in place aimed at improving emission estimates for this source.

6.4.1.2 *Animal Manure Applied to Soils*

Source Category Description

The application of animal manure as fertilizer to soils can increase the rate of nitrification and denitrification and result in enhanced N₂O emissions from agricultural soils. Note that emissions from this category include manure managed by drylot, liquid, and other AWMS. 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 these N₂O emissions is a country-specific IPCC Tier 2–type method that takes into account local climate, such as 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 level. All manure that is handled by the

AWMS, 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 N₂O emission estimates from animal manure applied as fertilizers result from uncertainties associated with estimates of manure nitrogen based on types of animal populations ($\pm 1\%$ to $\pm 15\%$), average animal manure nitrogen excretion rate ($\pm 20\%$), manure nitrogen loss ($\pm 20\%$), RF_{THAW} ($\pm 30\%$), and EF_{BASE} ($\pm 25\%$). The overall level and trend uncertainty associated with this source of emission estimates from 1990 to 2005 was 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 (1990–2005).

QA/QC and Verification

This category has undergone Tier 1–level QC checks as elaborated in QA/QC plan (refer to details and references in 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.

Recalculations

Recalculations have been carried out because of changes in manure management systems for horses, goats and buffaloes, updates to animal population accounts as noted in Enteric Fermentation as well as EF_{BASE} as noted in Synthetic Nitrogen Fertilizers. Overall, these recalculations increased N₂O emissions by about 0.07 to 0.1 Mt annually since 1990, and had a minimal impact on the long-term trend.

Planned Improvements

The relationships between soil texture and N₂O emissions will be investigated for inclusion in the emission factor equations.

6.4.1.3 Nitrogen-Fixing Crops

Source Category Description

Biological nitrogen fixation by the legume–rhizobium association was a major source of N₂O emissions in previous national GHG inventories reported by Canada until 2005 in accordance with the IPCC Guidelines methodology (IPCC/OECD/IEA, 1997). The decision to exclude this category as an emission source, in accordance with the 2006 IPCC Guidelines (IPCC, 2006), is supported by the conclusion of Rochette and Janzen (2005) that there is no evidence that measurable amounts of N₂O are produced during the

nitrogen fixation process. Therefore, Canada reports this source as “not occurring.” However, the contribution of legume nitrogen to N₂O emissions is included from crop residue decomposition on agricultural soils.

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 processes and thus produces N₂O. In some cases, the remaining crop residue is burned, but it is assumed that the amount of burning is negligible in Canada.

Methodological Issues

Emissions are estimated using an IPCC Tier 2 approach. 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, using moisture regimes and topographic conditions. Emissions of N₂O 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.

Uncertainties and Time-Series Consistency

Uncertainties associated with N₂O 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 belowground crop residue nitrogen concentration ($\pm 15\%$), RF_{THAW} ($\pm 30\%$), and EF_{BASE} ($\pm 25\%$). The overall level and trend uncertainty associated with this source of emission estimates from 1990 to 2005 was 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 (1990–2005).

QA/QC and Verification

This category has undergone Tier 1–level QC checks as elaborated in QA/QC plan (refer to details and references in 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.

Recalculations

Recalculations have been carried out firstly due to the increase in the emission factors EF_{BASE} as explained under Synthetic Fertilizers and, secondly, due to updates to estimates

of crop residue nitrogen. Some minor crops are present in a province, but not significant enough to be reported by Statistics Canada at the provincial level. In this case, the areas reported at the ecodistrict level were used. In the 2006 NIR a non-weighted national yield was used for minor crops and all provinces reporting these crops received equal weighting for yield to estimate production for these minor crops. In the 2007 NIR, a weighted national yield was used to estimate yield for these minor crops. This has resulted in a very slight change in residue nitrogen available to be converted to N₂O. This change has an impact for those years with high crop yields, such as 1999. Overall, these recalculations increased the 1990 emissions reported in the 2006 submission by 0.3 Mt and the 2004 emissions reported in the 2006 submission by 0.4 Mt and have changed the long-term trend from 0% to +2%.

Planned Improvements

There is no immediate plan in place aimed at improving emission estimates from this source.

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 belowground water table, increasing aeration, and speeding up the decomposition of organic matter. Denitrification and nitrification also take place, releasing N₂O emissions.

Methodological Issues

The IPCC Tier 1 methodology is used to estimate N₂O emissions from cultivated organic soils. N₂O 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, which is carried out regularly at five-year intervals by Statistics Canada. In the absence of these data, consultations with numerous soil and crop specialists across Canada have been made. The total area of cultivated organic soils in Canada has been estimated at 16 156 ha at a constant level for the period 1990–2005 (G. Padbury and G. Patterson, personal communication).

Uncertainties and Time-Series Consistency

Uncertainties associated with N₂O 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 uncertainty associated with this source of emission estimates from 1990 to 2005 was 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 (1990–2005).

QA/QC and Verification

This category has undergone Tier 1–level QC checks as elaborated in QA/QC plan (refer to details and references in 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.

Recalculations

No recalculation has been carried out for this source category.

Planned Improvements

There is no immediate plan in place aimed at improving emission estimates from this source.

6.4.1.6 *Change in N₂O Emissions 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 N₂O emissions from fertilizer and crop inputs because of the switch to conservative soil management practices — namely, reduced tillage (RT) and no-tillage (NT). Compared with conventional or intensive tillage (IT), direct seeding or NT as well as RT affect several factors that influence N₂O production, including decomposition of soil organic matter, soil carbon and nitrogen availability, soil bulk density, and water content (McConkey *et al.*, 1996; McConkey *et al.*, 2003; Liang *et al.*, 2004). As a result, compared with conventional tillage, conservation tillage reduced N₂O emissions for the prairies, but increased N₂O emissions for the non-prairies regions of Canada. The net result across the country amounts to a small reduced source (hence the negative sign).

Methodological Issues

Changes in N₂O 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. The tillage ratio factor, defined as the ratio of mean N_2O fluxes on NT or RT to mean N_2O fluxes on IT ($\text{N}_2\text{O}_{\text{NT}}/\text{N}_2\text{O}_{\text{IT}}$), represents the effect of NT or RT on N_2O emissions (F_{TILL}). Field studies in Quebec and Ontario comparing emissions between NT and mouldboard plowing yielded an F_{TILL} of 1.1 (Gregorich *et al.*, 2005), while a similar exercise for the Prairie region yielded an F_{TILL} of 0.8 for the Brown, Dark Brown, Grey, and Black soil zones (Rochette *et al.*, 2007). For other regions of Canada, F_{TILL} is assumed to be 1.0. Thus, compared with conventional tillage, conservation tillage increased N_2O emissions by 10% in the Eastern Canada and decreased N_2O emissions by 20% in the Brown, Dark Brown, Grey, and Black soil zones of the prairies, and showed no change in the other regions of Canada.

Uncertainties and Time-Series Consistency

Uncertainties associated with reduced N_2O emission estimates from adoption of NT and RT on the Canadian prairies result from uncertainties associated with area estimates of NT and RT from the Census of Agriculture ($\pm 15\%$), F_{TILL} ($\pm 20\%$), and EF_{BASE} ($\pm 25\%$). The overall level and trend uncertainty associated with this source of emission estimates from 1990 to 2005 has not been assessed.

The same methodology and emission factors are used for the entire time series (1990–2005).

QA/QC and Verification

This category has undergone Tier 1–level QC checks as elaborated in QA/QC plan (refer to details and references in 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.

Recalculations

Recalculations have been carried out because of changes in the method to include Eastern Canada and British Columbia as well as the increase in EF_{BASE} . The area of cropland subject to conservation tillage reported in the 2006 NIR was 6.84 M ha in 1990, and 16.4 M ha in 2004, whereas this area reported in the 2007 NIR changes to 10.2 M ha in 1990, and 20.2 M ha in 2004. As a result, decreased N_2O emissions due to conservation tillage in 1990 changed from - 0.22 Mt to -0.18 Mt and from -0.58 Mt to -0.55 in 2004 in this submission with a minimal impact on the trends in the Agriculture sector.

Planned Improvements

Agriculture and Agri-Food Canada is planning to publish experimental data on changes in N_2O emissions from adoption of NT and RT relative to IT. This will increase the scientific credibility and international acceptance for inclusion of this category in the

NIR. The level and trend uncertainty associated with changes in N₂O emission estimates from adoption of NT and RT is planned to be assessed.

6.4.1.7 *N₂O Emissions Resulting from Summerfallowing*

Source Category Description

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 N₂O emissions relative to a cropped situation, such as higher soil water content, temperature, and available carbon and nitrogen (Campbell *et al.*, 1990). Experimental studies have shown that N₂O emissions in fallow fields are similar to emissions from continuously cropped fields (Rochette *et al.*, 2007).

Methodological Issues

The emissions due to summerfallow are calculated through a country-specific method by summing emissions from fertilizer and manure application to annual crops for a given ecodistrict and multiplying the sum by the proportion of that ecodistrict under summerfallow (Rochette *et al.*, 2007).

Uncertainties and Time-Series Consistency

Uncertainties associated with N₂O emission estimates from summerfallow result from uncertainties associated with area estimates of summerfallow from the Census of Agriculture (cropland area: 1.25 to 10%; $\text{Frac}_{\text{FALLOW}}$: 1.25 to 10%) and EF_{BASE} ($\pm 25\%$). The overall level and trend uncertainty associated with this source of emission estimates from 1990 to 2005 was estimated to be $\pm 24\%$ and $\pm 21\%$, respectively (Hutchinson *et al.*, 2007).

The same methodology and emission factors are used for the entire time series (1990–2005).

QA/QC and Verification

This category has undergone Tier 1–level QC checks as elaborated in QA/QC plan (refer to details and references in 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.

Recalculations

Recalculations have been carried out because of the increase in emission factors EF_{BASE} for the driest ecodistricts as noted for emissions from Synthetic Nitrogen Fertilizers. Overall, N_2O emissions from summerfallow increased by about 0.2 Mt for 1990 and 0.1 Mt for 2004 with little impact on the Agriculture sector trend.

Planned Improvements

Agriculture and Agri-Food Canada is planning to publish experimental data on N_2O emissions from summerfallow. This will increase the scientific credibility and international acceptance for inclusion of this category in NIR.

6.4.1.8 *N₂O Emissions from Irrigation*

Source Category Description

This is a new category in Canada's inventory of direct N_2O emissions from soils (CRF subcategory "Other"). Higher soil water content under irrigation increases potential N_2O emissions by increasing biological activity and reducing soil aeration (Jambert et al., 1997). The highest N_2O emissions from agricultural soils in northwestern USA (Liebig et al., 2005) and western Canada (Hao et al., 2001) were observed on irrigated cropland, followed by non-irrigated cropland and rangeland.

Methodological Issues

The methodology is country specific and is based on the assumptions that 1) the irrigation water stimulates N_2O production in a way similar to rainfall water, and 2) that 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_2O emissions from agricultural soils was estimated using an EF_{BASE} estimated at a P/PE = 1 (e.g., $EF_{BASE} = 0.012 \text{ N}_2\text{O-N kg}^{-1} \text{ N}$) for the irrigated areas of a given ecodistrict.

Uncertainties and Time-Series Consistency

Uncertainties associated with N_2O emission estimates from irrigation result from uncertainties associated with synthetic ($\pm 20\%$) and animal manure nitrogen ($\pm 20\%$) inputs, crop residue nitrogen ($\pm 15\%$), area estimates of irrigated cropland from the Census of Agriculture (1.25 to 10%), as well as EF_{BASE} ($\pm 25\%$). The overall level and trend uncertainty associated with this source of emission estimates has not been assessed at this time.

The same methodology and emission factors are used for the entire time series (1990–2005).

QA/QC and Verification

This category has undergone Tier 1–level QC checks as elaborated in QA/QC plan (refer to details and references in Annex 6) in a manner consistent with IPCC Good Practice Guidance (IPCC, 2000). The activity data and methodology are documented and archived in both paper and electronic form.

Recalculations

As this is the first year of reporting for this category, there is no recalculation associated with this source of emission estimates.

Planned Improvements

The level and trend uncertainty associated with this source of emission estimates is planned to be assessed.

6.4.2 Manure on Pasture, Range, and Paddock (CRF Category 4.D.2)

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, N₂O is produced.

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 N₂O.

The animal population data are the same as those used in Section 6.2. The nitrogen excretion rates are based on the IPCC defaults (IPCC, 2006). The fraction of manure nitrogen available for conversion to N₂O is calculated as the percentage of total manure nitrogen produced on pasture, range, and paddock multiplied by the IPCC default values of 0.02 kg N₂O-N/kg N for cattle, poultry, and swine and 0.01 kg N₂O-N/kg N for sheep/lamb, goat, and horse (IPCC, 2006), which represents the fraction of excreted manure nitrogen converted to N₂O-N.

Uncertainties and Time-Series Consistency

Uncertainties associated with N₂O emission estimates from animal manure on pasture, range, and paddock result from uncertainties associated with animal populations ($\pm 1\%$ to $\pm 15\%$), manure nitrogen excretion rate ($\pm 20\%$), fraction of manure nitrogen on pasture,

range, and paddock ($\pm 20\%$), as well as emission factors (-25% to $+150\%$). The overall level and trend uncertainty associated with this source of emission estimates from 1990 to 2005 was 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 (1990–2005).

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_2O emissions from the manure on pasture and paddock from grazing animals in Canada. Therefore, it is extremely difficult to verify how well the IPCC emission factor reflects Canadian conditions.

Recalculations

Recalculations have been carried out because of changes and updates in animal populations and manure management systems for goats, horses and buffaloes as explained in 6.2. Overall, these recalculations resulted in small reductions of N_2O emissions by ~ 0.01 Mt annually from 1990 to 1995, and had no impact on the long-term trend.

Planned Improvements

There is no immediate plan on improvement associated with N_2O emission estimates from animal manure on pasture, range, and paddock.

6.4.3 Indirect Emissions of N_2O 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_2O .

Note that 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 this nitrogen is lost through volatilization in the form of NH_3 or NO_x . This volatilized nitrogen can be

redeposited somewhere else and can undergo further transformations, such as nitrification and denitrification, thus resulting in N_2O 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, soil pH, etc.

Methodological Issues

The IPCC Tier 1 methodology is used to estimate indirect N_2O emissions due to volatilization and redeposition of nitrogen from synthetic fertilizer and manure (IPCC/OECD/IEA, 1997). The portions of volatilized NH_3 or NO_x from animal manure vary with animal types and manure management systems based on the default values from the 2006 IPCC Guidelines (IPCC, 2006). The amount of synthetic fertilizer and manure nitrogen is multiplied by the fraction of nitrogen that is volatilized as $\text{NH}_3\text{-N}$ and $\text{NO}_x\text{-N}$ 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 the amounts excreted by animals. The amount of nitrogen that volatilizes is assumed to be 10% of the total amount of synthetic fertilizer applied (IPCC/OECD/IEA, 1997). The default IPCC emission factor, 0.01 kg $\text{N}_2\text{O-N/kg N}$, is applied to derive the N_2O emission estimate (IPCC/OECD/IEA, 1997).

Uncertainties and Time-Series Consistency

Uncertainties associated with N_2O emission estimates from volatilization of NH_3 and NO_x 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_3 and NO_x from synthetic nitrogen fertilizers ($\pm 20\%$), animal populations ($\pm 1\%$ to $\pm 15\%$), manure nitrogen excretion rate ($\pm 20\%$), fraction of volatilized NH_3 + NO_x from animal manure ($\pm 20\%$), as well as emission factors (-50% to $+300\%$). The overall level and trend uncertainty associated with this source of emission estimates from 1990 to 2005 was 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 (1990–2005).

QA/QC and Verification

This category has undergone Tier 1–level QC checks as elaborated in QA/QC plan (refer to details and references in 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.

Recalculations

Recalculations have been carried out because of changes and updates in animal populations and manure management systems for goats, horses and buffaloes. Overall,

these recalculations resulted in very small reductions of N₂O emissions between 0 to 0.16%, in particular for 1990-1995 because some animal population accounts were updated for those years, and had no impact on the long-term trend.

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 this nitrogen is lost through leaching, erosion, and runoff. The magnitude of this nitrogen loss depends on a number of factors, such as rates, methods, and time of nitrogen application, crop type, soil texture, rainfall, landscape, etc. This portion of lost nitrogen can further undergo transformations, such as nitrification and denitrification, thus producing N₂O emissions off site.

Methodological Issues

A modified IPCC Tier 1 methodology is used to estimate indirect N₂O emissions from leaching, runoff, and erosion of fertilizers, manure, and crop residue nitrogen from agricultural soils.

The default value for the fraction of nitrogen that is lost through leaching and runoff (Frac_{LEACH}) in the 1996 IPCC Guidelines (IPCC/OECD/IEA, 1997) was 0.3. Frac_{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 Frac_{LEACH} would vary among ecodistricts from a low of 0.05 to a high of 0.3. For ecodistricts with P/PE values for the growing season (May through October) greater than or equal to 1, the maximum Frac_{LEACH} value recommended by the 2006 IPCC Guidelines (IPCC, 2006) of 0.3 was assigned. For ecodistricts with the lowest P/PE value (0.22), a minimum Frac_{LEACH} value of 0.05 was assigned. For ecodistricts with a P/PE value that ranged between 0.22 and 1, Frac_{LEACH} was estimated by the linear function that joins the points (P/PE, Frac_{LEACH}) = (1,0.3; 0.22,0.05).

Indirect N₂O emissions from runoff and leaching of nitrogen at the ecodistrict level are estimated using Frac_{LEACH} multiplied by the amount of synthetic fertilizer nitrogen, non-volatilized manure nitrogen, and crop residue nitrogen and by an emission factor of 0.0125 kg N₂O-N/kg N (IPCC, 2006).

Uncertainties and Time-Series Consistency

Uncertainties associated with N₂O 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 ($\pm 1\%$ to $\pm 15\%$), crop residue nitrogen ($\pm 15\%$), $\text{Frac}_{\text{LEACH}}$ ($\pm 50\%$), as well as the leaching/runoff emission factor EF_{LEACH} (-48% to $+200\%$). The overall level and trend uncertainty associated with this source of emission estimates from 1990 to 2005 was 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 (1990–2005).

QA/QC and Verification

This category has undergone Tier 1–level QC checks as elaborated in QA/QC plan (refer to details and references in 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.

Recalculations

Recalculations have been carried out because of updates in animal populations and changes in manure management systems and crop residue nitrogen. In the 2006 NIR, N_2O emission estimates from the conversion of perennial forage crops to annual crops as a result of soil organic matter mineralization were initially included, but removed of the need for further investigation. This additional source of nitrogen from perennial/annual crop conversion however was still subject to the leaching of indirect soil N_2O emissions in the database. This error has been corrected in the 2007 submission. Overall, these recalculations decreased the 1990 emissions reported in the 2006 submission by 0.14 Mt and the 2004 emissions reported in the 2006 submission by 0.18 Mt and have had some minimal impact on the long-term trend.

Planned Improvements

The impact of the soil organic matter mineralization due to losses of soil organic carbon according to the 2006 IPCC Guidelines is being investigated.

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 CO₂, additional emissions of CH₄, N₂O, and CO due to wildfires and controlled burning, and N₂O released following land conversion to cropland. All emissions from and removals by the LULUCF Sector are excluded from the national totals.

In 2005, the estimated net GHG flux in the LULUCF Sector, calculated as the sum of CO₂ emissions and removals and non-CO₂ emissions, amounted to removals of 17 Mt. If these were included in the national totals, they would reduce the total Canadian GHG emissions by about 2%. Table 7-1 provides the net flux estimates for 1990 and most recent years in the major LULUCF Sector categories and subcategories.

In view of the high inter-annual variability displayed by some categories and the 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 5 of the CRF series.

Table 7-1: LULUCF Sector Net GHG Flux Estimates, Selected Years

Sectoral Category	Net GHG Flux		
	1990	2004 (<i>kt CO₂ eq</i>)	2005
Land Use, Land-Use Change and Forestry TOTAL¹	-120 000	81 000	-17 000
a. Forest Land	-150 000	70 000	-27 000
Forest Land Remaining Forest Land	-150 000	71 000	-26 000
Land Converted to Forest Land	-1 000	-1 000	-1 000
b. Cropland	14 000	1 000	500
Cropland Remaining Cropland	-2 600	-9 000	-10 000
Land Converted to Cropland	17 000	11 000	10 000
c. Grassland			
Grassland Remaining Grassland	NE	NE	NE
Land Converted to Grassland	NE	NE	NE
d. Wetlands	5 000	2 000	2 000
Wetlands Remaining Wetlands	100	400	400
Lands Converted to Wetlands	5 000	1 000	1 000
e. Settlements	9 000	8 000	8 000
Settlements Remaining Settlements	-100	-200	-200
Land Converted to Settlements	9 000	8 000	8 000
Forest conversion (memo item) ²	29 000	21 000	21 000
Grassland conversion (memo item) ^{2,3}	1 000	800	700

Notes:

1 Totals may not add up due to rounding. Annex 13 describes the rounding protocol.

2 Already included in lands converted to cropland, wetlands, and settlements; and in cropland remaining cropland, and wetlands remaining wetlands (for residual emissions post 20 years).

3 Includes conversion of agricultural grassland to cropland, and of tundra to settlement.

NE = Not estimated

The Forest Land category has the largest influence on sectoral totals. In general, the net fluxes are negative (removals), with notable exceptions in 1995, 1998, 2002 and 2004, which were years with large areas burned by wildfire. As a consequence, the inter-annual variability is high, with net category totals fluctuating between -151 Mt (1992) and 155 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, for a nearly neutral GHG budget in 2005. The decline of emissions from land converted to cropland and growing removals by cropland remaining cropland equally contribute to the 14 Mt reduction in net emissions over the period 1990-2005.

Estimates in the Wetlands category (managed peatlands and flooded lands) are reported for the second time in the GHG inventory. The contribution of wetlands remaining wetlands is minor; emissions from land converted to wetlands declined from a little less than 5 Mt to 1 Mt during the period; flooded lands account for over 94% of these emissions.

With this submission, Canada continues the implementation of a multiyear effort to substantially improve its estimates for the LULUCF Sector.³⁸ The contribution of the best Canadian expertise to this and the previous submission occurred within Canada's national, multi-disciplinary 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 the Forest Land category, and comprehensive scientific documentation of estimate development and inventory preparation procedures.

The remainder of this chapter highlights the salient features of each LULUCF Sector category, beginning with key changes since the previous submission (Section 7.2). Section 7.3 gives an overview of the representation of managed lands; each subsequent section provides a short description of a land category (Sections 7.4 to 7.8). A special section (Section 7.9) is devoted to the cross-category estimates of forest conversion to other lands.

7.2 Changes since Previous Submission

Methodological changes are minor in this submission and there is no new category being reported. Table 7–2 compares the 2004 estimates submitted in the previous and current submissions. Recalculations conducted for the 2007 submission have the largest effects on inventory years 1994 (-96 Mt), 2002 (+49 Mt), 1990 (-41 Mt), 1995 (-39 Mt), 2003 (+34 Mt), 2001 (+27 Mt) and 2000 (+24 Mt), and these are largely driven by recalculations in the Forest Land remaining Forest Land category (Section 7.4.1.4).

In general, on-going improvements and recalibration of estimation parameters, corrections and refinements to the areas of managed forests and flooded land, quality assurance activities and expanded coverage of deforestation samples, corrections of programming errors in cropland estimation procedures, integration of expert knowledge of peatland management, and enhanced harmonization of multi-source data, account for most changes. Sections 7.4 to 7.8 provide details specific to each category on the most important recalculations. Progress was also made in the documentation of uncertainty in the Cropland category, and of Tier 2 QC procedures.

³⁸ First described in the 2004 NIR, and implemented for the 2006 submission.

Table 7-2: 2004 GHG Estimates in the 2006 and 2007 Submissions

Sectoral Category	Net Flux	
	2006 Submission	2007 Submission
	<i>(kt CO₂ eq)</i>	
TOTAL¹	81 000	81 000
Forest Land	73 000	70 000
Forest Land Remaining Forest Land	74 000	71 000
Land Converted to Forest Land	-1 000	-1 000
Cropland	0	1 000
Cropland Remaining Cropland	-9 000	-9 000
Land Converted to Cropland	9 000	11 000
Grassland		
Grassland Remaining Grassland	NE	NE
Land Converted to Grassland	NE	NE
Wetlands	1 000	2 000
Wetlands Remaining Wetlands	100	400
Land Converted to Wetlands	1 000	1 000
Settlements	7 000	8 000
Settlements Remaining Settlements	-200	-200
Land Converted to Settlements	7 000	8 000

Notes:

1 Totals may not add up due to rounding.

NE = Not estimated

7.3 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 forests.” For the purpose of the GHG inventory, managed forests are those potentially subject to harvesting or to measures of fire protection. Section A3.5 of Annex 3 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 revert to forest if abandoned: the natural short grass 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, industrial, and recreational; 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 7–3 illustrates the land-use areas (diagonal cells) and cumulative land-use change areas (non-diagonal cells) in 2005. 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.

Table 7-3: Managed Land Areas (kha) in the 2005 LULUCF accounting system¹

		Final Land Use					
		Forest	Cropland	Grassland	Wetlands	Settlements	Other
Initial Land Use	Forest	235,674	753	NO	40	428	NO
	Cropland	185	49,753	NO	NE	NE	NO
	Grassland	NO	190	NE	NE	1	NE
	Wetlands	NO	NE	NE	23	NE	NE
	Settlements	NO	NE	NO	NO	NE	NO
	Other	NO	NO	NO	18	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).

NE = Not estimated

NO = Not occurring

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 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 semiarid 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 A3.5 in Annex 3.

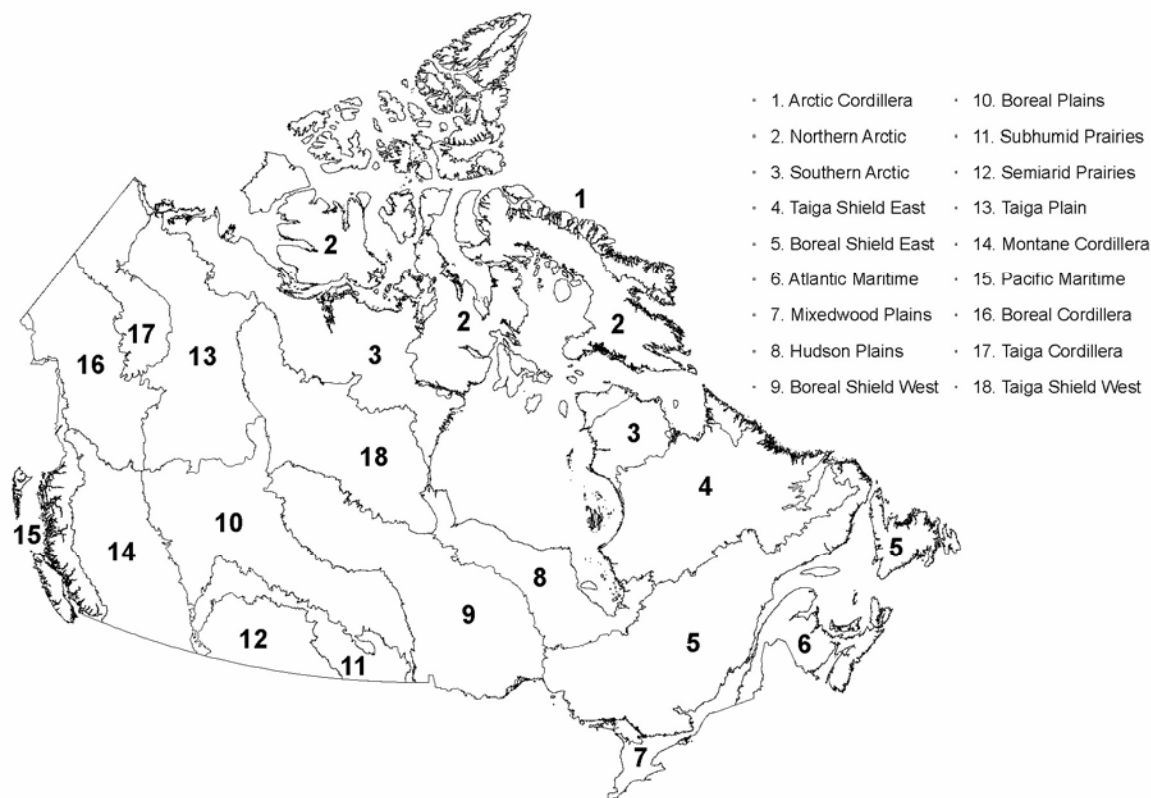


Figure 7-1: Reporting Zones

It is important to note that 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, etc.) 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.

7.4 Forest Land

Forest and other wooded lands cover 402 Mha of the Canadian territory; forest lands alone occupy 310 Mha (NRCan, 2001). Managed forests, those under the direct human

influence, extend over 236 Mha, or 75% of all forests. Four reporting zones account for 67% of managed forests (see Table 7-4).

In 2005, the net GHG balance of managed forest land amounted to removals of 27 Mt (Table 7-1 above and CRF Table 5). For the purpose of UNFCCC reporting, managed forest lands are divided into forest lands remaining forest lands (235 674 kha, net removals of 26 Mt) and land converted to forests (185 kha, net removals of 1.0 Mt). Both categories include net emissions and removals of CO₂, as well as N₂O, CO, and CH₄ emissions from wildfires.

GHG fluxes from and to managed forests are not spatially homogeneous. Table 7-4 illustrates how the 2005 net balance is divided among reporting zones. 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.

Table 7-4: GHG Balance of Managed Forests by Reporting Zone, 2005

Reporting Zone Number	Reporting Zone Name	Managed Forest Area (kha)	Net GHG Balance (Mt CO ₂ eq)
1	Arctic Cordillera	-	NA
2	Northern Arctic	-	NA
3	Southern Arctic	-	NA
4	Taiga Shield East	1 103	1.1
5	Boreal Shield East	55 556	37
6	Atlantic Maritime	15 932	15
7	Mixedwood Plains	2 724	-7.7
8	Hudson Plains	302	-1.0
9	Boreal Shield West	28 752	-14
10	Boreal Plains	36 185	-20
11	Subhumid Prairies	1 823	-2.0
12	Semiarid Prairies	-	NA
13	Taiga Plains	20 043	-30
14	Montane Cordillera	37 889	-6.8
15	Pacific Maritime	14 788	40
16	Boreal Cordillera	18 521	-37
17	Taiga Cordillera	412	-0.2
18	Taiga Shield West	1 830	-3.0

Note:

NA = Not applicable

7.4.1 Forest Land Remaining Forest Land

7.4.1.1 Methodological Issues

Vegetation absorbs CO₂ from the atmosphere through photosynthesis, and some of this carbon is sequestered in standing vegetation, dead biomass, and soils. CO₂ is returned to the atmosphere by vegetation respiration and the decay of organic matter in dead biomass

and soils. The natural CO₂ exchanges between the atmosphere and biota are large fluxes, recycling on the order of one-seventh of the total atmospheric CO₂ 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.

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, 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 the IPCC (2003), in which net removals or emissions are calculated as the difference between CO₂ 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 A3.5 of Annex 3.

Carbon stock changes in managed forests are reported in CRF Table 5A, by reporting zone. 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 –3 024 and 2 124 Mt CO₂ in 2005). Over the 1990-2005 period, sudden drops in carbon removals occur in years of severe wildfires (1995, 1998, 2002 and 2004); the upward trend in dead organic matter decay reflects the long-term, growing effect of past disturbances leaving substantial quantities of dead organic matter, especially insect epidemics (Figure 7-2). Over the last three years, insect epidemics have affected over 5 Mha of managed forests. Much of the inter-annual variability of the GHG budget of managed forests hinges on the occurrence and severity of fires. During 1990–2005, annual wildfire emissions fluctuated between 11 and 291 Mt. During fires, emissions from dead organic matter consumption account for 83% of immediate emissions; much biomass is killed by forest fires, but it 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 CO₂ equivalents are in the form of CO, 7% as CH₄, and 4% in the form of N₂O.

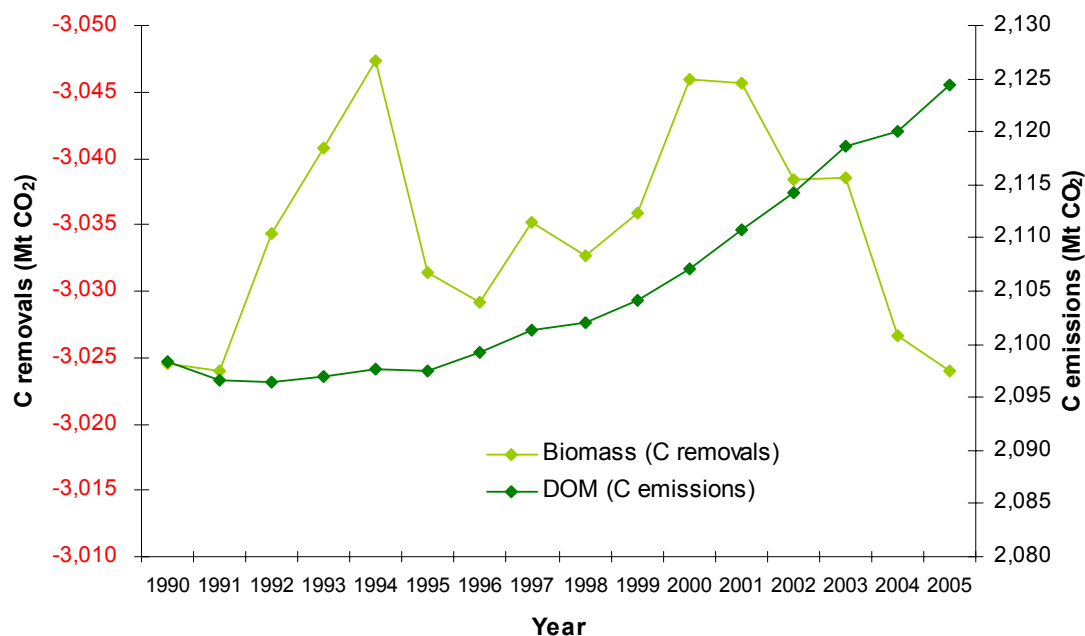


Figure 7-2: Large Annual Carbon Fluxes to and from the Atmosphere in Managed Forests, 1990-2005.

In order to avoid double-counting, estimates in CRF Table 5A exclude carbon emissions as CO₂, CH₄, 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 (2003) default methodology, emissions from forest management activities comprise all the CO₂-C 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, the transfer of carbon from forests to harvested wood products from forest management activities (harvesting) accounts for annual average emissions of 151 Mt. Section A3.5.7 of Annex 3 provides additional information on estimation of delayed CO₂ emissions from harvested wood products. 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 harvested wood products (HWPs). These approaches account for carbon storage in HWPs and emissions from the decay of 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 Section A3.5 of Annex 3.

7.4.1.2 *Uncertainties and Time-Series Consistency*

Considering the on-going and important efforts required for the continued implementation of a Tier 3 approach in the managed forests, it was not possible, due to resource limitations, to develop formal uncertainty estimates on time for this submission. A discussion of the main uncertainty sources is provided for each land category in Annex 7. The preparation of uncertainty estimates for future inventory submissions has been given a high priority.

All estimates have been developed in a consistent manner. Estimates for wildfire areas in 2004-2005 were derived from real-time, remotely sensed imagery. Estimates for 1990-2003 were derived from the CFS large fires database. In addition, the available forest inventory data do not span the same periods across the country; Annex 3.5 explains how forest inventory data from various sources were harmonized to provide complete, coherent and consistent forest data for 1990.

7.4.1.3 *QA/QC and Verification*

Tier 2 QC checks, implemented and documented by the Canadian Forest Service (White and Dymond, 2007), 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.

7.4.1.4 *Recalculations*

Recalculations of the 2007 submission have the largest effects on inventory years 1994 (-98 Mt), 2002 (+47 Mt), 1990 (-42 Mt), 1995 (-41 Mt), 2003 (+32 Mt), 2001 (+25 Mt) and 2000 (+23 Mt) (refer to Figure 7-3). They 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 and of fire disturbance matrices (Shaw et al. unpub., Smyth et al. submitted; DeGroot et al., submitted); modification of the base carbon transfer rate between the aboveground and belowground slow DOM pools (ibid); improved spatial attribution of fire events; and improvements in the parameters of stand volume: biomass equations. These changes, while explicitly documented in internal reports, cannot be always be isolated and their individual effect tracked separately in the complex carbon modelling framework.

The most obvious change is a reduction of 19 Mha in the area of managed forests. In this submission, the area of managed forests in 1990 was 236,583,549 ha (against

255,477,469 ha in the 2006 submission) - and 235,859,707 ha in 2005. Table 7-5 shows how these areas compare for the year 2004 in recent submissions.

The areas of forest mistakenly considered managed in the previous submission are located in:

RZ 13 (Taiga Plain): 9 Mha;
 RZ 18 (Taiga Shield West): 5 Mha;
 RZ 4 (Taiga Shield East): 3.6 Mha;
 RZ 5 (Boreal Shield East): 775 Kha;
 RZ 17 (Taiga Cordillera): 492 Kha;
 RZ 16 (Boreal Cordillera): 235 Kha;
 RZ 15 (Pacific Maritime): 102 Kha.

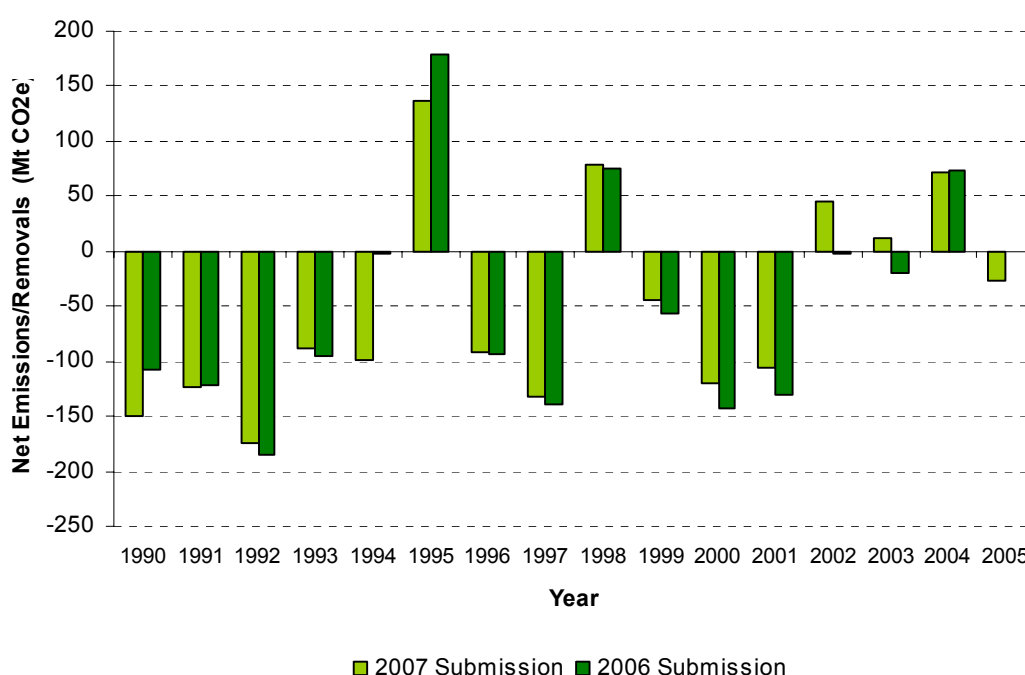


Figure 7-3: Trends in the Forest Land Category Reported in the 2006 and 2007 Submissions

The average net biomass increment per hectare has not significantly changed, except in the Taiga Shield East and West, and the Taiga Cordillera where the areas of managed forests were subject to relatively large corrections that excluded either productive or unproductive forests (Table 7-6). A smaller area of managed forests did result in reduced C removals throughout the time period, but more importantly this led to considerable changes in the area of managed forests burned by wildfires on certain years, notably in 1994, 1995, 1998, and 2004 (Table 7-7). Consequently immediate emissions from wildfires decreased substantially in the 2007 submission, especially in inventory years 1994 (-100 Mt CO₂ e), 1995 (-51 Mt CO₂ e) and 2004 (-22 Mt CO₂ e).

Significantly smaller areas (by 145 to 855 kha) were also affected by insect epidemics, although the immediate impact is negligible.

Table 7-5: Managed Forest Area in Recent Submissions

Managed Forest Area (kha)			
Reporting Zones	2005 Submission (2004)	2006 Submission (2004)	2007 Submission (2004)
Arctic Cordillera	0	0	0
Northern Arctic	1	0	0
Southern Arctic	32	0	0
Taiga Plains	9 940	29 055	20 043
Taiga Shield (E+W)	3 026	11 638	2 932
Boreal Shield (E+W)	96 372	85 152	84 325
Atlantic Maritime	15 792	15 943	15 933
Mixedwood Plains	3 468	2 726	2 725
Boreal Plains	30 343	36 320	36 207
Prairies	2 039	1 832	1 826
Taiga Cordillera	266	904	412
Boreal Cordillera	11 574	18 758	18 521
Pacific Maritime	9 839	14 897	14 789
Montane Cordillera	29 600	37 906	37 892
Hudson Plains	1 221	0	302
Total	213 512	255 130	235 910

Table 7-6: Average Net Forest Primary Productivity, (tC ha⁻¹) in the 2006 and 2007 Submissions

Reporting Zone	Total Biomass Increment(t C/ha per year)	
	2006 Submission	2007 Submission
Boreal Shield East	0.48	0.47
Taiga Shield East	0.13	0.24
Atlantic Maritime	0.81	0.74
Mixedwood Plains	0.83	0.86
Boreal Shield West	0.44	0.47
Boreal Plains	0.65	0.60
Subhumid Prairies	0.38	0.32
Taiga Plains	0.52	0.55
Taiga Shield West	0.50	0.61
Montane Cordillera	0.62	0.61
Boreal Cordillera	0.54	0.52
Pacific Maritime	0.56	0.61
Taiga Cordillera	0.90	0.67

Table 7-7: Forest Area (ha) Burned in Managed Forests, Recent Submissions

Year	2005 Submission	2006 Submission	2007 Submission
1990	334 769	350 884	268 155
1991	827 781	656 818	551 005
1992	275 667	123 004	94 905
1993	761 879	979 005	776 822
1994	446 754	1 808 272	514 972
1995	3 075 418	3 209 054	2 180 297
1996	827 439	684 714	530 222
1997	328 159	201 663	147 826
1998	1 476 411	1 920 796	1 509 074
1999	645 817	790 876	637 806
2000	96 464	192 980	90 348
2001	257 687	231 388	191 268
2002	1 533 260	1 010 576	1 173 320
2003	898 364	775 625	754 651
2004		1 216 688	849 666
2005			598 033

The recalibration of decay rates in fresh and humified litter to lower values, and the reduced transfer rates of decayed carbon belowground as dissolved carbon, both contributed to greater accumulation of aboveground DOM fuel. This explains a 21% increase on average carbon emission rates (t/ha) during fires – partially offset on years where areas burned were revised downwards. On average, immediate emissions of CO₂ from wildfires have decreased by 11% compared to the 2006 submission.

Finally, a reduction in soil emissions accounts for lower residual emissions overall, although it is offset by smaller net removals in the biomass pool.

7.4.1.5 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 on-going to improve the spatial representation of fire emissions, and incorporate an improved framework and new data sources for the calibration of soil C decay rates. Improvements are prioritized based on impact, and the level of effort required.

7.4.2 Land Converted to Forest Land

7.4.2.1 Category Description

This category includes all lands converted to forest land through direct human activity. Post-harvesting 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 185 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 are consequently declining throughout the period, from 1.2 Mt in 1990 to 1.1 Mt in 2005. Because the activity data are restricted to plantations younger than 20 years, and considering the relatively slow net increment of plantations in the early years, the subcategory as a whole is not expected to contribute significantly to the net balance of forest lands.

7.4.2.2 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 2003–2005 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 A3.5 in Annex 3 for details).

GHG emissions and removals on lands newly converted to forests were estimated using CBM-CFS3, as described in Section A3.5 of Annex 3. 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.

7.4.2.3 Uncertainties and Time-Series Consistency

It was not possible, due to resource limitations, to develop formal uncertainty estimates on time for this submission. The preparation of uncertainty estimates for future inventory submissions has been given a high priority.

All recalculations were applied to the entire time series of estimates, ensuring that the same approach and methods were consistently applied.

7.4.2.4 QA/QC and Verification

Tier 2 QC checks, implemented and documented by the Canadian Forest Service (White and Dymond, 2007), 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 its geodatabase and entered into the CRF reporter.

7.4.2.5 Recalculations

No recalculations were conducted for the 2007 submission in this category.

7.5 Cropland

Croplands cover approximately 50 Mha of the Canadian territory. In 2005, the net GHG balance of the Cropland category amounted to emissions of 0.5 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 9.9 Mt in 2005) and land converted to cropland, from forest conversion (net emissions of about 10.1 Mt in 2005) and grassland conversion (net emissions of about 0.4 Mt in 2005). The latter subcategory includes net emissions and removals of CO₂, as well as N₂O, CO, and CH₄ emissions.

7.5.1 Cropland Remaining Cropland

This section briefly reviews the methodological issues related to the estimation procedures for CO₂ emissions from and removals by cropland remaining cropland. An enhanced Tier 2 approach is used for estimating CO₂ emissions from and removals by mineral soils. The calculations and data sources are described in more detail in Section A3.5 of Annex 3.

Cropland remaining cropland includes CO₂ emissions/removals in mineral soils, CO₂ emissions from agricultural lime application and cultivation of organic soils, and CO₂ emissions/removals resulting from changes in woody biomass from specialty crops. Table 7-8 summarizes the trend in emissions and removals for these categories.

Table 7-8: Emissions and Removals Associated with Various Land Management Changes on Croplands Since 1990

Land Management Practices		Land Management Change		Emissions/Removals		
		1990	2004	2005		
		(Gg CO ₂)				
Change in Crop Mixture	Increase in Perennial	-2,100	-4,800	-5,100		
	Increase in Annual	3,200	4,000	4,100		
Change in Tillage	Conventional to RT	-900	-1,000	-980		
	Conventional to NT	-560	-3,600	-3,800		
	Other Tillage Change	NO	-360	-390		
Change in Summerfallow	Increase in Summerfallow	1,600	1,300	1,300		
	Decrease in Summerfallow	-4,700	-7,700	-7,800		
Land conversion - Residual Emissions ¹		290	2,100	2,200		
Total Mineral Soils		-3200	-10,100	-10,500		
Cultivation of Histosols		300	300	300		
Liming		200	290	290		
Perennial Woody Crops		36	32	25		
Total Cropland Remaining Cropland		-2,600	-9,400	-9,900		

Notes:

1 These net residual CO₂ emissions come from conversion of forest land and grassland to cropland that occurred more than 20 years prior to the inventory year.

NO - Not occurring

RT - Reduced tillage

NT - No-till

7.5.1.1 CO₂ Emissions and Removals in Mineral Soils

Cultivated agricultural land in Canada includes area of field crops, summerfallow, hayland, and tame or seeded pasture. Cropland is only found in the nine southernmost reporting zones. About 83% of Canada's cropland is in the interior plains of western Canada, made up of the Semiarid and Subhumid Prairies and Boreal Plains reporting zones.

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 organic carbon stored in soils. This change in SOC results in a CO₂ emission to or removal from the atmosphere, as described in the methodological section below.

As can be found in Table 7-8, management of mineral soils amounted to a net CO₂ removal of about 3.2 Mt in 1990. This net sink has steadily increased since then to about 10.5 Mt CO₂ in 2005 because of 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 -6.6 Mt in 2005) is supported by a 55% decrease in total summerfallow area over 1990–2005. The increase in net sink due to the adoption of conservation practices (from -1.5 Mt in 1990 to -5.2 Mt in 2005) is substantiated by a

net total increase of over 10 Mha in areas under no till and reduced till over the 1990–2005 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 CO₂ emissions from annual dead organic matter and soil decomposition 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, these emissions are split among the dead organic matter and soil pools (as opposed to only the soil pool).

Methodological Issues

Following the IPCC Good Practice Guidance for LULUCF (IPCC, 2003), it was assumed that the changes in SOC were driven by changes in soil management. Where no change in management was detected, it is assumed that mineral soils are neither sequestering nor losing carbon.

A number of management practices are known to increase 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 to be used for estimating 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 CO₂ 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 LMCs, such as changes in irrigation, manure application, and fertilization, are also known to have positive impacts on SOC, although the effect is often small. The lack of activity data for these LMCs was 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 (refer to Annex 3, Section A3.5.1). The carbon emission/removal factors represent the rate of SOC change per year and per unit area that underwent an LMC. The annual CO₂ emissions/removals by mineral soils undergoing a specific LMC is expressed as:

Equation 7-1:

$$\Delta C = F \times A$$

where:

ΔC	=	change in soil carbon stock (Mg C)
F	=	average annual change in SOC subject to LMC (Mg C/ha per year)
A	=	area of change in 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 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 in land management practice can be estimated for each SLC polygon. Estimates based on these LMCs are as close to gross area of LMC as is feasible for regional or national analyses. The area of LMC was determined individually for 3264 SLC polygons having agricultural activities, each one having an area in the order of 1000 to 100 000 ha. This is the finest possible resolution of activity data, given the limitations imposed by confidentiality requirements of Census data.

The methods require 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 A3.5 of Annex 3.

Uncertainties and Time-Series Consistency

Uncertainty was estimated using analytical uncertainty analysis (Coleman and Steele, 1999). The uncertainties associated with estimates of CO₂ 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 average ecodistrict was based on the relative proportion of the area of that management practice compared to 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 C 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 Annex 3.5. The overall level and trend uncertainty estimates associated with various land management changes are presented in Table 7.9.

Table 7-9: Level and Trend Uncertainty Estimates for Various Land Management Changes in Mineral Soils of Cropland Remaining Cropland¹

Land Management Practices	Land Management Change	Level (2005)		Trend (1990-2005)	
		Lower Limit	Upper Limit	Lower Limit	Upper Limit
		<i>kt CO₂ eq</i>			
Change in Crop Mixture	Increase in Perennial	-6500	-3900	-4600	-1400
	Increase in Annual	2800	5400	-810	2600
Change in Tillage	Conventional to RT	-1200	-760	-390	290
	Conventional to NT	-4800	-2900	-4200	-2300
	Other Tillage Change	-590	-200	-630	-170
Change in Summerfallow	Increase in Summerfallow	1000	1500	-860	540
	Decrease in Summerfallow	-9300	-6500	-4700	-1500
Residual Emissions ²		500	590	350	470
Total Mineral Soils		-15000	-9900	-12000	-5700

Notes:

1 Negative sign indicates removal of CO₂ from the atmosphere

2 These net residual CO₂ 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 CO₂ estimates is ensured through the use of the same methodology for the entire time series of estimates (1990 – 2005).

QA/QC and Verification

Tier 1 QC checks, implemented by Agriculture and Agri-Food Canada, specifically address estimate development in the Cropland remaining cropland 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 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 to empirical coefficients in VandenBygaart et al. (2007). This assessment showed that empirical data comparing C change between CT and NT were highly variable, particularly for Eastern Canada. Nonetheless, the modeled 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 $0.59 \text{ Mg C ha}^{-1} \text{ yr}^{-1}$ and this compared favourably to the range of $0.46\text{--}0.56 \text{ Mg C ha}^{-1} \text{ yr}^{-1}$ in the modeled factors in Western Canada soil zones. In Eastern Canada only two empirical change factors were available but they appeared to be in line with the modeled values ($0.60\text{--}1.07 \text{ Mg C ha}^{-1} \text{ yr}^{-1}$ empirical versus $0.74\text{--}0.77 \text{ Mg C ha}^{-1} \text{ yr}^{-1}$ modeled). For conversion of crop-fallow to continuous cropping, the modeled rate of C storage obtained ($0.33 \text{ Mg ha}^{-1} \text{ yr}^{-1}$) was more than twice the average rate of $0.15 \pm 0.06 \text{ Mg ha}^{-1} \text{ yr}^{-1}$ 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 Annex 3.5.

Recalculations

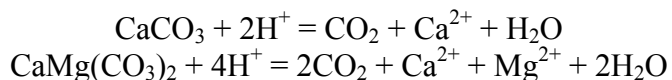
There were no changes in methodologies or factors associated with emissions or removals estimates related to LMC changes. Changes were made to correct program codes and to update activity data from 1990 to 2004. Issues were discovered on how the system was using time parameters in the calculation of soil carbon residual losses related to the timing of deforestation activities. Different sections of the code were affected which, depending on the inventory period, may have resulted in over or underestimation of soil carbon residual losses in the previous submission. Additional coverage and revisions of deforestation activity data (refer to section 7.9.4) generated higher annual deforestation rates by 4 to 5 kha for the entire 1970-2004 period. In spite of higher historical deforestation rates, soil residual emissions in Cropland remaining Cropland are lower than in the 2006 submission by 0.3 Mt in 2004. These updates also caused area changes in perennial and annual crops. The overall impact of these changes resulted in an increased sink of approximately 0.3 Mt in 1990 and 0.4 Mt in 2004.

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 underway. Improvements to the CENTURY model and the use of alternative models are also being explored, to improve the simulation of Canadian agricultural conditions.

7.5.1.2 *CO₂ Emissions from Lime Application*

Limestone (CaCO_3) or dolomite ($\text{CaMg}(\text{CO}_3)_2$) is often used to neutralize acidic mineral and organic 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_2 is released in the following bicarbonate equilibrium reactions that take place in the soil:



The rate of release will vary with soil conditions and the types of 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 CO₂ and other minerals. Methods and data sources are outlined in Section A3.5 of Annex 3.

Uncertainties and Time-Series Consistency

The 95% confidence limits associated with annual lime consumption data was estimated to be ±50% (B. McConkey, personal communication). 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 and the maximum value of emission factor was used. The overall mean and uncertainties were estimated to be 0.3±0.14 Mt for the level and 0.09±0.15 Mt for the trend. The same methodology is used for the entire time series of emission estimates (1990–2005).

QA/QC and Verification

This category has undergone the Tier 1 QC checks (refer to 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.

Recalculations

No recalculation has been carried out for this source category.

Planned Improvements

There is no immediate plan in place aimed at improving emission estimates for this source.

7.5.1.3 CO₂ 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 updated default emission factor of 5 t C/ha per year as found in the 2006 IPCC Guidelines (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 1990–2005) 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 of the emission factor. The 95% confidence limits associated with the area estimate of cultivated histosols is assessed to be $\pm 50\%$ (Hutchinson *et al.*, 2007). The 95% confidence limits of the emission factor as provided in the 2006 IPCC Guidelines is $\pm 90\%$ (IPCC, 2006). The overall mean and uncertainties associated with this source of emissions were estimated to be 0.3 ± 0.09 Mt for the level and 0 ± 0.14 Mt for the trend (McConkey *et al.*, 2007).

The same methodology and emission factors are used for the entire time series of emission estimates (1990–2005).

QA/QC and Verification

This category has undergone the Tier 1 QC checks (refer to 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.

Recalculations

No recalculation has been carried out for this category.

Planned Improvements

There is no immediate plan in place aimed at improving emission estimates for this source.

7.5.1.4 *CO₂ 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 re-cultivation. Owing to these data limitations, only vineyards, fruit orchards, and Christmas trees are considered in the present submission, and they contribute a minuscule source of about 25 Gg CO₂; 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 A3.5 of Annex 3.

Uncertainties and Time-Series Consistency

For loss of area, all C in woody biomass is assumed to be immediately released. It is assumed that the uncertainty for C loss is the uncertainty of mass of woody biomass C. There is no Canadian specific data on this uncertainty. Therefore, the default uncertainty of $\pm 75\%$ (i.e. 95% confidence limits) for woody biomass on cropland from 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 to that carbon change that contributes to C change uncertainty. For area of gain in area of fruit trees, vineyards, or Christmas trees, the uncertainty of annual C

change was also assumed to be the default uncertainty of $\pm 75\%$ (i.e. 95% confidence limits) for woody biomass on cropland from IPCC Good Practice Guidance (IPCC 2003).

The overall mean and uncertainties associated with emissions or removals of C from woody speciality crops were estimated to be 0.025 ± 0.049 Mt for the level, and -0.015 ± 0.075 Mt for the trend (McConkey et al., 2007).

The same methodology was used for the entire time series of emission estimates (1990–2005).

QA/QC and Verification

This category has undergone the Tier 1 QC checks (refer to 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.

Recalculations

No recalculation has been carried out for this category.

Planned Improvements

There is no immediate plan in place aimed at improving emission estimates for this category.

7.5.2 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 N₂O emissions following land conversion to cropland. Estimation approaches for other pools (biomass and dead organic matter upon forest conversion to cropland), including those due to controlled burning, are described in Section 7.9, Forest Conversion.

7.5.2.1 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 1970 was 1343 kha in 1990 and 753 kha in 2005. Apart from biomass and DOM losses, this category includes the net carbon stock change from soils due to the actual land conversion and a very small net CO₂ sink from change in management practices (tillage, etc.) since the cropland was converted (using the same methods as for cropland remaining cropland), as well as the N₂O 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

Eastern Canada

Generally, all land in the eastern part of the country including Ontario, was forested before its land use was changed to agriculture. There are many observations that compare SOC for land under forest with adjacent land under agricultural purposes in eastern Canada. The mean loss of carbon was 20% for depths to approximately 20–40 cm (refer to Section A3.5). Average nitrogen change was –5.2%, representing 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 SOC 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 A3.5.

Following a Tier 2–type methodology, as was done for direct N₂O emissions from agricultural soils (refer to Agriculture Sector, Chapter 6), emissions of N₂O 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_{BASE}). EF_{BASE} was determined for each ecodistrict using the precipitation over evapotranspiration variable P/PE (Section A3.5).

Western Canada

Much of the current agricultural soil 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 numerous 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 important land uses.

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 belowground tree biomass and from loss or decay of other above- and belowground coarse woody dead organic matter that existed in the forest at the time of deforestation (refer to Section A3.5). The average nitrogen change in western Canada for sites at least 50 years from breaking was +52%, reflecting substantial added nitrogen in agricultural systems compared with the situation in forests (Section A3.5). 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 N₂O.

Uncertainties and Time-Series Consistency

The uncertainty was only assessed for changes in SOC after forestland 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 input. For eastern and western Canada, the uncertainty of the factor for SOC change was estimated differently. More detail on estimation methods is presented in Annex 3.5. The overall mean and uncertainty associated with emissions due to SOC losses on forest land converted to cropland (excluding N₂O) were estimated to be 1.1 ±0.20 Mt in 2005. The uncertainty associated with the trend since 1990 has not been determined.

The same methodology and emission factors are used for the entire time series of emission estimates (1990–2005).

QA/QC and Verification

This category has undergone the Tier 1 QC checks (refer to Annex 6 for further details) in a manner consistent with IPCC Good Practice Guidance (IPCC, 2000). Quality checks were also performed internally by Agriculture and Agri-Food Canada, 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

Additional coverage and revisions of deforestation activity data (refer to section 7.9.4) generated higher annual deforestation rates by 4 to 5 kha for the entire 1970-2004 period, and resulted in increases of 58 kha (in 1990) up to 87 kha (in 2004) in total areas of forest land converted to cropland compared to the 2006 submission. Residual emissions in this submission are lower or remained virtually the same however because of corrections in program codes.

Planned Improvements

Ongoing work is planned to improve and validate the soil carbon change factors from forestland converted to cropland.

7.5.2.2 *Grassland Converted to Cropland*

Conversion of native grassland to cropland occurs in the Prairie region of the country and generally results in losses of SOC and soil organic nitrogen and emissions of CO₂ and N₂O to the atmosphere. It was assumed that there was no loss of aboveground, belowground, or dead organic matter upon conversion. Total emissions in 2005 from soils amounted to 0.5 Mt. This includes the carbon losses and N₂O 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, and these results are summarized in Section A3.5 of Annex 3. 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.

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 A3.5.

Similar to N₂O emissions in forest converted to cropland, emissions of N₂O 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 an emission factor (EF_{BASE}). EF_{BASE} was determined for each ecodistrict using precipitation over potential evapotranspiration (P/PE) data (refer to Section A3.5).

Uncertainty and Time-Series Consistency

The conversion from agricultural grassland to cropland is allowed but the conversion in other direction is not allowed. Therefore, the uncertainty of the area of this conversion cannot be larger than the uncertainty of the area of cropland or the area of grassland. Therefore, the uncertainty of the area of conversion was set to the lower of the uncertainty of the area of cropland and grassland. The uncertainty of SOC change was estimated similarly with FL-CL. The overall mean and uncertainty associated with emissions due to SOC losses on grassland conversion to cropland (excluding N₂O) was estimated to be 0.48±0.19 Mt in 2005. The uncertainty associated with the trend since 1990 has not been determined at this time.

The same methodology and emission factors are used for the entire time series of emission estimates (1990–2005).

QA/QC and Verification

This category has undergone the Tier 1 QC checks (refer to 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.

Recalculations

No recalculations have been carried out for this category.

Planned Improvements

Ongoing work is planned to improve and validate the soil carbon change factors from grassland conversion.

7.6 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 revert 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: Semiarid Prairies (5,600 kha in 2001) and the Montane Cordillera (160 kha in 2001). IPCC Good Practice Guidance for LULUCF (IPCC, 2003) methodology indicates that it is the change in management that triggers a change in carbon stocks. Very little information is available on management practices on agricultural grassland as defined in the land-use framework. Where there is grazing, it is unknown whether the 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 A3.5 of Annex 3. The category land converted to grassland, within the current definitional framework as explained in Section 7.3, is reported either as not estimated (wetlands converted to grassland), or as not occurring (Table 7-3).

7.7 Wetlands

In Canada, a wetland is land that is saturated with water long enough to promote wetland or aquatic 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.

The IPCC Good Practice Guidance for LULUCF report (IPCC, 2003) emphasizes the reporting of emissions from the conversion of forest to managed wetlands. As the conversion of forest to wetlands is occurring in Canada, the submission of estimates under the Wetlands category enhances compliance with reporting requirements and improves the estimate of forest conversion.

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.

7.7.1 Managed Peatlands

7.7.1.1 Source Category Description

Of the estimated 123 Mha of peatlands in Canada,³⁹ approximately 18 kha are, or were at some point in the past, drained for peat extraction. Some 14 kha are currently actively being managed, the difference (4 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 former cut-block method, is poor natural vegetation regrowth on the post-production phase. In the 1990s, peatland restoration activities took on greater significance.

³⁹ This area includes peatlands that would be classified as forest, cropland, and grassland in the IPCC land classification.

Peat extraction activities expanded during the 1990-2005 period, with a near doubling of the land area under active peat extraction, from 10 kha in 1990 to 18.5 kha in 2005. Owing to this expansion and to the significant contribution of vegetation clearing and decay to the overall GHG budget, emissions from managed peatlands show a significant increase over the assessment period (----- Figure 7-4).

Emissions from managed peatlands are reported under land converted to wetlands for the first 20 years after conversion and under wetlands remaining wetlands thereafter.

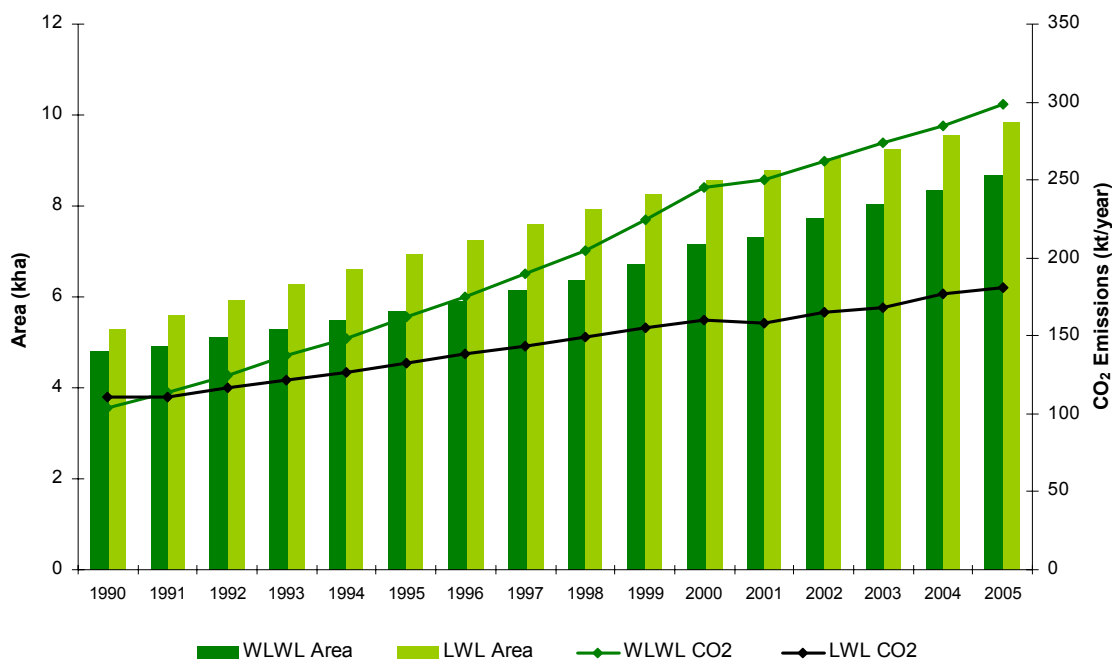


Figure 7-4: Areas and CO₂ Emissions from Managed Peatlands in 1990–2005 (LWL: Lands converted to wetlands; WLWL: wetlands remaining wetlands)

7.7.1.2 Methodological Issues

CO₂ is the dominant GHG emitted from commercial peatlands and the only gas reported under this category. The general phases of peat extraction are i) drainage, ii) vegetation clearing, iii) extraction, iv) stockpiling, v) abandonment, and vi) 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 CO₂ 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 A3.5 of Annex 3.

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.

7.7.1.3 Uncertainty and Time-Series Consistency

There was no formal uncertainty assessment for C 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 aboveground 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.

7.7.1.4 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.

7.7.1.5 Recalculations

The recalculations of area cleared annually have been conducted based on expert input from the industry. The cumulative land areas converted in 2004 was reduced from 13 kha (2006 submission) to 10 kha (this submission), while the 2004 areas of peatlands remaining peatlands have increased from 5 kha to 8 kha. This is due to updates in the deforested areas and combined with the use of data from industry. The 2004 emission estimates from all peatlands were revised from 313 kt to 535 kt. A small area of land previously reported as Other Land converted to Wetlands/peatlands is now reported as Forest Land converted to Wetlands/peatlands. Based on expert knowledge (G. Hood, Canadian Sphagnum Peat Moss Association) the pre-clearing vegetation qualifies as forest. This did not change the pre-clearing C stocks or estimate values, but the reporting category.

7.7.2 Flooded Lands (Reservoirs)

Since this is a relatively new reporting category, work is still ongoing, and refinements will be made in consultation with scientists in industry, academia, and government to ensure that the best and most relevant data available are utilized. Although 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 894 kha in 1990 to 62.5 kha in 2005. In 2005, 50% of the 36 kha of reservoirs flooded for 10 years or less were previously forested (mostly unmanaged).

Total emissions from land converted to reservoirs declined from less than 5 Mt in 1990 to less than 1 Mt in 2005.

7.7.2.1 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 were estimated as in all forest conversion events, with the CBM-CFS3 (refer to Section 7.9 below and Section A3.5). Emissions from burning and decay of all non-flooded dead organic matter are reported under land converted to wetlands for the first 20 years post clearing, and in wetlands remaining wetlands beyond this time period. The recent construction of several new, large reservoirs in northern Québec (Toulousteuc, Péribonka, Eastmain-1) whose impoundment was yet to be completed in 2005 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 CO₂ 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 of time. A domestic approach was developed and used to estimate emissions from reservoirs based on measured CO₂ fluxes above reservoir surfaces, consistent with the descriptions of IPCC Tier 2 methodology (IPCC (2003), (2006)) and following the guidance in the Appendix 3a.3 of IPCC (2003). Section A3.5 in Annex 3 contains more detail on this estimation methodology. In keeping with good practice, only CO₂ emissions are included in the assessment. As recommended in the

IPCC Good Practice Guidance for LULUCF (2003) and in the 2006 IPCC Guidelines (IPCC, 2006), emissions from the surface of flooded lands are reported for a period of 10 years after flooding, as an attempt to minimize the potential double-counting of carbon lost from managed lands in the watershed in the form of dissolved organic carbon and subsequently emitted from reservoirs. Therefore, only CO₂ emissions are calculated for hydroelectric reservoirs where flooding had been completed from 1980 to 2005.

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 inventory year) and older reservoirs (more than 10 years), whose areas are thus transferred out of the inventory. The reporting system does not encompass all the reservoir areas in Canada.

7.7.2.2 Uncertainties and Time-Series Consistency

For forest land converted to wetlands, refer to the corresponding subheading in Section 7.9, Forest Conversion. Section A3.5 in Annex 3 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 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; regardless, any effect will be very small.

7.7.2.3 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 7.9, Forest Conversion.

Canada’s approach to estimating emissions from forest flooding is more realistic temporally than the default IPCC 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 from 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) which clearly is not verified.

7.7.2.4 Recalculations

Recalculations have occurred in this category due to methodological refinements, corrections to activity data, and new events.

Emissions from the long-term decay of non-flooded dead organic matter are newly reported in the 2007 submission, under land converted to wetlands and beyond 20 years under wetlands remaining wetlands.

In the 2006 submission, the area of the Laforge 1 reservoir (flooding completed in 1995) was underestimated by 600 km². This partially explains a large increase in other land converted to WL/flooded land in 1995 (it did not affect the area of forest land converted to wetland, which was obtained from records). Flooding in Laforge 2 was mistakenly attributed to 1997 in the 2006 submission, while in reality the flooding was complete in 1985, but power generation began more than a decade later. This partly offsets the previous error, and explains a large decrease in the area of other land converted to wetlands in 1997 - but a corresponding increase in the 1990-1994 area of flooded land.

New events include the Peribonka reservoir (flooding expected in 2007), Toulouste (flooding completed in 2006), Eastmain-1 (flooded mainly in 2006); since flooding of these reservoirs was not complete in 2005, in the 2007 submission these are associated with emissions from forest clearing only.

7.7.2.5 Planned Improvements

A research project in Québec investigating C fluxes between terrestrial and aquatic systems will contribute to the body of science which in the medium to long term may work towards reducing uncertainties.

7.8 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 conversion to settlements in the Canadian north. In 2005, 429 kha of lands converted to settlements accounted for emissions of 8 Mt. Forest conversion to settlements represents over 98% of these emissions. The conversion of cropland to settlements is known to occur in Canada; an estimation methodology is under development.

7.8.1 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.

7.8.2 Lands Converted to Settlements

7.8.2.1 *Source Category Description*

This section covers non-forest conversion to settlements in the Canadian north. Section 7.9, Forest Conversion, summarizes issues and emissions associated with the conversion of forest to settlements.

In 2005, the conversion of non-forest land to settlements in the Canadian North accounted for emissions of 0.2 Mt.

7.8.2.2 *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 pre-conversion vegetation known — a significant challenge, considering that the area of interest extends over 557 Mha, intersecting with six reporting zones (2, 3, 4, 8, 10, 13, 17, and 18). For all reporting zones except 4 and 8, information sources 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 million hectares (56%) of the potential land-use change area identified using the geographic information system (GIS) data sets. 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 areas.

Emissions include only the carbon in pre-conversion aboveground biomass. In spite of the existing relevant literature, the estimation of actual or average biomass density over such a large area is challenging.

7.8.2.3 *Uncertainties and Time-Series Consistency*

For forest land converted to settlements, refer to the corresponding subheading in Section 7.9, 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 pre-conversion standing biomass varies between 35% and 50%. Section A3.5 provides more information.

7.8.2.4 *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 7.9, Forest Conversion.

7.8.2.5 *Recalculations*

Recalculations were conducted due to new activity data in RZ 4 and 8, which increased the 2004 emissions by 1 t CO₂.

7.9 *Forest Conversion*

Forest conversion is not a reporting category, since it overlaps with the subcategories of lands converted to cropland, wetlands, and 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. It is worth noting that a consistent approach was applied for all types of forest conversion, minimizing omissions and overlaps, while maintaining spatial consistency as much as possible.

In 2005, forest conversion to cropland, wetlands, and settlements amounted to total emissions of about 21 Mt, down from 29 Mt in 1990. This decline includes a 4 Mt decrease over the period of immediate emissions due to forest conversion to cropland; a 3 Mt decrease in emissions from the surface of reservoir attributed to forest conversion, as these reservoirs were flooded for over 10 years and were withdrawn from the accounting; and a reduction of 1 Mt in emissions from forest conversion to settlements.

Care should be taken to distinguish annual deforestation rates (from 70 kha in 1990 down to 56 kha in 2005) from the total area of forest land converted to other uses as reported in the CRF tables for each inventory year. The latter 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. Similarly, immediate emissions from forest conversion, which occur in the year of conversion, are only a fraction of the total emissions due to current and previous forest conversion activities reported in any inventory year. In 2005, immediate emissions from forest conversion (10

Mt) were slightly lower than residual emissions (11 Mt). Decay rates for dead organic matter are such that residual emissions continue beyond 20 years, after which they are reported in the C stock changes in cropland remaining cropland and wetlands remaining wetlands.

Conversion to cropland accounts for the largest share of forest losses to other land categories; conversion rates dropped from 47 kha/year in 1990 to 30 kha/year in 2005, when it represented 45% of all forest area lost. Conversion to settlements is the second most important cause of forest losses. While conversion rates remained stable during the period, at a little over 21 kha/year, the share of forest losses contributed by conversion to settlements increased from 26% to 33% of all forest losses over 16 years.

Geographically, the highest rates of forest conversion occur in the Boreal Plains and Boreal Shield East (reporting zones 10 and 5), which respectively account for 40% and 24% of the total area deforested in 2005.

While forest conversion affects both managed and unmanaged forests, the geographical distribution is distinct. Losses of unmanaged forests occur mainly in reporting zone 4 (Taiga Shield East) and are mostly caused by reservoir impoundment, but also occurs in reporting zones 8 and 9 due to individual events.

7.9.1 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 remote sensing mapping of deforestation on samples from 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 correctly 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 resolve large discrepancies between the 1975–1990 and 1990–2000 area estimates. A more detailed description of the approach and data sources is provided in Section A3.5 in Annex 3. Imagery post-2000 has not yet been assembled for use in extending the time series. Section A3.5.2 also describes the interpolation and extrapolation procedures adopted in such cases.

All estimates of emissions due to forest conversion were generated with 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 A3.5 summarizes the estimation procedures.

7.9.2 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 2005 between 35 kha and 78 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). Section A3.5 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.

7.9.3 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 quality control 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 A3.5 of Annex 3.

7.9.4 Recalculations

Several incremental enhancements, changes and corrections were implemented for forest conversion that triggered recalculations of the entire times series. 1990 emissions rose by 2 Mt and 2004 emissions increased by almost 5 Mt. An upward revision in FLCL by more than 4 kha annually is due to a combination of factors. These factors include additional QA of deforestation mapping in Manitoba; recalculation of scaling factors

where the actual area mapped was smaller than initially calculated (5-7% increase in Alberta and Manitoba); correction of misallocation of some circa 1990 events to post-1990 rather than pre-1990 (up to 10-12% increase post 1990 accompanied by a 6% reduction in pre-1990 deforestation); and refinement of deforestation strata units. In addition, corrections in the year the Laforge 2 reservoir was flooded (from 1997 to 1985) resulted in a decrease of area in 1997 (-7 kha).

7.9.5 Planned Improvements

Planned improvements emphasize quality assurance and control, 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 CH₄ emissions from solid waste disposal on land, CH₄ and N₂O emissions from wastewater treatment, and CO₂, CH₄, and N₂O emissions from waste incineration.

Much of the waste treated or disposed of is biomass or biomass based. CO₂ emissions attributable to such wastes are not included in inventory totals but are reported in the inventory as a memo item. CO₂ emissions from biogenic origin are not reported if they are reported elsewhere in the inventory or the corresponding CO₂ 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 CO₂ 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, CO₂ 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. On the other hand, CH₄ 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 2005, the GHG emissions from the Waste Sector contributed 28 Mt to the national inventory as compared with 23 Mt for 1990, representing an increase of 21%. In comparison, the national total emissions had increased by 25% over the same time interval. The emissions from this sector represent 3.7% and 3.9 % of the overall Canadian GHG emissions in 2005 and 1990, 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 27 Mt or 96% of the emissions from this sector in 2005. The chief contributor to the Waste Sector emissions is the CH₄ released from MSW landfills, which amounted to 24 Mt (1.1 Mt CH₄) in 2005. This net emission value is determined by subtracting the amount of CH₄ captured from the total estimated CH₄ generated within the landfill by the Scholl Canyon model, then adding the quantity of the captured CH₄ that was not combusted by the flaring operation, where applicable. Approximately 21% of the CH₄ generated in Canadian MSW landfills in 2005 was captured and combusted.

Overall, the increase in the CH₄ 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 million tonnes 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, 2000, 2003, 2004, 2007).

Table 8-1 summarizes the Waste Sector and subsectors GHG contributions for 1990, 2004 and 2005 inventory years.

Table 8-1: Waste Sector GHG Emissions Summary, Selected Years

GHG Source Category	GHG Emissions		
	1990	2004 (kt CO ₂ eq)	2005
Waste Sector TOTAL	23,000	28,000	28,000
a. Solid Waste Disposal on Land	22,000	26,000	27,000
b. Wastewater Handling	780	930	930
c. Waste Incineration	400	230	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, if not all, 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 constructed. Typically, these landfills do not require CH₄ collection systems as the methane 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 CH₄ emissions; however, there is a great deal of uncertainty in the estimates. Wood waste landfills are a minor source of methane emissions in comparison with MSW landfills.

The 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 population growth. 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 methane 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 CH₄ and CO₂, 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 CH₄ and CO₂ 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 CH₄ 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

CH₄ 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.

CH₄ emissions are determined by calculating the amount of CH₄ generated from landfill waste decomposition through the Scholl Canyon model, subtracting the CH₄ captured through landfill gas recovery systems, then adding the quantity of uncombusted CH₄ 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.

8.2.2.1 CH₄ Generation

The Scholl Canyon model was used to estimate the quantity of CH₄ 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:

$Q_{T,x}$	=	the amount of methane generated in the current year (T) by the waste M_x , kt CH ₄ /year
x	=	the year of waste input
M_x	=	the amount of waste disposed in year x , Mt
k	=	methane generation rate constant, /year
L_0	=	methane generation potential, kg CH ₄ /t waste
T	=	current year

Equation 8-2:

$$Q_T = \sum Q_{T,x}$$

where:

Q_T	=	the amount of methane generated in the current year (T), kt CH ₄ /year.
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In order to estimate CH₄ 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, 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 CH₄ emission value is the summation of emissions from all regions.

8.2.2.1.1 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, 2007). 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 and the Northwest, Nunavut and Yukon Territories, the waste disposed quantities were estimated from an interpolation using a multiple linear regression approach applied to the Levelton (1991) and Statistics Canada (2000, 2003, 2004, 2007) MSW landfill values. MSW landfill values for Prince Edward Island and Northwest, Nunavut and Yukon Territories for the period 1991–2005 are obtained by trending historical landfill data with the provincial populations for 1971–2005 (Statistics Canada, 2006).

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 1999–2005.

8.2.2.1.2 CH₄ Generation Rate (k)

The CH₄ kinetic rate constant (k) represents the first-order rate at which CH₄ 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. 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 and Lagerkvist, 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 CH₄ 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 emissions from both types of landfills 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

Provincial/Territorial k Value Estimates											
NL	PE	NS	NB	QC	ON	MB	SK	AB	BC	NT ¹	YT
0.052	0.044	0.056	0.046	0.042	0.037	0.025	0.022	0.023	0.048	0.018	0.018

Note:

1 NT includes NU.

Wood Waste Landfills

Based upon the default value for estimating wood products industry landfill methane emissions recommended by the National Council for Air and Stream Improvement, Inc., a k value of 0.03/year was assumed to represent the methane generation rate constant for all of the wood waste landfills in Canada (NCASI, 2003).

8.2.2.1.3 CH₄ Generation Potential (L₀)

MSW Landfills

The values of theoretical and measured L₀ range from 4.4 to 194 kg CH₄/t of waste (Pelt *et al.*, 1998). The majority of recycling programs in Canada began in or after 1990; therefore, there was no substantial waste diversion prior to this date. In order to calculate the CH₄ generation potential prior to 1990, Statistics Canada recycling information from the 2002 survey year was used to estimate the percentage of diverted organic materials per province (Statistics Canada, 2000, 2003, 2004, 2007). The 1990–2005 calculated L₀ values were increased by the percentage currently diverted in order to calculate the CH₄ generation potential between 1941 and 1989 (Table 8-3). For provinces where diversion data were not available, the default value (165 kg/t of waste) was used (Thompson *et al.*, 2006). This default value of L₀ was obtained from the U.S. EPA (EPA, 1990). As waste disposal practices in Canada change and as new information is made available, the L₀ value will be adjusted accordingly.

L₀ was determined employing the methodology provided by the 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:

$$L_0 = \text{MCF} \times \text{DOC} \times \text{DOC}_F \times F \times 16/12 \times 1000 \text{ kg CH}_4/\text{t CH}_4$$

where:

L ₀	=	CH ₄ generation potential (kg CH ₄ /t waste)
MCF	=	CH ₄ correction factor (fraction)
DOC	=	degradable organic carbon (t C/t waste)
DOC _F	=	fraction DOC dissimilated
F	=	fraction of CH ₄ in landfill gas
16/12	=	stoichiometric factor

According to the IPCC Guidelines, the MCF for managed landfill sites has a value of 1.0 (IPCC/OECD/IEA, 1997). The fraction of CH₄ (F) emitted from a landfill ranges from 0.4 to 0.6 and was assumed to be 0.5. The IPCC default DOC_F value of 0.77 was used.

The DOC calculation is derived from the biodegradable portion of the MSW (Equation 8-4).

Equation 8-4:

$$\text{DOC} = (0.4 \times \text{A}) + (0.17 \times \text{B}) + (0.15 \times \text{C}) + (0.3 \times \text{D})$$

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: CH₄ Generation Potential (L₀) from 1941 to Present¹

Location	2002 Organic Waste Diversion ² (%)	L ₀ Value Following 1990 (kg/t of waste)	L ₀ Value Prior to 1990 (kg/t of waste)
British Columbia	23.3	108.8	134.1
Alberta	16.7	100.0	116.7
Saskatchewan	4.3	106.8	111.3
Manitoba	4.9	92.4	96.5
Ontario	16.4	90.3	105.1
Quebec	13.7	127.8	145.3
New Brunswick	19.8	117.0 ³	140.2
Prince Edward Island	NA ⁴	117.0 ³	165.0 ³
Nova Scotia	29.7	89.8	116.5
Newfoundland and Labrador	NA ⁴	102.2	165.0 ³
Northwest Territories and Nunavut	NA ⁴	117.0 ³	165.0 ³
Yukon	NA ⁴	117.0 ³	165.0 ³

Notes:

1 Source: Thompson *et al.* (2006), except where otherwise noted.

2 Source: Statistics Canada (2003).

3 Default value.

4 NA = Unavailable categorical information.

Wood Waste Landfills

Equation 8-3 generated an L₀ value of 80 kg CH₄ /t of wood waste, which was used to estimate emissions from wood waste landfills by the Scholl Canyon model. IPCC defaults were used for the: CH₄ correction factor - unmanaged deep landfills (MCF = 1); the fraction of CH₄ in the landfill gas (F = 0.5); and the fraction DOC dissimilated (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 CH₄ that is generated in MSW landfills is captured and combusted. Through combustion, this landfill CH₄ converts into CO₂, reducing the CH₄ emissions. In order to calculate the net CH₄ emissions from landfills, the quantity of captured CH₄ that passes through the flare uncombusted must be added to the difference between the quantity of CH₄ estimated by the Scholl Canyon model to have been generated and the amount of CH₄ captured based upon survey data. 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 CH₄ in landfill gas of 99.7% was used to determine the quantity of CH₄ that circumvented the flare. This value was obtained from Table 2.4-3 of Chapter 2.4 of EPA AP 42 (EPA, 1995) and is their typical value, although it ranges from 38% to 99% efficiency.

The quantities of landfill gas collected from 1983 to 1996 were obtained from Environment Canada (1998). Then, from 1997 to 2003, data on the amount of landfill gas captured are collected directly from individual landfill operators biennially by Environment Canada's National Office of Pollution Prevention (Environment Canada, 1997, 1999, 2001, 2003a). As of 2006, this survey is now being conducted by Environment Canada's Greenhouse Gas Division beginning with the 2005 data year (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.

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 GHG NIR (ICF, 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 CH₄ emissions from this key category include the CH₄ emissions from the MSW landfills and from the wood waste landfills. The level of uncertainty associated with the CH₄ 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 CH₄ emissions from the MSW landfills. The level uncertainty range provided by the ICF (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 (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 CH₄ emissions from this key category in 2001 (Environment Canada, 2003b). The uncertainty estimates for the CH₄ emissions from the MSW landfills seem to have been largely influenced by the uncertainty in the inventory values for the CH₄ generation potentials (L_0) for 1941–1989 and for 1990–2001 and the CH₄ generation rate constant (k), where the uncertainty for both the 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 CH₄ emission uncertainty by the use of the year 2000 value (instead of the 2001 value) for the total CH₄ 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 the wood waste landfills was significantly higher (i.e., –60% to +190%) than that for the MSW landfills, its contribution to the uncertainty in the key category was much lower due 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 CH₄ generation rate, carbon content of the waste landfilled, and the biodegradable fraction of the waste, where the uncertainties were assumed by ICF Consultants (ICF, 2004) based upon 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 for total emissions from Solid Waste Disposal on Land resulted in decreases of 6.7% and 3.2% in total emissions for 1990 and 2004, respectively, from emissions reported in the 2006 inventory year submission.

Updates to the provincial CH₄ generation rate constants, used in the Scholl Canyon model to estimate the CH₄ generation rate from MSW landfills, resulted in an overall downward shift in emissions for this subsector across the time series ranging from 4% to 6% CO₂ eq

from the 2006 NIR submission. A quality control check of the historical (1990-1996) information collected on the captured MSW landfill gas estimates revealed that the methane density used to convert the methane gas volumes to mass units was inconsistent with the density used in subsequent years. This problem was corrected and is reflected in a slight increase in the methane emissions over the 1990 to 1996 period.

MSW landfilled waste quantities were updated from the most current issue of the biennial waste management report from Statistics Canada resulting in a recalculation of CH₄ emissions for the years 2002, 2003 and 2004.

A correction of the wood waste landfill emission model resulted in the appropriate distribution of CH₄ emissions from the provinces for the complete time series; however this change did not necessitate a recalculation of the national estimates.

8.2.6 Planned Improvements

A multiyear study, being conducted by the University of Manitoba and funded by Environment Canada, was initiated in 2005 and will be completed in the winter of 2007. The study, which is a review of the activity data, emission factors and methane emission estimation models for municipal solid waste landfill sites, is being conducted in two phases. The first phase is completed and consisted of a review and verification of the Scholl Canyon model used by Environment Canada and the development of new provincial CH₄ generation rate constants and CH₄ generation potentials.

The second phase of the study is presently near completion and includes the development of a national facility level inventory of Canadian landfills. This inventory will be used to justify further study for the consideration of a Tier 3 approach to CH₄ generation estimation from MSW landfills for future NIR submissions. Information regarding the landfill gas collection aspect of the survey has been completed and quantities of methane gas captured obtained from the survey was used to update the activity data for the 2007 NIR submission. Subsequent landfill gas collection and utilization surveys will now be conducted directly by the Greenhouse Gas Division of Environment Canada on a biennial basis.

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 emission factors and model presently 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, CH₄ is produced; however, it is typical that systems with anaerobic digestion in Canada contain and combust the produced CH₄. CH₄ emissions from aerobic systems are assumed to be negligible. Both types of treatment systems generate N₂O through the nitrification and denitrification of sewage nitrogen (IPCC/OECD/IEA, 1997).

CO₂ is also a product of aerobic and anaerobic wastewater treatment. However, as detailed in Section 8.1, CO₂ emissions originating from the decomposition of organic matter are not included with the national total estimates, in accordance with IPCC Guidelines (IPCC/OECD/IEA, 1997).

The emission estimation methodology for municipal wastewater handling is divided into two areas: CH₄ from anaerobic wastewater treatment and N₂O from human sewage.

8.3.2 Methodological Issues

A more detailed discussion of the methodologies is presented in Annex 3.

8.3.2.1 CH₄ 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 CH₄, it was estimated that 4.015 kg CH₄/person per year could potentially be emitted from anaerobically treated wastewater.

CH₄ emissions were calculated by multiplying the emission factors by the population of the respective province (Statistics Canada, 2006) and by the fraction of wastewater that is treated anaerobically.

Industrial Wastewater Treatment

CH₄ emissions from treatment of industrial wastewater were found to be negligible since aerobic treatment of industrial wastewater is typically the standard practice.

The following equation was used to estimate the CH₄ emissions from this source:

Equation 8-5:

$$\text{CH}_4 (\text{Industry Type}) = V_{(\text{Industry Type})} \times \text{COD}_{(\text{Industry Type})} \times \text{EF}_{\text{CH}_4} \times \text{Frac}_{(\text{Anaerobic})}$$

where:

CH ₄ (Industry Type)	=	CH ₄ emissions generation per industry type (t)
V _(Industry Type)	=	volume of wastewater treated (L/year)
COD _(Industry Type)	=	chemical oxygen demand per industry type (kg/L)
EF _{CH₄}	=	CH ₄ emission factor (t CH ₄ /kg COD)
Frac _(Anaerobic)	=	fraction of anaerobically treated wastewater

Process effluent volumes were obtained from surveys conducted by Environment Canada for the years 1986, 1991, and 1996 (Environment Canada, 1986, 1991, 1996a). Volumes were then derived for the complete time series using polynomial curve-fitting interpolation for the intervening years between 1990 and 1996 and a growth function to estimate values from 1997 to 2005. Data were available for the following industries: food, beverages, rubber products, plastic products, total textiles, paper allied products, petroleum and coal products, and chemical products. IPCC default values for the chemical oxygen demand (COD) for each industry were then matched to these industrial sectors (IPCC, 2000). In the absence of a country specific emission factor, an IPCC default value for the CH₄ emission factor of 0.00025 t CH₄/kg COD was selected.

However, through communications with the Ministries of Environment of the provinces (Ontario, Quebec, and British Columbia) where these industries are mainly based and with selected industry associations, it was concluded that on-site anaerobic treatment of industrial wastes was negligible. Pulp and paper process water accounts for approximately 79.6% of the water consumed for industrial processes, and it was confirmed that no anaerobic processes were employed in Canada for treatment of this effluent. One slaughterhouse in Quebec was identified as using anaerobic digestion as a treatment process; however, the biogas is captured and combusted. A follow-up study is being considered to improve the resolution of the information and ensure completeness and accuracy of the data.

8.3.2.2 N₂O Emissions

Municipal Wastewater Treatment

The N₂O emissions from municipal wastewater treatment facilities were calculated using the IPCC default method (IPCC/OECD/IEA, 1997). This method estimates the N₂O emission factor as the product of the annual per capita protein consumption, the assumed protein nitrogen content (16%), the quantity of N₂O-N produced per unit of sewage nitrogen (0.01 kg N₂O-N/kg sewage nitrogen) and the N₂O/N₂O-N conversion factor (1.57). Protein consumption estimates, in kg/capita/yr, were obtained from an annual food statistics report published by Statistics Canada (Statistics Canada, 2005). Emissions

were calculated by multiplying the emission factor by the population of the respective provinces (Statistics Canada, 2006). A summary of the values for these two parameters over the time series is given in Table 8-4.

Table 8-4: N₂O Emission Factors

Year	Annual per capita protein consumption <i>(kg Protein/capita/yr)</i>	N₂O Emission Factor <i>(kg N₂O/capita/yr)</i>
1990	25.65	0.064
1991 ¹	25.00	0.063
1992	25.83	0.065
1993	25.94	0.065
1994	26.05	0.065
1995	26.17	0.066
1996 ¹	26.00	0.065
1997	26.43	0.066
1998	26.57	0.067
1999	26.71	0.067
2000	26.85	0.068
2001 ¹	27.72	0.070
2002 ¹	27.54	0.069
2003 ¹	27.17	0.068
2004 ¹	27.41	0.069
2005 ¹	27.18	0.068

Note:

1 Data Source: Statistics Canada (2005). The data have been adjusted for retail, household, cooking and plate loss

Industrial Wastewater Treatment

The IPCC Guidelines (IPCC/OECD/IEA, 1997) do not address the methodology for the estimation of N₂O emissions from industrial wastewater treatment. Due to a lack of activity data, the N₂O 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 GHG NIR (ICF, 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 (2004) study is less than the $\pm 60\%$ 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 (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 CH₄ and N₂O) 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 2005 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.

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

The recalculations for Wastewater Handling resulted in decreases of 28.7% and 25.4% in total emissions for 1990 and 2004, respectively, from emissions reported in the 2005 inventory year submission.

A significant decrease in N₂O emissions from the municipal wastewater handling subsector, over the complete time series, had resulted from the use of a more complete and accurate estimation of protein consumption per capita for Canada. The difference in emissions varied from 37% to 30% for this category.

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.

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 CO₂, CH₄, and N₂O.

As per the IPCC Guidelines (IPCC/OECD/IEA, 1997), CO₂ emissions from biomass waste combustion are not included in the inventory totals. The only CO₂ emissions detailed in this section are from fossil fuel-based carbon waste, such as plastics and rubber.

CH₄ emissions from MSW incineration are assumed to be negligible and are not calculated due 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. GHG's emitted from the incineration of sewage sludge include CO₂, CH₄, and N₂O, as in the case of MSW incinerators, however, since the carbon present in the wastewater sewage sludge is of biological origin, the CO₂ emissions are not accounted 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.

8.4.2.1 CO₂ Emissions

The IPCC Guidelines (IPCC/OECD/IEA, 1997) do not specify a method to calculate CO₂ 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:

1. *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).
2. *Developing Emission Factors*: Provincial CO₂ emission factors are founded on the assumption that carbon contained in waste undergoes complete oxidation to CO₂. 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 CO₂ per tonne of waste by multiplying by the ratio of the molecular mass of CO₂ to that of carbon.
3. *Calculating CO₂ Emissions*: Emissions were calculated on a provincial level by multiplying the amount of waste incinerated by the appropriate emission factors.

The CO₂ 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 N₂O and CH₄ Emissions

MSW Incineration

Emissions of N₂O 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. CH₄ 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 CH₄ emissions, the amount of dry 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, 1994). 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 2002–2005, a regression analysis was completed using the Chandler and Compass Environmental Inc. incineration values.

CH₄ 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 CH₄/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 emission values were then determined as the summation of these emissions for all provinces.

Emissions of N₂O from sewage sludge incineration were estimated using the IPCC default emission factor for fluidized beds, 0.8 kg N₂O/t of dry sewage sludge incinerated (IPCC, 2000). To estimate emissions, the emission factor was multiplied by the amount of waste incinerated by each province. The national emission values 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 GHG NIR (ICF, 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 CO₂, CH₄, and N₂O) from incineration of wastes (comprising MSW and sewage sludge) was estimated to be in the range of about 10% to 11%. The inventory trend was estimated at 10%. The extrapolation of trend uncertainty in 2001 to the 2005 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. CH₄ 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: CO₂ emissions from MSW incineration. A formula linkage issue was identified in the model for one province for the quantities of sewage sludge incinerated over 1997 and 1998. This error was corrected. No other significant anomalies were identified.

8.4.5 Recalculations

This year's recalculations resulted in no change for 1990 and a decrease of 8.8% for 2004 in total emissions from values reported in the 2006 inventory year submission. Overall, as a consequence of the recalculations, emissions were reduced for the years 1991, 2002, 2003 and 2004 and increased for 1993-1998 as compared to the 2006 NIR submission. No changes were made to the emission values for 1990, 1992, 1999, 2000 and 2001.

MSW incineration saw increases in CO₂ and CH₄ emissions over the period 1993-1998 and decreases in emissions from 1999 to 2004 as compared to the 2006 NIR submission. The present extrapolation approach incorporates the trending of historical MSW incineration data with population rather than with time as was the case in the 2004 inventory, since a more defensible correlation can be made between waste disposal and population trends.

8.4.6 Planned Improvements

An analysis of the municipal incineration activity data is planned. The study proposal includes a historical compilation of the activity data from 1990 to 2005, 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 presents a summary of the recalculations and improvements performed and a summary of the planned improvements to the overall inventory. The reader will find in Chapters 3 through 8 the category-specific details of the recalculations, along with a description by category of planned improvements to the methodologies and data.

9.1 Explanations and Justifications for Recalculations

Each year, Environment Canada reviews and, if necessary, revises and recalculates the emissions and removals 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.

In this submission, a number of important improvements and recalculations have been incorporated for all Sectors. These originate from improved allocation of emissions to source Sectors or from revised and updated methodologies, emission factors and activity data.

Notably, some recalculations in the Energy Sector were triggered by higher precision and revised data of fossil fuel consumption as published by Statistics Canada. Updates to the activity data of multiple categories and some methodological changes entailed recalculations in the Industrial Processes, and Solvent and Other Product Use Sectors. The Agriculture Sector recalculations have been carried out due to methodological upgrades and updates in animal populations. The LULUCF Sector recalculations have notably been carried out due to updates in activity data and estimation parameters. Corrections were also made to remove programming errors in estimation model. Finally, recalculations in the Waste Sector were triggered by updated activity data and corrections made to the model.

This section provides a summary of the major recalculations performed in each Sector, followed by a description of the impacts on GHG levels and trends.

9.1.1 Energy

Overall, higher precision of fossil fuel consumption data (from 1990 to 1998) and revised 2004 data, as published by Statistics Canada, have resulted in recalculations to the stationary combustion, transport and fugitive emission estimates. For example, the revised 2004 fossil fuel data affected the estimates for the Energy Industries, Transport, Manufacturing Industries and Construction, and the Other Sectors. The largest impact was in the Public Electricity and Heat Production source category and was due to the changes in the types of coal consumed. Specific discussions associated with improvements to the Energy Sector that resulted in emissions recalculation or reporting reallocation is presented in the subsequent sections.

9.1.1.1 *Stationary Fossil Fuel Combustion*

The stationary fuel combustion model was upgraded, by conversion into a database software format, and resulted in a complete review of all aspects of the model, and specifically methodology, activity data and emission factors. Methodological inconsistencies were corrected where warranted. Historical activity data were obtained in an electronic format and at a higher degree of precision that affected data, primarily between 1990 and 1998. Also, QA/QC checks identified typographical errors and unsubstantiated assumptions in the application of emission factors. The overall impact to the previous estimates is in the range of -1 to -2 Mt CO₂ eq.

The largest recalculation impact was the result of applying new methodologies and emission factors to fuels used in the bitumen upgrading and the 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 emissions estimates in the two industries and CRF categories. The methodology change reflects an improvement in previous assumptions such that these two fuels can now be also attributed to the bitumen upgrading (Manufacture of Solid Fuels and Other Energy) whereas previously all emissions were allocated to the Petroleum Refining sector. These refinements had an impact of 1 to 2 Mt CO₂ eq on total estimates, and an even more significant impact at the subsector level.

In addition to the review of the stationary combustion methodology, emission estimates for still gas were recalculated for the entire time series based on its consumption value in energy units, since the physical volumetric data are reported in liquid fuel oil equivalent while revised emission factors are on a gaseous basis.

QC checks on CO₂ and CH₄ emissions from gaseous fuels under the Manufacturing of Solid Fuels and Other Energy Industries categories identified that the flaring emissions in the oil and gas sector had been double counted (that is, fugitive emissions were not subtracted from the gaseous total under their respective categories). This impact was observed throughout the time series.

9.1.1.2 *Transport*

Transportation estimates were revised for the 1990-2004 period due to the following factors:

- Statistics Canada fuel consumption data: two changes are noted that contribute 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 MGEM07 model: vehicle populations in MGEM07 are now disaggregated by class and model year for all provinces and territories. Other data improvements in MGEM07 included refined technology penetration assumptions, fuel consumption ratio, and vehicle kilometres travelled. 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 CH₄ and N₂O emission factors was carried out to ensure the most appropriate emission factors were being used. As part of the technical review the applicability of separate N₂O emission factors for new and aged (over 20,000km) Tier 0 vehicles was reviewed. It was concluded that age alone does not affect the N₂O removal efficiency of Tier 0 catalysts. An average N₂O emission factor based on aged Tier 0 vehicles is used for all Tier 0 vehicles in the 1990-2005 estimates. Minor adjustments resulted for all years.
- Modification of the on and off-road fuel allocation methodology: due to an improved understanding of the vehicle fleet, the fuel allocated by MGEM07 to road transportation has a higher certainty. The fuel normalization routine used by MGEM07 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 re-allocated fuel to off-road applications from on-road transportation for all years.

9.1.1.3 *Fugitive Sources*

Key improvements that resulted in a recalculation or a reallocation of the fugitive estimates were due to the following reasons:

- Revised estimates for the oil sands and heavy oil upgrading industry based on the Canadian Association of Petroleum Producers' study of the industry (CAPP, 2006) for 1990 to 2004;

- Reporting reallocation of unintentional and intentional emissions for the oil and gas industry for 1990 to 2004;
- Revised coal production data for 2001 to 2004;
- Revised petroleum refining energy consumption data for 1991 to 1994 and from 2003 onwards
- Revised pipeline distance and distribution length for 2002 to 2004

Improvements and updates to the fugitive model for the oil and gas industry were based on the CAPP's bitumen study (which is also referred to as '*An Inventory of GHGs, CACs and H₂S Emissions by the Canadian Bitumen Industry*'). The reallocation of unintentional and intentional sources of emissions resulted in a complete time series recalculation, while only certain years were affected by revised coal activity data (for 2001 to 2004). Also revised were refinery energy consumption data (1991 to 1994 and from 2003 onwards); and, pipeline distance and distribution length (2002 to 2004). Discussion on the impacts of fugitive emission recalculations associated with coal mining, refinery flares, pipeline distance and distribution length is presented in section 3.3 Fugitive Emissions of this report.

A complete time series recalculation of emissions associated with the bitumen and synthetic crude oil production industry was implemented to the Fugitive Oil and Gas subsector, based on results from the bitumen study as prepared by David Picard of Clearstone Engineering Ltd. for CAPP. An extrapolation model was used to estimate emissions from 2004 onward. In general, IPCC Tier 3 methodology was applied by each operator to develop a bottom up approach in estimating GHG emissions from oil sands and heavy oil upgrading operations. Wherever gaps existed, estimates were prepared by Clearstone Engineering Ltd., and were provided to each operator for their review. QA/QC and an uncertainty analysis following the IPCC Good Practice Guidance (IPCC, 2000) Tier 1 uncertainty methodology were also included in the study.

For the 1990 to 2003 fugitive emissions from oil sands and heavy oil upgrading operations resulting from process venting (such as hydrogen production), flaring, venting (including mine surfaces and pond surfaces), storage and handling losses, and equipment leaks were directly incorporated into the national inventory fugitive model. For the 2004 and 2005, an extrapolation model was developed based on the bitumen study along with publicly available information to estimate GHG emissions.

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. Conversely, unintentional venting, that was reported in Venting Oil was allocated to Oil Production and Oil Refining/Storage. 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 was not revised, rather it was a reporting reallocation that did not generate a change at the overall category level.

9.1.2 Industrial Processes

Several categories in the Industrial Processes Sector were recalculated, mainly because of activity data updates and methodological changes, as described below.

Under Mineral Products, recalculations were made to the 2004 lime production CO₂ emission estimate, since updated 2004 activity data became available. Also, CO₂ emission from cement production was previously estimated using a rounded EF_{Clinker} of 0.507 t CO₂/t clinker. The EF_{Clinker} has been corrected to the exact unrounded value of 0.5071 t CO₂/t clinker (IPCC/OECD/IEA, 1997) resulting in a slight increase of 0.02%.

There were minor recalculations to the emissions from soda ash use and limestone and dolomite use. The import and export data for soda ash for 2004 was updated and, as a result, the associated emissions increased by 9.5%. The emissions for limestone and dolomite use for 2004 have also been recalculated due to a change in stone use that was reported in the *Canadian Mineral Year book* (NRCan). As a result, the emissions increased by 15% for 2004.

Under Chemical Industry, updated data on ammonia production that did not involve steam methane reforming, and on urea export, have been obtained (Cheminfo, 2006). These data were used to revise 1990–2004 emission estimates for ammonia production. Emissions from nitric acid for 1990–2004 were also recalculated, since plant-specific information on nitric acid production and the emission abatement technologies used were obtained through the Cheminfo Services study in 2006 (Cheminfo, 2006).

Under Metal Production, changing the emission factor for steel production in electric arc furnaces from 4.58 kg CO₂/ t steel to 5 kg CO₂/ t steel resulted in the recalculations of 1990–2004 CO₂ emission estimates for the category of iron and steel production. Slight revisions of the 1990–1998 metallurgical coke use data (i.e. data with higher resolution) also contributed to the recalculations of the 1990–1998 emission estimates for this category. Updates in the 1990–2004 SF₆ emission estimates were provided by the aluminium industry. Revisions were done to the 1991–2004 SF₆ emission estimates for magnesium casting to correct transcription errors and to include updated data provided by companies.

Under Production and Consumption of Halocarbons, data on HFC consumption for 2004 were gathered by Environment Canada's Use Patterns and Controls Implementation Section in 2005. These data were used to revise the 2004 HFC emission 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.

The modifications made to the estimation methodology for semi-conductor manufacturing caused recalculations of emission estimates of consumption of SF₆ for 1990–2004.

The Other and Undifferentiated Production category was recalculated for 1990–2004 because of the changes made to the ammonia production emission estimates. A minor change in the estimation methodology, which was to subtract the CO₂ already accounted for in the category of iron and steel, also contributed to the recalculations made to this category. Slight revisions of the 1990-1998 activity data and update to the 2004 data further explained the emission recalculations for these years.

9.1.3 Solvent and Other Product Use

1990-2004 emission estimates for this sector were recalculated because updated activity data (i.e. N₂O sales data) were obtained during the Cheminfo study in 2006 (Cheminfo, 2006).

9.1.4 Agriculture

This submission incorporates a number of small changes compared with the 2006 submission, as detailed in Chapter 6 on the Agriculture Sector. As a result, recalculations have been carried out due to methodological upgrades and updates in animal populations.

Recalculations affected mostly N₂O estimates from direct soil sources due to the following changes: impact of conservation tillage on direct soil N₂O emissions has been expanded to cover eastern Canada and British Columbia; the emission factors have been revised upwards for the driest ecodistricts in the country, impacting N₂O emissions upward for synthetic fertilizers, manure applied as fertilizers, tillage practices and summer fallow; crop yield data were updated for some minor crop categories; and irrigation, as a new minor source of N₂O, was taken into account.

Averaged manure N handled by Pasture, Range and Paddock, as well as Solid and Drylot for goats and horses has been changed based on the original study by Marinier *et al.* (2004). Moreover, animal population accounts have been modified slightly for the categories of minor significance.

Finally, the amount of leached N subject to indirect emissions of N₂O has been revised because of corrections on perennial forage crops to annual crops in the previous year's submission.

9.1.5 Land Use, Land-Use Change and Forestry

While the overall approach and methods implemented in 2006 remained the same, incremental changes and improvements in this submission triggered some recalculations for the entire time series, most importantly in the forest land category (managed forests) and to a lesser extent, in deforestation estimates. The changes for managed forests include inter alia, updates to and recalibration of estimation parameters, in particular decay rates for selected pools, recalibration of fire disturbance matrices, corrections and

refinements to the area of managed forests in northern Canada and improvements to the spatial allocation of fire events.

Deforestation areas were revised due to a combination of factors including increased QA in certain regions, increased sample size, recalculation of scaling factors, corrections of certain misallocations and improvements to deforestation strata units to reduce the required expert judgement.

In addition, programming errors were corrected in estimation procedures in the Cropland category; activity data for managed peatlands were updated to reflect expert knowledge, and work was undertaken to enhance the harmonization of data originating from multiple sources.

Sections 7.4 to 7.8 provide details specific to each category on the most important recalculations. Progress was also made in the uncertainty analysis in the Cropland category, and on the coverage and documentation of Tier 2 QC procedures.

9.1.6 Waste

Updates to the provincial CH₄ generation rate constants, used in the Scholl Canyon model to estimate the CH₄ generation rate from MSW landfills, resulted in an overall downward shift in emissions for this subsector across the time series ranging from 4% to 6% CO₂ eq from the 2006 NIR submission. Methane density used for the conversion of captured MSW landfill gas volumes to mass units over the period from 1990 to 1996 was corrected resulting in a slight increase in the methane emissions over those years. MSW landfilled waste quantities were updated from the most current issue of the biennial waste management report from Statistics Canada resulting in a recalculation of CH₄ emissions for the years 2002, 2003 and 2004. A correction of the wood waste landfill emission model resulted in the appropriate distribution of CH₄ emissions from the provinces for the complete time series; however this change did not necessitate a recalculation of the national estimates.

A significant decrease in N₂O emissions from the municipal wastewater handling subsector, over the complete time series, had resulted from the use of a more complete and accurate estimation of protein consumption per capita for Canada. The difference in emissions varied from 37% to 30% for this category.

MSW incineration saw increases in CO₂ and CH₄ emissions over the period 1993-1998 and decreases in emissions from 1999 to 2004 as compared to the 2006 NIR submission. This was due to a refinement of the extrapolation method used to estimate quantities of MSW incinerated.

Finally, minor recalculations of the CH₄ emissions from MSW landfills and municipal wastewater handling, and N₂O emissions from municipal wastewater handling, were due to the updated population statistics generated by Statistics Canada, for population estimates of 2003 and 2004.

9.2 Implications for Emission Levels

Table 9-1 provides a summary, by Sector and for national GHG totals, of the quantitative effects of recalculations.

Table 9-1: Recalculations Summary

Sector		GHG Emissions															
		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
		(Mt CO ₂ eq)															
National Total ¹	Previous	599	592	609	611	631	649	667	680	686	698	725	719	726	754	758	N/A
	Current	596	589	607	608	628	646	664	677	683	695	721	714	720	745	747	747
	% Change	-0.5	-0.4	-0.3	-0.4	-0.5	-0.5	-0.4	-0.5	-0.5	-0.5	-0.6	-0.6	-0.7	-1.2	-1.4	-
Energy	Previous	475	467	485	485	502	517	532	545	555	569	596	590	597	622	620	N/A
	Current	473	465	483	484	499	514	530	543	552	566	592	586	593	613	608	609
	% Change	-0.4	-0.4	-0.3	-0.3	-0.6	-0.5	-0.5	-0.4	-0.5	-0.5	-0.7	-0.7	-0.8	-1.4	-1.9	-
Industrial Processes	Previous	53	55	53	53	55	56	57	57	52	50	50	49	48	50	54	N/A
	Current	54	55	53	53	55	56	57	56	53	50	50	49	49	51	55	53
	% Change	0.4	0.5	0.4	0.4	0.5	0.4	0.5	-0.1	0.3	0.6	0.8	0.9	0.8	0.9	2.1	-
Solvent	Previous	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	N/A
	Current	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
	% Change	-58	-61	-68	-64	-61	-53	-52	-50	-54	-53	-48	-55	-65	-54	-56	-
Agriculture	Previous	45	44	45	46	47	49	51	51	51	51	51	51	51	53	55	N/A
	Current	46	45	46	47	49	50	52	52	52	52	53	52	52	54	56	57
	% Change	2	2	2	2	2	2	3	3	3	3	3	2	2	2	2	-
Waste	Previous	25	25	26	26	26	26	26	27	28	28	28	28	28	29	29	N/A
	Current	23	24	24	25	25	25	25	25	26	26	26	26	27	27	28	28
	% Change	-7	-7	-6	-6	-6	-6	-5	-7	-7	-6	-6	-6	-6	-5	-5	-
LULUCF	Previous	-82	-97	-163	-75	15	194	-78	-125	89	-45	-131	-121	6	-11	81	N/A
	Current	-123	-97	-151	-67	-81	155	-75	-117	95	-31	-107	-94	55	22	81	-17
	% Change	50	0	-7	-11	-646	-20	-4	-7	6	-31	-18	-23	800	-298	0	-

Notes:

1 National totals exclude all gases from the LULUCF Sector

N/A = Not applicable

Emissions have been rounded from the estimated values. Percent differences were calculated based on the non-rounded estimated values.

Overall, recalculations in the Energy and Waste Sectors had the greatest impact on emission levels. When combined with smaller recalculation changes in the Industrial Processes, Solvent and Agriculture Sectors, total GHG emissions (excluding the LULUCF Sector) were overall revised downwards. For the complete time series, the revisions are fairly consistent and vary between approximately -11 Mt (-1.4%) for 2004 and about -2 Mt (-0.3%) for 1992.

Recalculations in the Energy Sector resulted in an overall decrease in reported emissions for the entire time series. In general, the change in reported emissions between 1990 and 2004 decreased from about -12 Mt (-1.9%) in 2004 to about -1 Mt (-0.3%) in 1992.

For the Industrial Processes Sector, recalculations resulted in an emission increase of about +0.2 Mt (+0.4%) for 1990. The reported emissions varied, for 1990-2003, by less than 1%, as compared to those presented in the previous inventory. Recalculations had impacted the 2004 estimates the most; the reported emissions increased by +1.1 Mt (+2.1%).

For the Solvent and Other Product Use Sector, the use of updated N₂O sales data as activity data resulted in downward revisions. The changes from the previous inventory varied from -0.3 Mt (-65%, 2002) to -0.2 Mt (-48%, 2000).

For the Agriculture Sector, overall recalculations resulted in changes between +1 Mt (+2%, 1990) and +1.4 Mt (+3 %, 1999) in reported emissions.

For the LULUCF Sector (not included in national totals), the effect of recalculations on the level of estimates is significant and is driven by changes in the forest land category. Years with the largest absolute recalculations include 1994 (-96 Mt difference between 2006 and 2007 submissions), 1990 (-41 Mt), 1995 (-39 Mt), and 2002 (+49 Mt). The entire LULUCF sector continues to show large inter-annual fluctuations

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).

9.3 *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), amounting to a decrease of -1.2% in the overall emissions growth. The 1990–2004 increase, previously reported as 26.6%, is now 25.4%.

For the Energy Sector, emissions decreased throughout the time series and changed the emission trend over 1990–2004 from +30.3% to +28.4%.

For the Industrial Processes Sector, the emission trend over 1990-2004 has slightly changed due to the recalculations made to various categories. It was +1.9% in the previous inventory, but it is now +3.6%.

For the Solvent and Other Product Use Sector, recalculations has changed the emission trend over 1990-2004 from +15.3% (as per the previous inventory) to +20.6%.

For the Agriculture Sector, the increase in GHG emissions over 1990–2004 was revised from 22.6% (previous submission) to 22.9%. Updates on data and parameters for N₂O emissions from soils were responsible for most of this impact on the trend.

In the Waste Sector, the increase in emissions over 1990–2004 is now 18.9%, compared with 15.9% previously reported.

In the LULUCF Sector (excluded from national totals), both short- and long-term trends are not particularly meaningful, given that net emissions and removals are driven by the forest fire emissions, which are extremely variable from one year to the next.

9.4 *Planned Improvements*

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. The following is a discussion of current improvement activities and plans based on recommendations provided by the external review process, the UNFCCC ERTs' annual reports, collaboration with industry, other government departments, academia, and inventory sector experts. Improvement plans are developed and prioritized based on key category contributions and resource availability. Prior to initiation, all proposed planned improvements must be approved by the GHG Division's Prioritisation and Planning Committee. Some improvements span several years.

9.4.1 Quality Assurance/Quality Control

The quality management framework has been reviewed and redesigned and new QA/QC plan and procedures were developed. 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 and to publication. In addition, the plan encompasses a quality management cycle that spans several years, ensuring that all inventory categories are subject to a suite of QA/QC procedures.

The plan includes a system of continuous improvement that includes, but is not limited to: procedures to capture lessons-learned as part of the inventory cycle; benchmarking of inventory processes through verification; and processes to ensure improvements identified are incorporated into the operating procedures.

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The plan 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 and QA activities will be performed every year on a rolling schedule so that all categories (whether key or non-key) will be subject to QC and QA.

9.4.2 Uncertainties

Building on the Tier 2 uncertainty studies completed in 2004 (ICF, 2004), and 2005 (ICF, 2005), further methodology and activity data improvements have been achieved in various Sectors, with commensurate reductions in the uncertainty estimates. Updates to the 2001 uncertainty estimates are provided in this NIR, in the relevant Sector chapters. The implementation of the enhanced methodologies in the LULUCF Sector required an important and concerted effort; complete uncertainty estimates could not be produced for

the categories in this Sector in time for the 2007 submission. Work is ongoing to document and quantify uncertainties in each LULUCF category excluding the Cropland category.

A midterm goal is to build internal capacity for uncertainty analysis through the development of an uncertainty quantification system with linkages to the emissions/removals system, that would allow automated updates to the uncertainty estimates, as activities, data, and methods change. A Tier 1 study of the uncertainties for the 2005 emissions will be initiated, followed by acquisition of tools and implementation of staff training, to enable continuous in-house updates using a Tier 1 methodology.

9.4.3 Key Categories

Future 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.

9.4.4 Data Management System

The GHG Division will initiate a planning process to develop a data management system for the entire GHG inventory. This has been delayed, but a first step has been planned to define and assess the business requirements, including the option of a multi-user relational inventory database. A second phase of what is anticipated to be a multi-year project will consist of designing, testing, and implementing the system.

9.4.5 Energy Sector

9.4.5.1 Stationary Fossil Fuel Combustion

Future improvements include a study on the performance characteristics of landfill gas utilization system, and the validation of the residential wood combustion model. A study on the sources of foreign bituminous coal used in Canada may also be undertaken as it is currently assumed that all foreign bituminous coal is supplied by the United States.

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 is planned to ensure a cohesive approach to emissions estimates to ensure accuracy, transparency and consistency.

9.4.5.2 *Transport*

The transportation model was upgraded in 2006/2007 and is continuously evolving to take advantage of the relational database's power to accommodate an increasing number of higher resolution data sets.

Future improvements will concentrate on:

- Investigating the possibility of applying off-road emission factors based on a modified version of USEPA's NONROAD model, which employs time dependant device populations, fuel consumption ratios and duty cycles representative of Canada's regions.
- Developing a Tier 2 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 and aviation bunkers.
- Developing region and time specific fuel carbon characteristics.
- Acquiring historic biodiesel consumption data.

9.4.6 **Industrial Processes Sector**

The main improvements intended to be undertaken, in the next inventory cycle, for the Industrial Processes Sector, are:

- Use of Canadian activity data instead of the U.S. activity data to estimate the emissive portion of the sub-category "other chemical uses" in the limestone and dolomite use category.
- Disaggregate the estimates of energy and process-related emissions for ammonia production.
- Discuss with Statistics Canada and the chemicals industry to determine whether the non-energy hydrocarbon values could be disaggregated into different subcategories. And assess the applicability of use-specific emission factors for different types of fuels.
- Collaborate with Canadian Electricity Association to develop an SF₆ emissions estimation protocol.
- Reallocate part of CO₂ emissions from the non-energy use of fossil fuels, currently reported under the category of Other and Undifferentiated Production, to the category of Iron and Steel Production.
- Establish a mechanism to continuously collect data on HFC uses and quantities of HFCs in imported and exported products.

In respect of quality assurance activities - which are scheduled when methodology improvements have been made to a category, or performed based on multi-year QA cycles - the following is intended for the next year:

- Undertake a quality assurance review with the Cement Association of Canada on the methodology used for emission estimates from cement production.
- Undertake a quality assurance review of the CO₂ emissions from ammonia production. This category has recently undergone a methodology change.
- Gain a better understanding of the QC procedures followed by aluminum companies in developing estimates relied upon by the inventory.

For more detailed information on future improvements please see chapter 4.

9.4.7 Agriculture Sector

In the current method for methane emissions, the digestible energy for beef and dairy cattle is 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 CH₄ emissions. In addition, work is being planned to potentially update CH₄ producing potentials for various manure types.

For N₂O 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.

9.4.8 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 improve further 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.

9.4.9 Waste Sector

9.4.9.1 Solid Waste Disposal on Land

A multi-year study, being conducted by the University of Manitoba and funded by Environment Canada, was initiated in 2005 and will be completed in the spring of 2007. The study, which is a review of the activity data, emission factors and methane emission estimation models for municipal solid waste landfill sites, is being conducted in two

phases. The first phase is completed and consisted of a review and verification of the Scholl Canyon model used by Environment Canada and the development of new provincial CH₄ generation rate constants and CH₄ generation potentials.

The second phase of the study is presently near completion and includes the development of a national facility level inventory of Canadian landfills. This inventory will be used to justify further study for the consideration of a Tier 3 approach to CH₄ generation estimation from MSW landfills, for future NIR submissions. Information regarding the landfill gas collection aspect of the survey has been completed and quantities of methane gas captured obtained from the survey were used to update the activity data for the 2007 NIR submission. Subsequent landfill gas collection and utilization surveys will now be conducted directly by the Greenhouse Gas Division of Environment Canada on a biennial basis.

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 emission factors and model presently employed.

9.4.9.2 *Wastewater Handling*

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 to the organization conducting the survey to better suit the survey data to the requirements of the NIR.

9.4.9.3 *Waste Incineration*

An analysis of the municipal incineration activity data is planned. The study proposal includes a historical compilation of the activity data from 1990 to 2005, a current inventory of all Canadian MSW incinerators, waste composition, annual throughputs for each unit, and estimated GHG emission factors.

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Annex 1 Key Categories

A1.1 Key Categories — Methodology

Both the IPCC GPG (IPCC, 2000) and the IPCC GPG 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:

- I. IPCC categories should be used with emissions expressed in CO₂ equivalent units according to standard GWPs.
- II. A category should be identified for *each* gas emitted by the source, since the methods, emission factors, and related uncertainties differ for each gas.
- III. Source categories that use the same emission factors based on common assumptions should be aggregated before analysis.

The Canadian analysis of categories for key sources and sinks proceeds according to the Tier 1 Good Practice Guidance approaches of IPCC (2000, 2003). Using the Tier 1 method, key categories are first identified by *quantitative* methods using a predetermined cumulative emissions 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 Tier 1 are multiplied by the relative uncertainty of the source and sink category. Since complete uncertainty estimates are not available for the LULUCF Sector, a Tier 1 approach has been used for this analysis.

The quantitative approach identifies key categories from two perspectives. The first analyzes the emission contribution that each category makes to the national total (with and without LULUCF). The second perspective analyzes the trend of emission contributions from each category to identify where the greatest absolute changes (either increases or decreases) have taken place over a given time (with and without LULUCF).

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. IPCC has determined that 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). The 95% cumulative contribution threshold has been used in this analysis to define an upper boundary for key category identification. Therefore, when source and/or sink contributions are sorted in decreasing order of importance, those that 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 (CO ₂ eq) estimate of source category x in year t
E_t	=	the total inventory estimate (CO ₂ 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.
$E_{x,t}^*$	=	$ E_{x,t} $: absolute value of the emission or removal estimate of source or sink category x in year t
E_t^*	=	$\sum_x E_{x,t} $: total contribution, which is the sum of the absolute values of emissions and removals in year t.

Trend contribution of each source is calculated according to Equation A1-3, which follows IPCC (2000), while 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:

$$T_{x,t} = L_{x,t} \cdot \left| \left\{ \frac{(E_{x,t} - E_{x,0})}{E_{x,t}} - \frac{(E_t - E_0)}{E_t} \right\} \right|$$

where:

$T_{x,t}$	=	the contribution of the source category trend to the overall inventory trend (i.e., the trend assessment); the contribution 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 of source category x in years t and 0, respectively
E_t and E_0	=	the total inventory estimates in years t and 0, respectively

Equation A1-4 for source and sink category trend assessment:

$$T_{x,t} = E_{x,t}^* / E_t \cdot \left| \left\{ \frac{(E_{x,t} - E_{x,0})}{E_{x,t}} - \frac{(E_t - E_0)}{E_t} \right\} \right|$$

where:

$T_{x,t}$	=	trend assessment, which is the contribution of the source or sink category trend to the overall inventory trend. The trend assessment is always recorded as an absolute value, i.e., a negative value is always recorded as the equivalent positive value.
$E_{x,t}^*$	=	$ E_{x,t} $: absolute value of the emission or removal estimate of source or sink category x in year t
$E_{x,t}$ and $E_{x,0}$	=	real values of estimates of source or sink category x in years t and 0, respectively
E_t and E_0	=	$\sum_x E_{x,t}$ and $\sum_x E_{x,0}$ are total inventory estimates 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. In most cases, the application of these criteria identifies categories identical to those prioritized by the quantitative analysis. However, additional categories identified as key may be added to the primary list. IPCC GPG (IPCC, 2000) and GPG for LULUCF (IPCC, 2003) identify several general criteria for qualitative analysis. They are as follows:

1. *Mitigation techniques and technologies*: Identify those sources where emissions are being reduced significantly through the use of mitigation techniques or technologies.
2. *High expected emissions growth*: Identify sources with significant growth forecast.
3. *High uncertainty*: Identify most uncertain sources as key to help improve the accuracy of the inventory.
4. *Unexpectedly low or high emissions*: Identify calculation errors and discrepancies by doing order-of-magnitude checks.

5. *Land Use Land Use Change and Forestry*: if sub-categories display large CO₂ fluxes that tend to cancel each other, or if deforestation is larger than the smallest key category level.

This analysis uses several sources of information to support the qualitative assessment, notably the emission forecasts by Natural Resources Canada (NRCan, 1999) (NRCan, 2006); some announcements by the Government of Canada (2006) (2007) and the quantitative uncertainty analysis (ICF, 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 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

The results of key category assessment in accordance with both IPCC GPG (IPCC, 2000) and the IPCC GPG for LULUCF (IPCC, 2003) are given in Table A1-1.

Table A1-1: Key Category Analysis Summary, 2005 Inventory

CRF Reporter Table	IPCC Categories	Direct GHG	Key Category (Yes/No)	If Yes, Criteria for Identification
1.A.1.a	Fuel Combustion - Public Electricity and Heat Production	CO ₂	Yes	Level, Trend, and Quality
1.A.1.a	Fuel Combustion - Public Electricity and Heat Production	CH ₄		
1.A.1.a	Fuel Combustion - Public Electricity and Heat Production	N ₂ O		
1.A.1.b	Fuel Combustion - Petroleum Refining	CO ₂	Yes	Level, Trend, and Quality
1.A.1.b	Fuel Combustion - Petroleum Refining	CH ₄		
1.A.1.b	Fuel Combustion - Petroleum Refining	N ₂ O		
1.A.1.c	Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries	CO ₂	Yes	Level, Trend, and quality
1.A.1.c	Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries	CH ₄		
1.A.1.c	Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries	N ₂ O		
1.A.2	Fuel Combustion - Manufacturing Industries and Construction	CO ₂	Yes	Level and Trend
1.A.2	Fuel Combustion - Manufacturing Industries and Construction	CH ₄		
1.A.2	Fuel Combustion - Manufacturing Industries and Construction	N ₂ O		
1.A.3.a	Fuel Combustion - Civil Aviation	CO ₂	Yes	Level, Trend, and Quality
1.A.3.a	Fuel Combustion - Civil Aviation	CH ₄	Yes	Quality
1.A.3.a	Fuel Combustion - Civil Aviation	N ₂ O	Yes	Quality
1.A.3.b	Fuel Combustion - Road Transportation	CO ₂	Yes	Level, Trend, and Quality
1.A.3.b	Fuel Combustion - Road Transportation	CH ₄	Yes	Quality
1.A.3.b	Fuel Combustion - Road Transportation	N ₂ O	Yes	Trend and Quality
1.A.3.c	Fuel Combustion - Railways	CO ₂	Yes	Level and Trend
1.A.3.c	Fuel Combustion - Railways	CH ₄		
1.A.3.c	Fuel Combustion - Railways	N ₂ O	Yes	Quality
1.A.3.d	Fuel Combustion - Navigation	CO ₂	Yes	Level and Quality
1.A.3.d	Fuel Combustion - Navigation	CH ₄	Yes	Quality
1.A.3.d	Fuel Combustion - Navigation	N ₂ O	Yes	Quality
1.A.3.e	Fuel Combustion - Other Transportation	CO ₂	Yes	Level, Trend, and Quality
1.A.3.e	Fuel Combustion - Other Transportation	CH ₄	Yes	Quality
1.A.3.e	Fuel Combustion - Other Transportation	N ₂ O	Yes	Quality
1.A.3.e	Fuel Combustion - Pipeline Transport	CO ₂	Yes	Level and Trend
1.A.3.e	Fuel Combustion - Pipeline Transport	CH ₄		
1.A.3.e	Fuel Combustion - Pipeline Transport	N ₂ O		
1.A.4	Fuel Combustion - Other Sectors	CO ₂	Yes	Level and Trend
1.A.4	Fuel Combustion - Other Sectors	CH ₄	Yes	Trend
1.A.4	Fuel Combustion - Other Sectors	N ₂ O		
1.B.1.a	Fugitive Emissions - Coal Mining	CH ₄	Yes	Trend
1.B.2.a	Fugitive Emissions - Oil	CO ₂		
1.B.2.a	Fugitive Emissions - Oil	CH ₄	Yes	Level
1.B.2.a	Fugitive Emissions - Oil	N ₂ O		
1.B.2.b	Fugitive Emissions - Natural Gas	CO ₂		
1.B.2.b	Fugitive Emissions - Natural Gas	CH ₄	Yes	Level and Trend

CRF Reporter Table	IPCC Categories	Direct GHG	Key Category (Yes/No)	If Yes, Criteria for Identification
1.B.2.c.1.1	Fugitive Emissions - Oil and Natural Gas - Venting - Oil	CO ₂	Yes	Level and Trend
1.B.2.c.1.1	Fugitive Emissions - Oil and Natural Gas - Venting - Oil	CH ₄	Yes	Level and Trend
1.B.2.c.1.2	Fugitive Emissions - Oil and Natural Gas - Venting - Natural Gas	CO ₂	Yes	Level and Trend
1.B.2.c.1.2	Fugitive Emissions - Oil and Natural Gas - Venting - Natural Gas	CH ₄	Yes	Level and Trend
1.B.2.c.1.3	Fugitive Emissions - Oil and Natural Gas - Venting - Combined	CO ₂		
1.B.2.c.1.3	Fugitive Emissions - Oil and Natural Gas - Venting - Combined	CH ₄		
1.B.2.c.2.1	Fugitive Emissions - Oil and Natural Gas - Flaring - Oil	CO ₂	Yes	Trend
1.B.2.c.2.1	Fugitive Emissions - Oil and Natural Gas - Flaring - Oil	CH ₄		
1.B.2.c.2.1	Fugitive Emissions - Oil and Natural Gas - Flaring - Oil	N ₂ O		
1.B.2.c.2.2	Fugitive Emissions - Oil and Natural Gas - Flaring - Natural Gas	CO ₂		
1.B.2.c.2.2	Fugitive Emissions - Oil and Natural Gas - Flaring - Natural Gas	CH ₄		
1.B.2.c.2.3	Fugitive Emissions - Oil and Natural Gas - Flaring - Combined	CO ₂	Yes	Trend
1.B.2.c.2.3	Fugitive Emissions - Oil and Natural Gas - Flaring - Combined	CH ₄		
2.A.1	Industrial Processes - Cement Production	CO ₂	Yes	Level and Quality
2.A.2	Industrial Processes - Lime Production	CO ₂	Yes	Quality
2.A.3	Industrial Processes - Limestone and Dolomite Use	CO ₂	Yes	Trend
2.A.4	Industrial Processes - Soda Ash Production and Use	CO ₂		
2.A.7.2	Industrial Processes - Magnesite Use	CO ₂		
2.B.1	Industrial Processes - Ammonia Production	CO ₂	Yes	Level and Quality
2.B.2	Industrial Processes - Nitric Acid Production	N ₂ O		
2.B.3	Industrial Processes - Adipic Acid Production	N ₂ O	Yes	Trend
2.C.1	Industrial Processes - Iron and Steel Production	CO ₂	Yes	Level and Trend
2.C.3	Industrial Processes - Aluminium Production	CO ₂	Yes	Level and Trend
2.C.3	Industrial Processes - Aluminium Production	PFCs	Yes	Trend
2.C.4.1	Industrial Processes - Aluminium Production	SF ₆		
2.C.4.2	Industrial Processes - Magnesium Production	SF ₆	Yes	Trend and Quality
2.C.5	Industrial Processes - Magnesium Casting	SF ₆		
2.F	Industrial Processes - Consumption of Halocarbons	HFCs	Yes	Level, Trend, and Quality
2.F	Industrial Processes - Consumption of Halocarbons	PFCs		
2.F.8	Industrial Processes - Consumption of SF ₆ for Electrical Equipment	SF ₆	Yes	Trend
2.F.7	Industrial Processes - Consumption of SF ₆ for Semiconductor	SF ₆		
2.G	Industrial Processes - Other (Undifferentiated Processes)	CO ₂	Yes	Level, Trend, and Quality
3.D	Solvent and Other Product Use	N ₂ O		
4.A	Agriculture - Enteric Fermentation	CH ₄	Yes	Level and Trend
4.B	Agriculture - Manure Management	CH ₄		
4.B	Agriculture - Manure Management	N ₂ O	Yes	Level
4.D.1	Agriculture - Direct Agricultural Soils	N ₂ O	Yes	Level and Trend
4.D.2	Agriculture - Animal Manure on Pasture, Range, and Paddock	N ₂ O	Yes	Level
4.D.3	Agriculture - Indirect Agricultural Soils	N ₂ O	Yes	Level and Trend

CRF Reporter Table	IPCC Categories	Direct GHG	Key Category (Yes/No)	If Yes, Criteria for Identification
5.A.1	LULUCF - Forest Land Remaining Forest Land	CO ₂	Yes	Level, Trend, and Quality
5.A.1	LULUCF - Forest Land Remaining Forest Land	CH ₄	Yes	Quality
5.A.1	LULUCF - Forest Land Remaining Forest Land	N ₂ O	Yes	Quality
5.A.2	LULUCF - Land Converted to Forest Land	CO ₂		
5.B.1	LULUCF - Cropland Remaining Cropland	CO ₂	Yes	Level, Trend, and Quality
5.B.2	LULUCF - Land Converted to Cropland	CO ₂	Yes	Level and Trend
5.B.2	LULUCF - Land Converted to Cropland	CH ₄		
5.B.2	LULUCF - Land Converted to Cropland	N ₂ O		
5.D.1	LULUCF - Wetlands Remaining Wetlands	CO ₂		
5.D.2	LULUCF - Land Converted to Wetlands	CO ₂	Yes	Trend
5.D.2	LULUCF - Land Converted to Wetlands	CH ₄		
5.D.2	LULUCF - Land Converted to Wetlands	N ₂ O		
5.E.1	LULUCF - Settlements remaining Settlements	CO ₂		
5.E.2	LULUCF - Land converted to Settlements	CO ₂	Yes	Level and Trend
5.E.2	LULUCF - Land converted to Settlements	CH ₄		
5.E.2	LULUCF - Land converted to Settlements	N ₂ O		
6.A	Waste - Solid Waste Disposal on Land	CH ₄	Yes	Level, Trend, and Quality
6.B	Waste - Wastewater Handling	CH ₄	Yes	Quality
6.B	Waste - Wastewater Handling	N ₂ O	Yes	Quality
6.C	Waste - Waste Incineration	CO ₂	Yes	Quality
6.C	Waste - Waste Incineration	CH ₄		
6.C	Waste - Waste Incineration	N ₂ O		
5 Information Items	Forest Land Converted to Other Land-Use Categories		Yes	Quality

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: 2005 Key Categories by Level Assessment¹ with and without LULUCF

Source Table	IPCC Source Categories	Direct GHG	1990 (Base Year) <i>kt CO₂ eq</i>	2005 (Current Year) <i>kt CO₂ eq</i>	Level Assessment (without LULUCF)	Level Assessment (with LULUCF)	Cumulative Total (without LULUCF)	Cumulative Total (with LULUCF)
1.A.3.b	Fuel Combustion - Road Transportation	CO ₂	97674	131122	0.176	0.180	18%	18%
1.A.1.a	Fuel Combustion - Public Electricity and Heat Production	CO ₂	94670	127657	0.171	0.175	35%	35%
1.A.4	Fuel Combustion - Other Sectors	CO ₂	69428	78046	0.104	0.107	45%	46%
1.A.2	Fuel Combustion - Manufacturing Industries and Construction	CO ₂	62202	62127	0.083	0.085	53%	55%
1.A.1.c	Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries	CO ₂	34058	52041	0.070	0.071	60%	62%
5.A.1	LULUCF - Forest Land remaining Forest Land ²	CO ₂	-154350	-34371	NA	0.047	NA	67%
1.A.3.e	Fuel Combustion - Other Transportation	CO ₂	20303	28434	0.038	0.039	64%	70%
6.A	Waste - Solid Waste Disposal on Land	CH ₄	21968	26775	0.036	0.037	68%	74%
4.A	Agriculture - Enteric Fermentation	CH ₄	18392	24527	0.033	0.034	71%	77%
1.B.2.b	Fugitive Emissions - Natural Gas	CH ₄	12876	20769	0.028	0.028	74%	80%
1.A.1.b	Fuel Combustion - Petroleum Refining	CO ₂	15501	18368	0.025	0.025	76%	83%
1.B.2.c.1.1	Fugitive Emissions - Oil and Natural Gas - Venting - Oil	CH ₄	9937	17210	0.023	0.024	79%	85%
4.D	Agriculture - Direct Agricultural Soils	N ₂ O	12098	12690	0.017	0.017	80%	87%
2.G	Industrial Processes - Other (Undifferentiated Processes)	CO ₂	8317	12613	0.017	0.017	82%	89%
5.B.2	LULUCF - Land converted to Cropland ²	CO ₂	16529	10120	NA	0.014	NA	90%
5.B.1	LULUCF - Cropland remaining Cropland ²	CO ₂	-2615	-9936	NA	0.014	NA	91%
1.A.3.e	Fuel Combustion - Pipeline Transport	CO ₂	6705	9846	0.013	0.013	83%	93%
1.A.3.a	Fuel Combustion - Civil Aviation	CO ₂	6216	8417	0.011	0.012	84%	94%
5.E.2	LULUCF - Land converted to Settlements ²	CO ₂	9202	8072	NA	0.011	NA	95%
1.B.2.c.1.2	Fugitive Emissions - Oil and Natural Gas - Venting - Natural Gas	CO ₂	4173	7217	0.010	NA	85%	NA
2.A.1	Industrial Processes - Cement Production	CO ₂	5436	7184	0.010	NA	86%	NA
2.C.1	Industrial Processes - Iron and Steel Production	CO ₂	7060	7010	0.009	NA	87%	NA
4.D	Agriculture - Indirect Agricultural Soils	N ₂ O	5389	6344	0.008	NA	88%	NA
1.A.3.d	Fuel Combustion - Navigation	CO ₂	4726	6072	0.008	NA	89%	NA
1.A.3.c	Fuel Combustion - Railways	CO ₂	6314	5623	0.008	NA	90%	NA
1.B.2.a	Fugitive Emissions - Oil	CH ₄	4055	5463	0.007	NA	90%	NA
4.B	Agriculture - Manure Management	N ₂ O	4070	5354	0.007	NA	91%	NA
2.B.1	Industrial Processes - Ammonia Production	CO ₂	3924	5002	0.007	NA	92%	NA
2.F	Industrial Processes - Consumption of Halocarbons	HFCs	0	4844	0.006	NA	92%	NA
2.C.3	Industrial Processes - Aluminium Production	CO ₂	2715	4842	0.006	NA	93%	NA
1.B.2.c.1.2	Fugitive Emissions - Oil and Natural Gas - Venting - Natural Gas	CH ₄	3198	4776	0.006	NA	94%	NA
4.D	Agriculture - Animal Manure on Pasture, Range and Paddock	N ₂ O	3183	4402	0.006	NA	94%	NA
1.B.2.c.1.1	Fugitive Emissions - Oil and Natural Gas - Venting - Oil	CO ₂	1917	3620	0.005	NA	95%	NA

Notes:

¹ IPCC *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, Chapter 7, Tier 1 Analysis - Level Assessment- Sorted

² These additional key categories were generated as a result of incorporating the LULUCF categories in the level assessment evaluation

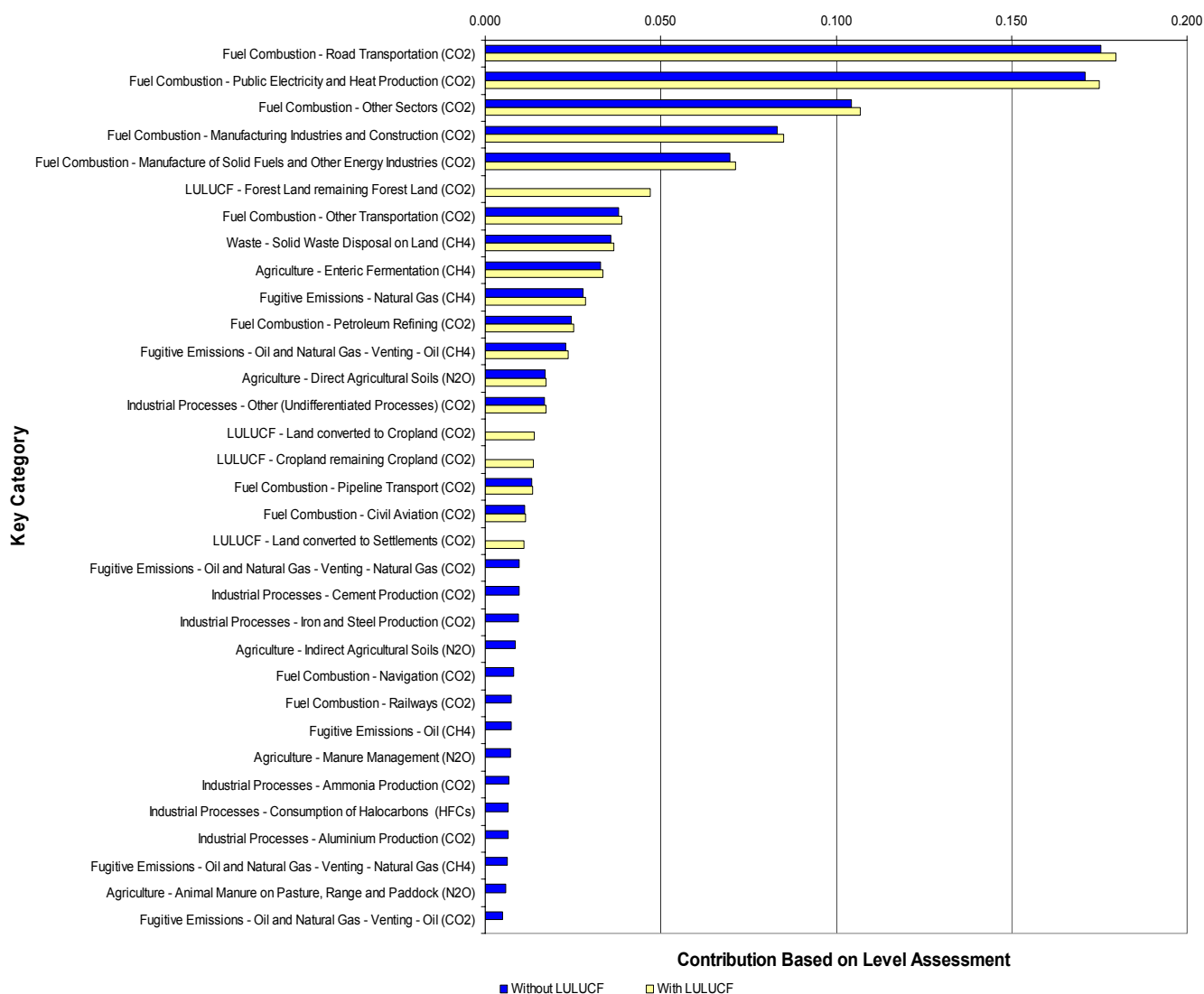


Figure A1-1: Contributions of Key Categories to Level Assessment with and without LULUCF

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.

Table A1-3: 2005 Key Categories by Trend Assessment¹ with and without LULUCF

Source Table	IPCC Source Categories	Direct GHG	1990 (Base Year) <i>kt CO₂ eq</i>	2005 (Current Year) <i>kt CO₂ eq</i>	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 ²	CO ₂	-154350	-34371	NA	0.181	NA	0.469	NA	47%
1.A.2	Fuel Combustion - Manufacturing Industries and Construction	CO ₂	62202	62127	0.017	0.030	0.133	0.078	13%	55%
2.B.3	Industrial Processes - Adipic Acid Production	N ₂ O	10718	2649	0.012	0.012	0.090	0.032	22%	58%
1.A.1.c	Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries	CO ₂	34058	52041	0.010	NA	0.078	NA	30%	NA
1.A.1.a	Fuel Combustion - Public Electricity and Heat Production	CO ₂	94670	127657	0.010	0.016	0.076	0.042	38%	62%
1.A.4	Fuel Combustion - Other Sectors	CO ₂	69428	78046	0.010	0.026	0.075	0.067	45%	69%
1.A.3.b	Fuel Combustion - Road Transportation	CO ₂	97674	131122	0.009	0.017	0.073	0.045	53%	73%
2.C.3	Industrial Processes - Aluminium Production	PFCs	6539	3048	0.005	0.006	0.043	0.016	57%	75%
2.F	Industrial Processes - Consumption of Halocarbons	HFCs	0	4844	0.005	0.004	0.041	0.011	61%	76%
1.B.2.c.1.1	Fugitive Emissions - Oil and Natural Gas - Venting - Oil	CH ₄	9937	17210	0.005	0.002	0.040	0.004	65%	76%
1.B.2.b	Fugitive Emissions - Natural Gas	CH ₄	12876	20769	0.005	NA	0.039	NA	69%	NA
5.B.2	LULUCF - Land converted to Cropland ²	CO ₂	16529	10120	NA	0.014	NA	0.035	NA	80%
1.A.3.e	Fuel Combustion - Other Transportation	CO ₂	20303	28434	0.003	0.003	0.025	0.007	71%	81%
2.C.4.2	Industrial Processes - Magnesium Production	SF ₆	2870	1092	0.003	0.003	0.021	0.008	73%	81%
4.D	Agriculture - Direct Agricultural Soils	N ₂ O	12098	12690	0.003	0.005	0.021	0.014	75%	83%
1.A.3.c	Fuel Combustion - Railways	CO ₂	6314	5623	0.002	0.004	0.019	0.009	77%	84%
2.G	Industrial Processes - Other (Undifferentiated Processes)	CO ₂	8317	12613	0.002	NA	0.018	NA	79%	NA
1.B.2.c.1.2	Fugitive Emissions - Oil and Natural Gas - Venting - Natural Gas	CO ₂	4173	7217	0.002	NA	0.017	NA	81%	NA
6.A	Waste - Solid Waste Disposal on Land	CH ₄	21968	26775	0.001	0.006	0.006	0.016	82%	85%
2.C.1	Industrial Processes - Iron and Steel Production	CO ₂	7060	7010	0.002	0.003	0.015	0.009	83%	86%
5.D.2	LULUCF - Land converted to Wetlands ²	CO ₂	4653	1045	NA	0.005	NA	0.014	NA	88%
5.E.2	LULUCF - Land converted to Settlements ²	CO ₂	9202	8072	NA	0.005	NA	0.014	NA	89%
1.B.1.a	Fugitive Emissions - Coal Mining	CH ₄	1914	726	0.002	0.002	0.014	0.005	84%	90%
5.B.1	LULUCF - Cropland remaining Cropland ²	CO ₂	-2615	-9936	NA	0.005	NA	0.014	NA	91%
1.A.1.b	Fuel Combustion - Petroleum Refining	CO ₂	15501	18368	0.001	0.005	0.009	0.013	85%	92%
4.A	Agriculture - Enteric Fermentation	CH ₄	18392	24527	0.002	0.003	0.012	0.009	87%	93%
1.A.3.e	Fuel Combustion - Pipeline Transport	CO ₂	6705	9846	0.002	NA	0.012	NA	88%	NA
2.C.3	Industrial Processes - Aluminium Production	CO ₂	2715	4842	0.002	NA	0.012	NA	89%	NA
1.B.2.c.1.1	Fugitive Emissions - Oil and Natural Gas - Venting - Oil	CO ₂	1917	3620	0.001	NA	0.010	NA	90%	NA
2.F.8	Industrial Processes - Consumption of SF ₆ for Electrical Equipment	SF ₆	1796	1188	0.001	0.001	0.009	0.004	91%	93%
1.B.2.c.2.3	Fugitive Emissions - Oil and Natural Gas - Flaring - Combined	CO ₂	275	1365	0.001	NA	0.009	NA	92%	NA
1.B.2.c.1.2	Fugitive Emissions - Oil and Natural Gas - Venting - Natural Gas	CH ₄	3198	4776	0.001	NA	0.006	NA	92%	NA
1.A.4	Fuel Combustion - Other Sectors	CH ₄	2117	1972	0.001	0.001	0.006	0.003	93%	94%
2.A.3	Industrial Processes - Limestone and Dolomite Use	CO ₂	734	250	0.001	NA	0.006	NA	94%	NA
1.A.3.a	Fuel Combustion - Civil Aviation	CO ₂	6216	8417	0.001	NA	0.005	NA	94%	NA
4.D	Agriculture - Indirect Agricultural Soils ²	N ₂ O	5389	6344	NA	0.002	NA	0.005	NA	94%
1.B.2.c.2.1	Fugitive Emissions - Oil and Natural Gas - Flaring - Oil	CO ₂	3311	3546	0.001	0.001	0.005	0.004	95%	95%
1.A.3.b	Fuel Combustion - Road Transportation ²	N ₂ O	3202	3472	NA	0.001	NA	0.003	NA	95%

Notes:

1 IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, Chapter 7, Tier 1 Analysis - Trend Assessment- Sorted

2 These additional key categories were generated as a result of incorporating the LULUCF categories in the trend assessment evaluation

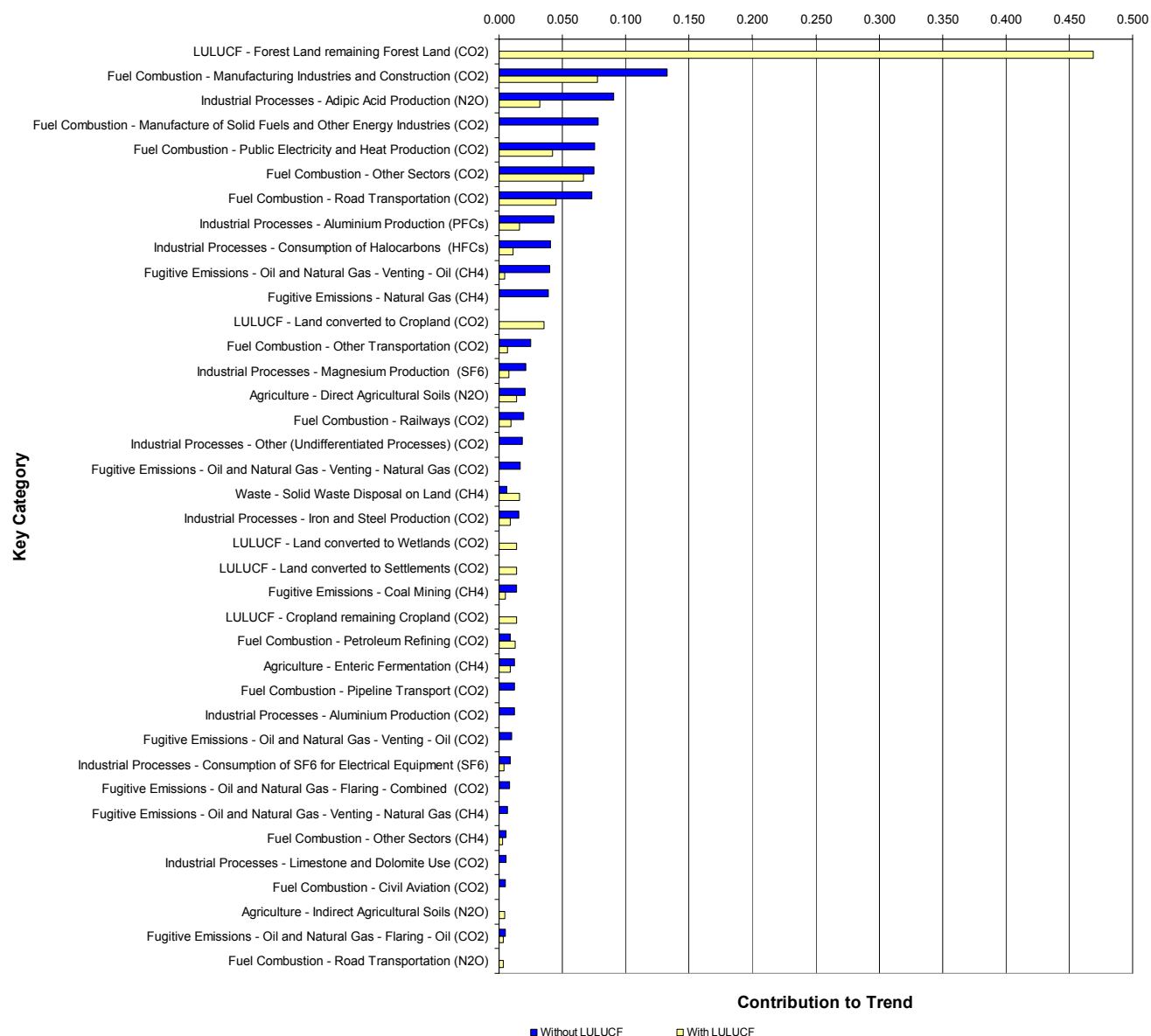


Figure A1-2: Contributions of Key Categories to Trend Assessment with and without LULUCF

A1.2.3 Qualitative Assessment

A1.2.3.1 Mitigation Techniques and Technologies

Mitigation techniques are important for good practices, 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 ₂	Government of Canada, 2006	Increased biofuel use
Fuel Combustion - Road Transportation	N ₂ O	Government of Canada, 2006	Memorandum of Understanding between Government of Canada and Canadian Automakers
Fuel Combustion - Public Electricity and Heat Production	CO ₂	Government of Canada, 2007; NRCan 2006; NRCan 2007	Utility deregulation continues to open markets and reduces barriers to inter-provincial trade. Increased co-generation 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 & 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 ₄	Environment Canada, 1999 Environment Canada, 2007	Landfills are collecting CH ₄ emissions for combustion or power generation: Policy measure
Industrial Processes - Magnesium Production	SF ₆	NRCan, 1999	Gradual replacement of SF ₆ in magnesium casting and smelting by alternative cover gases: Voluntary measure
Cropland remaining Cropland	CO ₂	See Chap.7	Voluntary adoption of no till and reduced summerfallow by farmers does increase soil carbon stocks

A1.2.3.2 High Emissions Growth

Table A1-5 shows key categories identified as a result of having emissions 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 Emissions Growth

Key Category	GHG	Reference(s)	Comments
Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries	CO2	NRCan, 2006	Increased heavy oil production
Fuel Combustion - Petroleum Refining	CO2	NRCan, 2006	Increased heavy oil use
		CPPI, 2004	Growth in emissions as a result of desulphurization initiatives for liquid fuels (for gasoline, diesel, and furnace oil)
Fuel Combustion - Transport - Road	CO2	NRCan, 2006	Growth in road transport
Fuel Combustion - Transport - Road	N2O	NRCan, 2006	Growth in road transport
Fuel Combustion - Transport - Road	CH4	NRCan, 2006	Growth in road transport
Fuel Combustion - Transport - Civil Aviation	CO2,	NRCan, 2006	Growth in air travel
Fuel Combustion - Transport - Civil Aviation	N2O	NRCan, 2006	Growth in air travel
Fuel Combustion - Transport - Civil Aviation	CH4	NRCan, 2006	Growth in air travel
Fuel Combustion - Transport - Aviation Bunkers	CO2	NRCan, 2006	Growth in air travel
Fuel Combustion - Transport - Aviation Bunkers	N2O	NRCan, 2006	Growth in air travel
Fuel Combustion - Transport - Aviation Bunkers	CH4	NRCan, 2006	Growth in air travel
Fuel Combustion - Transport - Navigation	CO2	NRCan, 2006	Growth in Navigation
Fuel Combustion - Transport - Navigation	N2O	NRCan, 2006	Growth in Navigation
Fuel Combustion - Transport - Navigation	CH4	NRCan, 2006	Growth in Navigation
Fuel Combustion - Transport - Marine Bunkers	CO2	NRCan, 2006	Growth in Navigation
Fuel Combustion - Transport - Marine Bunkers	N2O	NRCan, 2006	Growth in Navigation
Fuel Combustion - Transport - Marine Bunkers	CH4	NRCan, 2006	Growth in Navigation
Fuel Combustion - Transport - Other	CO2	NRCan, 2006	Growth in off-road use, especially fossil fuel mining
Consumption of HFCs	HFCs	NRCan, 1999	Increase due to replacement of CFCs

A1.2.3.3 High Uncertainty

Although many updates have been made to the source category uncertainty since the ICF (2004, 2005) studies of uncertainty associated with 2001 inventory estimates, these studies still provide for 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 - Manufacturing of Solid Fuels and Other Energy Industries	CO ₂	ICF, 2004
Fuel Combustion - Petroleum Refining	CO ₂	ICF, 2004
Waste - Solid Waste Disposal on Land	CH ₄	ICF, 2004
Waste - Waste Incineration	CO ₂	ICF, 2004
Waste - Wastewater Handling	N ₂ O	ICF, 2004
Waste - Wastewater Handling	CH ₄	ICF, 2004
Fuel Combustion - Off Road: Diesel	N ₂ O	ICF, 2004
Fuel Combustion - Rail	N ₂ O	ICF, 2004
Fuel Combustion - Road	CO ₂	ICF, 2004
Fuel Combustion - Off Road: Diesel	CO ₂	ICF, 2004
Fuel Combustion - Off Road: Gasoline	CO ₂	ICF, 2004
Fuel Combustion - Marine (Navigation)	N ₂ O	ICF, 2004
Fuel Combustion - Aviation	N ₂ O	ICF, 2004
Fuel Combustion - Off Road: Gasoline	CH ₄	ICF, 2004
Industrial Processes - Other and Undifferentiated Production	CO ₂	ICF, 2004
Industrial Processes - Ammonia Production	CO ₂	ICF, 2004
Industrial Processes - Cement Production	CO ₂	ICF, 2004
Industrial Processes - Lime Production	CO ₂	Chapter 4

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 split 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 key category in the national inventory because it is larger than the smallest key category identified in the quantitative analysis. In addition, CO₂ estimates in the Forest Land remaining Forest Land category are the net result of very large fluxes of emissions and removals due to ecosystem processes (photosynthesis, decay, respiration etc.). Therefore, this category was also identified as key. CH₄ and N₂O sources from Forest land remaining Forest land are also tagged as key because of unexpected high or low emissions due to the elevated inter-annual variability in wildfires.

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Annex 2 Methodology and Data for Estimating Emissions from Fossil Fuel Combustion

The following, present an overview of the methodology, activity data and emission factors used to estimate carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O) emissions from fuel combustion sources for the Energy sector. While additional methodological details and refinements to the general approach are presented in section A2.4.1 for stationary and section A2.4.2 for transport sources.

A2.1 Methodology

In general, a top-down method following the *Revised 1996 IPCC Tier 3 and Tier 2* sectoral approach (IPCC/OECD/IEA, 1997) are used to estimate greenhouse gas (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 derivations from the general approach to the combustion estimate are discussed in the stationary combustion and the transport section of this Annex. The purpose for these refinements is to increase the accuracy and allocation of emissions associated with each source categories when additional details or parameters are available, while 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:

$E_{Category,G}$ = Greenhouse gas emissions by source category and by gases

$FC_{F,R}$ = Quantity of fuel consumed (in physical units such as kg, l or m³) by type of fuel (i.e., natural gas, sub-bituminous coal, kerosene, etc.) and by regions

$EF_{G,F,R,T}$ = Country specific emission factors (in physical units) by greenhouse gases, by fuel type, by regions for each coal type and by technology (for non-CO₂ factors)

Mainly relational databases are used by the stationary and transport models to process the activity data and the emission factors at the national and/or provincial level of details 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. This data is considered more accurate and country specific emission factors were developed based on physical units as to minimize the number of additional conversion factors to limit the uncertainty associated with the estimate. To further reduce

the uncertainty of these estimates, when higher resolution of emission factors at the regional level are available then regional information are applied rather than national values such as coal emission factors to account for the variation in the carbon content of coal over various regions and over time. While combustion technology differences are addressed by non-CO₂ emission factors.

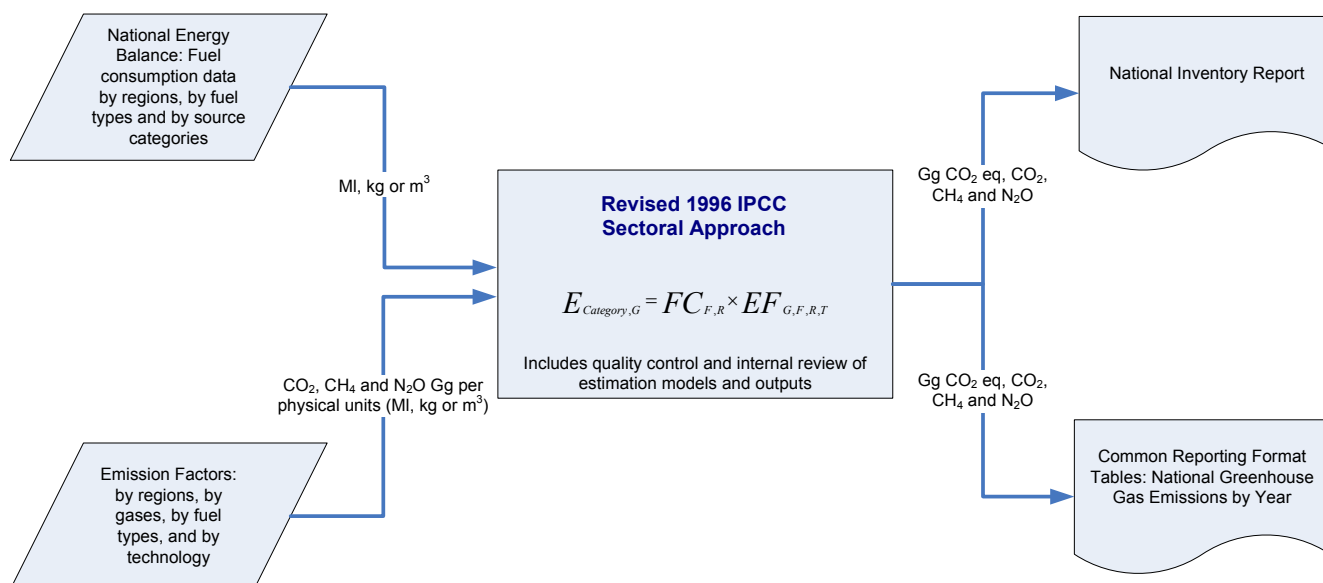


Figure A2-1: GHG Estimation Process Flow

A2.2 Activity Data – Statistics Canada

The principal source of fossil fuel and energy data used to estimate combustion emissions are from the *Annual Report on Energy Supply-Demand in Canada* (ARESD, Statistics Canada, #57-003), compiled by Statistics Canada, Canada's statistics agency.

The ARESD uses a top-down approach to estimate the supply and demand of 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, residential, etc. Industrial energy-use data are divided into broad sectors based on Standard Industrial Classification (SIC).

While the ARESD 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 ARESD 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 Industrial Consumption of Energy (ICE) survey. This bottom-up

approach to estimating fuel use by industry (as opposed to the top-down approach used in the ARES) may provide more accurate information at the sectoral level for future inventories. Refer to Annex 4 for additional discussions on the development of the ARES and the ICE data set including a discussion on Statistics Canada's quality control and quality assurance 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 quantity of fossil fuel consumed are also available in gross calorific units, 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, by applying an overall energy conversion factor for different fuels over all source categories and regions

Additional activity data sources used by the combustion and transport models are included in the specific methodological discussions such as vehicle fleet information.

A2.3 Fuel Combustion Emission factors

Description of emission factors employed in estimating the emissions for the current fossil fuel combustion models can be found in Annex 12. In general, for:

- *Natural Gas Fuels*: The emission factors vary by fuel type and/or combustion technology.
- *Refined Petroleum Product Fuels*: The emission factors vary by fuel type and/or combustion technology.
- *Coal Fuels*: The emission factors for CO₂ 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 CH₄ and N₂O vary with the combustion technology.

A2.3.1 CO₂ Emission Factors

CO₂ 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 CO₂ 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 CO₂ emissions. It is assumed

that CO in the atmosphere undergoes complete oxidation to CO₂ shortly after combustion (within 5–20 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 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 N₂O and CH₄ emissions, the combustion technology employed.

A2.3.2 Non-CO₂ Emission Factors

Emission factors for all non-CO₂ 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 CH₄. Additional research is necessary to better establish CH₄ 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, CH₄ emission factors are not known.

During combustion some of the nitrogen in the fuel and air is converted to N₂O. The production of N₂O is dependent upon the combustion temperature and the control technology employed. Additional research is necessary to better establish N₂O 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, N₂O emission factors are not known. Non-CO₂ emission factors in this inventory are listed in Annex 12.

A2.3.3 Biomass

For UNFCCC reporting, CO₂ emissions from biomass fuels are not be included in the Energy Sector total. CO₂ emissions from biomass fuel combustion are accounted for in the LULUCF Sector as a loss of biomass (forest) stocks. CO₂ from biomass combustion for energy purposes is reported as a memo item for information only. CH₄ and N₂O

emissions from biomass fuel combustion are reported in the Energy Sector in the appropriate subsectors and included in inventory totals.

A2.4 Methodology

A2.4.1 Stationary Combustion

The methodology used to estimate greenhouse gas emissions from stationary fuel combustion are consistent with the *Intergovernmental Panel on Climate Change (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, 1997). The methodology and emissions of SF₆ from the transmission of electricity generation (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 A2-2 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 sub-sectors are also provided:

- Electricity and Steam Generation
- Fossil Fuel Industry
- Manufacturing Industries and Construction
- Other Sectors
- Pipelines

Details on specific source categories are included in the notes section of Table A2-2. The complexity of the stationary combustion model lies in the allocation and distribution of the data presented in the ARES in order to comply with the UNFCCC common reporting format framework. Emissions estimates are calculated based on equation A2-1 exclusively and are consistent with *IPCC Tier 2 approach*.

Table A2-2 presents the methodology and emission factors according to the fuel types presented in Table A2-1. 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, natural gas liquids (NGLs) such as propane, ethane and butane are classified as gaseous fuels while petroleum coke is included under solid fuels.

Table A2-1: General Fuel Type Categories for Stationary Combustion Methodology

Fuel Types	Fuels
Liquid Fuels	Motor gasoline Kerosene & 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

A2.4.1.1 Electricity and Steam Generation (CRF 1.A.1.a)

The electricity and steam generation sectors include the sub-sectors 1.A.1.a.i Electricity Generation, 1.A.1.a.ii Combined Heat and Power Generation (CHP), and 1.A.1.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 ARES D does not distinguish between electricity and heat generated by industry for their own use and the amount that is supplied to the public.

CO₂, CH₄ and N₂O 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 is 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 Industry (CRF 1.A.1.b & 1.a.1.c)**

The fossil fuel industry includes the 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 Industry has a higher level of accuracy due to the resolution of the activity data. To meet the reporting requirements following the CRF category, assumptions were applied to re-allocate some of activity data for the industry as a whole into two separate categories. These categories include combustion emissions that support the production and processing of crude oil, 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 ARES D includes 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 is subtracted to avoid double-counting.

To determine the activity data associated with the Petroleum Refining sector, some data reported in the ARES D must be reallocated. All refined petroleum products 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* is 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 N₂O are used to estimate emissions for petroleum coke and motor gasoline, and are based on the calorific value of the fuel. The gross calorific value (GCV) for petroleum coke is reported in the ARES D and can change annually. As such, the emission factor for petroleum coke for both oilsands/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 Industry Energy End-Use Data and 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 ARES D are used in equation A2-1:

- Natural gas, coal

The following fuels are reported as *producer consumed* in oilsands/crude bitumen production industry in the ARES D. These amounts are subtracted from this Petroleum Refining sector and included in the Manufacture of Solid Fuels and other Energy Industries sector.

- Petroleum coke, still gas

As previously mentioned in 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 1.A.2)*

The Manufacturing Industries and Construction sector include a number of subsectors and industries. Activity data in the ARES D are reported for the main economic and fuel-consuming industrial categories. Future improvement to the ARES D will allow for further disaggregation of these industrial categories to be consistent with the North American Industrial Classification Systems (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, and Beverage & Tobacco)

GHG emissions associated with the Manufacturing Industries and Construction sectors are calculated by applying equation A2-1 to activity data reported in the ARES D and emission factors for specific fuels on a national basis. Coal emissions are handled as described in A.2.4.1.1. Emissions resulting from fuels used as feedstocks are reported under the Industrial Processes Sector while emissions generated from the use of transportation fuels (e.g., diesel and gasoline) are reported under the Transport sector.

CO₂ 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. CH₄ and N₂O emissions however, are included as they are by-products of the combustion process.

CO₂ emission associated with biomass combustion in the Pulp, Paper and Print sector are not included in the national totals; however CH₄ and N₂O emissions are included in the totals. Industrial consumption of biomass and spent pulping liquors is reported in the ARES. It is assumed that industrial fuelwood is reported on a wet basis and the average moisture content of solid wood waste is 50%. This assumption is currently being reviewed.

A2.4.1.4 Other Sectors (CRF 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 are calculated by applying equation A2-1 to activity data reported in the ARES and emission factors for specific fuels on a national basis.

CO₂ emission associated with biomass combustion in the Residential category is not included in the national total; however CH₄ and N₂O emissions are included. Further detail on estimating CO₂ emissions from biomass is presented in the Residential Firewood section (3.4.2.1) of chapter 3.

The Agriculture/Forestry/Fisheries sector (CRF Category 1.A.4.c) includes emissions from stationary fuel combustion only from in 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 ARES. 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.

A2.4.1.5 Pipelines (CRF 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.

Table A2-2: Stationary Combustion GHG Estimation Methodology

Source Category ⁽¹⁾	Fuels List ⁽²⁾	Activity Data Source ⁽³⁾	Emission Factor Source ⁽⁴⁾	Notes ⁽⁵⁾
1.A.1.a.i Electricity Generation - Utilities	Solid (I) Solid (II)	(A) [I, IV]	CO ₂ : (3), (7), (8), (9) CH ₄ : (10) N ₂ O: (6), (10)	Canada total for CO ₂ is the sum of each provinces/territories emission due to regional emission factors being used EXCEPT for <u>petroleum coke</u> emissions, which are based on the national total reported in the ARES D. Canada total for CH ₄ and N ₂ O are based on the national total reported in the ARES D.
	Liquid (I) Liquid (II)	(A) [II]	CO ₂ : (7) CH ₄ : (10) N ₂ O: (10)	Canada totals for CO ₂ , CH ₄ and N ₂ O are based the national total reported in the ARES D.
	Gas (I)	(A) [I, V]	CO ₂ : (8) CH ₄ : (10) N ₂ O: (10)	Canada totals for CO ₂ , CH ₄ and N ₂ O are based the national total reported in the ARES D.
	Biomass (n/a)			
1.A.1.a.ii Electricity Generation - Industry	Solid (I) Solid (II)	(A) [I, IV]	CO ₂ : (3), (7), (8), (9) CH ₄ : (10) N ₂ O: (6), (10)	Canada total for CO ₂ is the sum of each 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 ARES D. Canada total for CH ₄ and N ₂ O are based on the national total reported in the ARES D.
	Liquid (I) Liquid (II)	(A) [II]	CO ₂ : (7) CH ₄ : (10) N ₂ O: (10)	Canada totals for CO ₂ , CH ₄ and N ₂ O are based the national total reported in the ARES D.
	Gas (I)	(A) [I, V]	CO ₂ : (8) CH ₄ : (10) N ₂ O: (10)	Canada totals for CO ₂ , CH ₄ and N ₂ O are based the national total reported in the ARES D.
	Biomass (n/a)			

Source Category ⁽¹⁾	Fuels List ⁽²⁾	Activity Data Source ⁽³⁾	Emission Factor Source ⁽⁴⁾	Notes ⁽⁵⁾
1.A.1.a.iii Heat & Steam Generation	Solid (I) Solid (II)	(A) [I, IV]	CO ₂ : (3), (7), (8), (9) CH ₄ : (10) N ₂ O: (6), (10)	Canada total for CO ₂ is the sum of each province/territory emissions due to regional emission factors being used. Canada total for CH ₄ and N ₂ O are based on the national total reported in the ARES D.
	Liquid (I)	(A) [II]	CO ₂ : (7) CH ₄ : (10) N ₂ O: (10)	Canada totals for CO ₂ , CH ₄ and N ₂ O are based the national total reported in the ARES D. Liquid (II) not included in this sub-sector because there is no data reported in the table such as no consumption of propane, butane and ethane in Table 17 for the generation of heat and steam.
	Gas (I)	(A) [I, V]	CO ₂ : (8) CH ₄ : (10) N ₂ O: (10)	Canada totals for CO ₂ , CH ₄ and N ₂ O are based the national total reported in the ARES D.
	Biomass (n/a)			
1.A.1.b. Petroleum Refining (Upstream & Downstream Oil and Gas Industries)	Solid (I) Solid (II) Solid (III)	(A) [I, IV, VII]	CO ₂ : (3), (7), (8), (9) CH ₄ : (10) N ₂ O: (6), (10)	Canada total for CO ₂ is the sum of each provinces/territories emission 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 ARES D. Canada total for CH ₄ and N ₂ O are based on the national total reported in the ARES D.

Source Category ⁽¹⁾	Fuels List ⁽²⁾	Activity Data Source ⁽³⁾	Emission Factor Source ⁽⁴⁾	Notes ⁽⁵⁾
	Liquid (I) Liquid (II) Liquid (III)	(A) [II, III] (B)	CO ₂ : (7) CH ₄ : (10) N ₂ O: (10)	Canada totals for CO ₂ , CH ₄ and N ₂ O are based on the national total reported in the ARES minus emission related to flaring. The activity data reported in the ARES includes the amount fuel used to flare. CO ₂ and CH ₄ emissions from flaring activity is considered a fugitive source following the IPCC Guideline, therefore the fugitive emission and fuel value is subtracted from the estimated emissions and the ARES value. Due to alack of greater resolution with the activity data, negative values does occurs when fugitives are excluded (i.e., CH ₄ emissions) resulting with zero CH ₄ emissions for the petroleum refining category, the remaining emissions are accounted for in the Manufacture of Solid Fuel and Other Energy Industries. Future improvements need to ensure that the activity data are allocated accurately to both fossil fuel sectors.
	Gas (I)	(A) [I, V, VII]	CO ₂ : (8) CH ₄ : (1), (4) N ₂ O: (10)	Canada totals for CO ₂ , CH ₄ and N ₂ O are based the national total reported in the ARES.
	Biomass (n/a)			
1.A.1.c. Manufacture of Solid Fuels and Other Energy Industries	Solid (I) Solid (II)	(A) [I, IV, VII]	CO ₂ : (2), (7), (8), (9) CH ₄ : (10) N ₂ O: (6), (10)	Canada total for CO ₂ is the sum of each 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 ARES. Canada total for CH ₄ and N ₂ O are based on the national total reported in the ARES.
	Liquid (n/a)	IE	IE	Liquid fuels included in inventory elsewhere (1.A.1.b).

Source Category ⁽¹⁾	Fuels List ⁽²⁾	Activity Data Source ⁽³⁾	Emission Factor Source ⁽⁴⁾	Notes ⁽⁵⁾
	Gas (I)	(A) [I, V, VII] (B)	CO ₂ : (8) CH ₄ : (10) N ₂ O: (10)	The activity data for natural gas reported in the ARES D 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 ARES D value to avoid double counting, respectively.
	Biomass (n/a)			
1.A.2.a. Iron & Steel	Solid (I) Solid (II)	(A) [I, IV]	CO ₂ : (3), (7), (8), (9) CH ₄ : (10) N ₂ O: (6), (10)	Canada total for CO ₂ is the sum of each 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 ARES D. Canada total for CH ₄ and N ₂ O are based on the national total reported in the ARES D. CO ₂ emissions from <i>Coke</i> are not included here, but are included in Industrial Processes. However, CH ₄ and N ₂ O emissions are counted here. The CO ₂ is considered part of the processes (i.e., acts as a catalyst), while the CH ₄ and N ₂ O are by products of combustion.
	Liquid (I) Liquid (II)	(A) [II]	CO ₂ : (7) CH ₄ : (10) N ₂ O: (10)	Canada totals for CO ₂ , CH ₄ and N ₂ O are based the national total reported in the ARES D. CO ₂ , CH ₄ and N ₂ O associated with Transport fuels (i.e., gasoline and diesel) are included in the Transport subsector.
	Gas (I)	(A) [I, V]	CO ₂ : (8) CH ₄ : (10) N ₂ O: (10)	Canada totals for CO ₂ , CH ₄ and N ₂ O are based the national total reported in the ARES D.
	Biomass (n/a)			

Source Category ⁽¹⁾	Fuels List ⁽²⁾	Activity Data Source ⁽³⁾	Emission Factor Source ⁽⁴⁾	Notes ⁽⁵⁾
1.A.2.b. Non-Ferrous Metals	Solid (I) Solid (II)	(A) [I, IV]	CO ₂ : (3), (7), (8), (9) CH ₄ : (10) N ₂ O: (6), (10)	Canada total for CO ₂ is the sum of each 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 ARES D. Canada total for CH ₄ and N ₂ O are based on the national total reported in the ARES D.
	Liquid (I) Liquid (II)	(A) [II]	CO ₂ : (7) CH ₄ : (10) N ₂ O: (10)	Canada totals for CO ₂ , CH ₄ and N ₂ O are based the national total reported in the ARES D. CO ₂ , CH ₄ and N ₂ O associated with Transport fuels (i.e., gasoline and diesel) are included in the Transport subsector.
	Gas (I)	(A) [I, V]	CO ₂ : (8) CH ₄ : (10) N ₂ O: (10)	Canada totals for CO ₂ , CH ₄ and N ₂ O are based the national total reported in the ARES D.
	Biomass (n/a)			
1.A.2.c. Chemicals	Solid (I) Solid (II)	(A) [I, IV]	CO ₂ : (3), (7), (8), (9) CH ₄ : (10) N ₂ O: (6), (10)	Canada total for CO ₂ is the sum of each 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 ARES D. Canada total for CH ₄ and N ₂ O are based on the national total reported in the ARES D.
	Liquid (I) Liquid (II)	(A) [II, V]	CO ₂ : (7) CH ₄ : (10) N ₂ O: (10)	Canada totals for CO ₂ , CH ₄ and N ₂ O are based the national total reported in the ARES D. CO ₂ , CH ₄ and N ₂ O associated with Transport fuels (i.e., gasoline and diesel) are included in the Transport subsector.
	Gas (I)	(A) [I]	CO ₂ : (8) CH ₄ : (10) N ₂ O: (10)	Canada totals for CO ₂ , CH ₄ and N ₂ O are based the national total reported in the ARES D.

Source Category ⁽¹⁾	Fuels List ⁽²⁾	Activity Data Source ⁽³⁾	Emission Factor Source ⁽⁴⁾	Notes ⁽⁵⁾
	Biomass (n/a)			
1.A.2.d. Pulp, Paper & Print	Solid (I) Solid (II)	(A) [I, IV]	CO ₂ : (3), (7), (8), (9) CH ₄ : (10) N ₂ O: (6), (10)	Canada total for CO ₂ is the sum of each 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 ARES D. Canada total for CH ₄ and N ₂ O are based on the national total reported in the ARES D.
	Liquid (I) Liquid (II)	(A) [II, V]	CO ₂ : (7) CH ₄ : (10) N ₂ O: (10)	Canada totals for CO ₂ , CH ₄ and N ₂ O are based the national total reported in the ARES D. CO ₂ , CH ₄ and N ₂ O associated with Transport fuels (i.e., gasoline and diesel) are included in the Transport subsector.
	Gas (I)	(A) [I]	CO ₂ : (8) CH ₄ : (10) N ₂ O: (10)	Canada totals for CO ₂ , CH ₄ and N ₂ O are based the national total reported in the ARES D.
	Biomass (I)	(A) [VI]	CO ₂ : (C) CH ₄ : (C) N ₂ O: (C)	Total biomass is the amount of Industrial Fuelwood and Spent Pulping Liquors combusted. Canada totals for CO ₂ , CH ₄ and N ₂ O are based the national total reported in the ARES D. Biomass CO ₂ emissions are not included in the national totals although CH ₄ and N ₂ O emissions are.
1.A.2.e. Food Processing, Beverages and Tobacco	Solid	IE	IE	Emissions for this sub-sector are included 1.A.2.f.iv. Other Manufacturing.
	Liquid	IE	IE	Emissions for this sub-sector are included 1.A.2.f.iv. Other Manufacturing.
	Gas	IE	IE	Emissions for this sub-sector are included 1.A.2.f.iv. Other Manufacturing.
	Biomass	IE	IE	Emissions for this sub-sector are included 1.A.2.f.iv. Other Manufacturing.

Source Category ⁽¹⁾	Fuels List ⁽²⁾	Activity Data Source ⁽³⁾	Emission Factor Source ⁽⁴⁾	Notes ⁽⁵⁾
1.A.2.f.i. Cement	Solid (I) Solid (II)	(A) [I, IV]	CO ₂ : (3), (7), (8), (9) CH ₄ : (10) N ₂ O: (6), (10)	Canada total for CO ₂ is the sum of each 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 ARES D. Canada total for CH ₄ and N ₂ O are based on the national total reported in the ARES D.
	Liquid (I) Liquid (II)	(A) [II, V]	CO ₂ : (7) CH ₄ : (10) N ₂ O: (10)	Canada totals for CO ₂ , CH ₄ and N ₂ O are based the national total reported in the ARES D. CO ₂ , CH ₄ and N ₂ O associated with Transport fuels (i.e., gasoline and diesel) are included in the Transport subsector.
	Gas (I)	(A) [I]	CO ₂ : (8) CH ₄ : (10) N ₂ O: (10)	Canada totals for CO ₂ , CH ₄ and N ₂ O are based the national total reported in the ARES D.
	Biomass (n/a)			
1.A.2.f.ii. Mining	Solid (I) Solid (II)	(A) [I, IV]	CO ₂ : (3), (7), (8), (9) CH ₄ : (10) N ₂ O: (6), (10)	Canada total for CO ₂ is the sum of each 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 ARES D. Mining according to the ARES D includes fuel consumed for mining and extraction of oil and gas. Canada total for CH ₄ and N ₂ O are based on the national total reported in the ARES D.
	Liquid (I) Liquid (II)	(A) [II, V]	CO ₂ : (7) CH ₄ : (10) N ₂ O: (10)	Canada totals for CO ₂ , CH ₄ and N ₂ O are based the national total reported in the ARES D. CO ₂ , CH ₄ and N ₂ O associated with Transport fuels (i.e., gasoline and diesel) are included in the Transport subsector.

Source Category ⁽¹⁾	Fuels List ⁽²⁾	Activity Data Source ⁽³⁾	Emission Factor Source ⁽⁴⁾	Notes ⁽⁵⁾
	Gas (I)	(A) [I]	CO ₂ : (8) CH ₄ : (10) N ₂ O: (10)	Canada totals for CO ₂ , CH ₄ and N ₂ O are based the national total reported in the ARES D.
	Biomass (n/a)			
1.A.2.f.iii. Construction	Solid (I) Solid (II)	(A) [I, IV]	CO ₂ : (3), (7), (8), (9) CH ₄ : (10) N ₂ O: (6), (10)	Canada total for CO ₂ is the sum of each 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 ARES D. Canada total for CH ₄ and N ₂ O are based on the national total reported in the ARES D.
	Liquid (I) Liquid (II)	(A) [II, V]	CO ₂ : (7) CH ₄ : (10) N ₂ O: (10)	Canada totals for CO ₂ , CH ₄ and N ₂ O are based the national total reported in the ARES D. CO ₂ , CH ₄ and N ₂ O associated with Transport fuels (i.e., gasoline and diesel) are included in the Transport subsector.
	Gas (I)	(A) [I]	CO ₂ : (8) CH ₄ : (10) N ₂ O: (10)	Canada totals for CO ₂ , CH ₄ and N ₂ O are based the national total reported in the ARES D.
	Biomass (n/a)			
1.A.2.f.iv. Other Manufacturing	Solid (I) Solid (II)	(A) [I, IV]	CO ₂ : (3), (7), (8), (9) CH ₄ : (10) N ₂ O: (6), (10)	CO ₂ , CH ₄ and N ₂ O emissions for Coal are calculated by summing Provincial/Territorial Total Manufacturing emissions and Total Mining emissions, then subtracting the sum of (Petroleum Refining, Iron & Steel, Smelting & Refining, Chemicals, Pulp & Paper, Cement, Construction, and Forestry). A weighted emission factor is calculated for all three GHGs and applied on an annual basis.

Source Category ⁽¹⁾	Fuels List ⁽²⁾	Activity Data Source ⁽³⁾	Emission Factor Source ⁽⁴⁾	Notes ⁽⁵⁾
	Liquid (I) Liquid (II)	(A) [II, V]	CO ₂ : (7) CH ₄ : (10) N ₂ O: (10)	CO ₂ , CH ₄ and N ₂ O emissions are calculated by subtracting the sum of Total mining, Petroleum refining, Iron & Steel, Smelting & Refining, Chemicals, Pulp & Paper, Cement, Construction, and Forestry from Total Industrial reported in the ARES D. A weighted emission factor is calculated for all three GHGs and applied on an annual basis. CO ₂ , CH ₄ and N ₂ O associated with Transport fuels (i.e., gasoline and diesel) are included in the Transport subsector.
	Gas (I)	(A) [I]	CO ₂ : (8) CH ₄ : (10) N ₂ O: (10)	CO ₂ , CH ₄ and N ₂ O emissions are calculated by subtracting the sum of Total mining, Petroleum refining, Iron & Steel, Smelting & Refining, Chemicals, Pulp & Paper, Cement, Construction, and Forestry from Total Industrial reported in the ARES D. A weighted emission factor is calculated for all three GHGs and applied on an annual basis.
	Biomass (n/a)			
1.A.3.e. Pipelines (Transport)	Solid (I) Solid (II)	(A) [I, IV]	CO ₂ : (3), (7), (8), (9) CH ₄ : (10) N ₂ O: (6), (10)	Canada total for CO ₂ is the sum of each provinces/territories emission due to regional emission factors being used. Canada total for CH ₄ and N ₂ O are based on the national total reported in the ARES D.
	Liquid (I) Liquid (II)	(A) [II, V]	CO ₂ : (7) CH ₄ : (10) N ₂ O: (10)	Canada totals for CO ₂ , CH ₄ and N ₂ O are based the national total reported in the ARES D.
	Gas (I)	(A) [I]	CO ₂ : (8) CH ₄ : (10) N ₂ O: (10)	Canada totals for CO ₂ , CH ₄ and N ₂ O are based the national total reported in the ARES D.
	Biomass (n/a)			

Source Category ⁽¹⁾	Fuels List ⁽²⁾	Activity Data Source ⁽³⁾	Emission Factor Source ⁽⁴⁾	Notes ⁽⁵⁾
1.A.4.a.i. Commercial and Other Institutional	Solid (I) Solid (II)	(A) [I, IV]	CO ₂ : (3), (7), (8), (9) CH ₄ : (10) N ₂ O: (6), (10)	Canada total for CO ₂ is the sum of each provinces/territories emission due to regional emission factors being used. Canada total for CH ₄ and N ₂ O are based on the national total reported in the ARES D.
	Liquid (I) Liquid (II)	(A) [II, V]	CO ₂ : (7) CH ₄ : (10) N ₂ O: (10)	Canada totals for CO ₂ , CH ₄ and N ₂ O are based the national total reported in the ARES D. CO ₂ , CH ₄ and N ₂ O associated with Transport fuels (i.e., gasoline and diesel) are included in the Transport subsector.
	Gas (I)	(A) [I]	CO ₂ : (8) CH ₄ : (10) N ₂ O: (10)	Canada totals for CO ₂ , CH ₄ and N ₂ O are based the national total reported in the ARES D.
	Biomass (n/a)			
1.A.4.a.ii. Public Administration	Solid (I) Solid (II)	(A) [I, IV]	CO ₂ : (3), (7), (8), (9) CH ₄ : (10) N ₂ O: (6), (10)	Canada total for CO ₂ is the sum of each provinces/territories emission due to regional emission factors being used. Canada total for CH ₄ and N ₂ O are based on the national total reported in the ARES D.
	Liquid (I) Liquid (II)	(A) [II, V]	CO ₂ : (7) CH ₄ : (10) N ₂ O: (10)	Canada totals for CO ₂ , CH ₄ and N ₂ O are based the national total reported in the ARES D. CO ₂ , CH ₄ and N ₂ O associated with Transport fuels (i.e., gasoline and diesel) are included in the Transport subsector.
	Gas (I)	(A) [I]	CO ₂ : (8) CH ₄ : (10) N ₂ O: (10)	Canada totals for CO ₂ , CH ₄ and N ₂ O are based the national total reported in the ARES D.
	Biomass (n/a)			
1.A.4.b. Residential	Solid (I) Solid (II)	(A) [I, IV]	CO ₂ : (3), (7), (8), (9) CH ₄ : (10) N ₂ O: (6), (10)	Canada total for CO ₂ is the sum of each provinces/territories emission due to regional emission factors being used. Canada total for CH ₄ and N ₂ O are based on the national total reported in the ARES D.

Source Category ⁽¹⁾	Fuels List ⁽²⁾	Activity Data Source ⁽³⁾	Emission Factor Source ⁽⁴⁾	Notes ⁽⁵⁾
	Liquid (I) Liquid (II)	(A) [II, V]	CO ₂ : (7) CH ₄ : (10) N ₂ O: (10)	Canada totals for CO ₂ , CH ₄ and N ₂ O are based the national total reported in the ARES D.
	Gas (I)	(A) [I]	CO ₂ : (8) CH ₄ : (10) N ₂ O: (10)	Canada totals for CO ₂ , CH ₄ and N ₂ O are based the national total reported in the ARES D.
	Biomass (I)	(C)	CO ₂ : (C) CH ₄ : (C) N ₂ O: (C)	Total biomass is the amount of Residential Fuelwood combusted and is based on Environment Canada's survey data. CO ₂ emissions are not included in the national totals but CH ₄ and N ₂ O emissions are.
1.A.4.c.i. Forestry	Solid (I) Solid (II)	(A) [I, IV]	CO ₂ : (3), (7), (8), (9) CH ₄ : (10) N ₂ O: (6), (10)	Canada total for CO ₂ is the sum of each provinces/territories emission due to regional emission factors being used. Canada total for CH ₄ and N ₂ O are based on the national total reported in the ARES D.
	Liquid (I) Liquid (II)	(A) [II, V]	CO ₂ : (7) CH ₄ : (10) N ₂ O: (10)	Canada totals for CO ₂ , CH ₄ and N ₂ O are based the national total reported in the ARES D. CO ₂ , CH ₄ and N ₂ O associated with Transport fuels (i.e., gasoline and diesel) are included in the Transport subsector.
	Gas (I)	(A) [I]	CO ₂ : (8) CH ₄ : (10) N ₂ O: (10)	Canada totals for CO ₂ , CH ₄ and N ₂ O are based the national total reported in the ARES D.
	Biomass (n/a)			
1.A.4.c.ii. Agriculture	Solid (I) Solid (II)	(A) [I, IV]	CO ₂ : (3), (7), (8), (9) CH ₄ : (10) N ₂ O: (6), (10)	Canada total for CO ₂ is the sum of each provinces/territories emission due to regional emission factors being used. Canada total for CH ₄ and N ₂ O are based on the national total reported in the ARES D.
	Liquid (I) Liquid (II)	(A) [II, V]	CO ₂ : (7) CH ₄ : (10) N ₂ O: (10)	Canada totals for CO ₂ , CH ₄ and N ₂ O are based the national total reported in the ARES D. CO ₂ , CH ₄ and N ₂ O associated with Transport fuels (i.e., gasoline and diesel) are included in the Transport subsector.

Source Category ⁽¹⁾	Fuels List ⁽²⁾	Activity Data Source ⁽³⁾	Emission Factor Source ⁽⁴⁾	Notes ⁽⁵⁾
	Gas (I)	(A) [I]	CO ₂ : (8) CH ₄ : (10) N ₂ O: (10)	Canada totals for CO ₂ , CH ₄ and N ₂ O are based the national total reported in the ARES D.
	Biomass (n/a)			
1.A.5. Other Information (not included elsewhere)	Included Elsewhere (IE)	IE	IE	Emissions for this sub-sector are included 1.A.2.f.iv. Other Manufacturing.

Notes:

- 1 CRF Categories listed are the lowest level sub-sectors for which emissions are estimated.
- 2 Fuel Lists describe the fuels included in the category. See Table A2.3 for detailed breakdown.
- 3 Activity data refers to the source reference and specific location of the data. For example, (A), [I, II] refers to the ARES D, Tables B & D. See Table A2.4 for additional info.
- 4 Emission factor source references refer to CO₂, CH₄ and N₂O emissions.
- 5 See Table A2.5 for detailed references and sources.

FUEL LISTS

Fuels are described below for inclusion in the various categories in the CRF.

Table A2-3: Fuels Reference List

Fuel Types	Reference Number	Fuels
Solid Fuels	I.	Coal: Canadian bituminous, Sub-bituminous, lignite, anthracite, foreign bituminous
	II.	Coke, Petroleum coke – Refineries & Others
	III.	Petroleum coke – Upgraders
Liquid Fuels	I.	Kerosene & stove oil, light fuel oil, heavy fuel oil
	II.	Motor gasoline, diesel fuel oil, aviation gasoline, aviation turbo fuel
Gaseous Fuels	I.	Natural gas, coke oven gas, still gas – refineries & others
	II.	Propane, butane, ethane
Biomass	I.	Industrial fuelwood, spent pulping liquor, residential firewood

ACTIVITY DATA

Activity data sources are presented below 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 to Statistics Canada's rounded, published values.

Table A2-4: Activity Data Model References:

Reference Number	Title
A.	Statistics Canada – Manufacturing, Construction and Energy Division; “Report on Energy Supply and Demand in Canada (ARESD)”. Catalogue No. 57-003-XPB. I. Table B – Primary and Secondary Energy II. Table D – Refined Petroleum Products III. Table E – Non-Energy Refined Petroleum Products Table F – Coal Details IV. Table 17 – Details of Natural Gas Liquids V. Table 20 – Solid Wood Waste and Spent Pulping Liquor VI. Table 21 – Estimated Additions to Still Gas, Diesel, Petroleum Coke and Crude Oil
B.	Fugitive Emissions Model – Based on: 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.
C.	Residential Fuelwood Consumption – Based on: 1995 Criteria Contaminants Emissions Inventory Guidebook, Version 1, Section 2.4, National emissions inventory and Projections Task Group, Environment Canada, CAC Division, March 1999.

EMISSION FACTORS

Emission factors are presented in Annex 12. The following reference list identifies the source of the emission factor for the stationary combustion model methodology.

Table A2-5: Emission Factor References:

Reference Number	Title
1.	CAPP (1999), CH ₄ and VOC Emissions from Upstream Oil and Gas Operations in Canada, Vol. 2, Canadian Association of Petroleum Producers, CAPP Publication No. 1999-0010.
2.	CIEEDAC (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, March.
3.	CIEEDAC (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, March.
4.	EPA (1996), compilation of Air Pollutant Emission Factors, Vol. 1, Stationary Point and Area Sources, 5th Edition, U.S. Environmental Protection Agency, AP-42.
5.	IPCC (1997), Greenhouse Gas Inventory Reporting Instruction, Vol. 1; and Greenhouse Gas Inventory Reference Manual. Vol 3, Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Intergovernmental Panel on Climate Change, Backnell, UK.
6.	IPCC (2006), 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T., and Tanabe K. (eds). Published: IGES, Japan.
7.	Jaques, A., (1992), Canada's Greenhouse Gas Emissions: Estimates for 1990, Environmental Protection, Conservation and Protection, Environment Canada, EPS 5/AP/4, December.
8.	McCann, T.J. (2000), 1998 Fossil Fuel and Derivative Factors, prepared for Environment Canada by T.J. McCann and Associates, March.
9.	Nyboer, J. (2006), CIEEDAC Database on Oil Sands Operations, Personal communication with C. Ha, GHG Division Environment Canada.
10.	SGA (2000), Emission Factors and Uncertainties for CH ₄ & N ₂ O from Fuel Combustion, SGA Energy Limited, August 2000.

A2.4.2 Transport (CRF 1.A.3)

Greenhouse Gas (GHG) emissions from the Transport subsector are divided into five categories:

- Civil Aviation;
- Road Transportation;
- Railways;
- Navigation (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 transportation sector are calculated using various adaptations of Equation A2-1.

CO₂ emissions are predominantly dependant on the type and characteristics of fuel being combusted while N₂O and CH₄ emissions are dependant on both the fuel combusted and emission control technologies present. Annex 12 provides a complete listing of Transport related emission factors and their specific references.

Due to the complexity of the Transport sector, emission estimates are calculated using Canada's Mobile Greenhouse Gas Emission Model (MGEM07) which is used to calculate the emissions from: road transportation, railways, navigation and off-road. The combustion emissions associated with pipeline transport and aviation are estimated separately.

A2.4.2.1 Road Transportation (CRF 1.A.3.b)

The methodology used to estimate road transportation GHG emission follow a detailed IPCC Tier 3 method.

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 vs. 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 (CVIOC) which is maintained by DesRosiers Automotive Consultants Inc. Light duty vehicle and truck populations for 2003-2005 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 2003-2005 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 3,900 kg while Heavy-duty classes have GVWR above 3,900 kg.

Motorcycle populations for 1990-2005 were obtained from the Motorcycle & Moped Industry Council.

Technology Penetration

To account for the effects that emission control technologies have on emissions of CH₄ and N₂O, 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 light duty gasoline vehicles and trucks in successive model years. Technology penetration for heavy duty gasoline vehicles (HDGVs), heavy duty diesel vehicles (HDDVs), light duty diesel vehicles (LDDVs) and light duty diesel trucks (LDDTs), and motorcycles (MCs) are detailed in Table A2-6 (EPA, 2006).

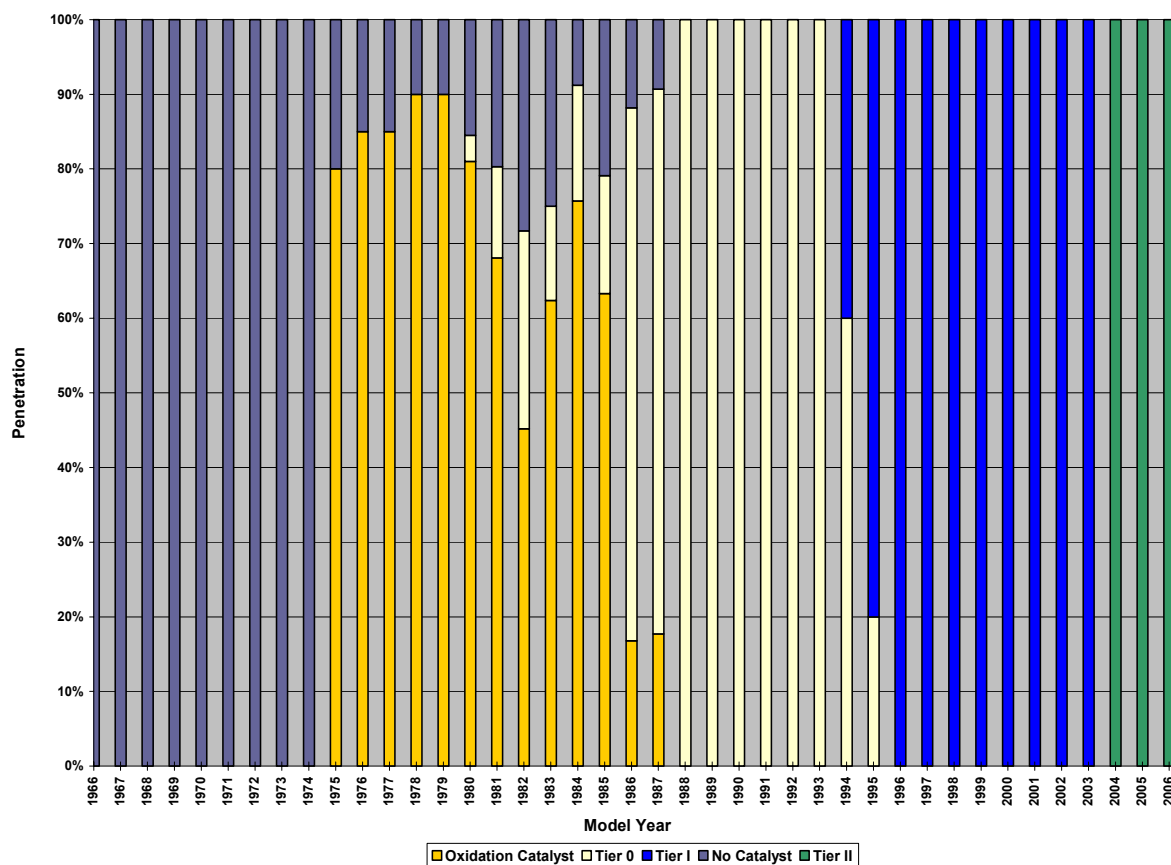


Figure A2-2: Technology Penetration for Light Duty Gasoline Vehicles and Trucks

Table A2-6: Technology Penetration for HDGVs, HDDVs, LDDVs & LDDTs, and MCs

Control Technology	Model years
<i>Heavy Duty Gasoline Vehicles (HDGVs)</i>	
Uncontrolled	1960-1984
Non-Catalytic Control	1985-1995
3 Way Catalyst	1996-2006
<i>Heavy Duty Diesel Vehicles (HDDVs)</i>	
Uncontrolled	1960-1982
Moderate Control	1983-1995
Advanced Controls	1996-2006
<i>Light Duty Diesel Vehicles & Trucks (LDDVs & LDDTs)</i>	
Uncontrolled	1960-1982
Moderate Controls	1983-1995
Advanced Controls	1996-2003
Tier 2	2004-2006
<i>Motorcycles (MCs)</i>	
Uncontrolled	1960-1995
Non-Catalytic Controlled	1996-2004

Catalyst Survival Rate

With use catalytic converters deteriorate effecting tailpipe emission rates. Based on information from industry experts, a technology specific deterioration rate is applied to light duty gasoline vehicles and trucks with catalytic controlled technologies. To model the deterioration effect, the percentage of 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 and Tier 2 technologies as these emission control technologies are inspected and replaced or repaired as necessary.

Fuel Consumption Ratios (FCR)

Average provincial FCRs by vehicle class and model year (based on provincial vehicle sales) are available for LDGVs and LDGTs (NRCan, 2005). LDDVs and LDDTs (NRCan, 2005) and HDGVs (IPCC/OECD/IEA, 1997) FCRs are based on a vehicle class and model year average. HDDVs and MCs FCRs are based on yearly fleet average (NRCan, 2005).

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 MGEM07 have been adjusted to 25% above the laboratory FCR ratings (Maples, 1993).

Vehicle Kilometres Traveled (Vkts)

Vkts, a measure of the annual mileage activity of light duty cars and trucks, is estimated based on a report examining the difference in odometer readings taken from these vehicles in successive Inspection and Maintenance tests in Ontario (SBA, 2004). Since Vkts by vehicle class and vehicle age are not available for the other provinces and territories, the Ontario Vkt data is 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:

- Light Duty Gasoline Vehicles (LDGVs);
- Light Duty Gasoline Trucks (LDGTs);

- Heavy Duty Gasoline Vehicles (HDGVs);
- Motorcycles (MCs);
- Light Duty Diesel Vehicles (LDDVs);
- Light Duty Diesel Trucks (LDDTs); and
- Heavy Duty Diesel Vehicles (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 MGEM07. This algorithm attempts to recognize the uncertainty in the values of fuel reportedly consumed by varying economic subsector and independent fuel surveys.

Gasoline:

The first on-road gasoline estimate is calculated in step 2 and represents a “Bottom-up” estimate based upon vehicle population, FCRs and V_{kts}.

The second estimate is based on the “top-down” gross and taxed gasoline sales reported by Statistics Canada (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 ARES (Annual Report on Energy Supply/Demand in Canada). 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 is taken as the final on-road gasoline estimate. If the top-down 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 (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 is 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.

A2.3.2.2 Off-Road (CRF 1.A.3.e)

The methodology used to estimate off-road transportation GHG emissions follow a simple IPCC Tier 1 method.

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.

A2.4.2.2 Civil Aviation (CRF 1.A.3.a)

The methodology used to estimate civil aviation GHG emissions follow a modified IPCC Tier 1 method.

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 due 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) are reported in the ARES (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 & #51-203 — Air Carrier Traffic at Canadian Airports) and freight activity, which includes the weight of passengers (Statistics Canada, #51-206 — Canadian Civil Aviation) is publicly available and illustrates the separation between domestic and international activity. The aviation model has been calibrated to align with more complex flight path models (SAGE – USA and AERO2K – UK).

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.

A2.4.2.3 Navigation (CRF 1.A.3.d)

The emission calculations methodology is considered to be modified IPCC Tier 1 method. Domestic marine fuel consumption reported in the ARES (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 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 is currently unavailable.

A2.4.2.4 Railways (CRF 1.A.3.c)

The methodology is considered to be a modified IPCC Tier 1 method. Railway fuel consumption reported in the ARES (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, while electrically driven locomotives are accounted for under electricity production.

A2.4.2.5 Biomass (CRF 1.A.3.e)

The methodology used to estimate emissions from biomass fuels (currently limited to ethanol) used in the Transport subsector follow the same methodology as gasoline on-road transportation (detailed IPCC Tier 3 method) and off-road transportation (IPCC Tier 1 method).

In lieu of reviewed CH₄ and N₂O emission factors for biofuels, the gasoline and diesel emission factors from the equivalent emission technology classes are applied. CO₂ emissions factors are developed according to the chemical properties of the fuel.

A2.4.2.6 Pipelines (CRF 1.A.3.e)

Although emissions associated with pipelines are reported under other transportation, they are estimated using the stationary combustion models. See Section A2.4.1.5 for the further information on the pipeline methodology.

References

CAC (1999), 1995 Criteria Contaminants Emissions Inventory Guidebook, Version 1, Section 2.4, National emissions inventory and Projections Task Group, Environment Canada, CAC Division, March 1999.

CAPP (1999), CH₄ and VOC Emissions from Upstream Oil and Gas Operations in Canada, Vol. 2, Canadian Association of Petroleum Producers, CAPP Publication No. 1999-0010.

CIEEDAC (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, March.

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EPA (1996), compilation of Air Pollutant Emission Factors, Vol. 1, Stationary Point and Area Sources, 5th Edition, U.S. Environmental Protection Agency, AP-42.

EPA (2006), Inventory of U.S. Greenhouse Gas Emissions and Sinks:1990-2004, USEPA#430-R-06-002.

IPCC (1996a), *Summary for Policy Makers: The Science of Climate Change – IPCC Working Group I*, Intergovernmental Panel of Climate Change. Available online at: www.ipcc.ch/pub/sarsum1.htm

IPCC/OECD/IEA (1997), *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, Intergovernmental Panel on Climate Change, Organization for Economic Co-operation and Development, and International Energy Agency. Available online at: www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm.

IPCC (2006), *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T., and Tanabe K. (eds). Published: IGES, Japan.

Jaques, A., (1992), *Canada's Greenhouse Gas Emissions: Estimates for 1990*, Environmental Protection, Conservation and Protection, Environment Canada, EPS 5/AP/4, December 1992.

McCann, T.J. (2000), *1998 Fossil Fuel and Derivative Factors*, prepared for Environment Canada by T.J. McCann and Associates, March.

Maples, J.D. (1993), *The Light-Duty Vehicle MPG Gap: It's Size Today and Potential Impacts in the Future*, University of Tennessee Transportation Centre, Knoxville, Tennessee, U.S.A.

NRCan (2005), *Transportation End-Use Model*.

Stewart Brown Associates (2004), *Vehicle Fleet Profiles for Ontario and British Columbia; Annual kilometer Accumulation Rates; Vehicle –Kilometer Traveled; and I/M Program Effectiveness*.

Statistics Canada – Manufacturing, Construction and Energy Division; “Report on Energy Supply and Demand in Canada (ARESD)”, Catalogue No. 57-003-XPB

SGA (2000), *Emission Factors and Uncertainties for CH₄ & N₂O from Fuel Combustion*, SGA Energy Limited, August 2000.

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 sectors is covered in this Annex. This discussion relates to the solid fuel production and oil and gas industries.

A primary source of fugitive emissions, Canada's large oil and gas industry consist of a mix of production types such as combined crude oil and gas production, conventional crude oil production, and crude production (bitumen and synthetic oil) from oil sands. 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 Stationary Combustion and Transportation sections of Chapter 3 and their respective methodologies can be found in Annex 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, 1994*, prepared by B. King for Neill and Gunter Ltd. (King Study). 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 were separated and both include post-mining activity emissions. The methodology used to estimate the emissions from both types are explained below. For further details please consult the King Study.

A3.1.1.1.1 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 A3.1-1:

Equation A3.1-1:

$$Y = 4.1 + (0.023 \times X)$$

where:

Y = cubic metres (m³) of CH₄ per tonne (t) of coal mined

X = depth of mine in metres (m)

Emissions from post-mining activities were estimated by assuming that 60% of the remaining coal CH₄ (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 CH₄ content was 1.5 m³/t (the global average for coals). Emissions from post-mining activities are included in the coal production emission factors.

A3.1.1.1.2 Surface Mines

For surface mines, it was assumed that the average CH₄ content of surface-mined bituminous or sub-bituminous coals was 0.4 m³/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 un-mined strata. An attempt was made to account for this by applying a high-wall adjustment to account for the out-gassing of the surrounding un-mined strata to a depth of 50 m below the mining surface. It was estimated that base emission factors for surface mining should be increased 50% (King, 1994) to account for this. The emission factors shown in Table A3.1-1 have been adjusted accordingly.

The emission factors for methane from coal mining determined in the King Study are used to estimate the methane 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, the Equation A3.1-2 is used:

Equation A3.1-2:

$$\text{Emissions}_{i,j} = \text{EF}_{i,j} \times \text{Amount of Coal}_i \text{ Mined in Province}_j$$

where:

Emissions_{i,j} are the CH₄ from the mining of coal_i in province_j;

EF_{i,j} is the emission factor from the King Study for coal_i in province_j; and

Amount of Coal_i Mined in Province_j is the Gross Mine Output Production data for coal_i in province_j.

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 is the Gross Mine Output Production Data for each type of coal mined in each province. The sources for the activity data are listed below. In 2002, Statistics Canada stopped publishing Catalogue 45-002 Table 2 and replaced it with 12CM Table 3 for 2004 to 2005. A consistent dataset was used to estimate emissions from 1990 to 2001 and 2004 to 2005. However, for 2002 to 2003, the data is confidential and not available to EC hence the estimates for those years have been estimated based on the 2004 and 2005 data.

- Statistics Canada
 - o 1990 to 2001
 - Coal and Coke Statistics Catalogue 45-002 Table 2 Production and Disposal of Coal, Gross Mine Output Production
 - o 2002 to 2003 are not available
 - o 2004 to 2005
 - 12CM Table 3. Production and Disposition of Coal, Year-to-date, December, Gross Mine Output Production

A3.1.1.3 Emission Factors

The mine and coal type specific emission factors that were determined in the King Study are listed in Table A3.1-1.

Table A3.1-1: Fugitive Emissions Factors for Coal Mining.

Area	Coal Type	Mine Type	Emission Factor	Units
Nova Scotia	Bituminous	Surface	0.13	t CH ₄ / kt coal mined
Nova Scotia	Bituminous	Underground	13.79	t CH ₄ / kt coal mined
New Brunswick	Bituminous	Surface	0.13	t CH ₄ / kt coal mined
Saskatchewan	Lignite	Surface	0.06	t CH ₄ / kt coal mined
Alberta	Bituminous	Surface	0.45	t CH ₄ / kt coal mined
Alberta	Bituminous	Underground	1.76	t CH ₄ / kt coal mined
Alberta	Sub-bituminous	Surface	0.19	t CH ₄ / kt coal mined
British Columbia	Bituminous	Surface	0.58	t CH ₄ / kt coal mined
British Columbia	Bituminous	Underground	4.1	t CH ₄ / kt coal mined

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 natural gas (UOG) industry are based on the study, *A National Inventory of Greenhouse Gas (GHG), Criteria Air Contaminant (CAC) and Hydrogen Sulphide (H₂S) Emissions by the Upstream Oil and Gas Industry* (UOG Study) prepared for CAPP by Clearstone Engineering. A tier 3 analysis was performed to estimate all GHG emissions from the upstream oil and gas (UOG) sector for 2000, with the exclusion of the mined bitumen/ oil sands extraction. The emissions were then back cast to the years 1990 through to 1999 to develop emission estimates for the sector from 1990 to 1999. The UOG fugitive emissions for 1990 to 2000 were taken directly from the UOG Study.

The *Extrapolation of the 2000 UOG Emission Inventory to 2001, 2002 and 2003* (UOG Extrapolation Model) was prepared for CAPP by Clearstone Engineering. It is an extrapolation model which is based upon the 2000 data from the UOG Study and uses annual activity data to extrapolate the emissions on an annual basis after 2000 to the present. The extrapolation model is divided into the same sectors and sources as the 1990 to 2000 inventory in the UOG Study. The UOG fugitive emissions for 2001 to 2003 were taken directly from the UOG Extrapolation Model.

Table A3.1-2 lists the sectors and sources that were estimated in the UOG Study and the allocation of these emissions following the CRF category.

Table A3.1-2: 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. Natural Gas iii Other Leakage at industrial plants and power stations
Accidents and Equipment Failures	Spills/Pipeline Ruptures	2.B. Natural Gas iii Other Leakage at industrial plants and power stations
Conventional Oil Production	Glycol Dehydrator Off-Gas	2.C. Venting i. Oil
Conventional Oil Production	Flaring	2.C. Flaring i. Oil
Conventional Oil Production	Fugitive Equipment Leaks	2.A. Oil ii. Production
Conventional Oil Production	Loading/Unloading	2.A. Oil ii. Production
Conventional Oil Production	Reported Venting	2.C. Venting i. Oil
Conventional Oil Production	Storage Losses	2.A. Oil ii. Production
Conventional Oil Production	Unreported Venting	2.C. Venting i. Oil
Oil and Gas Well Drilling	Reported Venting	2.C. Venting iii. Combined
Natural Gas Production	Glycol Dehydrator Off-Gas	2.C. Venting ii. Natural Gas
Natural Gas Production	Flaring	2.C. Flaring ii. Natural Gas
Natural Gas Production	Fugitive Equipment Leaks	2.B. Natural Gas i Production/Processing
Natural Gas Production	Reported Venting	2.C. Venting ii. Natural Gas
Natural Gas Production	Storage Losses	2.B. Natural Gas i Production/Processing
Natural Gas Production	Unreported Venting	2.C. Venting ii. Natural Gas
Natural Gas Processing	Glycol Dehydrator Off-Gas	2.C. Venting ii. Natural Gas

Sector	Source	CRF Fugitive Category
Natural Gas Processing	Flaring	2.C. Flaring ii. Natural Gas
Natural Gas Processing	Fugitive Equipment Leaks	2.B. Natural Gas i Production/Processing
Natural Gas Processing	Loading/Unloading	2.B. Natural Gas i Production/Processing
Natural Gas Processing	Formation CO ₂	2.C. Venting ii. Natural Gas
Natural Gas Processing	Storage Losses	2.B. Natural Gas i Production/Processing
Natural Gas Processing	Unreported Venting	2.C. Venting ii. Natural Gas
Heavy Oil/Cold Bitumen Production	Glycol Dehydrator Off-Gas	2.C. Venting i. Oil
Heavy Oil/Cold Bitumen Production	Flaring	2.C. Flaring i. Oil
Heavy Oil/Cold Bitumen Production	Fugitive Equipment Leaks	2.A. Oil ii. Production
Heavy Oil/Cold Bitumen Production	Loading/Unloading	2.A. Oil ii. Production
Heavy Oil/Cold Bitumen Production	Reported Venting	2.C. Venting i. Oil
Heavy Oil/Cold Bitumen Production	Storage Losses	2.A. Oil ii. Production
Heavy Oil/Cold Bitumen Production	Unreported Venting	2.C. Venting i. Oil
Thermal Operations	Flaring	2.C. Flaring i. Oil
Thermal Operations	Fugitive Equipment Leaks	2.A. Oil ii. Production
Thermal Operations	Loading/Unloading	2.A. Oil ii. Production
Thermal Operations	Reported Venting	2.C. Venting i. Oil
Thermal Operations	Storage Losses	2.A. Oil ii. Production
Thermal Operations	Unreported Venting	2.C. Venting i. Oil
Liquid Product Transportation	Flaring	2.C. Flaring i. Oil
Liquid Product Transportation	Fugitive Equipment Leaks	2.A. Oil. iii Transport
Liquid Product Transportation	Storage Losses	2.A. Oil. iii Transport
Liquid Product Transportation	Reported Venting	2.C. Venting i. Oil
Well Testing	Flaring	2.C. Flaring iii. Combined
Well Testing	Reported Venting	2.C. Venting iii. Combined

The methodology, emission factor, and activity data use to estimate the 2000, the 1990 to 1999, and the 2001 to 2005 emission was developed by Clearstone Engineering Ltd. and is presented in section A3.1.2.1.1 to A3.1.2.1.3. For further details please consult the UOG Study and the UOG Extrapolation Model.

A3.1.2.1.1 Methodology for the 2000 estimates

The 2000 UOG emissions was developed using a bottom-up approach, beginning with individual facilities and their equipment. To fulfill 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 CO₂, releases,
- venting (reported and unreported), 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
- Destruction and Removal Efficiencies (DREs)

The following data was 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;
- Emissions 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 was compiled and used to estimate the 2000 UOG fugitive emissions. Refer detail to the UOG Study for further details.

A3.1.2.1.2 Methodology for the 1990 to 1999 estimates

The emissions for 1990 to 1999 were backcast for the UOG industry at provincial level based on the 2000 UOG Study and annual production activity 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 detail to the UOG Study for further details.

A3.1.2.1.3 Methodology for the 2001 to 2005 estimates

The 2001 to 2005 emissions were estimated by extrapolating the 2000 UOG emission data using activity data for each emission source in each sub-sector. There are eleven activity parameters for each province/territory and year that were used to prorate the 2000 estimates from the UOG Study for the years 2001 to 2005: 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 A3.1-3 was used for prorating:

Equation A3.1-3:

$$ER_{ij}^k = ER_{ij}^{2000} \cdot (AF_j^k / AF_j^{2000})$$

where:

ER_{ij}^k = emission rate of compound i, source j and year k (t/y),

ER_{ij}^{2000} = base year (2000) emission rate for compound i and source j (t/y),

AF_j^k = activity factor for source j and year k, and

AF_j^{2000} = base year activity factor for source j.

The activity data listed in Table A3.1-3 is used to calculate the eleven activity parameters (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) which are used in the extrapolation of the emissions for 2001 to 2005. This data is input into the model and the output is the UOG fugitive emission estimates for the specified year.

Table A3.1-3: Required Activity Data and its Source

Publisher	Publication	Activity Data
Statistics Canada	Table 131-0001 Supply and disposition of natural gas, monthly	Gross New Production Less field flared and waste Net new Production Less injected and stored Net Withdrawals Field disposition and usage Gathering system disposal and use Shrinkage Plant uses Adjustment Deliveries of marketable gas Total Disposition Total marketable gas Received from distributor storage Imports Other receipts Total Net Supply
	Table 126-0001 Supply and disposition of crude oil and equivalent	Heavy Crude Oil Light and Medium Crude Oil Synthetic Crude Oil Crude Bitumen Total Crude Oil Condensate Pentanes Plus Total net Withdrawals Imports TOTAL SUPPLY
Saskatchewan Industry and Resources	Table 2-1-9 Mineral Statistics Yearbook. Misc. Rpt.	Light and Medium Crude Oil Production Heavy Crude Oil Production
	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	Total Wells Drilled (Including Dry and Service)
Alberta Energy and Utilities	EUB ST57 Field Surveillance Provincial Summary	Sum of blowout, blow, kick, pipeline rupture and spill incidents

Publisher	Publication	Activity Data
Board (EUB)		
	EUB ST-59 Alberta Drilling Statistics	December Capable Oil and Gas Wells (Alberta)
British Columbia - Ministry of Energy and Mines	Drilling and Production Statistics	Sum of Producing Oil Wells and Producing Gas Wells (BC)
Manitoba Industry, Economic Development and Mines	Table Manitoba Oil and Water Production. Oil Activity Review Year.	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

The Table A3.1-4 contains a list of the activity factors used to prorate the emissions and the dependant source category.

Table A3.1-4: Activity Data Used to Prorate Emissions Sectors and Sources

Emission Sector Category	Emission Source Category	Activity Factors
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

Emission Sector Category	Emission Source Category	Activity Factors
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 ₂	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, heavy oil and crude bitumen production
Product Transportation	Venting	Light/medium, heavy oil and crude bitumen production
Product Transportation	Storage Losses	Light/medium, 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*. Clearstone Engineering Ltd. (2005).

A3.1.2.2 Natural Gas Transmission

A3.1.2.2.1 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 *CH₄ and VOC Emissions from the Canadian Upstream Oil and Gas Industry - Draft Report*, prepared by Clearstone Engineering for Canadian Association of Petroleum Producers (CAPP) in July 1998. The second source is ancillary tables provided by Brian Ross of Clearstone Engineering in July 1998 that cover the CO₂ emissions. There are no N₂O fugitive emissions from natural gas transmission. The CO₂ and CH₄ emissions for 1990 to 1996 are taken directly from the two sources. The CO₂ and CH₄ emissions for 1997 to the present are estimated using specific provincial emission factors. Equation A3.1-4 is used to estimate the emissions:

Equation A3.1-4:

$$\text{Emission (kt)} = \text{Pipeline Length (km)} \times \text{Emission Factor (leakage rate kt/km)}$$

The emissions are calculated per province as the provinces have unique emission factors, and then summed to get the total CO₂ and CH₄ for Canada. Newfoundland, PEI, Yukon Territory, Northwest Territories, and Nunavut do not have natural gas transmission pipelines.

A3.1.2.2.2 Emission Factors

Provincial emission factors from 1997 and onward were developed based on the 1996 emissions and length of pipeline from the *CH₄ and VOC Emissions from the Canadian Upstream Oil and Gas Industry* study as prepared by Clearstone Engineering for CAPP. In 1998 and 1999, there were not fugitive emissions in Nova Scotia or New Brunswick since natural gas pipelines were not installed in these provinces at the time.

Table A3.1-5: Natural Gas Transmission Emission Factors for 1997 to 2005

	Nova Scotia	New Brunswick	Quebec	Ontario	Manitoba	Saskatchewan	Alberta	British Columbia
	<i>kt/km</i>							
CO ₂	2.40E-05	2.40E-05	7.20E-05	1.60E-05	2.90E-05	1.50E-05	2.80E-05	2.90E-05
CH ₄	0.0032	0.0032	0.0096	0.0022	0.0039	0.0021	0.0038	0.0039

A3.1.2.2.3 Activity Data

The activity data used to estimate the fugitive emissions for 1998 to 2005 is the length of the natural gas pipeline used for natural gas transmission. This data is published annually by Statistics Canada in *Catalogue 57-205 Natural Gas Transportation and Distribution* and the data is found in Table 5 Natural Gas Pipe Line Distance, by Province, as of December 31, under Transmission-Transport.

A3.1.2.3 Petroleum Refining

The Refinery Model is based on the *Economic And Environmental Impacts Of Removing Sulphur From Canadian Gasoline And Distillate Production* (Refinery Study), prepared for the Canadian Petroleum Products Institute (CPPI), Natural Resources Canada (NRCan), Environment Canada (EC), and Industry Canada (IC) in 2004 by Levelton Consultants Ltd. The study surveyed the refinery industry and used this data, along with data collected by the Canadian Industrial Energy End-Use Data Analysis Centre (CIEEDAC), to develop GHG emission estimates for 1990, 1994 to 2002. There are three sections in the refinery methodology: fugitive; flare; and process venting.

A3.1.2.3.1 Methodology

Fugitive Emissions

The fugitive emissions for 1991 to 1993 and for 2003 onwards are generated using Equation A3.1-5:

Equation A3.1-5:

$$\text{Fugitive GHG Emissions (t)} = \text{Emissions Factor (t/GJ)} \times \text{Refinery annual energy consumption (GJ)}$$

The refinery annual energy consumption (GJ) is the sum of the energy of all fuels consumed by refineries in the RESD published by Statistics Canada 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 (EF), one for CO₂ emissions and the other for CH₄ emissions, which were developed and used in the Refinery Study. 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:

Carbon dioxide:	2.78 tonnes CO ₂ /GJ
Methane:	11.89 tonnes CH ₄ /GJ

The Refinery Study has listed fugitive N₂O emissions for 1990 and 1994 to 2002 as a constant 0.1 kt N₂O/year; however, there was not enough data for the Refinery Study to develop an EF for them. The N₂O emissions were kept constant at 0.1 kt N₂O/year for the years 1991-1993 and 2003 to present.

Process Emissions (Venting)

Process emissions are mainly associated with the venting of CO₂ from the production of hydrogen using natural gas. The best correlation for process emissions was refinery energy consumption data. Therefore, the process emissions for the years 1991-1993 and 2003 to present were extrapolated based on the Refinery Study process emissions and energy consumption data for the years 1998 to 2002.

Flaring Emissions

Flaring emissions have been determined separately for the three gases using the estimates in the Refinery Study and the annual energy consumed by Canadian refineries. As the study did not generate any factors to use in its estimation and there is a lack of data on flared gas, a statistical correlation was performed using different published data. The published data which had the best correlation was refinery energy consumption value from Stationary Combustion model for 1.A.1.b. Petroleum Refining.

A3.1.2.3.2 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) Catalogue No. 57-003*
 - o Refinery and producer consumption (by refineries) annual energy consumption

Environment Canada

- Stationary Combustion GHG Model
 - o 1.A.1.b. Petroleum Refining Energy Consumption

Canadian Industry of Petroleum Producers (CPPI)

- *Economic And Environmental Impacts Of Removing Sulphur From Canadian Gasoline And Distillate Production* by Levelton Consultants Ltd., 2004
 - o Fugitive Emissions
 - Table 3-2 CPPI Regional GHG Inventory- Detailed (kilo tonnes)
 - o Process Emissions
 - Table 3-2 CPPI Regional GHG Inventory- Detailed (kilo tonnes)
 - o Flaring Emissions
 - Appendix E - Flare Gas

A3.1.2.4 Natural Gas Distribution

A3.1.2.4.1 Methodology

The fugitive emissions from natural gas distribution are based on the Canadian Gas Association report, *1995 Air Inventory of the Canadian Natural Gas Industry*. The emissions are estimated using activity data from Statistic Canada and the emission factors (leakage rate) from the report. This is the case for all years from 1990 to 2005. There are only fugitive CH₄ emissions from the distribution of natural gas. The relationship between the data and emission factors is as follows:

Equation A3.1-6:

$$Emission_x (kt) = Length\ of\ Pipeline\ (km) \times Emission\ Factors_x\ (leakage\ rate\ kt/km)$$

The fugitive emissions for natural gas distribution are estimated for each province and then summed to get the overall emission for Canada. For the years 1990 to 2005 there were no natural gas distribution pipelines in the following provinces and territories: Newfoundland; Prince Edward Island; Nova Scotia; New Brunswick; Nunavut; Yukon Territory; and the Northwest Territories.

A3.1.2.4.2 Emission Factors

The leakage rates are from the GCA report *1995 Air Emissions Inventory of the Canadian Natural Gas Industry*. These leakage rates are listed in the following table.

Table A3.1-6: CH₄ Emission Factors for Fugitive Natural Gas Distribution Emissions

Year	Leakage rate
	kt/km
1990-1992	0.08%
1993-2005	0.07%

A3.1.2.4.3 Activity Data

The activity data that is required is the length of natural gas pipeline per province. The data is published annually by Statistics Canada in *Catalogue 57-205 Natural Gas Transportation and Distribution*, and is located in Table 5 Natural Gas Pipeline Distance, by Province under Distribution- Distribution.

A3.1.2.5 Oil Sands and Heavy Oil Upgrade Industry

The Oil Sands and Heavy Oil Upgrading (OS/HOU) industry produce synthetic crude oil and other products from bitumen. Bitumen is a naturally occurring viscous mixture consisting of hydrocarbons heavier than pentane and other contaminants, such as 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. The Oil Sands is a term applied by the Government of Alberta to a particular geographical areas of the Province of Alberta wherein are located concentrations of bituminous sands but which also contain 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. Emissions included in the report *An Inventory of GHGs, CACs, and H₂S Emissions by the Canadian Bitumen Industry: 1990 to 2003* (Bitumen Report) prepared by Clearstone Engineering Ltd. for the Canadian Association of Petroleum Producers (CAPP) are from the mining, processing and upgrading of bitumen and heavy oil.

The Bitumen Report is the basis for the 1990 to 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. This model uses results from the Bitumen Report as its basis along with annual production data as reported by the Alberta Energy and Utility Board (EUB) and the National Energy Board (NEB). A description of the methodology, model, and data used is briefly discussed below. For more details please refer to the Bitumen Report.

The major emission sources in the OS/HOU Industry are the following:

- process emissions from the steam reforming of natural gas to produce hydrogen for upgraders;
- methane present in the oil sands deposits which is released during mining, mine dewatering, and ore handling activities;
- volatilization of hydrocarbons from the exposed oil sands and during transport and handling of the oil sands;
- biogenic gas formation (primarily methane) in some tailings ponds;
- volatilization and decomposition of residual bitumen and diluent which carries through to the tailings ponds;
- fugitive equipment leaks, venting, flaring and storage losses at ore preparation, extraction and upgrader plants and their associated utility and co-generation plants;

- spills and accidental releases; and
- 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 as listed in the following table.

Table A3.1-7: Emission Source Categories and Process Areas in the Bitumen Report

Source Category	Process Area
Flaring	All
Fugitives	API Separator
	Equipment Leaks
	Exposed Oil Sands
	Ponds
	Other
	Storage Tanks
Process Venting	Flue Gas Desulphurization
	Formation CO ₂ from Acid Gas
	H ₂ Plant
	Non-combustion Point Sources

A3.1.2.5.1 Bitumen Report: 1990 to 2003 Emission Estimates

The Bitumen Report 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); Albian Sands Energy (Muskeg River mining and extraction facility); and Shell Canada Limited (Fort Saskatchewan upgrader). The facility boundaries were determined to ensure all target emissions, including those from cogeneration facilities, were included.

Where available, the Bitumen Report used the emissions from the individual facility reports. These emissions were verified against inventories and data reported to the Alberta Environment, where applicable. 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 was no available activity data, the emission factor ratio technique was applied. Refer directly to the Bitumen Report 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 Alberta Energy and Utilities Board, source emission monitoring results reported to Alberta Environment, data from company submissions to the Voluntary Challenge Registry (VCR); and Environment Canada's National Pollutant Release Inventory (NPRI); environmental impact assessments files as part of recent energy development applications in the OS/HOU industry; and open literature. Consult the Bitumen Report for more details.

A3.1.2.5.2 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 along with publicly available activity data and company-specific emissions 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. Refer directly to the report for the Extrapolation Model for specific methodological discussions.

Extrapolation Methodology

The extrapolation model provides emission estimates for the OS/HOU Industry for the years 2004 to present by applying custom emission factors and prorating factors derived from the facility base inventories (1990 to 2003) to appropriate publicly-available activity for the specific year. It uses Equation A3.1-7 to extrapolate the emissions:

Equation A3.1-7:

$$ER_i = EF_i \times (A_1 + A_2)$$

where,

ER_i = Emission of substance i expressed in tonnes per 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 to 4 years of emissions data for the facility, from the Bitumen Report, with available site-specific production accounting data. The emission factors can be found in the Extrapolation Model.

Activity Data

There are two activity data sources used to extrapolate emissions. The source for Alberta facilities is the Alberta Energy and Utilities Board *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 (http://www.neb-one.gc.ca/Statistics/CrudeOil_PetroleumProducts/index_e.htm). The required data is listed in Table A3.1-8 below.

Table A3.1-8: Activity Data Required for the Extrapolation Model

Required data from the EUB ST-43 Report for Alberta emission estimates		
Operator	Site	Required Parameters
Albian Sands	Muskeg River	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	Bitumen Production Intermediate Hydrocarbon Production Synthetic Crude Fuel/Used Synthetic Crude Production
	Aurora	Bitumen Production Synthetic Crude Fuel/Used
Required Data from the NEB for Saskatchewan emission estimates		
Crude Type	Crude Subcategory	Province
Heavy Crude	Heavy Crude	AB CONV./CLASS.
Heavy Crude	Heavy Crude	AB NON-UPGRADED BITUMEN
Heavy Crude	Heavy Crude	AB SUB TOTAL
Heavy Crude	Heavy Crude	SK CONV

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 SF₆, and other and undifferentiated production. Each of these can be further divided into various categories, such as CO₂ emissions from iron and steel production and SF₆ 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:

- CO₂ from iron and steel production;
- CO₂ from other and undifferentiated production; and
- CO₂ from ammonia production.

A3.2.1 CO₂ Emissions from Iron and Steel Production

A3.2.1.1 Methodology

The IPCC Tier 2 method is used to estimate, at the national level, CO₂ emissions coming from iron and steel production. This method is based on the tracking of carbon through the process. Emissions from iron production and those from steel production are calculated separately, using the following equations (IPCC, 2000):

Equation A3.2-1a for emissions from pig iron production:

$$\text{Emissions}_{\text{pig iron}} = (\text{Emission Factor}_{\text{reductant}} \times \text{mass of reductant}) + (\text{mass of carbon in the ore} - \text{mass of carbon in pig iron}) \times 44/12$$

where:

Emissions _{pig iron}	=	Emissions from pig iron production (kt)
Emission Factor _{reductant}	=	2.479 tonnes CO ₂ / tonne 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 Good Practice Guidance (IPCC, 2000), the carbon content in ore is almost zero.
mass of carbon in pig iron	=	total pig iron production (kt) x carbon content in pig iron (which is about 4% (IPCC, 2000))
44/12	=	ratio of the molecular weight of CO ₂ to the molecular weight of carbon

Reducing agents used to produce crude iron from iron ore can be coke, coal, charcoal, and petroleum coke. However, it is assumed that the reductant used in the Canadian industry is 100% metallurgical coke. The emission factor for metallurgical coke is 2.479 t CO₂/t coke (Jaques, 1992). According to the IPCC Good Practice Guidance (IPCC,

2000), the carbon content in pig iron is about 4% and that in ore is almost zero. Hence, Equation A3.2-1a above can be simplified to Equation A3.2-1b, which is also shown in Section 4.6.2 of this report:

Equation A3.2-1b: Simplified equation for emissions from pig iron production:

$$\text{Emissions}_{\text{pig iron}} = (\text{Emission Factor}_{\text{reductant}} \times \text{mass of reductant}) - (\text{mass of carbon in pig iron} \times 44/12)$$

To calculate emissions from steel production, the IPCC Good Practice Guidance (IPCC, 2000) suggests the following Tier 2-type equation:

Equation A3.2-2 for emissions from crude steel production:

$$\text{Emissions}_{\text{crude steel}} = [(\text{mass of carbon in pig iron used for crude steel} - \text{mass of carbon in crude steel}) \times 44/12] + (\text{Emission Factor}_{\text{EAF}} \times \text{steel produced in EAFs})$$

where:

Emissions _{crude steel}	=	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 in 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 ₂ to the molecular weight of carbon
Emission Factor _{EAF}	=	emission factor for steel produced in electric arc furnaces (EAFs) (kg CO ₂ / t steel)
steel produced in EAFs	=	the amount of steel produced in EAFs (kt)

According to Equation A3.2-2, the amount of CO₂ 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 A3.2-2) does not equal the amount of total pig iron production (used in Equations A3.2-1a and b). The quantity charged to steel furnaces is usually higher than the quantity produced.

IPCC Good Practice Guidance (IPCC, 2000) suggests a range of 3–5% for carbon content of the iron used for making steel and 0.5–2% as the range of carbon content in steel. The midpoints of the IPCC default ranges of carbon content in iron and steel of 4% and 1.25% respectively have been applied to equation A3.2-2. When there is steel produced in EAFs, it is good practice to include the carbon released from consumed electrodes in the estimation of emissions. Electrodes in EAFs are made of carbon (either graphite or Söderberg paste). When they are kept above the steel melt, the electrical arc oxidizes the carbon to CO or CO₂. The IPCC Good Practice Guidance (IPCC, 2000) suggests, for equation A3.2-2, a default EAF emission factor of 5 kg CO₂/ t steel produced in EAFs.

The total emissions from the sector of iron and steel production are the sum of Equations A3.2-1b and A3.2-2 above:

Equation A3.2-3 for emissions from iron and steel production as a whole:

$$\text{Total emissions}_{\text{iron \& steel}} = \text{Emissions}_{\text{pig iron}} + \text{Emissions}_{\text{crude steel}}$$

CO₂ emissions are estimated, at provincial level, based on the percentage of metallurgical coke consumption attributed to each province.

Equation A3.2-4 for metallurgical coke consumption % split:

$$\% \text{split} = \left(\frac{\text{Metallurgical coke consumption in a province}}{\text{total metallurgical coke consumption in Canada}} \right) \times 100\%$$

Equation A3.2-5 for emission estimates at provincial/territorial levels:

$$\text{Provincial/territorial emissions} = \text{Total emissions}_{\text{iron \& steel}} \times \% \text{ split}$$

It should be noted that Ontario is responsible for almost all emissions coming from this category, since the Canadian iron and steel industry is concentrated in this province.

The method described above does not account for additional CO₂ 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 CO₂ emissions from the consumption of electrodes in the steel production process in EAFs are therefore subtracted from the total non-energy emissions.

A3.2.1.2 Data Sources

The RESD (Statistics Canada, #57-003) provides data on national and provincial/territorial consumption of metallurgical coke for 1990–2005. National data on pig iron production, pig iron charged to steel furnaces, steel production, and quantity of steel produced in EAFs come from *Primary Iron and Steel* (Statistics Canada, #41-001) for 1990-2003 and from *Steel, Tubular Products and Steel Wire* (Statistics Canada, #41-019) for 2004-2005.

A3.2.2 CO₂ Emissions from Other and Undifferentiated Production

A3.2.2.1 Methodology

CO₂ emissions from non-energy use of hydrocarbons are reported under the category of *Other and Undifferentiated Production*. 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 sections.

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 steam CH_4 reforming for producing the hydrogen needed in ammonia plants. To estimate CO_2 emissions, non-energy use of natural gas in each province/territory is multiplied by an emission factor of $1522 \text{ g CO}_2 \text{ emitted/m}^3$ (Cheminfo Services, 2005). Summing all the provincial/territorial emissions together gives the national estimate. At the national level, the CO_2 emissions from non-energy use of natural gas are adjusted for the CO_2 emissions associated with ammonia production. More specifically, CO_2 from ammonia production, at the national level, is subtracted from total CO_2 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_2 emissions coming from these solid fuels, fuel-, province-, and year-specific emission factors (Jaques, 1992; McCann, 2000), shown in Table A3.2-1, 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_2 from non-energy use of coal and coal products are the same as those for combustion, because it is assumed that the carbon in these products will eventually be oxidized and emitted as CO_2 .

Table A3.2-1: CO₂ Emission Factors for Coal and Coal Products

Province	Coals	CO ₂ Emission Factors								1998–2005
		1990	1991	1992	1993	1994	1995	1996	1997	
g/kg										
Newfoundland and Labrador	Canadian Bituminous ¹	2 300 ²	2 294	2 287	2 281	2 274	2 268	2 262	2 255	2 249 ³
	Anthracite	2 390 ²	2 390	2 390	2 390	2 390	2 390	2 390	2 390	2 390 ³
Prince Edward Island	Canadian Bituminous ¹	2 300 ²	2 294	2 287	2 281	2 274	2 268	2 262	2 255	2 249 ³
Nova Scotia	Canadian Bituminous	2 300 ²	2 294	2 287	2 281	2 274	2 268	2 262	2 255	2 249 ³
	U.S. Bituminous	2 330 ²	2 325	2 320	2 314	2 309	2 304	2 299	2 293	2 288 ³
New Brunswick	Canadian Bituminous	2 230 ²	2 201	2 172	2 142	2 113	2 084	2 055	2 026	1 996 ³
	U.S. Bituminous	2 500 ²	2 476	2 453	2 429	2 405	2 382	2 358	2 334	2 311 ³
Quebec	Canadian Bituminous ¹	2 300 ²	2 294	2 287	2 281	2 274	2 268	2 262	2 255	2 249 ³
	U.S. Bituminous	2 500 ²	2 480	2 461	2 441	2 421	2 402	2 382	2 362	2 343 ³
	Anthracite	2 390 ²	2 390	2 390	2 390	2 390	2 390	2 390	2 390	2 390 ³
Ontario	Canadian Bituminous	2 520 ²	2 487	2 454	2 420	2 387	2 354	2 321	2 287	2 254 ³
	U.S. Bituminous	2 500 ²	2 492	2 483	2 475	2 466	2 458	2 449	2 441	2 432 ³
	Sub-Bituminous ⁴	2 520 ²	2 422	2 323	2 225	2 126	2 028	1 930	1 831	1 733 ³
	Lignite	1 490 ²	1 488	1 486	1 485	1 483	1 481	1 479	1 478	1 476 ³
	Anthracite	2 390 ²	2 390	2 390	2 390	2 390	2 390	2 390	2 390	2 390 ³
Manitoba	Canadian Bituminous	2 520 ²	2 486	2 453	2 419	2 386	2 352	2 319	2 285	2 252 ³
	Sub-Bituminous	2 520 ²	2 422	2 323	2 225	2 126	2 028	1 930	1 831	1 733 ³
	Lignite	1 520 ²	1 508	1 496	1 484	1 472	1 460	1 448	1 436	1 424 ³
	Anthracite	2 390 ²	2 390	2 390	2 390	2 390	2 390	2 390	2 390	2 390 ³
Saskatchewan	Canadian Bituminous ⁵	1 700 ²	1 719	1 738	1 757	1 776	1 795	1 814	1 833	1 852 ³
	Lignite	1 340 ²	1 351	1 362	1 373	1 384	1 394	1 405	1 416	1 427 ³
Alberta	Canadian Bituminous	1 700 ²	1 719	1 738	1 757	1 776	1 795	1 814	1 833	1 852 ³
	Sub-Bituminous	1 740 ²	1 743	1 746	1 749	1 753	1 756	1 759	1 762	1 765 ³
	Anthracite	2 390 ²	2 390	2 390	2 390	2 390	2 390	2 390	2 390	2 390 ³
British Columbia	Canadian Bituminous	1 700 ²	1 747	1 793	1 840	1 886	1 933	1 979	2 026	2 072 ³
All Provinces	Metallurgical Coke	2 480 ²	2 480	2 480	2 480	2 480	2 480	2 480	2 480	2 480 ³

Notes:

- 1 Assumed same source of Canadian bituminous for Newfoundland and Labrador, Prince Edward Island, Nova Scotia, and Quebec.
- 2 Jaques (1992).
- 3 Adapted from McCann (2000).
- 4 Represents both domestic and imported sub-bituminous.
- 5 Assumed same source of Canadian bituminous for Saskatchewan and Alberta.

Liquid Fuels

In addition to the emissions coming from gaseous and solid fuels mentioned above, CO₂ emitted by the non-energy use of several refined petroleum products and NGLs is also included in the category of *Other and Undifferentiated Production*.

To estimate these emissions at provincial/territorial levels, the non-energy use quantity of each of the refined petroleum products and NGLs is multiplied by its corresponding emission factor, shown in Tables A3.2-2 and A3.2-3. The summation of the provincial/territorial estimates gives the national emission estimate.

Table A3.2-2: CO₂ Emission Factors for Various Refined Petroleum Products

	Emission factors (g CO₂/L)	Sources
Still Gas	2 000	Jaques (1992)
Motor Gasoline	2 360	Jaques (1992)
Kerosene	2 550	Jaques (1992)
Diesel Fuel Oil	2 730	Jaques (1992)
Light Fuel Oil	2 830	Jaques (1992)
Heavy Fuel Oil	3 090	Jaques (1992)
Petroleum Coke Oil	4 200	Nyboer (1996)
Aviation Gasoline	2 330	Jaques (1992)
Aviation Turbo fuel	2 550	Jaques (1992)

Table A3.2-3: CO₂ Emission Factors for Natural Gas Liquids

	Fraction of carbon stored in products	Emission Factors (g CO₂/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 emission factors shown in Table A3.2-2 are the same as those used for calculating combustion-related emissions, because it is assumed that the carbon in these refined petroleum products used for non-energy purposes will eventually be oxidized and emitted as CO₂. 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 IPCC Guidelines (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.

Finally, the use of petrochemical feedstocks, naphthas, lubricants, greases, and other petroleum products also results in CO₂ 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 CO₂ and carbon, 44/12, and by (1 – fraction of carbon stored) to give the CO₂ emission factors used to estimate emissions. As in the case of NGLs, the default values of fraction of carbon stored are found in the IPCC Guidelines (IPCC/OECD/IEA, 1997). Derivations of the non-energy use emission factors are shown in Table A3.2-4. To estimate emissions at

national and provincial/territorial levels, the volume of non-energy product used is multiplied by its corresponding emission factor.

Table A3.2-4: CO₂ Emission Factors for Non-Energy Petroleum Products

Non-Energy Products	Carbon Factor (g C/L)	Molecular Weight Ratio between CO ₂ and Carbon	Fraction of Carbon Stored (IPCC Default)	Resulting CO ₂ Emission Factor (g CO ₂ /L)
	A	B	C	$D = A \times B \times (1 - C)$
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

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 added together. 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, CO₂ 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 provincial level, CO₂ emissions from ammonia production are included in the *Other and Undifferentiated Production* emission estimates.

A3.2.2.2 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 versus non-energy use applications).

A3.2.3 CO₂ Emissions from Ammonia Production

A3.2.3.1 Methodology

To estimate emissions from ammonia production, an emission factor of 1.56 t CO₂/t NH₃ 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 one tonne of liquefied ammonia. Information on the feedstock requirement for the SMR process was originally obtained from *Industrial Chemicals* written by F. Lowenheim and M. Moran (Lowenheim, F. & Moran, M., 1980). Table A3.2-5 below details the derivation of the NH₃-based emission factor (1.56 t CO₂/t NH₃):

Table A3.2-5: Derivation for Ammonia Production-Based Emission Factor

Basis of derivation: 1 tonne of NH ₃						
Volume of natural gas required to make 1 tonne of NH ₃ : 812 m ³ (A)						
Molar volume of natural gas at 15°C: 0.02365 m ³ /mol (B)						
Natural Gas Component	# of carbons	Potential CO ₂ emissions per mol of component (g/ mol)	Natural Gas Composition (% by vol.)	Volume of each component in 812m ³ of natural gas (m ³)	# of moles of each component in 812m ³ of natural gas (mol)	CO ₂ emissions from each component (t)
	C	D = C × 44g CO ₂ /mol	E	F = E × A	G = F / B	H = G × D / 1000,000
Methane (CH ₄)	1	44	92%	747	31,554	1.39
Ethane (C ₂ H ₆)	2	88	3.6%	29	1,235	0.11
Propane (C ₃ H ₈)	3	132	1.0%	8	343	0.05
Butane (C ₄ H ₁₀)	4	176	0.3%	2	103	0.02
Nitrogen	0	0	3.1%	25	1063	0.00
Resulting Emission Factor (t CO₂ / t NH₃)						1.56

Since hydrogen needed for the Haber-Bosch process can be acquired from processes other than SMR, not all ammonia production involves emissions of CO₂. Therefore, it is necessary to multiply only the net CO₂-related ammonia production by the emission factor. Data on CO₂-related production used in the calculation can either be directly collected from ammonia plants or estimated nationally.

Not all of the ammonia manufacturing plants provided their 1990-2005 operational data. In order to estimate the unreported part of the CO₂-emitting ammonia production, the amount of ammonia produced using by-product hydrogen and that using hydrogen from (steam methane reforming) 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 CO₂-emitting ammonia plants only.) Multiplying both reported and unreported CO₂-related ammonia production by the emission factor of 1.56 t CO₂/ t NH₃ gives the total amount of CO₂ generated. To estimate by province the amount of CO₂ 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 CO₂ generation estimates for ammonia production are included in the category of *Other and Undifferentiated Production*.

In some cases, the generated CO₂ can be directed to a neighbouring urea plant, where it is recovered and utilized as a feedstock gas. Hence, to avoid overestimation of the net CO₂ emissions from ammonia production, the amount of CO₂ used to make urea should be accounted for in the calculations. However, since the carbon would only be trapped in urea temporarily and emitted upon its application, it is assumed that all CO₂ generated during the manufacturing of ammonia is released to the atmosphere, except the portion that is stored in exported urea. Subtracting the quantity of CO₂ in exported urea from the

amount of CO₂ generated in the SMR process gives the net CO₂ emission estimate for ammonia production. CO₂ trapped in exported urea was determined by multiplying urea export by a factor of 0.733 t CO₂ trapped/t urea. The latter factor was developed based on the stoichiometry of the urea manufacturing process:



As shown in the chemical equation above, 1 mole of CO₂ is needed to produce 1 mole of urea. Thus, taking the molar weight ratio of CO₂ (44) to urea (60) gives a factor of 0.733 t CO₂/ t urea.

Urea export data are provided in *Exports by Commodity* (Statistics Canada, #65-004) and available at www.statcan.ca/trade/scripts/trade_search.cgi. Since in some cases the province where there has been urea export is not necessarily a province where ammonia is manufactured, the following assumptions are made:

- For 1990-1996, it is assumed that the CO₂ used in exported urea from British Columbia came from Alberta;
- For 1990-1991, it is assumed that the CO₂ used in exported urea from Saskatchewan came from Alberta; and
- For all years, it is assumed that the CO₂ used in exported urea from Québec and all provinces of the east coast came from Ontario.

To prevent overestimation at provincial level, the amount of CO₂ trapped in exported urea is deducted from the category of *Other and Undifferentiated* for provinces where there has been ammonia 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 CO₂ emissions from ammonia production were subtracted from the total non-energy fossil fuel use CO₂ emissions.

The estimation technique (emission = production of ammonia x emissions factor) described in this section is one of the default methods suggested in the Revised 1996 IPCC Guidelines. However, it should be noted that the emission factor of 1.56 t CO₂/t NH₃ produced is a national average value. Methodological issues for calculating CO₂ emissions from ammonia production are not addressed specifically in the IPCC Good Practice Guidance (IPCC, 2000).

A3.2.3.2 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, 2006). For 2005, data are reported by companies to the GHG Division on a voluntary basis. *Industrial Chemicals and Synthetic Resins* (Statistics Canada, #46-002)

provides data on national total of ammonia production. Urea export data are found in *Exports by Commodity* (Statistics Canada, #65-004) and available at www.statcan.ca/trade/scripts/trade_search.cgi.

A3.3 Methodology for Solvent and Other Product Use

Readers are referred to Chapter 5 (Solvent and Other Product Use).

A3.4 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:

- CH₄ emissions from enteric fermentation;
- CH₄ and N₂O emissions from manure management; and
- N₂O emissions from agricultural soils (direct emissions, indirect emissions, and animal manure emissions on pasture, range, and paddock).

Animal population data sources, which are common to those three agricultural source categories, are described in the first section. Agricultural soils also emit/sequester CO₂, but this is reported in the LULUCF Sector. CO₂ methodology description can be found in Section A3.5 of this annex.

A3.4.1 Animal Population Data Sources

Annual livestock population data at a provincial level were used to develop emission estimates. An enhanced single livestock characterization was used for emission sources of enteric fermentation and manure management, since a Tier 2 approach based on IPCC Good Practice Guidance (IPCC, 2000) was adopted. A list of livestock categories and their corresponding data sources are given in Table A3.4-1.

Table A3.4-1: Data Sources for Animal Populations

Animal Category	Data Source
Cattle Bull, Dairy Cow, Beef Cow, Dairy Heifer, Beef Heifer, Beef Heifer for Slaughter, Steer, and Calves	Statistics Canada (2005a), Catalogue No. 23-012, Table 1, Cattle on Farms
Swine Boar, Sow, Pig <20 kg, Pig 20–60 kg, and Pig >60 kg	Statistics Canada (2005b), Catalogue No. 23-010, Table 1, Pigs on Farms
Goat, Horse, and Bison	Statistics Canada (2002a), Catalogue No: 23-502
Poultry Chicken, Layer, and Turkey	Statistics Canada (1987, 1992, 1997 and 2002b); 1986, 1991, 1996, and 2001 Census of Agriculture, Catalogue Nos: 96102, 93350, 93356, and 95F0301, Table 23.1; Poultry Inventory, by Province, Census Agricultural Region and Census Division
Sheep and Lamb	Statistics Canada (2005c), Catalogue No. 23-011, Table 1, Sheep and Lambs on Farms

Livestock population data are expressed on an annual basis, although data collection is on a quarterly (swine) or semi-annual basis (cattle, sheep, and lamb) or a five-year Census period basis (horse, goat, bison, and poultry). Therefore, there is a need to annualize these data.

For populations estimated every five years with the Census, data are adjusted through interpolation to avoid large annual changes, especially for years immediately before the Census year. In addition, bison population data were not collected in 1986; thus, bison population for 1990 was set constant at the 1991 level.

Cattle, sheep, and lamb data are reported in January and July by Statistics Canada. Average annual populations for these are calculated by taking the simple mean of the two semi-annual data sets. The same approach is taken for pig population data, which are collected quarterly.

A3.4.2 CH₄ Emissions from Enteric Fermentation

A3.4.2.1 Methodology

CH₄ emissions from enteric fermentation for dairy and beef cattle are estimated with the IPCC Tier 2 methodology (Tables A3.4-2 and A3.4-3). For the other animal categories, the IPCC Tier 1 methodology is used (Table A3.4-2). The release of CH₄ from enteric fermentation from various categories of livestock in Canada is calculated using Equation A3.4-1.

Equation A3.4-1:

$$CH_{4EF} = \sum_T (N_T \times EF_{(EF)T})$$

where:

CH_{4EF}	=	methane 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

See Table A3.4-2 and Table A3.4-3.

Table A3.4-2: CH₄ Emission Factors for Enteric Fermentation and Manure Management by Animal Category except Dairy Cows

Animal Category	Emission Factors	
	Enteric Fermentation $EF_{(EF)T}$ (kg CH ₄ /head/ year)	Manure Management $EF_{(MM)T}^1$
Cattle		
Bulls	94 ²	3.2
Beef Cows	90 ²	3.5
Beef Heifers	75 ²	2.8
Dairy Heifers	73 ²	15.4
Heifers for Slaughter	63 ²	1.8
Steers	56 ²	2.0
Calves	40 ²	1.1
Pigs		
Boars	1.5 ³	6.4
Sows	1.5 ³	6.3
Pigs <20 kg	1.5 ³	1.8
Pigs 20–60 kg	1.5 ³	5.1
Pigs >60 kg	1.5 ³	7.9
Other Livestock		
Sheep	8 ³	0.3
Lambs	8 ³	0.2
Goats	5 ³	0.3
Horses	18 ³	2.3
Bison	55 ³	2.0
Poultry		
Chickens	N/A	0.03
Hens	N/A	0.03
Turkey	N/A	0.08

Notes:

- 1 Emission factors are derived from Marinier *et al.* (2004) with modifications following the guidance provided by IPCC (2000).
 - 2 Emission factors are derived from Boadi *et al.* (2004) following the guidance provided by IPCC (2000).
 - 3 IPCC Tier 1 default emission factors (IPCC/OECD/IEA, 1997).
- N/A = Not available

Table A3.4-3: CH₄ Emission Factors for Enteric Fermentation and Manure Management for Dairy Cows from 1990 to 2005

Year	Emission Factors ¹	
	Enteric Fermentation	Manure Management
	EF _(EF) T (kg CH ₄ /head/ year)	EF _(MM) T
1990	116.9	25.7
1991	117.7	25.9
1992	120.3	26.5
1993	122.3	26.9
1994	123.0	27.1
1995	123.8	27.3
1996	125.6	27.4
1997	126.1	27.7
1998	128.0	27.9
1999	130.1	28.2
2000	132.1	29.0
2001	132.9	29.3
2002	135.2	29.6
2003	135.3	29.7
2004	134.8	29.6
2005	134.9	29.7

Note:

- 1 Dairy cow emission factors are derived from Boadi *et al.* (2004) for enteric fermentation and Marinier *et al.* (2004) for manure management following the guidance provided by IPCC (2000) and IPCC (2006), with modifications.

A3.4.2.2 *Determining CH₄ Enteric Fermentation Emission Factors for Various Categories of Cattle Using the IPCC Tier 2 Methodology*

The IPCC Tier 2 method is used to determine enteric CH₄ emission factors for beef and dairy cattle in Canada. To achieve this, the cattle population was characterized by animal type, physiological status, age, gender, weight, rate of gain, level of activity, and production environment. Much of this information was not available in the published literature and was obtained from beef and dairy cattle specialists across the country. This information was used to calculate emission factors associated with various cattle categories based on the IPCC Tier 2 equations, as detailed in the following sections. Many of these data were also used to derive manure management CH₄ emission factors for cattle. Since the previous inventory, additional modifications were made to derive a time series of emission factors for dairy cattle emissions to reflect changes in milk production from 1990 to 2005.

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 cattle specialists. Additional information was obtained from research scientists at universities and federal research institutions, as well as from provincial/national commodity groups and provincial/regional performance recording organizations (Boadi *et al.*, 2004). The derived emission factors are assumed to

be applicable to the entire time series for all animals with the exception of dairy cows, for which milk production and milk fat content since 1990 are factored in. This does not reflect the fact that performance and feeding practices may have changed since 1990, which would require a varying emission factor. However, time series of parameters such as average animal weight for cattle are not available, and consistent data on change in feeding practices since 1990 have not yet been obtained.

Production and Performance of Dairy Cattle

A summary of production performance of Canadian dairy cattle is provided in Table A3.4-4. An emission factor time series for dairy cattle was derived to reflect the increase in milk productivity of dairy cows over the 1990s and beyond. Average milk production from 1990 to 2005 and number of milk days per cow per year at the provincial level are provided in Table A3.4-5.

Table A3.4-4: Characteristics of Dairy Production in Canada

Animal Category/Parameters	Production Characteristics ¹	Data Sources ²
Dairy Cows		
Average weight, kg	634 (51)	Okine and Mathison, 1991; Kononoff <i>et al.</i> , 2000; Petit <i>et al.</i> , 2001
Mature weight, kg	646 (55)	
Conception rate, %	59.2 (7.3)	
Calves		
Birth weight, kg	41 (3.3)	
Average weight, kg	186 (18.5)	
Mature weight, kg	330.5 (37.6)	
Daily weight gain, kg/day	0.7 (0.3)	
Calf crop, ³ %	93 (6)	
Replacement Heifers		
Average weight, kg	461.6 (24.7)	Western Dairy Herd Improvement, 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.

Table A3.4-5: Average Milk Production from 1990 to 2005 and Number of Milking Days at a Provincial Level

Year	Average Milk Production									
	NL	PEI	NS	NB	QC	ON	MB	SK	AB	BC
	<i>(kg/cow/ day)¹</i>									
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
Milk days per year ²	306	297	300	302	303	303	293	292	295	301

Notes:

1 Data source: Agriculture and Agri-Food Canada (2005a,b).

2 Data source: Boadi *et al.* (2004).

Production practices varied across some provinces because of differences in land values, climate, forage availability, and market access. The predominant practices for each province were represented in the IPCC Tier 2 equations.

Milk Yield and Fat Data

Average milk production for each province from 1995 to 2005 was drawn from *Dairy Animal Improvement Statistics* (Agriculture and Agri-Food Canada, 2005a) and *Statistics of the Canadian Dairy Industry* (Agriculture and Agri-Food Canada, 2005b), and was used to calculate net energy for lactation, or $NE_{lactation}$ (NE_l). For 1990–1994, only the national milk yield data were published. The provincial annual average milk production per day was calculated by dividing the national average production by the number of milking days per year by province (Boadi *et al.*, 2004). Milk fat data (%) were also obtained from Agriculture and Agri-Food Canada (2005a,b) and were assumed to be identical across provinces.

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) using the following formula:

$$\text{Percent cows pregnant} = (\text{gestation length/calving interval} \times 100) - \text{percent cows culled due to reproductive failure}$$

Production Practices and Performance for All Classes of Beef Cattle

Table A3.4-6 presents the characteristics of beef cattle collected by Boadi *et al.* (2004) from publications and expert consultations, and values represent an average that was drawn for all provinces.

Duration of Time in a Production Environment

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 CH₄ emissions in these first few months were assumed to be zero. Replacement heifers over 15 months of age were assumed to be bred or pregnant. All replacement stock (breeding bulls, young and replacement heifers over 12 months of age) was assumed to enter the breeding herd (breeding bulls, mature and beef cows) at 24 months of age.

Table A3.4-6: Characteristics of Beef Production in Canada

Animal Category/Parameters	Production Characteristics¹	Data Sources²
Beef Cows		
Average weight, kg	603 (36)	Kopp <i>et al.</i> , 2004
Mature weight, kg	619 (52)	AAFRD, 2001
Milk, kg/day	7.3 (1.2)	Kopp <i>et al.</i> , 2004
Milk fat, %	3.6 (0.6)	Kopp <i>et al.</i> , 2004
Conception rate, %	93.7 (1.3)	Manitoba Agriculture and Food, 2000; AAFRD, 2001
Replacement Heifers		
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
Bulls		
Yearling weight, kg	541 (18)	
Average weight, kg	940 (98)	
Mature weight, kg	951 (112)	
Daily weight gain, kg/day	1.0 (0.17)	
Calves (including Dairy Calves)		
Birth weight, kg	40 (3)	AAFRD, 2001
Wean weight, kg	258.4 (19.1)	Small and McCaughey, 1999;
Age at weaning, days	215 (15)	
Daily weight gain, kg/day		
- Replacement heifers	0.67 (0.13)	Kopp <i>et al.</i> , 2004
- Backgrounder	0.98 (0.17)	
- Finisher	1.37 (0.12)	
Calf crop, %	95 (2.3)	
Heifer and Steer Stockers		
Average weight, kg	411 (47)	Kopp <i>et al.</i> , 2004
Mature weight, kg	620 (51)	
Daily weight gain, kg/day	0.98 (0.16)	
Proportion to feedlot, %	65 (30)	
Feedlot Animals		
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).

Characterization of the Feeding Practices for Beef and Dairy

When available, data from surveys examining feeding management strategies or practices that had subsequently been published in scientific journals were utilized to describe the feeding strategies for classes of animals. Additional information was obtained from research scientists at universities and federal research institutions, as well as from provincial/national commodity groups and provincial/regional performance recording organizations.

Ration Digestible Energy Calculations for Dairy Cattle

Forage 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. 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.

Ration Digestible Energy Calculations for Beef Cattle

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 Alberta Agriculture, Food and Rural Development (AAFRD) and University of Alberta (2003) were used for Alberta, while NRC (2001) values were used to estimate DE of rations for British Columbia, and the eastern provinces.

Calculating Enteric CH₄ Emission Factors

Emission factors were derived using IPCC 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. Dairy cattle emissions, for example, were estimated for two production categories — dry cows and lactating cows. As the duration of time an animal in a category was variable for some categories, a weighted emission factor was calculated. Criteria used in the weighting included duration of time in the category and relative percentage of the population in each stage of production. Provincial emission factors for non-dairy cattle weighted on the basis of provincial contribution to the national animal populations in 2001 were used to calculate a national emission factor for each category for the entire time series since 1990 (Table A3.4-7). For dairy cattle, provincial emission factors weighted on the basis of provincial contribution to the national dairy populations from 1990 to 2005 were used to calculate a national emission factor for each year since 1990 (Table A3.4-8).

Table A3.4-7: Provincial and National CH₄ Emission Factors for Enteric Fermentation from Various Beef Cattle in Canada

Provinces	Emission Factors						
	Dairy Heifers	Beef Cows	Bulls	Calves <1 Year	Heifer Replacement	Heifers >1 Year	Steers >1 Year
	(kg CH ₄ /head/ year)						
NL	93	85	105	45	68	99	91
PEI	75	88	88	33	71	48	44
NS	78	90	84	41	68	70	64
NB	77	98	96	39	80	46	42
QC	70	104	96	42	97	41	38
ON	75	105	90	40	90	60	55
MB	72	94	93	33	73	60	55
SK	75	77	87	37	61	55	50
AB	71	93	96	43	76	65	59
BC	72	95	106	37	82	64	59
Range	70–93	77–105	84–106	33–45	61–97	41–70	38–64
National mean ¹	73	90	94	40	75	63	56
Standard Deviation ²	7 (9%)	8 (9%)	7 (8%)	4 (10%)	11 (14%)	10 (17%)	9 (17%)

Notes:

1 Weighted means for each beef category based on animal population in 2001.

2 Numbers in parentheses expressed as percentage of the mean (Source: Boadi *et al.*, 2004).**Table A3.4-8: Provincial and National CH₄ Emission Factors for Enteric Fermentation from Dairy Cows from 1990 to 2005**

Year	Emission Factors									
	NL	PEI	NS	NB	QC	ON	MB	SK	AB	BC
	(kg CH ₄ /head / year)									
1990	123.0	118.1	111.0	116.8	112.6	120.5	122.6	118.9	114.5	126.1
1991	124.0	118.8	111.9	117.7	113.3	121.1	123.5	119.7	115.4	127.1
1992	126.6	121.7	114.5	120.4	115.9	123.7	126.2	122.2	117.9	129.8
1993	128.4	123.5	116.3	122.4	117.9	125.7	128.2	124.0	119.8	131.6
1994	129.4	124.4	117.2	123.1	118.6	126.3	129.1	124.9	120.7	132.5
1995	128.7	123.8	116.6	122.5	117.5	127.7	129.1	124.8	125.6	139.8
1996	129.3	124.4	117.5	123.3	119.5	129.7	130.6	126.6	127.0	141.1
1997	130.2	125.3	118.1	124.2	120.5	129.3	131.6	127.9	127.4	139.9
1998	131.1	126.4	119.2	125.0	122.8	131.4	132.1	129.4	128.4	140.9
1999	133.8	128.8	121.6	127.5	125.3	132.8	134.2	130.8	130.0	143.4
2000	137.7	131.2	125.7	130.7	127.7	133.7	137.1	133.2	132.1	146.0
2001	139.0	132.9	127.0	133.6	129.1	133.9	139.3	135.1	133.3	146.7
2002	138.8	135.1	126.8	134.4	130.9	137.1	138.8	136.9	135.3	149.8
2003	139.8	135.7	127.8	133.5	130.5	137.2	139.2	137.8	136.0	150.4
2004	139.4	134.5	127.4	132.6	130.1	136.5	139.6	138.3	135.0	149.5
2005	139.4	135.9	127.7	132.7	129.9	137.3	138.4	138.7	134.6	149.6

Note:

1 Emission factors at the national level are calculated by using each provincial emission factor weighted by its dairy cow population.

A3.4.3 CH₄ Emissions from Manure Management

A3.4.3.1 Methodology

The IPCC Tier 2 methodology is used to estimate CH₄ emissions from manure management systems that have been developed and outlined in the IPCC Good Practice Guidance (IPCC, 2000). Equation A3.4-2 is used to calculate CH₄ emissions from manure management for various categories of livestock in Canada.

Equation A3.4-2:

$$CH_{4MM} = \sum_T (N_T \times EF_{(MM)T})$$

where:

CH _{4MM}	=	emissions for all animal categories
N _T	=	animal population for the Tth animal category or subcategory in each province
EF _{(MM)T}	=	emission factor for the Tth animal category or subcategory <i>See Table A3.4-2 and Table A3.4-3.</i>

Sources of animal population data are the same as those used in the enteric fermentation estimations (see Table A3.4-1).

A3.4.3.2 Determining CH₄ Emission Factors for Various Animal Categories Based on Manure Management Practices Using the IPCC Tier 2 Methodology

The IPCC Tier 2 method for estimating CH₄ emissions from manure management used country-specific inputs, taking into account livestock diet, type and distribution of manure storage, and climate.

The following equation represents an IPCC Tier 2 estimate of CH₄ emission factors from manure management systems:

Equation A3.4-3:

$$EF_{(MM)T} = VS_T \times 365 \text{ days/year} \times B_{0T} \times 0.67 \text{ kg/m}^3 \times \sum_{ij} (MCF_{ij} \times MS_{Tij})$$

where:

EF _{(MM)T}	=	annual emission factor for defined animal population T, kg
VS _T	=	daily volatile solids excreted for an animal within the defined population T, kg
B _{0T}	=	maximum CH ₄ producing potential for manure produced by an animal within defined population T, m ³ /kg VS
MCF _{ij}	=	CH ₄ conversion factor for each manure management system i in climate region j
MS _{Tij}	=	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)

Tables A3.4-2 and A3.4-3 provide a list of emission factors used for this category for both non-cattle and cattle livestock, derived from a study by Marinier *et al.* (2004), with modifications to increase consistency with the enteric fermentation category and updates to incorporate the latest scientific information available from the 2006 IPCC Guidelines (IPCC, 2006). Dry matter intake (DMI) and volatile solids (VS) for dairy and non-dairy cattle were estimated using the same method as for enteric fermentation. An emission factor time series for dairy cattle was also derived to reflect the increase in milk productivity of dairy cows over the 1990s and beyond.

The following sections examine the data sources for estimating VS for major animal categories.

A3.4.3.2.1 Volatile solids (VS)

Volatile solids are the organic fraction of total solids within the manure and can be measured from manure samples, although this is rarely done in Canada. Alternatively, VS can be estimated using the IPCC (2000) methodology based on dietary intake:

Equation A3.4-4:

$$VS = DMI \times (1 - DE/100) \times (1 - ASH/100)$$

where:

VS	=	volatile solids excretion, kg/head per day
DMI	=	ration dry matter intake, kg/head per day
DE	=	digestible energy of the ration, %
ASH	=	mineral content of the manure, %

(IPCC 2000, Equation 4.16, p. 4.31)

Estimating VS based on the IPCC (2000) methodology requires an estimate of ration DMI. Ration DMI in livestock depends on many factors, including body size, lactation stage, and time of year and can be estimated through calculation of the gross energy (GE) intake:

Equation A3.4-5:

$$GE = \{[(NE_m + NE_a + NE_l + NE_p)/(NE_m/DE)] + [NE_g/(NE_g/DE)]\}/(DE/100)$$

where:

GE	=	gross energy, MJ/day
NE _m	=	net energy required for maintenance, MJ/day
NE _a	=	net energy required for activity, MJ/day
NE _l	=	net energy required for lactation, MJ/day
NE _p	=	net energy required for pregnancy, MJ/day
NE _m /DE	=	ratio of net energy available in a diet for maintenance to digestible energy
NE _g	=	net energy required for growth, MJ/day
NE _g /DE	=	ratio of net energy available in a diet for growth to digestible energy consumed
DE	=	digestible energy of the ration, %

(IPCC 2000, Equation 4.11, p. 4.20)

Gross energy values were converted to DMI using a feed energy factor of 18.45 MJ/kg (IPCC, 2000). The following sections outline the input values for Equation A3.4-4: DE, ASH, DMI, and VS.

Digestible Energy (DE)

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. Cattle categories are covered under the enteric fermentation category.

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 A3.4-9). It should be noted that this method does not account for additives that may increase or decrease digestibility.

Table A3.4-9: Approximate Digestible Energy (DE) for Selected Livestock and Data Sources

Animal Category	DE (%)	Data Sources¹
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
Feeding on Grain Diet		
Sheep	74	Weston (2002)
Horse	70	L. Warren, Colorado State University
Feeding on Roughage Diet		
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).

Manure Ash Content (ASH)

ASH is required to obtain an estimate of the organic portion of the manure. Table A3.4-10 contains the recommended values obtained from various sources.

Table A3.4-10: 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 <i>et al.</i> (2004)
Chicken	7	Marinier <i>et al.</i> (2004)
Turkey	5	Marinier <i>et al.</i> (2004)
Swine	5	Marinier <i>et al.</i> (2004)

Dry Matter Intake

Ranges for DMI for non-cattle were determined through consultation with experts and published values (Table A3.4-11). For various cattle categories, DMI values were estimated using Equation A3.4-4 based on the same variables and parameters used for estimating CH₄ emissions from enteric fermentation (Section A3.4.2).

Table A3.4-11: Dry Matter Intake for Selected Livestock

Animal Category	DMI <i>(kg/head per day)</i>	Data Sources
Sheep and Lamb		
Ewes	1.2–2.8	NRC (1985)
Rams	2.1–3.0	W. Whitmore, Manitoba Agriculture and Food
Replacement Lambs	1.2–1.5	NRC (1985)
Market Lambs	1.3–1.6	NRC (1985)
Horses		
Mature Idle Horses	7.4–11	NRC (1989) and L. Warren, Colorado State University
Mature Working Horses	7.4–13.7	NRC (1989) and L. Warren, Colorado State University
Weanlings	3.6–6.3	NRC (1989)
Swine		
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 ¹	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	M. Nyachoti, University of Manitoba; NRC (1998)
Goats		
Does	1.2–2.8	NRC (1981)
Bucks	1.4–2.3	CRAAQ (1999)
Kids	1.4	CRAAQ (1999)
Poultry		
Laying Hens	0.072–0.11	S. Leeson, University of Guelph; 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 (20 kg).

Volatile Solid Calculation and Error Assessment

Values for DMI, DE, and ASH were used to calculate VS for each non-cattle livestock category 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 3.4-4 was calculated 10 000 times using inputs within the assigned distributions to arrive at the mean VS and 95% confidence interval (Table A3.4-12).

Table A3.4-12: Mean VS and Associated 95% Confidence Interval Expressed as a Percentage of the Mean for Each Non-Cattle Category in Each Province

	Mean VS ¹									
	BC	AB	SK	MB	ON	QC	NB	NS	PEI	NL
	<i>kg/head/ day</i>									
Sheep										
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)
Horses										
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)
Swine										
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)
Goats										
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)
Poultry										
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 95% confidence interval expressed as a percentage of the mean.

Maximum CH₄ Producing Potential (B₀)

B₀ was determined from several studies examining anaerobic digestion (Hashimoto *et al.*, 1981; Safely *et al.*, 1992). B₀ is defined as the maximum volume of CH₄ that can be produced from 1 kg of VS loaded into a manure management system and is expressed in m³/kg VS loaded. Because it is a measure of the maximum CH₄ production, B₀ is not affected by the temperature at which manure is digested (Hashimoto *et al.*, 1981). Factors that affect B₀ include diet, age of manure, amount of foreign material, and species. Swine manure has the highest CH₄ producing potential, followed by poultry, beef cattle, and dairy cattle. Very little research has been done to determine the B₀ for horses, and no research could be found on sheep or goat manure. Because of lack of available data in Canada, the IPCC default B₀ values were used (Table A3.4-13).

Table A3.4-13: Values of Maximum CH₄ Producing Potential (B₀) for Various Livestock Types¹

Animal Category	Maximum CH ₄ Producing Potential (B ₀) (m ³ /kg VS)
Dairy Cattle	0.24
Non-Dairy Cattle ²	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.

Methane Conversion Factor (MCF)

MCF is the proportion of B₀ that is realized and is affected by the storage system (for cattle and swine) and climate region. Values are presented in Table A3.4-14.

Table A3.4-14: CH₄ Conversion Factor (MCF) for Each Animal Type¹

Animal Type	Liquid	Solid Storage	Pasture and Paddock	Others
Dairy Cattle	0.20	0.02	0.01	0.01
Non-Dairy Cattle ²	0.20	0.02	0.01	0.01
Swine	0.20	0.02	N/A	0.01
Poultry	0.015	0.015	0.015	N/A
Horse	N/A	0.01	0.01	N/A
Goat	N/A	0.01	0.01	N/A
Sheep	N/A	0.01	0.01	N/A
Lamb	N/A	0.01	0.01	N/A

Notes:

1 Data source: IPCC (2006), Volume 4: Agriculture, Forestry and Other Land Uses, Table 10A-5 to 10A-9 (cool climate, average annual temperature 12°C).

2 Non-dairy cattle values also used for buffalo.

N/A = Not applicable

Manure System Distribution Factor (MS)

MS is the proportional distribution of animal waste management systems (AWMS) 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), and the results are shown in Table A3.4-15. For beef, dairy, swine, and poultry, these values were calculated using a weighted average based on population. For horses, sheep, and goats, these values were a non-weighted average based on the

survey responses. No specific data were available for covered lagoons and biodigesters, but these are assumed to be part of Other Systems.

Table A3.4-15: Percentage of Manure Handled by Animal Waste Management Systems (AWMS)¹

Animal Category	Liquid Systems (N _L)	Solid Storage & Drylot (N _{SSD})	Pasture, Range, & 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
Swine	96	3	0	1
Goat	0	40	60	0
Horse	0	43	57	0
Bison ²	0	43	57	0

Notes:

1 Data source: Marinier *et al.* (2004).

2 Assuming manure N handled by AWMS the same as horses

A3.4.4 N₂O Emissions from Manure Management

A3.4.4.1 Methodology

The IPCC Tier 1 methodology is used to estimate N₂O emissions from AWMS. Estimates of N₂O emissions from AWMS, excluding those from manure on pasture, range, and paddock systems, are calculated using Equation A3.4-6. N₂O emissions from the manure on pasture, range, and paddock are reported under Agricultural Soils. Three factors were required for estimating emissions of N₂O resulting from manure management: i) nitrogen excretion rates for various animal types and categories, ii) types of AWMS, and iii) emission factors associated with each manure management system.

Equation A3.4-6:

$$N_2O_{AWMS} = \sum_{AWMS, T} (N_T \times N_{AWMS} \times N_{EX, T} \times EF_{AWMS}) \times \frac{44}{28}$$

where:

N ₂ O _{AWMS}	=	N ₂ O emissions for all AWMS, excluding manure nitrogen on pasture, range, and paddock
N _T	=	population for the Tth animal category or subcategory <i>Refer to Section A3.4.2 for livestock population data sources and calculations.</i>
N _{AWMS}	=	percentage of nitrogen produced by each AWMS (%) <i>Refer to Table A3.4-15.</i>
N _{EX, T}	=	Nitrogen excretion rate for the Tth animal category or subcategory <i>Refer to Table A3.4-16.</i>
EF _{AWMS}	=	N ₂ O emission factors from manure management for each specific AWMS <i>Refer to Table A3.4-17.</i>
44/28	=	molecular weight ratio of N ₂ O to N ₂

Manure management systems data for each animal type are the same as those used to derive CH₄ emissions from manure. Animal population data are identical to those used for CH₄ emissions from enteric fermentation and manure management.

A3.4.4.2 Nitrogen Excretion Rates for Various Domestic Animals

There have been very few comprehensive scientific studies on the rate of nitrogen excretion for various domestic animals in Canada. Nitrogen excretion rate is calculated using the average rate of nitrogen excretion for a specific animal category (IPCC, 2006) multiplied by its average weight (Table A3.4-16).

Table A3.4-16: Nitrogen Excretion Rate for Each Specific Animal Category

Animal Category	Average Manure Nitrogen Excretion per 1000 kg Live Animal Mass per Day (kg/1000 kg/day)	Average Live Weight ¹ (kg)	Nitrogen Excretion ² (N _{EX}) (kg N/head/year)
Non-Dairy Cattle	0.34	468	58.1
Dairy Cattle	0.45	659	108.2
Poultry	1.02	1.4	0.5
Sheep & Lamb	0.42	27	4.1
Swine	0.52	61	11.6
Goat	0.45	64	10.5
Horse	0.30	450	49.3
Bison ³	0.34	468	58.1

Notes:

- 1 Average live weights for non-dairy cattle were taken from Boadi *et al.* (2004); for others, from IPCC (2006).
- 2 For non-dairy cattle, manure nitrogen excretion rates were calculated by weighting the various non-dairy animal populations in 2001; for poultry, the manure nitrogen excretion rate was calculated by weighting layer, chicken, and turkey populations in 2001.
- 3 For bison, average manure nitrogen excretion and live weight were assumed to be the same as for non-dairy cattle.

A3.4.4.3 Emission Factors Associated with AWMS

The type of AWMS has a significant impact on N₂O emissions. Less aerated systems, such as liquid systems, generate little N₂O, while drylots or manure on pasture and paddock produce more. However, there is little scientific information in Canada specifying amounts of N₂O emissions associated with manure management systems. Therefore, IPCC default emission factors, as listed in Table A3.4-17, were used for emission estimates.

Table A3.4-17: Percentage of Manure Nitrogen Lost as N₂O-N for Specific AWMS¹

Animal Category	Liquid Systems (EF _L)	Solid Storage & Drylot (EF _{SSD})	Pasture, Range, & Paddock (EF _{PRP})	Other Systems (EF _O)
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	1.0 ²	0.5
Swine	0.1	2.0	2.0	0.5
Goat	0.1	2.0	1.0 ²	0.5
Horse	0.1	2.0	1.0 ²	0.5
Bison	0.1	2.0	2.0	0.5

Notes:

1 Data source: IPCC/OECD/IEA (1997).

2 Data source: IPCC (2006), Volume 4, Agriculture, Forestry and Other Land Uses, Table 11.1.

A3.4.5 N₂O Emissions from Agricultural Soils

Emissions of N₂O from agricultural soils consist of direct and indirect emissions as well as emissions from manure on pasture, range, and paddock. Direct emissions are those occurring on farmland as a result of nitrogen that has entered the soil from synthetic fertilizers, animal manure applied as fertilizer, and crop residue and as a result of adoption of tillage practices, summerfallow, irrigation and cultivation of histosols. Emissions from indirect sources are emitted off site following volatilization and leaching of synthetic fertilizer, manure, and crop residue nitrogen.

Country specific Tier 2 methodologies and modified Tier 1 methods have been developed in 2005 for most of the Direct N₂O sources from soils. Some refinements were implemented in this submission. A more complete description can be found in Rochette et al. (2007).

A3.4.5.1 Direct Soil N₂O Emissions

Synthetic Nitrogen Fertilizers

Methodology

Canada has developed a Tier 2 country-specific methodology to estimate N₂O emissions from synthetic nitrogen fertilizer application on agricultural soils, which takes into account local climate regimes and topographic conditions. Equation A3.4-7 is used to estimate N₂O emissions by ecodistrict⁴⁰. Emission estimates at the provincial and national scales are obtained by aggregating estimates at the ecodistrict level.

⁴⁰ Ecodistrict is defined as a subdivision of an ecoregion characterized by a distinctive assemblage of relief, landforms, geology, soil, vegetation, water bodies, and fauna.

Equation A3.4-7:

$$N_2O_{SFN} = \sum (N_{FERT,i} \times EF_{BASE,i} \times RF_{THAW}) \times \frac{44}{28}$$

where:

N_2O_{SFN}	=	emissions from synthetic nitrogen fertilizers, kg N ₂ O/year
$N_{FERT,i}$	=	total synthetic fertilizer consumption at the ith ecodistrict, kg N/year. N_{FERT} at an ecodistrict level is estimated using Equation A3.4-11.
$EF_{BASE,i}$	=	a weighted average of emission factors at the ith ecodistrict, which is a function of local climate (precipitation/potential evapotranspiration) and landforms, kg N ₂ O-N/kg N/ year <i>See “Determining Basic N₂O Emission Factor (EF_{BASE}) for an Ecodistrict” below.</i>
RF_{THAW}	=	a ratio factor adjusting EF_{BASE} for emissions during spring thaw: for Newfoundland and Labrador, Prince Edward Island, Nova Scotia, New Brunswick, Quebec, and Ontario, $RF_{THAW} = 1.4$; for other provinces, $RF_{THAW} = 1.0$ <i>See “Determining the Effect of Spring Thaw on N₂O Emission (RF_{THAW})” below</i>
44/28	=	molecular weight ratio of N ₂ O to N ₂

Data for mineral nitrogen 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 potential amount of mineral nitrogen fertilizers applied (N_{APPLDP}) is equal to the difference between recommended nitrogen rates (N_{RCMD}) and manure nitrogen available for application on cropland ($N_{MAN-AV,CROPS}$), (see Equation A3.4-8).

Equation A3.4-8:

$$N_{APPLDP,i} = N_{RCMD,i} - N_{MAN-AV,CROPS,i}$$

where:

$N_{APPLDP,i}$	=	total nitrogen 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 nitrogen 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 A3.4-9:

$$N_{RCMD,i} = \sum (CROPA_{ij} \times N_{RECRT,j})$$

where:

$CROPA_{ij}$	=	area of crop type j in ecodistrict i, ha
$N_{RECRT,j}$	=	recommended nitrogen 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 nitrogen from all farm animals in the ecodistrict as follows:

Equation A3.4-10:

$$N_{\text{MAN-AV,CROPS},i} = \sum_{j,k} [(AnimalNo_{ji} \cdot N_{EX,j}) \times (1 - FracPRP_j) \times (1 - Frac_{(LossMS)jk} - UNAV)]$$

where:

$AnimalNo_{ji}$	=	animal population of category j in ecodistrict i, number of head <i>See data sources in Table A3.4-1</i>
$N_{EX,j}$	=	nitrogen excretion rate for animal category j, kg N/head/year <i>See Table A3.4-16.</i>
$FracPRP_j$	=	fraction of $N_{EX,j}$ that is deposited on pasture by grazing animals for animal category j <i>See Table A3.4-15.</i>
$Frac_{(LossMS)jk}$	=	fraction of $N_{EX,j}$ that is lost during manure storage and handling in manure management system k for animal category j <i>See Table A3.4-18.</i>
UNAV	=	fraction of $N_{EX,j}$ that is either in organic form or unavailable for crops: 0.35 (Yang <i>et al.</i> , 2007).

Table A3.4-18: Total and NH_3 and NO_x Nitrogen Losses Associated with Various Livestock and Manure Management Systems

Animal Category	Manure Management Systems	Total Manure Nitrogen Loss (%) ¹ ($Frac_{(LossMS)}$)	NH_3 -N and NO_x -N Loss (%) ¹ ($Frac_{GASM}$)
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	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), Rotz (2004), and EPA (2004).

Because the potential amount of fertilizer needs to be reconciled with the total amount sold in the province (N_{SALES}) to estimate the actual amount applied (N_{FERT}), N_{APPLDP} is adjusted in each ecodistrict as follows:

Equation A3.4-11:

$$N_{\text{FERT},i} = N_{\text{APPLDP},i} \times (\sum_{ip} N_{\text{APPLDP}p} / N_{\text{SALES}p})$$

where:

$N_{\text{FERT},i}$	=	total fertilizer nitrogen actually applied to all crops in ecodistrict i, kg
$N_{\text{APPLDP},i}$	=	total fertilizer nitrogen potentially applied to all crops in ecodistrict i, kg
$\sum_{ip} N_{\text{APPLDP}p}$	=	sum of all fertilizer nitrogen potentially applied in province p, kg
$N_{\text{SALES}p}$	=	total amount of fertilizer nitrogen sold in province p, kg

In ecodistricts where $N_{\text{MAN-AV,CROPS}}$ exceeded N_{RCMD} , N_{FERT} was set to 0. For years between two consecutive Census years (e.g., 1991 and 1996), N_{RCMD} was linearly interpolated to successively estimate annual values of N_{APPLDP} and N_{FERT} at the ecodistrict level.

Determining Basic N₂O Emission Factor (EF_{BASE}) for an Ecodistrict

The influence of local climatic conditions was assessed by the determination of regional nitrogen-induced emission factors (EF_{BASE}). 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_{BASE} = slope of the “N₂O emissions versus N fertilizer rate” relationship. EF_{BASE} was estimated for the three regions where field N₂O measurements are available: Quebec–Ontario; Brown and Dark Brown; and Grey and Black soil zones. The “EF_{BASE} versus fertilizer N” relationship determined for the Quebec–Ontario region has a similar slope (0.0119 kg N₂O-N/kg N) 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 N₂O emissions were measured across the range of nitrogen fertilizer rates (Brown-Dark Brown soils = 0.0016 kg N₂O-N/kg N; Black soils = 0.008 kg N₂O-N/kg N). These observations suggest that soil N₂O production in the Prairie region is not limited by mineral nitrogen availability but rather by the low denitrification activity under well-aerated dry soil conditions.

N₂O is mostly produced during denitrification and, as a result, is greatly influenced by the soil oxygen status. Accordingly, N₂O emission factors have been shown to increase with increasing rainfall (Dobbie *et al.*, 1999), and climate-variable emission factors have been used in soil N₂O 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) of precipitation to potential evapotranspiration (P/PE) from May to October (Figure A3.4-1). Despite the uncertainty in the determination of emission factors in the Prairie region, this approach appears as a valid option to account for the water-limited N₂O emissions in that region. To account for the topographical effect, an EF_{BASE} was estimated at a P/PE = 1 (0.012 kg N₂O-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.

To derive a basic N₂O emission factor (EF_{BASE}) for an ecodistrict, the following equation was used:

Equation A3.4-12:

$$EF_{BASE} = EF_{CT, P/PE=1} \times F_{TOPO} + EF_{CT} \times (1 - F_{TOPO})$$

where:

EF _{CT}	=	Emission factor, estimated at actual P/PE accounting for climate and topography in an ecodistrict, kg N ₂ O-N/kg N <i>See Figure A3.4-1.</i>
EF _{CT, P/PE=1}	=	Emission factor estimated at P/PE = 1 in an ecodistrict, 0.012 kg N ₂ O-N/kg N
F _{TOPO}	=	Fraction of the ecodistrict area in the lower section of the toposequence <i>See Table A3.4-19.</i>
P	=	Long-term mean precipitation from May to October in an ecodistrict, mm
PE	=	Long-term mean potential evapotranspiration, mm

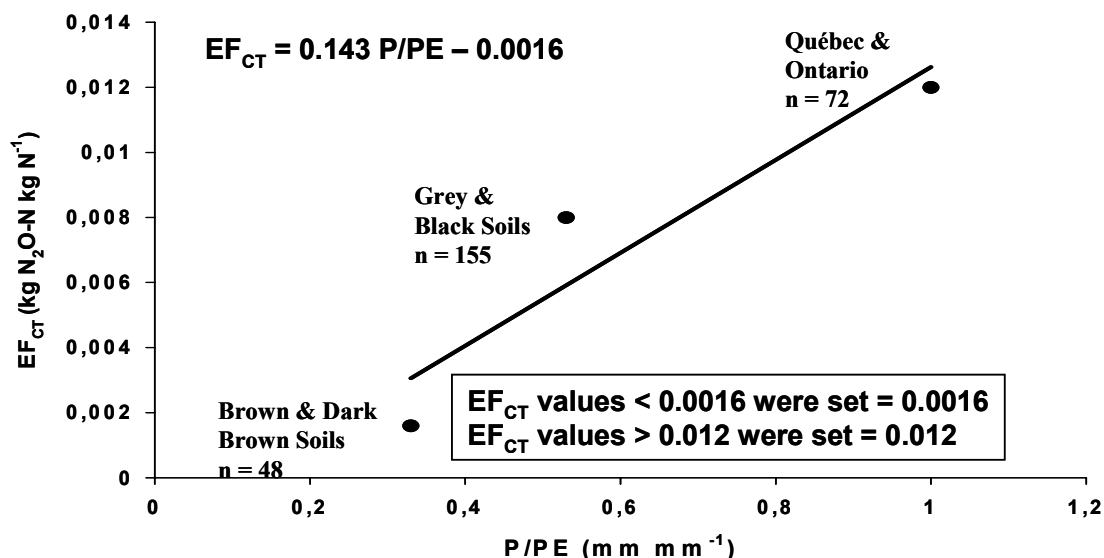


Figure A3.4-1: N₂O Emissions as a Function of P/PE

Landscape segmentation data were incorporated into the calculation of the national N₂O emission estimates, based upon the observations that N₂O emissions are greater in lower sections of the Prairie landscape where intermittently saturated soil conditions that are favourable to denitrification occur (Corre *et al.*, 1996, 1999; Pennock and Corre, 2001; Izaurralde *et al.*, 2004). The fraction of the landscape occupied by such lower sections, or F_{TOPO}, 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 mottles⁴¹ 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 Landscape of Canada (SLC), which was the basis for determining the proportion of the landscape to apply F_{TOPO} for deriving N_2O emission estimates (Rochette et al., 2007).

Determining the Effect of Spring Thaw on N_2O Emission (RF_{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 favour N_2O production. Accordingly, results from micrometeorological studies show that significant N_2O emissions can occur during spring thaw in Ontario (Wagner-Riddle *et al.*, 1997; Wagner-Riddle and Thurtell, 1998; Grant and Pattey, 2003) and that estimating emissions only in the snow-free period underestimates total annual emissions of N_2O . For reasons including lower annual snowfall, spring thaw emissions are usually smaller in the Prairies than in eastern Canada (Lemke *et al.*, 1999).

Gregorich *et al.* (2005) summarized field measurements of N_2O emissions from agricultural soils under various conditions in Quebec and Ontario. Based on these data reported on annual crops, the ratio factor for spring thaw (RF_{THAW}) was defined as the ratio of the mean N_2O emissions during spring thaw (1.19 kg N_2O -N/ha; $n = 10$ site-years) to emissions during the snow-free season (2.82 kg N_2O -N/ha; $n = 58$ site-years) (Gregorich *et al.*, 2005). Thus, RF_{THAW} was estimated as “ $1.4 = 1 + 1.2/2.8$ ” for the Quebec-Ontario region and the Atlantic provinces.

Chamber flux measurements used to estimate EF_{CT} in the Prairies include spring thaw emissions, because low snow accumulation in that region allows chamber deployments during that period. Cumulative snow-free-season N_2O emissions include spring thaw emissions (R. Lemke, personal communication). Therefore, no adjustment to the EF_{CT} for the spring thaw emissions is required in the Prairies ($\text{RF}_{\text{THAW}} = 1$).

Data Source

Accounting in agriculture relies on data from the Census of Agriculture, a self-administered questionnaire that all farmers are required by law to complete every five years. Data include the type of operating arrangement, the legal location of the farm headquarters, the area of each crop, summerfallow, tillage practices, improved and unimproved pasture, idle agricultural land and “other” land, such as forest, wetlands, and building sites, the area of manure, fertilizer, and pesticide application, individual and total income, and expenses.

⁴¹ 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.

The Farm Input Markets Unit of the Farm Income and Adaptation Policy Directorate of AAFC collected annual fertilizer nitrogen consumption data at the provincial level and published *Canadian Fertilizer Consumption, Shipments and Trade* from 1990 to 2002 (Korol, 2003)⁴². Since 2003, fertilizer nitrogen data were obtained from the Canadian Fertilizer Institute⁴³.

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 1951 to 1991 to the ecodistrict centroids. AAFC–archived weather data were provided by the Meteorological Service of Canada, Environment Canada.

Manure Applied as Fertilizer

Methodology

Emissions of N₂O from manure applied as fertilizer include N₂O produced from the application of manure from drylot or solid storage, liquid, and other waste management systems on agricultural soils. Similarly to synthetic fertilizer N₂O emissions, a country-specific tier-2 methodology is developed to estimate N₂O emissions from manure applied as fertilizer. The methodology is based on the quantity of manure nitrogen produced by domestic animals and country-specific EF_{BASE} taking into account regional climate moisture and topographic conditions at the ecodistrict level. N₂O emission estimates from this source are calculated using Equation A3.4-13.

Equation A3.4-13:

$$N_2O_{MAN} = \sum (N_{MAN, CROPS, i} \times EF_{BASE, i} \times RF_{THAW}) \times \frac{44}{28}$$

where:

N ₂ O _{MAN}	=	emissions from animal manure applied to cropland as fertilizers, kg N ₂ O/year
N _{MAN, CROPS, i}	=	total amount of animal manure nitrogen applied as fertilizer to cropland in ecodistrict i, kg N/year, (see Equation A3.4-14).
EF _{BASE, i}	=	a weighted average emission factor for ecodistrict i accounting for climate and topography, kg N ₂ O-N/kg N/ year See “ <i>Determining Basic N₂O Emission Factor (EF_{BASE}) for an Ecodistrict.</i> ”
RF _{THAW}	=	a ratio factor adjusting EF _{BASE} for emissions during spring thaw: for Newfoundland and Labrador, Prince Edward Island, Nova Scotia, New Brunswick, Quebec, and Ontario, RF _{THAW} = 1.4; for other provinces, RF _{THAW} = 1.0 See “ <i>Determining the Effect of Spring Thaw on N₂O Emission (RF_{THAW}).</i> ”
44/28	=	molecular weight ratio of N ₂ O to N ₂

⁴² Available online at: <http://www.agr.ca/policy/cdnfert/text.html>.

⁴³ Available online at: http://www.cfi.ca/Publications/Statistical_Documents.asp.

Equation A3.4-14:

$$N_{MAN, CROPS, i} = \sum_T [(N_T \times N_{EX, T}) \times (1 - N_{PRP, T}) \times (1 - Frac_{(LossMS, T)})]$$

where:

$N_{MAN, CROPS, i}$	=	animal manure applied as nitrogen fertilizers on cropland in ecodistrict i, kg N/year
N_T	=	population for the Tth animal category or subcategory <i>Refer to Section A3.4.2 for livestock population data sources and calculations.</i>
$N_{EX, T}$	=	nitrogen excretion rate for the Tth animal category or subcategory <i>Refer to Table A3.4-16.</i>
$N_{PRP, T}$	=	fraction of manure nitrogen on pasture, range, and paddock for each animal category T in ecodistrict i <i>See Table A3.4-15.</i>
$Frac_{(LossMS, T)}$	=	fraction of total losses of manure nitrogen for each animal category T excluding pasture, range, and paddock in ecodistrict i <i>See Table A3.4-18.</i>

Data Source

Animal population data sources and population accounts are the same as those used for CH₄ emissions from enteric fermentation and manure management.

Biological Nitrogen Fixation

Biological nitrogen fixation by the legume–rhizobium association, a major source of N₂O in the IPCC Guidelines (IPCC/OECD/IEA, 1997), is not included in the 2006 IPCC Guidelines (IPCC, 2006). This decision is supported by the conclusion of Rochette and Janzen (2005) that there is no evidence that measurable amounts of N₂O are produced during the nitrogen fixation process itself. Therefore, Canada decided to report this source as “not occurring”. However, the contribution of legume nitrogen to N₂O emissions is included as a source of N₂O emissions from crop residue decomposition on agricultural soils (N_{RES}).

Crop Residue Decomposition*Methodology*

The transformations (nitrification and denitrification) of the nitrogen released during the decomposition of crop residues returned to fields result in N₂O emissions into the atmosphere. A country-specific tier-2 methodology similar to that for fertilizer and manure applied as fertilizer is used to estimate N₂O emissions from crop residues, based on Equation A3.4-15, Equation A3.4-16, and Equation A3.4-17.

Equation A3.4-15:

$$N_2O_{RES} = \sum (N_{RES,i} \times EF_{BASE,i} \times RF_{THAW}) \times \frac{44}{28}$$

where:

N_2O_{RES}	=	emissions from crop residue decomposition, kg N ₂ O-N/year
$EF_{BASE,i}$	=	a weighted average of emission factors for ecodistrict i, kg N ₂ O-N/kg N/ year <i>See “Determining Basic N₂O Emission Factor (EF_{BASE}) for an Ecodistrict.”</i>
RF_{THAW}	=	a ratio factor adjusting EF_{BASE} for emissions during spring thaw: for Newfoundland and Labrador, Prince Edward Island, Nova Scotia, New Brunswick, Quebec, and Ontario, $RF_{THAW} = 1.4$; for other provinces, $RF_{THAW} = 1.0$ <i>See “Determining the Effect of Spring Thaw on N₂O Emission (RF_{THAW}).”</i>
$44/28$	=	molecular weight ratio of N ₂ O to N ₂
$N_{RES,i}$	=	total amount of crop residue nitrogen that is returned to the cropland annually for ecodistrict i, kg N/year, calculated as follows:

Equation A3.4-16:

$$N_{RES,i} = \sum_T [P_{T,i} \times \text{Frac}_{Renew,T,i} \times (R_{AG,T} \times N_{AG,T} + R_{BG,T} \times N_{BG,T})]$$

where:

$\text{Frac}_{Renew,T,i}$	=	fraction of total area under crop T that is renewed annually in ecodistrict i
$R_{AG,T}$	=	ratio of aboveground residues to harvested yield for crop T, kg dry matter DM/kg
$N_{AG,T}$	=	nitrogen content of aboveground residues for crop T, kg N/kg DM
$R_{BG,T}$	=	ratio of belowground residues to harvested yield for crop T, kg DM/kg
$N_{BG,T}$	=	nitrogen content of belowground 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, as calculated below (Equation A3.4-17), kg DM/year

Equation A3.4-17:

$$P_{T,i} = \frac{A_{T,i} \times Y_{T,i}}{\sum_{i=1}^N (A_{T,i} \times Y_{T,i})} \times P_{T,p} \times H_2O_T$$

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

Data Source

Estimates of N₂O emissions from crop residue decomposition rely on crop production data from the Census of Agriculture and crop yield surveys of Statistics Canada. Both areas and yields are available at all levels of ecostratification (Soils Landscape of Canada, ecodistrict, ecoregion, ecozone), provincially and nationally; area seeded to each crop is available for the Census years (1991, 1996, 2001), and yields of select crops are available annually. Specific parameters for each crop type are listed in Janzen et al. (2003).

Statistics Canada (2005d, #22-002) collects and publishes annual field crop production data. 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 Soils Landscape of Canada polygons through area overlays by AAFC.

Cultivation of Histosols

Methodology

Cultivation of organic soil (histosols) for annual crop production produces N₂O. The IPCC Tier 1 methodology is used to estimate N₂O emissions from cultivated organic soils as shown in Equation A3.4-18.

Equation A3.4-18:

$$N_2O_H = \sum (A_{os,i} \times EF_{HIST}) \times \frac{44}{28}$$

where:

N ₂ O _H	=	N ₂ O emissions from cultivated histosols, , kg N ₂ O-N/year
A _{os,i}	=	total area of cultivated organic soils in each province, ha
EF _{HIST}	=	IPCC default emission factor for mid-latitude organic soils, 8.0 kg N ₂ O-N/ha/year (IPCC, 2000)
44/28	=	molecular weight ratio of N ₂ O to N ₂

Data Source

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 2005 in Canada is 16 156 ha (G. Padbury and G. Patterson, AAFC, personal communication).

N₂O Emissions or Removals from Adoption of No-Till and Reduced Tillage

Methodology

This category is specific to Canada. It does not derive from additional nitrogen input such as fertilizer, manure, and crop residue nitrogen, but is rather like a “modifier” to several factors affecting N₂O emissions when tillage practices are modified. For example, compared with conventional or intensive tillage (IT), direct seeding or no-tillage (NT) as well as reduced tillage (RT) affect the decomposition of soil organic matter, soil carbon and nitrogen availability, soil bulk density, and water content.

N₂O emissions or removals resulting from the adoption of NT and RT can be expressed as follows (Rochette et al., 2007):

Equation A3.4-19:

$$N_2O_{TILL} = \sum [(N_{FERT,i} + N_{MAN,CROPS,i} + N_{RES,i}) \times (EF_{BASE,i} \times FRAC_{NT-RT,i} \times (F_{TILL} - 1))] \times \frac{44}{28}$$

where:

N_2O_{TILL}	=	N ₂ O emissions or removals resulting from the adoption of NT and RT, kg N ₂ O/year
$N_{FERT,i}$	=	total synthetic fertilizer nitrogen consumption in ecodistrict i, kg N/year
$N_{MAN,CROPS,i}$	=	total amount of animal manure nitrogen applied as fertilizer to cropland in ecodistrict i, kg N/year
$N_{RES,i}$	=	total amount of crop residue nitrogen that is returned to the cropland annually for ecodistrict i, kg N/year
$EF_{BASE,i}$	=	a weighted average of emission factor for ecodistrict i, kg N ₂ O-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} (see “ <i>Determining Basic N₂O Emission Factor (EF_{BASE}) for an Ecodistrict</i> ”) due to the adoption of NT and RT: $F_{TILL} = 1.1$ in eastern Canada; $F_{TILL} = 0.8$ in the Prairies (see below)
44/28	=	molecular weight ratio of N ₂ O to N ₂

Data Source

The fraction of cropland on NT and RT ($FRAC_{NT-RT}$) for each ecodistrict originated from the Census of Agriculture (Statistics Canada, #93350, #93356, #95F0301) and is identical to that used in the LULUCF cropland remaining cropland category for NT and RT practices. These data are published at the Census Agricultural Region, Census Division, provincial, and national level. Annual $FRAC_{NT-RT}$ between the two consecutive census years is adjusted through interpolation.

N₂O Emissions Resulting from Summerfallowing

Methodology

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 N₂O emissions relative to a cropped situation, such as higher soil water content, temperature, and available carbon and nitrogen (Campbell *et al.*, 1990). Experimental studies have shown that N₂O emissions in fallow fields are similar to emissions from continuously cropped fields (Rochette *et al.*, 2007). Therefore, the following country-specific methodology is used to estimate the effect of summerfallowing on N₂O emissions.

During a crop year, direct N₂O emissions from a given field are summarized as follows:

Equation A3.4-20:

$$N_2O_{CROP} = N_2O_{SFN} + N_2O_{MAN} + N_2O_{RES}$$

where N₂O_{SFN}, N₂O_{MAN}, and N₂O_{RES} are defined in Sections – Synthetic Nitrogen Fertilizers, Manure Applied as Fertilizer and Crop Residue Decomposition.

During a fallow year, no fertilizer or manure is applied. In the absence of external nitrogen inputs, N₂O emissions during the fallow year (N₂O_{FALLOW}) can be seen as consisting of i) “background” emissions that would have occurred regardless of fallow (N₂O_{BACK}) and ii) emissions due to the modifications to the soil environment by fallow (N₂O_{FALLOW-EFFECT}):

Equation A3.4-21:

$$N_2O_{FALLOW} = N_2O_{BACK} + N_2O_{FALLOW-EFFECT}$$

Since N₂O emissions are assumed equal during fallow and cropped years:

Equation A3.4-22:

$$N_2O_{SFN} + N_2O_{MAN} + N_2O_{RES} = N_2O_{BACK} + N_2O_{FALLOW-EFFECT}$$

Assuming that background emissions during the fallow year are approximately equal to those associated with previous-year crop residue decomposition (N₂O_{BACK} = N₂O_{RES}), N₂O_{FALLOW-EFFECT} is estimated as the sum of emissions resulting from fertilizer and manure nitrogen applications during the crop year of the rotation:

Equation A3.4-23:

$$N_2O_{FALLOW-EFFECT} = N_2O_{SFN} + N_2O_{MAN}$$

At the ecodistrict level, the emissions due to the practice of summerfallow were then calculated by summing emissions from fertilizer and manure application to annual crops

for the ecodistrict and multiplying the sum by the proportion of the area under annual cropping in that ecodistrict that is under summerfallow, as follows:

Equation A3.4-24:

$$N_2O_{\text{FALLOW-EFFECT},i} = (N_2O_{\text{SFN},i} + N_2O_{\text{MAN},i}) \times \text{Frac}_{\text{FALLOW},i}$$

where:

$\text{Frac}_{\text{FALLOW},i}$	=	fraction of cropland in ecodistrict i that is under summerfallow, %
$N_2O_{\text{SFN},i}$	=	N_2O_{SFN} in annual crops in ecodistrict i, kg N_2O -N
$N_2O_{\text{MAN},i}$	=	N_2O_{MAN} in annual crops in ecodistrict i, kg N_2O -N

Thus, total national emissions of N_2O resulting from the practice of summerfallow ($N_2O_{\text{FALLOW-EFFECT}}$) can be calculated as:

Equation A3.4-25:

$$N_2O_{\text{FALLOW-EFFECT}} = \sum [(N_2O_{\text{SFN},i} + N_2O_{\text{MAN},i}) \times \text{Frac}_{\text{FALLOW},i}]$$

Data Source

Estimates of N_2O_{SFN} and N_2O_{MAN} at an ecodistrict level are those derived from the synthetic fertilizer and manure applied as fertilizer source categories. $\text{Frac}_{\text{FALLOW}}$ is derived from the Census of Agriculture for each ecodistrict (Statistics Canada, #93350, #93356, #95F0301) 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

Methodology

Higher soil water content under irrigation increases potential N_2O emissions by increasing biological activity and reducing soil aeration (Jambert et al., 1997). Accordingly, highest N_2O emissions from agricultural soils in northwestern USA (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 is based on the assumptions that 1) the irrigation water stimulates N_2O production in a way similar to rainfall water, and 2) that irrigation is applied at rates 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_{BASE} estimated at a P/PE = 1 (e.g., $EF_{\text{BASE}} = 0.012 \text{ } N_2O\text{-N kg}^{-1} \text{ N}$) for the irrigated areas of an ecodistrict:

Equation A3.4-26:

$$N_2O_{IRRI} = \sum [(N_{FERT,i} + N_{MAN,CROPS,i} + N_{RES,i}) \times (0.012 - EF_{BASE,i}) \times Frac_{IRRI,i}] \times \frac{44}{28}$$

where:

N_2O_{IRRI}	=	N_2O emissions from irrigation, kg N_2O /year
$N_{FERT,i}$	=	total synthetic fertilizer nitrogen consumption in ecodistrict i, kg N/year
$N_{MAN,CROPS,i}$	=	total amount of animal manure nitrogen applied as fertilizer to cropland in ecodistrict i, kg N/year
$N_{RES,i}$	=	total amount of crop residue nitrogen that is returned to the cropland annually for ecodistrict i, kg N/year
0.012	=	fraction of N emitted for ecodistrict i, kg N_2O -N/kg N/ year
$EF_{BASE,i}$	=	a weighted average of 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	=	molecular weight ratio of N_2O to N_2

Data Source

$Frac_{IRRI}$ is derived from the Census of Agriculture for each ecodistrict (Statistics Canada, #93350, #93356, #95F0301). Annual $Frac_{IRRI}$ between the two consecutive census years is adjusted through interpolation.

*A3.4.5.2 Manure on Pasture, Range, and Paddock from Grazing Animals**Methodology*

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 nitrogen produced by domestic animals on pasture, range and paddock, and N_2O emissions are calculated using Equation A3.4-27. Note that N_2O emissions from manure on pasture, range and paddock are reported under Agricultural Soils.

Equation A3.4-27:

$$N_2O_{PRP} = \sum_T (N_T \times N_{EX, T} \times N_{PRP, T} \times EF_{PRP, T}) \times \frac{44}{28}$$

where:

N_2O_{PRP}	=	N_2O 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 <i>Refer to Section A3.4.2 for livestock population data sources and calculations.</i>
$N_{EX, T}$	=	nitrogen excretion rate for the animal category T, kg N/head/ year <i>See Table A3.4-16.</i>
$EF_{PRP, T}$	=	emission factor for manure nitrogen deposited by animals on pasture, range, and paddock: 0.02 kg N_2O -N/kg N for dairy cattle, non-dairy cattle, bison, swine, and poultry, and 0.01 kg N_2O -N/kg N for sheep, lamb, goat, and horse (IPCC, 2006) <i>See Table A3.4-17</i>
$N_{PRP, T}$	=	fraction of manure nitrogen excreted on pasture, range, and paddock by animal category T <i>See Table A3.4-15</i>
44/28	=	molecular weight ratio of N_2O to N_2

Data Source

Animal population data and data sources are the same as those used for CH_4 emission estimates from enteric fermentation.

*A3.4.5.3 Indirect Soil N_2O Emissions***Volatilization and Redeposition of Nitrogen***Methodology*

The IPCC Tier 1 methodology is used to estimate indirect N_2O emissions due to volatilization and redeposition of fertilizer and manure nitrogen applied to agricultural soils. The emission calculation is shown in Equation A3.4-28.

Equation A3.4-28:

$$N_2O_{VD} = \sum \left[(N_{FERT,i} \times VOLAT_{FERT}) + N_{MAN-VOLAT,i} \right] \times EF_{VD} \times \frac{44}{28}$$

where:

N_2O_{VD}	=	indirect N_2O emissions due to volatilization and redeposition, kg N_2O /year
$N_{FERT,i}$	=	synthetic nitrogen fertilizer consumption in ecodistrict i, kg N/year
$VOLAT_{FERT}$	=	fraction of synthetic fertilizer nitrogen applied to soils that volatilizes as NH_3 -N and NO_x -N: 0.1 kg (NH_3 -N + NO_x -N)/kg N (IPCC/OECD/IEA, 1997)
EF_{VD}	=	emission factor due to volatilization and redeposition: 0.01 kg N_2O -N/kg N (IPCC/OECD/IEA, 1997)
44/28	=	molecular weight ratio of N_2O to N_2
$N_{MAN-VOLAT,i}$	=	total manure nitrogen lost as NH_3 -N and NO_x -N from livestock excretion in ecodistrict i, kg N, calculated as follows:

Equation A3.4-29:

$$N_{MAN-VOLAT,i} = \sum_{m,T} (N_T \times N_{EX,T} \times AWMS_{m,T} \times Frac_{GASMm,T})$$

where:

N_T	=	animal population for animal category T, head
$N_{EX,T}$	=	nitrogen excretion from animal category T, kg N/year <i>Refer to Section A3.4.4 methodology for calculation and data source (Table A3.4-16).</i>
$AWMS_{m,T}$	=	fraction of manure nitrogen from animal category T managed under manure management system m <i>See Table A3.4-15.</i>
$Frac_{GASMm,T}$	=	fraction of manure nitrogen excreted by animal category T and managed under manure management system m that volatilizes as NH_3 -N and NO_x -N <i>See Table A3.4-18.</i>

Data Source

Data sources for estimating N_{FERT} and $N_{MAN-VOLAT}$ at an ecodistrict level are provided in the previous sections (Synthetic Nitrogen Fertilizers and Table A3.4-18).

Leaching, Runoff, and Erosion*Methodology*

A modified IPCC Tier 1 methodology is used to estimate indirect N_2O emissions from leaching, runoff, and erosion of fertilizer, manure, and crop residue N from agricultural soils:

Equation A3.4-30:

$$N_2O_L = \sum [(N_{FERT,i} + N_{MAN,i} + N_{PRP,i} + N_{RES,i}) \times Frac_{LEACH,i} \times EF_{LEACH}] \times \frac{44}{28}$$

where:

N_2O_L	=	indirect N_2O emissions due to leaching and runoff, kg N_2O /year
$N_{FERT,i}$	=	synthetic nitrogen fertilizers applied for ecodistrict i, kg N
$N_{MAN,i}$	=	manure nitrogen applied as fertilizers for ecodistrict i, kg N
$N_{PRP,i}$	=	manure nitrogen on pasture, range, and paddock for ecodistrict i, kg N
$N_{RES,i}$	=	crop residue nitrogen for ecodistrict i, kg N
$Frac_{LEACH,i}$	=	fraction of nitrogen that is lost through leaching and runoff for ecodistrict i, as defined below
EF_{LEACH}	=	leaching/runoff emission factor: 0.0125 kg N_2O -N/kg N (IPCC, 2006)
44/28	=	molecular weight ratio of N_2O to N_2

Determining the Fraction of Nitrogen that is Leached ($Frac_{LEACH}$) at the Ecodistrict Level in Canada

In Canada, leaching losses of nitrogen vary widely among regions. High nitrogen 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, accounting for 0–20% of nitrogen inputs from seed, fertilizer, manure, animals, nitrogen fixation, and atmospheric deposition. Leaching losses in most of the Prairie region may be smaller due to lower precipitation and lower nitrogen 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 nitrogen leaching in non-irrigated, heavily manured plots, despite large accumulations of soil nitrate in the soil profile.

The default value for $Frac_{LEACH}$ in the IPCC Guidelines (IPCC/OECD/IEA, 1997) was 0.3. $Frac_{LEACH}$ 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 $Frac_{LEACH}$, 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 $Frac_{LEACH}$ value recommended by the 2006 IPCC Guidelines of 0.3 was assigned. For ecodistricts with the lowest P/PE value (0.21), a minimum $Frac_{LEACH}$ value of 0.05 was assigned. For ecodistricts with a P/PE value that ranged between 0.21 and 1, $Frac_{LEACH}$ was estimated by the linear function that joins the points (P/PE, $Frac_{LEACH}$) = (1,0.3; 0.21,0.05) (Figure A3.4-2).

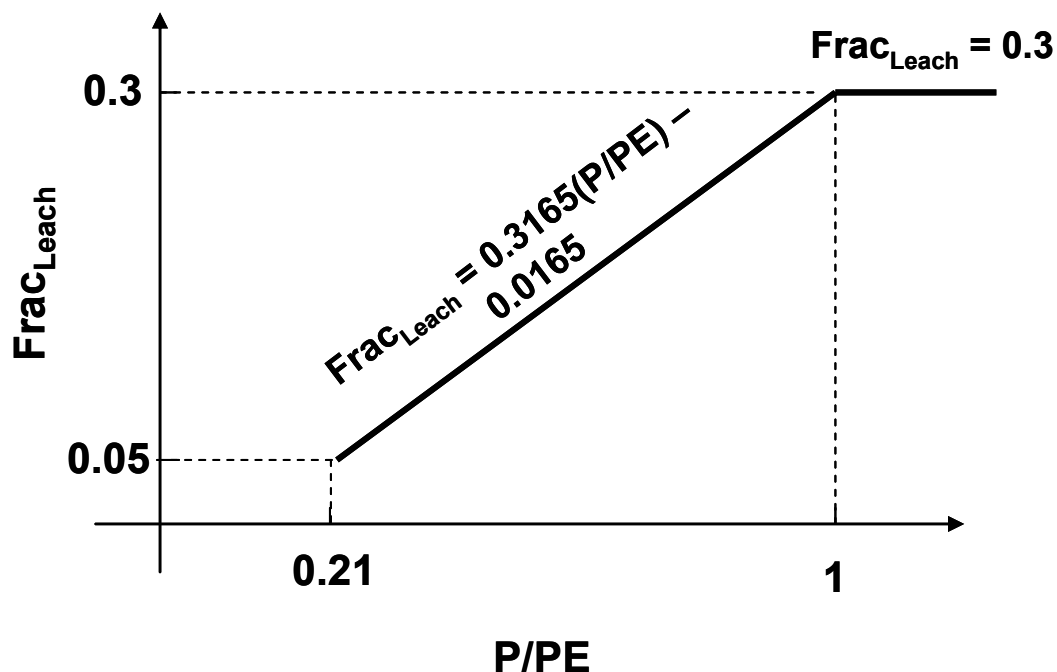


Figure A3.4-2: Determination of the Ecodistrict $\text{Frac}_{\text{LEACH}}$ Values

Data Source

Data sources for N_{FERT} , N_{MAN} , N_{PRP} , and N_{RES} at an ecodistrict level are provided in the previous sections.

Long-term normals of monthly precipitation and potential evapotranspiration from May to October, 1951–2001 (Agriculture and Agri-Food Canada archived database, S. Gameda, personal communication), were used to calculate $\text{Frac}_{\text{LEACH}}$ at an ecodistrict level.

A3.5 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 A3.5.1 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 A3.5.2. Sections A3.5.3 to A3.5.6 provide similar information for Cropland, Grassland, Wetlands, and Settlements.

Several approaches to the estimation of delayed emissions due to carbon storage in harvested wood products are briefly described in Section A3.5.7, along with implications for Canada.

A3.5.1 Spatial Framework for LULUCF Estimate Development and Area Reconciliation

The enhanced complexity of estimate development and active participation of several scientists and experts create 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 Land Use, Land-Use Change and Forestry Monitoring, Accounting and Reporting System (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 1427 analysis units across 12 provinces and territories (Table A3.5-1). Analysis units typically result from the intersection of administrative areas used for timber management and ecological boundaries.

Table A3.5-1: Spatial Analysis Units of Managed Forests

	Canada	NL	PE	NS	NB	QC	ON	MB	SK	AB	BC	YK	NT
No. of Analysis Units	1427	35	1	12	1	138	319	74	39	69	688	13	38

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. The most suitable spatial framework for GHG monitoring of agricultural lands (Cropland and Grassland) is the National Soil Database of the Canadian Soil Information System (CanSIS⁴⁴) and its underlying Soil Landscapes of Canada (SLC). 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, water table depth, etc., is called a soil landscape. SLC polygons (the “analysis units”) may contain one or more distinct soil landscape components. The SLC polygons are in the order of 1000 – 1 000 000 ha and are appropriate for mapping at the scale of 1:1 million. 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.

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 (1021 ecodistricts), which are further grouped in 194 ecoregions and 15 ecozones.

The LULUCF Sector of the GHG inventory reports information in 18 “reporting zones” (Chapter 7, Figure 7-2). 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 semiarid and a subhumid component. These subdivisions do not alter the hierarchical nature of the spatial framework. Table A3.5-2 provides the land and water areas of each reporting zone. Methods and data sources used for developing this information are described in McGovern (2006).

⁴⁴ <http://sis.agr.gc.ca/cansis>

Table A3.5-2: Land and Water Areas of Reporting Zones

Zone Number	Zone Name	Total Area (ha)	Total Land Area (ha)	Total Fresh Water 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
5	Boreal Shield East	111 056 710	99 129 131	11 927 579
6	Atlantic Maritime	20 938 606	19 736 815	1 201 791
7	Mixedwood Plains	16 780 897	11 014 617	5 766 280
8	Hudson Plains	37 371 084	36 393 778	977 306
9	Boreal Shield West	83 951 074	71 111 613	12 839 461
10	Boreal Plains	73 611 950	67 185 834	6 426 116
11	Subhumid Prairies	22 341 203	21 598 791	742 412
12	Semiarid Prairies	23 966 465	23 493 794	472 671
13	Taiga Plains	65 803 607	58 218 579	7 585 028
14	Montane Cordillera	48 470 844	47 226 428	1 244 416
15	Pacific Maritime	20 809 934	20 487 877	322 057
16	Boreal Cordillera	46 785 399	45 841 568	943 831
17	Taiga Cordillera	26 530 375	26 373 796	156 579
18	Taiga Shield West	63 167 721	52 178 220	10 989 501

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 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).

A3.5.2 Forest Land and Forest-Related Land-Use Change

A3.5.2.1 Carbon Modelling

The estimation of carbon stock changes, emissions, and removals from managed forests, forest conversion to other land uses, and land converted to forests was conducted with version 3 of the Carbon Budget Model of the Canadian Forest Sector (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 and insect infestations, and forest conversion. Management activities represented are commercial thinning (since 2000), clear-cutting, partial cutting, and salvage cutting.⁴⁵ Different practices of forest conversion are also simulated, including controlled burning.

Table A3.5-3 matches the representation of forest carbon pools in the CBM-CFS3 with the IPCC forest carbon pools (IPCC, 2003). Living biomass pools are further subdivided into two sets, for each of hardwood and softwood tree species. The first sixteen carbon pools were implemented for the national estimation.

Table A3.5-3: Forest Carbon Pools in IPCC and CBM-CFS3

IPCC Carbon Pools		Pool Names in CBM-CFS3
Living Biomass	Aboveground biomass	Merchantable stemwood Other (submerchantable stemwood, tops, branches, stumps, non-merchantable trees) Foliage
	Belowground biomass	Fine roots Coarse roots
Dead Organic Matter (DOM)	Dead wood	Aboveground fast Belowground fast Medium Softwood stem snag Softwood branch snag Hardwood stem snag Hardwood branch snag
	Litter	Aboveground very fast Aboveground slow
Soils	Soil organic matter	Belowground very fast ^a Belowground slow Black carbon ^b Peat ^b

Notes:

a Belowground very fast pool includes dead and decaying fine roots, which in practice cannot be separated from soil

b Black carbon and peat are currently not represented.

Carbon transfers between pools as shown in Figure A3.5-1 are simulated either as annual processes or as disturbance events.

⁴⁵ 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.

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. Rates of carbon transfer are defined for each pool, based on pool-specific turnover rates (for biomass pools) or decay rates (dead organic matter [DOM] and soil pools). Turnover rates can be very high (e.g., 95% for hardwood foliage) or very slow (e.g., <1% for stemwood). Annual decay rates are defined for a reference mean annual temperature of 10°C; they vary between 50% (for the very fast DOM pools, such as dead fine roots) and 0.0032% (for slow soil pools). During annual processes, carbon is taken up in the biomass pool; some biomass carbon is transferred to DOM pools; upon further decay carbon in DOM pools is transferred 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).

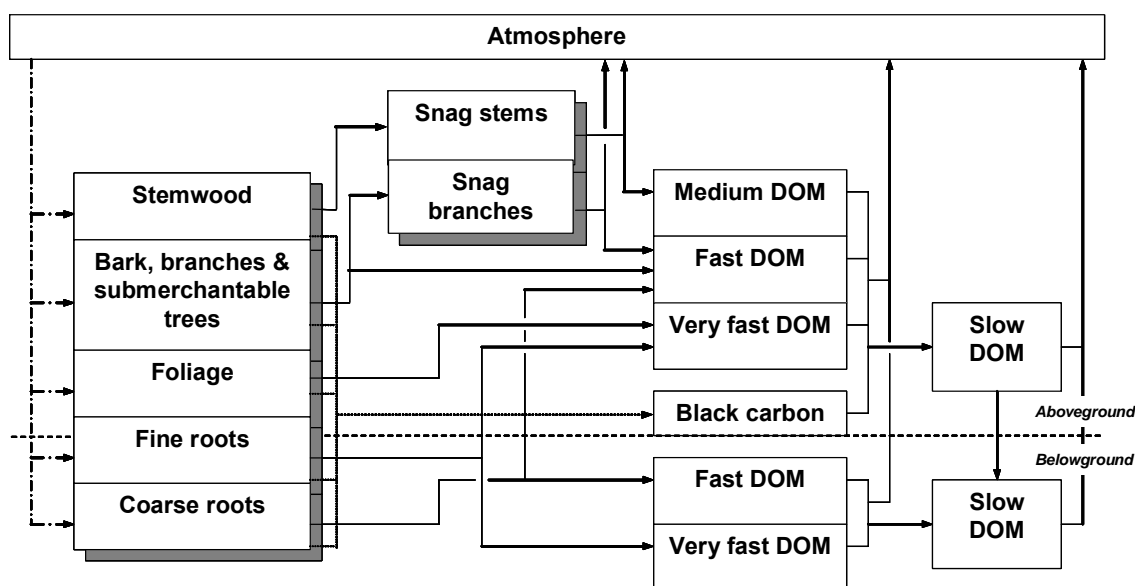


Figure A3.5-1: Carbon Transfers Between Pools at Each Annual Time Step as Modelled in CBM-CFS3

Growth is simulated as an annual process. Every record in the forest inventory used in each of the 1427 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 aboveground biomass curves is performed with a set of equations developed for Canada's National Forest Inventory (Boudewyn *et al.*, in review). These equations estimate, for each province/territory, ecozone, leading species, or forest type, the aboveground biomass of each stand component from merchantable stemwood volume (per hectare). Finally, belowground 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 Harvested Wood Products. Figure A3.5-2 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 2007 submission, the impact of wildfires and insect infestations was represented with 15 different disturbance types. Management activities were represented with 15 disturbance types and land-use change practices with 34 such types. Including the adjustment of parameter values for each ecozone, the simulation used a total of 205 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.

Figure A3.5-2: 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)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	CO ₂	CH ₄	CO	Products		
1.Softwood merchantable																	0.027	0.003							0.150	0.018	0.002	0.800	
2.Softwood foliage													0.320					0.010								0.600	0.064	0.006	
3.Softwood others															0.320			0.010								0.600	0.064	0.006	
4.Softwood submerchantable															0.600											0.350	0.045	0.005	
5.Softwood coarse roots															0.500	0.500													
6.Softwood fine roots													0.401	0.401												0.180	0.018		
7.Hardwood merchantable																	0.027	0.003								0.150	0.018	0.002	0.800
8.Hardwood foliage													0.320					0.010								0.600	0.064	0.006	
9.Hardwood others															0.320			0.010								0.600	0.064	0.006	
10.Hardwood submerchantable															0.600											0.350	0.045	0.005	
11.Hardwood coarse roots															0.500	0.500													
12.Hardwood fine roots													0.401	0.401												0.180	0.018		
13.Aboveground Very Fast DOM C													0.800													0.180	0.018	0.002	
14.Belowground Very Fast DOM C														0.800												0.180	0.018	0.002	
15.Aboveground Fast DOM C															0.800											0.180	0.018	0.002	
16.Belowground Fast DOM C																0.800										0.180	0.018	0.002	
17.Medium DOM C																	0.900									0.090	0.009	0.001	
18.Aboveground Slow DOM C																		1.000											
19.Belowground Slow DOM C																			1.000										
20.Softwood Stem Snag																	0.900									0.090	0.009	0.001	
21.Softwood Branch Snag															0.800											0.180	0.018	0.002	
22.Hardwood Stem Snag																	0.900									0.090	0.009	0.001	
23.Hardwood Branch Snag															0.800											0.180	0.018	0.002	

There are no CO₂ emission factors applicable to all fires, as the proportion of CO₂-C emitted for each pool, documented in each disturbance matrix, can be specific to the pool, the types of forest and disturbance intensity, and the ecological zone. With a few exceptions, the proportion of total carbon emitted in each carbon-containing GHG (CO₂, CO, and CH₄) is constant: 90% of carbon is emitted as CO₂, 9% as CO, and 1% as CH₄ (B. Stocks, personal communication to W. Kurz).

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 (Figure A3.5-3). The next section documents the key data sources used for this submission.

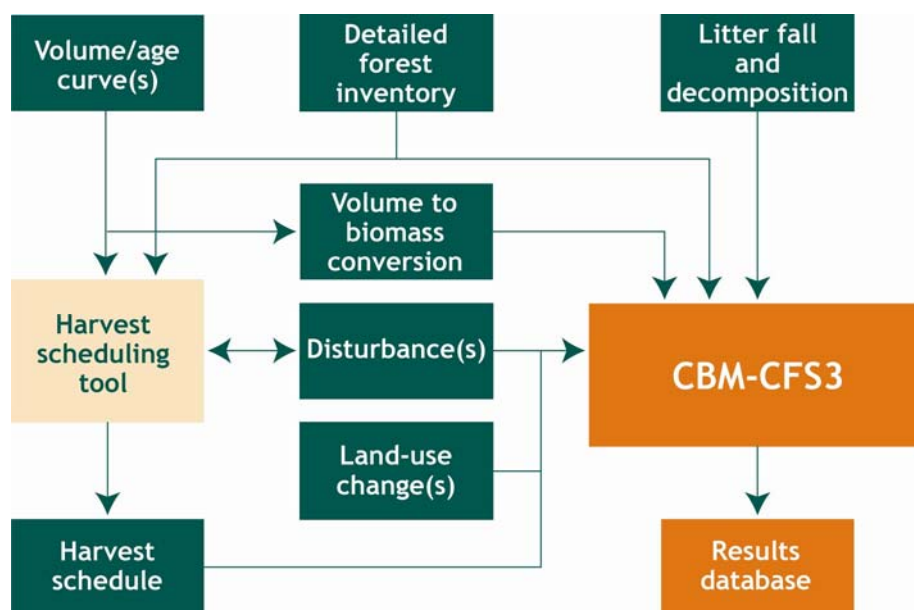


Figure A3.5-3: Generic Data Inputs to the CBM-CFS3

A3.5.2.2 Data Sources

Data sources for managed forest land, forest conversion and land converted to forest are provided below.

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 A3.5-4). The forest inventory data in Canada's 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 ‘methods 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 (Stinson et al., 2006a).

Table A3.5-4: Main Sources of Information and Data, Managed Forests

Description	Source	Spatial resolution	Temporal coverage	Reference
Fire data	Canadian Wildland Fire Information System	Spatially explicit	2004 and 2005	Expert http://cwfis.cfs.nrcan.gc.ca/
	Canadian Large Fire Database	Spatially referenced	1959–2003	http://fire.cfs.nrcan.gc.ca/research/climate_change/lfdb_e.htm
Forest inventories	Canadian Forest Inventory (CanFI)	CanFI grid cell	1949–2004	http://nfi.cfs.nrcan.gc.ca/canfi/index_e.html
	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	http://nfdp.ccfm.org/
	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	Canadian Forest Service (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 licenses, 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 A3.5-4 illustrates the location of managed and unmanaged forests in Canada, for the purpose of GHG estimation and reporting. In 2005, the total area of managed forests was 235 860 kha, of which 67% lies in the four reporting zones: Boreal Shield East, Montane Cordillera, Boreal Plains, and Boreal Shield West. Table A3.5-5 provides the breakdown of the managed forests into reporting zones.

Table A3.5-5: Distribution of Managed Forests in Reporting Zones

Reporting Zone Number	Reporting Zone Name	Distribution of Managed Forests (%)
1	Arctic Cordillera	0.0
2	Northern Arctic	0.0
3	Southern Arctic	0.0
4	Taiga Shield East	0.5
5	Boreal Shield East	23.6
6	Atlantic Maritime	6.8
7	Mixedwood Plains	1.2
8	Hudson Plains	0.1
9	Boreal Shield West	12.2
10	Boreal Plains	15.3
11	Subhumid Prairies	0.8
12	Semiarid Prairies	0.0
13	Taiga Plains	8.5
14	Montane Cordillera	16.1
15	Pacific Maritime	6.3
16	Boreal Cordillera	7.9
17	Taiga Cordillera	0.2
18	Taiga Shield West	0.8

Note:

Total does not add up to 100% due to rounding.

Forest management activities are documented in the National Forestry Database; additional information on specific activities was 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 and 2005 (Table A3.5-4).

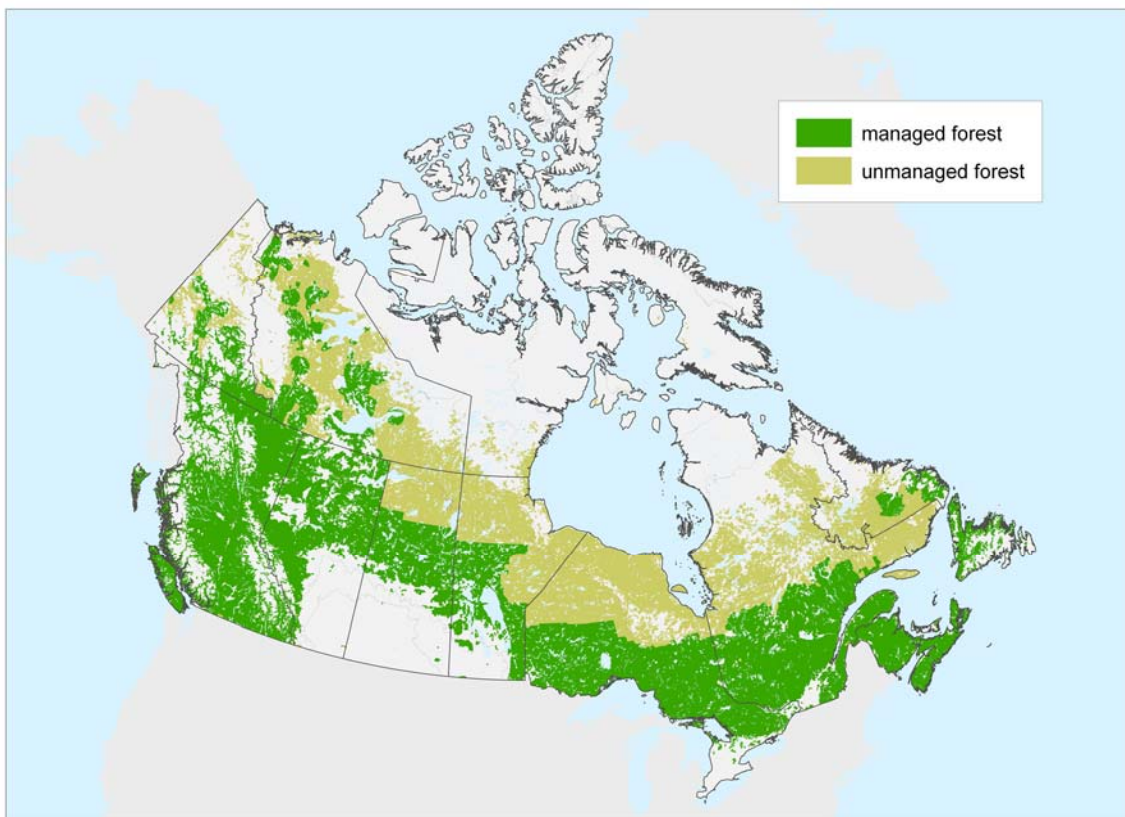


Figure A3.5-4: Managed and Unmanaged Forests in Canada

Insect disturbances are monitored on aerial surveys (Table A3.5-4). 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. While the basic methods have been tested in several pilot projects (CFS, 2006a), the methodology is not fully implemented due to constraints of time, resources, and data availability.

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 help 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 was 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 was also used.

Each deforestation event identified in the images as greater than 1 ha was manually delineated. The broad forest type prior to deforestation was interpreted⁴⁶ and the post-deforestation land use recorded (“post-class”). Confidence ratings on the land use at Time 1 and Time 2 were used in subsequent QC and field validation procedures.

Resource constraints continue to limit the size of the remote sensing sample used for the deforestation estimates. The forested areas of Canada were broadly stratified into regions of expected forest conversion level and dominant cause, which dictated the sampling intensity. The total areas, either fully mapped or sampled (Figure A3.5-5), cover approximately 200 million hectares, of which 15 million hectares were actually mapped for 1975–1990 and 38 million hectares for 1990–2000.

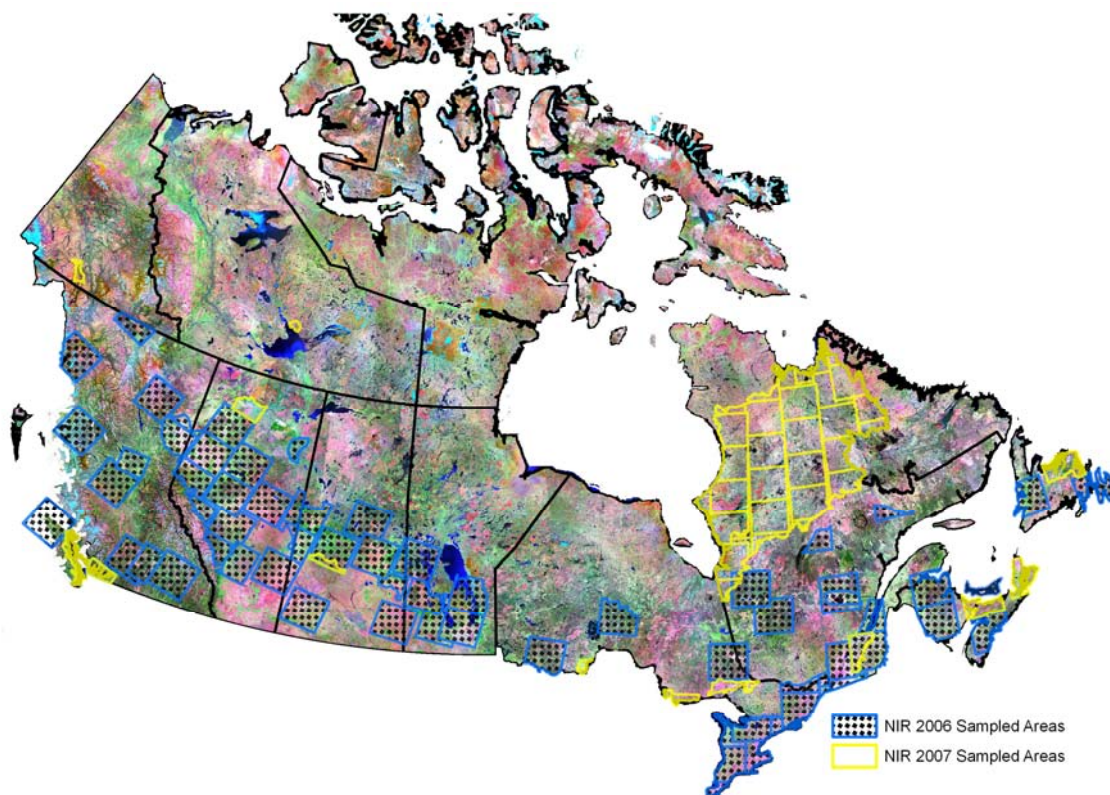


Figure A3.5-5: Deforestation Strata and Areas Sampled for the 2006 and 2007 Submissions

⁴⁶ See Chapter 7 for the definitional parameters of “forest.”

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 3.5×3.5 km sample cells on a systematic 10-km grid (---- Figure A3.5-6).

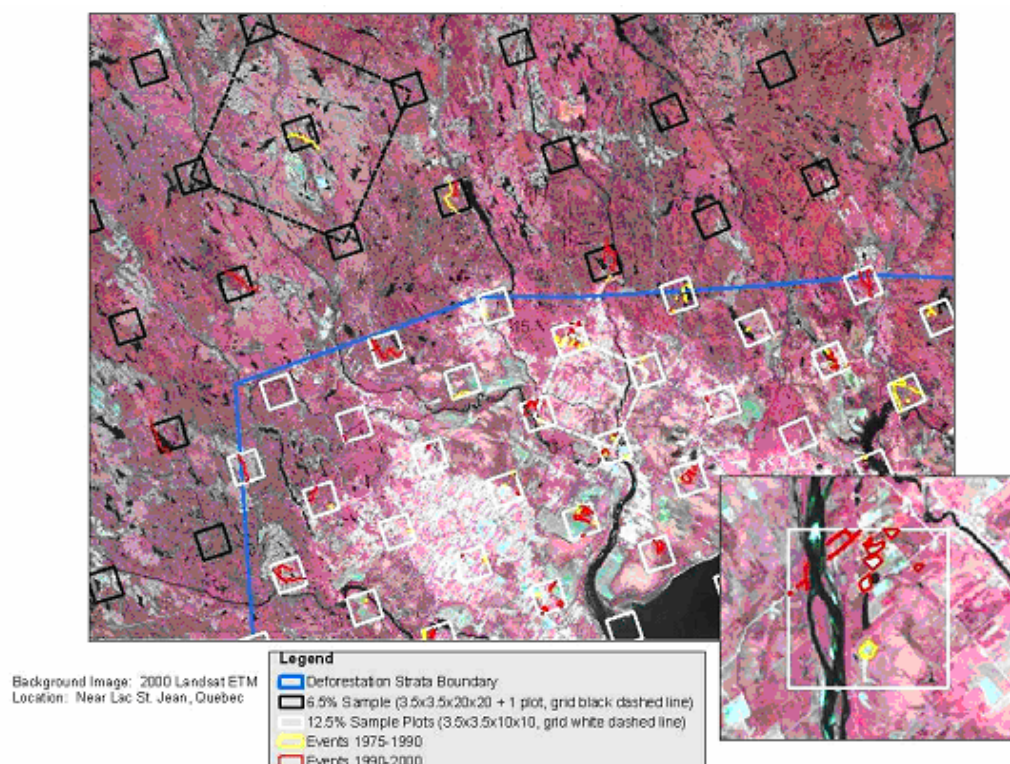


Figure A3.5-6: Sampling Grids over Imagery for Forest Conversion Mapping and Delineated Forest Conversion Events

Representative samples were 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 agriculture 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 was used, augmented in Quebec, Ontario, and British Columbia with additional samples (e.g., pilot studies). Special cases of known, localized, and large deforestation activities were also identified, such as hydroelectric reservoirs and the Alberta oil sands developments. These were handled as single events, with spatially complete mapping.⁴⁷ The extent of forests affected by land submersion was estimated by

⁴⁷ In the case of hydroelectric reservoirs, some records were also used to determine flooded area.

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 mostly consisted of information on forest roads, power lines, oil and gas infrastructure, and hydroelectric reservoirs (Leckie *et al.*, 2006). Temporal coverage, availability, and appropriateness were the criteria used to make decisions as to the data sources (records or imagery) on which to ultimately rely. Records from six provinces were used for forestry roads and from three provinces for power lines. The assessment of forest conversion in Alberta⁴⁸ due to pipeline component of the oil and gas infrastructure was based on a commercial GIS database of pipelines and well pads and a separate database on the width of pipeline corridors. Approximately 95% of pipelines are less than 20 m wide, and most are 14–16 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 pre-conversion 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 pre-conversion land use was missing, records from Canada's National Forest Inventory (CanFI, 1991) were used to determine the proportion of land converted to pipelines that was forest.

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 reconcile differences among records and remote sensing information, and resolve large discrepancies between the 1975–1990 and 1990–2000 area estimates. In such cases, available expert opinion and data sources were brought together, remote sensing and records data were reviewed, and decisions were made (CFS, 2006b). Most estimates, certainly those where the land-use change categories had the largest impacts, were derived directly from remote sensing samples.

The deforestation data were compiled and summarized on the basis of deforestation strata and reconciliation units. All “deforestation events” were assembled into a large “deforestation event database.” A compilation system summarized events for each deforestation stratum and aggregated deforestation rates to reconciliation units. Compilation also involved insertion of records data and expert judgement. In the course of these procedures, each deforestation event was 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 covered different time periods. At the data compilation phase, each forest conversion event was assigned to one of two time periods (1975–1990 or 1990–2000), and the corresponding deforestation rate was 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 be assigned to the period 1975–1990. The total area interpreted in a stratum for that time period was then used to determine a relative deforestation rate ((ha/year)/km² interpreted) for all events of the same type. Data were grouped by post-class (e.g., the rate for

⁴⁸ 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.

agricultural crop or rural residential). These, in turn, were summarized by broader categories when re-compiled by reconciliation unit.

The remote sensing data were derived using the circa 1975, 1990, and 2000 imagery, while records data were annual or summarized over time periods. As explained above, the remote sensing core method provided 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 required the simultaneous application of two procedures: i) extrapolation of annual rates prior to 1975 and beyond 2000; and ii) interpolation between the 1975–1990 and 1990–2000 data. In the absence of documented and tested procedures, the simplest approach was 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 was applied between the two temporal anchor points (1983 and 1995), which resulted in an estimate of the annual deforestation rate for each intervening year. The procedure is illustrated in Figure A3.5–7. Noted exceptions to this procedure are individual large events like hydroelectric reservoirs, for which year of flooding was known, and some records-based events.

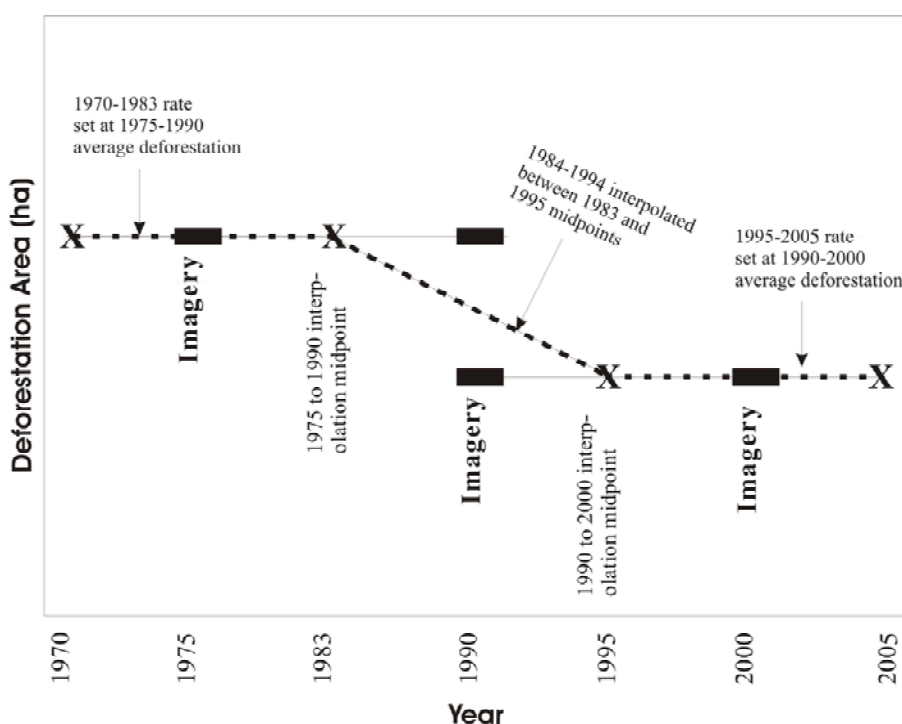


Figure A3.5-7: Procedure to Develop a Consistent Time Series of Rates of Forest Conversion

Figure A3.5–8 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, oil & gas extraction, as well as urban, commercial,

industrial and recreation areas. Note that these figures differ from the ones reported in the CRF tables, which are cumulative areas in the “land converted to” categories.

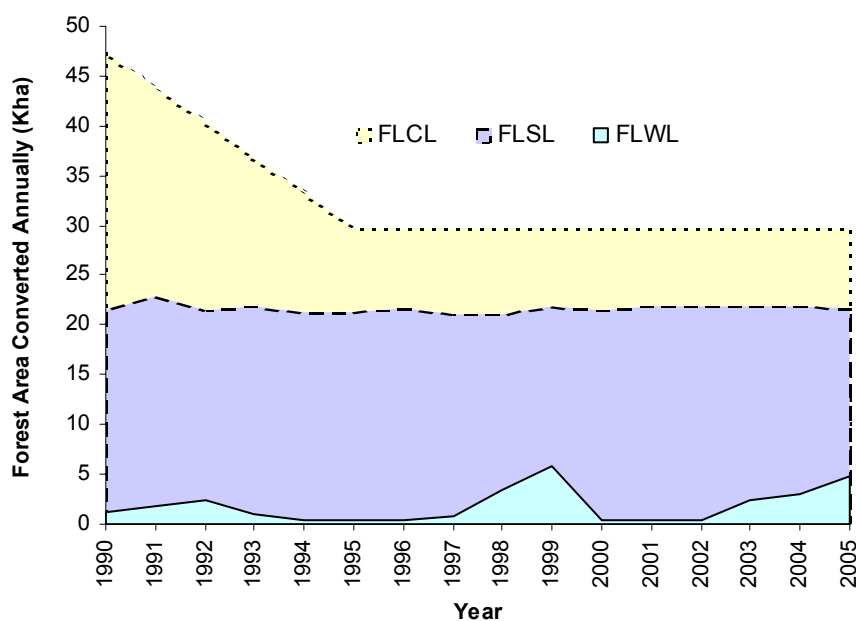


Figure A3.5-8: Annual Rates of Forest Conversion in Canada

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 was completed following defined practices (Paradine *et al.*, 2004) by a variety of organizations, including provincial government forestry or geomatics groups, remote sensing or mapping companies, research and development organizations, and in-house expertise in the CFS. The basic QC process included internal checks within the mapping agency or company by a senior person; “real-time” QA by CFS 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 CFS. Field checking was undertaken on established pilot projects. Each QC point and revision was 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 2007 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:

1. omission and commission;
2. sampling error; and
3. boundary delineation error.

The deforestation mapping process also involves three additional sources of uncertainty impacting the emission estimates:

4. forest type being removed;
5. post-conversion land category; and
6. 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, while commission errors are usually from a misinterpretation rather than an oversight and thus are less size dependent. Commission errors arise either from 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 2005 between 35 kha and 77 kha.

Due to availability of data sources and lower deforestation mapping sample intensity, the uncertainty in the 1970-1990 estimates are 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). 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. Acquiring a complete set of imagery every year is cost-prohibitive, and planning a complete update in the short term would be unrealistic. Target dates are under consideration for complete updates. Work on uncertainty quantification will continue. New data from circa 2007 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 Feasibility Assessment of Afforestation for Carbon Sequestration (FAACS⁴⁹) 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 Assessment⁵⁰ 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 were 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 did not have their own yield curve, they were 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 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.

A3.5.2.3 *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. Disturbances are processed 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 to all forests 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 atmosphere and to forest

⁴⁹ <http://cfs.nrcan.gc.ca/subsite/afforestation/feasibilityafforestation>

⁵⁰ <http://cfs.nrcan.gc.ca/subsite/afforestation/forest2020pda/forest2020pda>

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 growth), but is reported in the new land category — e.g., land converted to cropland (CRF Table 5.B Row 2), to wetlands (CRF Table 5.D Row 2), and 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 A3.5.3.3. Likewise, estimation methods for emissions (as opposed to carbon stock changes) from forest land converted to flooded lands are described in Section A3.5.5.2.

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 A3.5-6 gives 2005 estimates of the broad components of the GHG emissions/removals in managed forests generated by the CBM-CFS3. The largest fluxes are carbon uptake by biomass and 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 A3.5-6: GHG Emissions/Removals of Managed Forests, 2005

Process/Event	GHG Balance				
	Biomass	DOM	Soil	N ₂ O	Ecosystem Net Balance
	<i>(Gg CO₂ eq)</i>				
Annual processes	-3 024 039	2 124 484	629 041	0	-270 515
Harvesting	157 517	13 099	0	0	170 616
Wildfires	14 116	56 467	0	3 139	73 722
Insects ¹	0	0	0	0	0
Total	-2 852 406	2 194 050	629 041	3 139	- 26 177

Notes:

1 “0” emissions indicate that insects do not consume or deplete C as do fires and harvest. Rather they kill biomass that is transferred to DOM.

Carbon in CH₄ and CO emissions is included in each pool’s assessment, but N₂O emissions are computed separately, from total CO₂ emissions (see also Annex 13).

A3.5.2.4 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 hectare, 25% crown closure and 5m 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. They are usually prepared on a ten year or longer cycle, and typically with a forward looking focus. Uncertainty in this respect is primarily related to the vintage of the industry and concerns over whether it has been updated for depletions since.

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 small, 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 dead organic matter decay rates for the 2007 submission, which affected the size of all dead organic matter 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.

A3.5.3 Cropland

The methodologies for cropland include CO₂ emissions and removals from cropland management, soil carbon stock change from forest and grasslands conversion to cropland, as well as N₂O emissions from soil disturbance upon conversion to cropland. The estimation methodology for carbon stock changes and GHG emissions from the biomass and DOM pools upon conversion of forest land to cropland are provided in Section A3.5.2.3.

A3.5.3.1 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 rate of primary production (CO₂ transfer from the atmosphere to the soil) and Soil Organic Carbon (SOC) decomposition (CO₂ transfer from the soil to the atmosphere). How the soil is managed determines whether the amount of organic carbon stored in a soil is increasing or decreasing. The IPCC (2003) approach, which guided the development of the CO₂ estimates methodology, is based on the premise that changes in soil carbon stocks over a certain period 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 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 reestablishment 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 conventional tillage practices (Campbell *et al.*, 1995, 1996a,b; 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 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 availability of activity data (time series of management practices) 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 in mineral soils were estimated for the following land management changes (LMC):

1. Change in mixture of cropland type:
 - 1.1. Increase in perennial crops
 - 1.2. Increase in annual crops
2. Change in tillage practices:
 - 2.1. Intensive tillage (IT) to reduced tillage (RT)
 - 2.2. IT to no-till (NT)
 - 2.3. RT to IT
 - 2.4. RT to NT
 - 2.5. NT to IT
 - 2.6. NT to RT
3. Change in area of summerfallow
 - 3.1. Increase in area of summerfallow
 - 3.2. Decrease in area of summerfallow

Other land management practices can also affect SOC. Although manure application has positive local effects on SOC, the actual amount of carbon stock change is small to non-existent when considering the total carbon input in feed and/or bedding from which the manure carbon is derived (Schlesinger, 1999). Where nutrients are greatly limiting, proper fertilization can increase SOC; in such conditions, however, fertilizer or other nutrient-enhancing practices are generally already applied. Losses or gains of irrigated

land in semiarid areas can affect SOC, but the impact is unclear, and the area of irrigated land has been relatively constant. Therefore, it was assumed that the selected LMC represented the most important and consistent influences on SOC in mineral soils.

Carbon Emission/Removal Factor

To estimate carbon emissions and removals, a carbon emission/removal factor specific to each combination of SLC polygon and management change is multiplied by the area of change. The carbon emission/removal factor is the average rate of SOC change per year and per unit of area of LMC.

Equation A3.5-1:

$$\Delta C = F \times A$$

where:

ΔC	= change in soil carbon stock, Mg C
F	= average annual change in SOC subject to LMC, Mg C/ha per year
A	= area of land management change, ha

The change in soil C stock is summed across various LMCs and Soil Landscapes of Canada polygons. Areas of LMC (i.e., changes in tillage, crop type, or 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 change occur. However, because only net change data are available, two assumptions were made: additivity and reversibility of carbon 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-based data; i) treatments often varying among research sites and making comparisons difficult; ii) difficult to determine duration of effect; iii) difficult to estimate full uncertainty from range of interactions with initial soil state and combination of different practices; and iv) difficult to determine the variability of carbon change without management change.

Because of these limitations, a well-calibrated and validated model of soil carbon dynamics, the CENTURY model (Parton *et al.*, 1987, 1988), was used to derive carbon 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

for Canadian conditions (Voroney and Angers, 1995; Liang *et al.*, 1996; Monreal *et al.*, 1997; Bolinder, 2004; Campbell *et al.*, 2000, 2005; Pennock and Frick, 2001; Carter *et al.*, 2003).

Smith *et al.* (1997, 2000, 2001) developed an approach using the CENTURY model to estimate carbon 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, following closely the work of Smith *et al.* (1997, 2000). These have been used for the first comprehensive assessments of soil carbon 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 soil attribute database. These database SOC values were derived from measurements made for soil surveys and land resource studies (Tarnocai, 1997) and were assumed to represent the SOC in 1985. On average, the simulated SOC from the initialization in 1985 was within a few percent of the database values.

Carbon factors were estimated using the difference in soil carbon 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 SLC 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 carbon factor was determined as:

Equation A3.5-2:

$$\text{Factor} = \frac{(\text{C for CTS with LMC substitutions} - \text{C for base CTS}) / [(\text{fraction of CTS substituted with the LMC}) \times (\text{duration considered})]}{1}$$

If a land management system is defined as a particular mix of crops and tillage practices on a specified land area, a change in carbon due to an LMC (ΔC_{LMC}) can be estimated as

the difference in carbon between two land management systems divided by the proportionate amount of LMC between the two land management systems:

Equation A3.5-3:

$$\Delta C_{LMC}(t) = \Delta C / p_{LMC}$$

where $\Delta C_{LMC}(t)$ is the difference in carbon between land management systems from year-to-year, and p_{LMC} is the proportion of area of land management system that received the LMC. This proportion can be derived as the proportion of the particular LMC in the base system less the amount of the LMC in the new system after LMC. That is,

Equation A3.5-4:

$$p_{LMC} = p_{LMbase} - p_{LMnew}$$

where p_{LMbase} is the proportion of the base land management and p_{LMnew} is 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 Semiarid 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 A3.5-9). The next step was to calculate the $\Delta C_{LMC}(t)$ function by subtracting the simulated SOC values for the base mix values from those imposed by the LMC (Figure A3.5-10). Finally, the $\Delta C_{LMC}(t)$ was calculated as the proportion of area of farming system dividing by the p_{LMC} (Equation A3.5-3). The respective values of p_{LMC} for the IT to NT reduction and for the addition of perennial crops were 4/10 and 7/10.

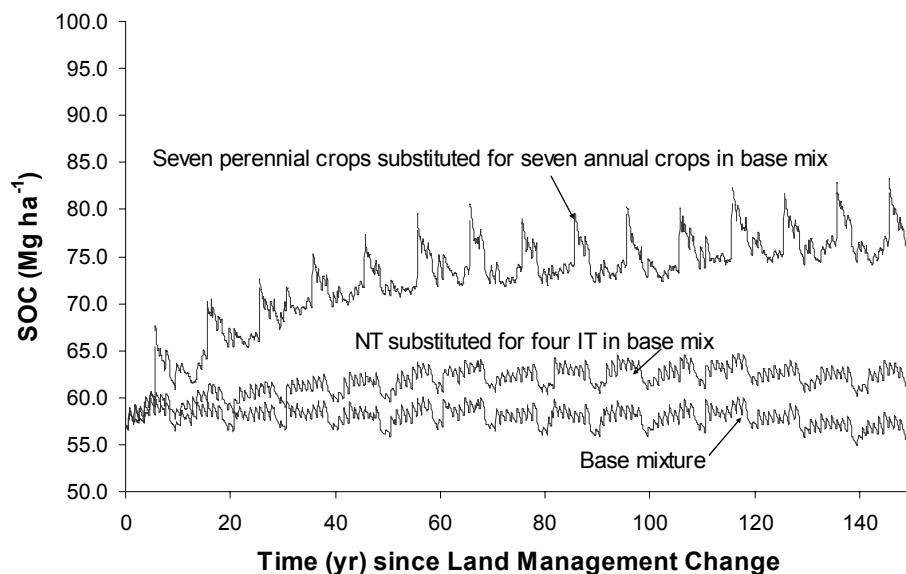


Figure A3.5-9: Soil Carbon for a Base Crop Mix and for Perennial (Alfalfa) Substituted for Annual Crops (Wheat) and for No-Till (NT) Substituted for Intensive Till (IT) Based on CENTURY Runs for a Lethbridge Loam

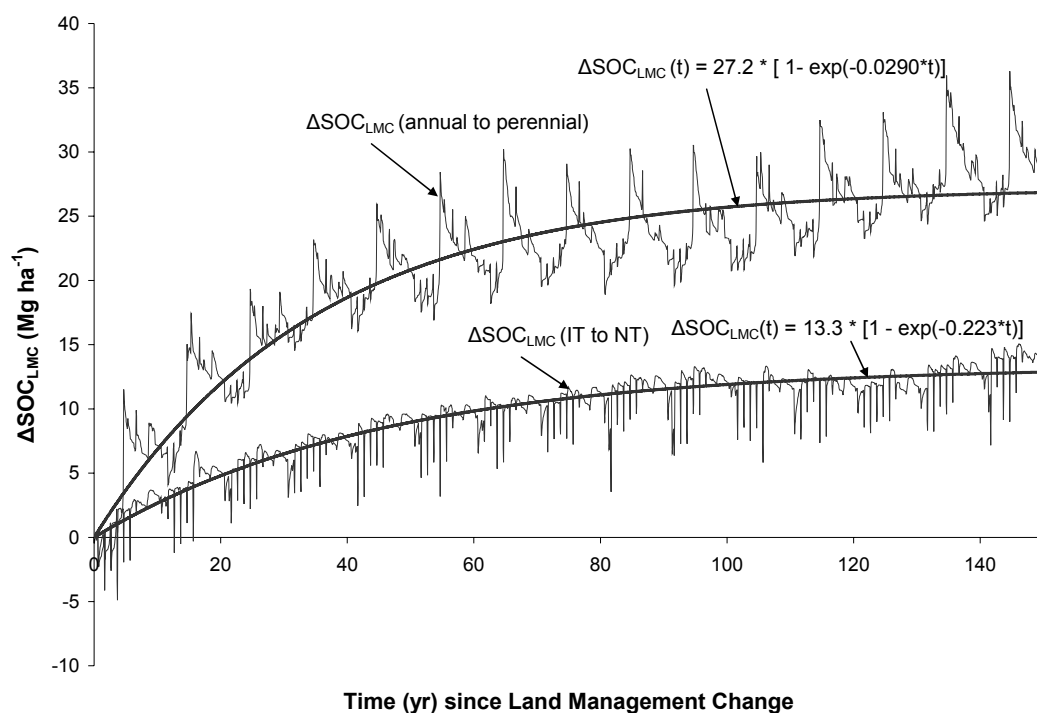


Figure A3.5-10: Change in SOC for Simulations with Substitutions Relative to Simulations with Base Crop Mix

Soil carbon dynamics are believed to be governed by first-order kinetics. Therefore, carbon change can be expressed as:

Equation A3.5-5:

$$\Delta C_{LMC}(t) = \Delta C_{LMCmax} \times [1 - \exp^{(-k \times t)}]$$

where ΔC_{LMCmax} is the maximum carbon change induced by the LMC, k is the rate constant, and t is 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. The equation for the slope of the function is:

Equation A3.5-6:

$$F_{SLOPE}(t) = \Delta C_{LMCmax} \times k \times \exp^{(-k \times t)}$$

Since the accounting 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 t) is:

Equation A3.5-7:

$$F_{LMC}(t) = \Delta C_{LMCmax} \times [\exp^{(-k \times (t-1))} - \exp^{(-k \times t)}]$$

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 A3.5-12).

Estimating Mean k and ΔC_{LMCmax} for Practical Factor Calculations

The ΔC_{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 A3.5-7). 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 zero or greater than 0.15 resulted from the fit to ΔC_{LMC} ; the k and ΔC_{LMCmax} from these fits were excluded from the reporting zone means.

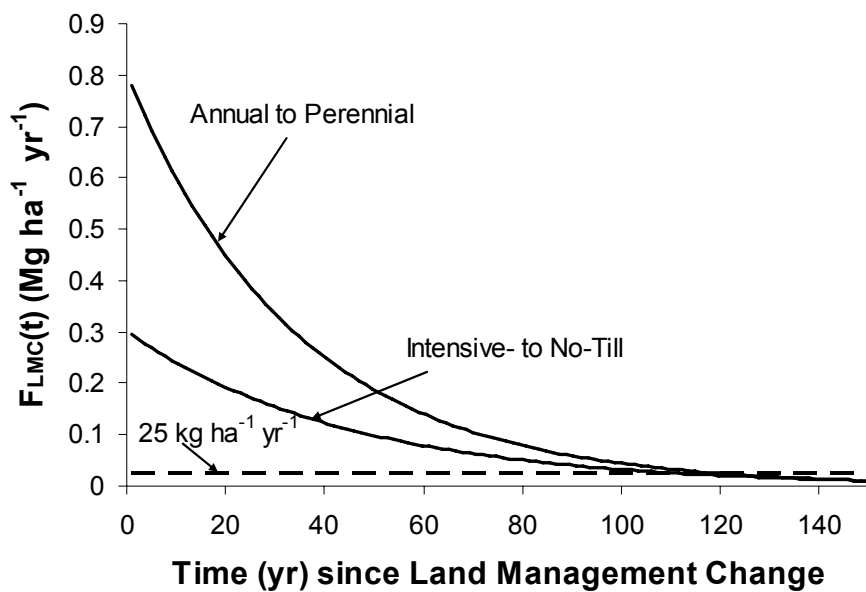


Figure A3.5-11: F_{LMC} from Exponential Equation

Table A3.5-7: 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 ¹	LMC ²	k (/year)	ΔC_{LMCmax} (Mg/ha)	Final Year of Effect after LMC ³	Linear Coefficient for Duration of Effect of LMC (Mg/ha per year)	Linear Coefficient for 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
Semiarid 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 Montane Cordillera reporting zones with agricultural activity contiguous to agricultural activity within the rest of the Parkland zone, and West is the Pacific Maritime reporting zone plus Montane Cordillera reporting zone excepting that portion of the latter that is included in the Parkland zone as described above.
- 2 For land management changes in opposite direction 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 carbon change in summerfallow have been well studied in Canada. Therefore, rather than using the value for ΔC_{LMCmax} from the CENTURY simulations, the ΔC_{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 (i.e., no fallow from 50% 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 a LMC than rates of SOC gain upon the reverse LMC. However, this effect depends greatly on the relative SOC amount at time of LMC. In particular, if the SOC amount is relatively high, rates of SOC gain will be low when practices are adopted that would be expected to increase SOC (e.g., from annual to perennial crops), while rates of SOC loss will be large when practices are adopted that would be expected to decrease SOC (e.g., from perennial to annual crops). The converse occurs if SOC is relatively low. In the simulations, generally, but not consistently, the rates of carbon gain for a LMC in one direction were predicted to be larger than rates of loss for the LMC in the opposite direction. This behaviour would suggest that many Canadian soils are relatively low in SOC. Detailed knowledge of the exact initial SOC conditions would be needed to determine how the direction of LMC affects rates of change, but a reasonable estimate would be that rates of gain for an LMC in one direction are the negative of the rates of loss for the LMC in the opposite direction. There is a major advantage if F_{LMC} for an LMC in one direction is the negative of the rate for the LMC in the opposite direction (e.g., from perennial to annual crops). The advantage is that concurrent LMCs in opposite directions cancel each other out. Therefore, it was decided to make the factors 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

Carbon change factors for LMCs used in the inventory were compared to empirical coefficients in VandenBygaart *et al.* (2007). They showed that empirical data comparing C change between CT and NT were highly variable, particularly for Eastern Canada. Nonetheless, the modeled factors were still within the range derived from the empirical data. The mean CT-NT factor for experiments in the Subhumid Prairie region was over four times that of the Semiarid Prairie. The mean CENTURY model-derived factor for the Semiarid Prairie region was similar to the factor derived from the field experiments. However, the CENTURY-derived CT-NT factor for the Subhumid Prairie region 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⁻¹ yr⁻¹ and this compared favourably to the range of 0.46-0.56 Mg C ha⁻¹ yr⁻¹ in the modeled factors in western Canada soil zones. In Eastern Canada only two empirical change factors were available but they appeared to be in line with the modeled values (0.60-1.07 Mg C ha⁻¹ yr⁻¹ empirical versus 0.74-0.77 Mg C ha⁻¹ yr⁻¹ modeled). For conversion of crop-fallow to continuous cropping, the rate of C storage (0.33 Mg ha⁻¹ yr⁻¹) was more than double the average rate of 0.15 ± 0.06 Mg ha⁻¹ yr⁻¹ 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 C 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.

Estimates of Change in Soil Carbon Stocks

Estimate development was based on processing relational databases of LMCs for which an estimate of carbon change was required. Soil carbon changes as a result of LMC were reported for 1990–2005. 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 carbon change for the SLC polygon. This is the smallest georeferenced unit of carbon stocks and carbon stock changes, with accounting using an IPCC Tier 2 approach as follows:

Equation A3.5-8:

$$\Delta C_{LMC,t} = \sum_{i1,i2} \sum_{ALLSLC} (\Delta C_{TILL} + \Delta C_{SF} + \Delta C_{CROPPING})$$

where:

$\Delta C_{LMC,t}$	=	change in soil carbon stocks due to LMC for a specific year (t_2) since 1951 (t_1)
ΔC_{TILL}	=	change in soil carbon stocks due to change in tillage practices from each SLC, since each particular tillage change
ΔC_{SF}	=	change in soil carbon stocks due to the change in summerfallow in each SLC
$\Delta C_{CROPPING}$	=	change in soil carbon stocks due to the change of 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 2005, 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 Soils Landscape of Canada (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.⁵¹ The advantage of using SLC Version 3.0 for the LULUCF

⁵¹ Available online at: <http://sis.agr.gc.ca/cansis/nsdb/slc/v1/intro.html>.

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, cropping systems from the Census of Agriculture) and cropland converted from forest and grassland to modelled carbon factors.

Analysis Units

There are 3264 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.

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. Agricultural activities were linked to specific components. 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.

Tillage Practices

Data for tillage practices were taken from the Census according to the following categories: i) IT – tillage that incorporates most of the crop residue into the soil, ii) RT – tillage that retains most of the crop residue on the surface, and iii) NT – no-till seeding or zero-till seeding. For summerfallow, i) NT – the area on which “chemicals only” were used for weed control, ii) IT – the area on which tillage only was labelled, and iii) 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: i) Statistics Canada and expert opinion indicate that the conservation

components tend to be underestimated, and ii) tillage distributions as reported for a region must be applied equally to all crops within that region.

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, while 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, while 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 1975–2005 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 Agriculture and Agri-Food Canada (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, a self-administered questionnaire that all farmers are required by law to complete every five years (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.

Uncertainty

Uncertainty was estimated using analytical uncertainty analysis (Coleman and Steele, 1999). The uncertainties associated with estimates of CO₂ 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, 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 uncertainties can be more reliably be considered in relative terms for an ecodistrict than a SLC polygon where small or no area under a practice also has a low absolute error.

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 compared to 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 C 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.

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 C change not measured.

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 land management changes.

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 C change was the sum of the deviation from process and situational uncertainty.

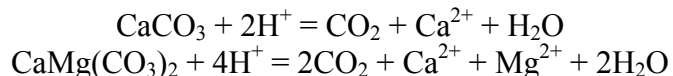
To estimate the process error, the variation from measured C change for controlled experiments was used. It was assumed this represents the inherent uncertainty even when the situation is accurately described. Since models of SOC dynamics are validated and calibrated against such data, it was also assumed 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).

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 C. There were many combinations of management within which C 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 C change. Average situational uncertainty scaling coefficients were derived for Canada (McConkey et al., 2007b).

CO₂ Emissions from Agricultural Lime Application

Lime is applied to raise the alkalinity and pH of acidic soils. The breakdown of lime releases CO₂ into the atmosphere. Limestone (CaCO₃) or dolomite (CaMg(CO₃)₂) is 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, CO₂ is released in the following 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 A3.5-9:

$$C = \sum (A_i \times 12/100)$$

where:

A_i	=	annual limestone consumption in province i (t/year)
12/100	=	ratio of molecular weight of carbon to molecular weight of limestone

Similarly, the amount of carbon released as a result of dolomite application is calculated as:

Equation A3.5-10:

$$C = \sum (A_i \times 12 / 184.3)$$

where:

A_i	=	annual consumption of dolomitic lime in province i (t/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 the Western Canada, Atlantic, Ontario, and Quebec fertilizer associations.

Uncertainty

The 95% confidence limits associated with annual lime consumption data was estimated to be $\pm 50\%$ (B. McConkey, personal communication). 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 and the maximum value of emission factor was used.

CO₂ 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 aboveground or belowground 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.

Based on work by Mailvaganam (2002), it was assumed that, on average, vines are replaced at 28 years of age and that the average vine is therefore 14 years old. Carbon accumulation in biomass was calculated within that time horizon. Because of intensive pruning, the biomass of shoots and leaves is set at the constant value of 4 Mg/ha, while linear rates of aboveground and belowground biomass accumulation in trunks and roots were 0.4 and 0.3 Mg/ha per year, respectively (Nendel & Kersebaum, 2004). These were converted to carbon values using a 50% carbon content in biomass. Upon a decrease of vineyard areas, an instantaneous loss of 6.9 Mg C/ha is assumed, equal to the average standing biomass for 14-year-old vines.

The approach to estimate biomass carbon stocks on fruit orchards used a general allometric equation (Fournier *et al.*, 2003; Jimenez and Diaz, 2003; 2004). While the average biomass of a mature tree ranged between 18 kg for an apple tree to 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. 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 belowground 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).

Typically, Christmas trees are marketed at about 10 years of age (Leuty, 1999; Agriculture and Agri-Food Canada, 2003). Wood accounts for approximately 70% of Christmas tree biomass (Hinesley and Derby, 2004), 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 aboveground 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 biomass carbon 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 aboveground and belowground 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 C in woody biomass is assumed to be immediately released. There is no Canadian specific data on this uncertainty. Therefore, the default uncertainty of $\pm 75\%$ (i.e. 95% confidence limits) for woody biomass on cropland from 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 to that carbon change that contributes to C 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 CO₂ to the atmosphere.

Methods

The IPCC Tier 1 methodology is based on the rate of carbon released per unit land area:

Equation A3.5-11:

$$C = \sum (A_i \times EF)$$

where:

A_i = area (ha) of organic soils that is cultivated for annual crop production in province i
 EF = carbon emission factor, t C loss/ha per year. A country-specific 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 16 156 ha (G. Padbury and G. Patterson, Agriculture and Agri-Food Canada, personal communication).

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 is assessed to be $\pm 50\%$ (Hutchinson *et al.*, 2007). The 95% confidence limits of the emission factor as provided in the 2006 IPCC Guidelines (IPCC, 2006) is $\pm 90\%$.

A3.5.3.2 *Grassland Converted to Cropland*

Conversion of native grassland to cropland generally results in losses of organic carbon and nitrogen and in turn leads to emissions of CO₂ and N₂O 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 in Table A3-37 of Canada's National Inventory Report (Environment Canada, 2006).

Losses of Soil Organic Carbon

The average loss of SOC based on field observations was 22% (Environment Canada, 2006). Many of the studies involved comparisons within 30 years of breaking, while 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 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 (Figure A3.5-12). Shortly after breaking, there is an increase in soil organic matter, as belowground 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, these SOC dynamics are described by the following equation:

Equation A3.5-12:

$$\Delta\text{SOC}(t) = \Delta\text{SOC}_{\text{Bmax}} \times [1 - \exp(-k_{\text{B}} \times (t - t_{\text{lag}}))]$$

where $\Delta\text{SOC}(t)$ is the change of SOC over time, $\Delta\text{SOC}_{\text{Bmax}}$ is the maximum ultimate change in SOC from grassland to cropland, k_{B} is the rate constant for describing the decomposition, t is the time since breaking of grassland, and t_{lag} is the time lag before ΔSOC becomes negative. The fit of this equation to the grassland simulation is shown in Figure A3.5-12; using an average k_{B} of 0.12, 92% of carbon is lost within 25 years of breaking the grassland.

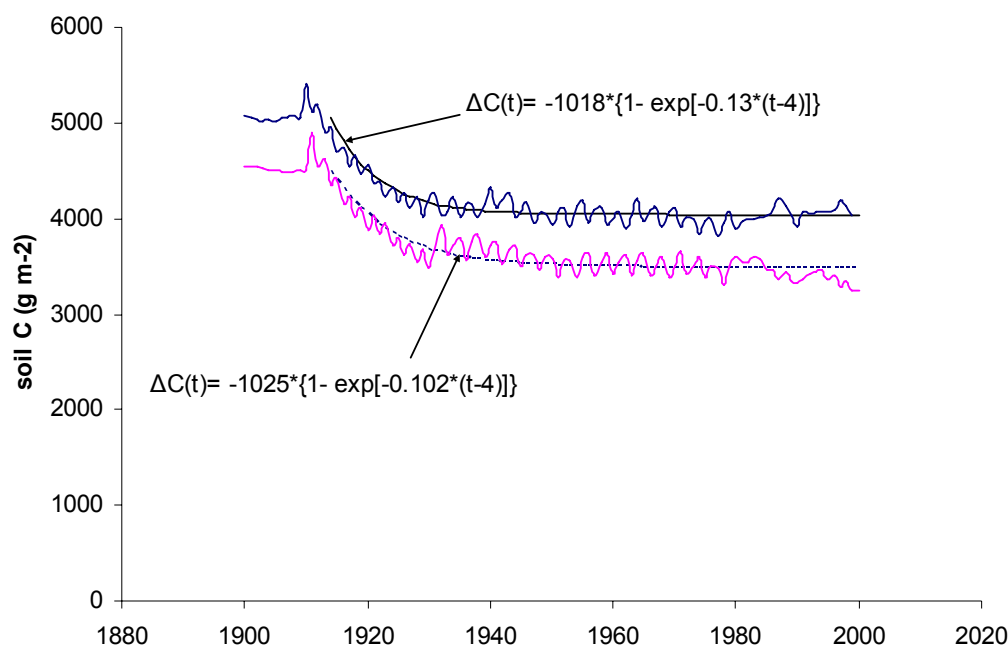


Figure A3.5-12: Soil Carbon Change since Breaking of Grassland to Cropland

It was assumed that the 22% loss corresponded to about 50–60 years after initial breaking and represented 100% of total loss. Therefore, the $\Delta\text{SOC}_{\text{Bmax}}$ is $0.22/(1-0.22) = 28\%$ of the SOC under agriculture. Given the uncertainty of actual dynamics, we assumed no time lag in SOC loss from breaking grassland, so that soil carbon starts to decline immediately upon breaking. With these assumptions, the general equation for predicting SOC loss from breaking grassland becomes:

Equation A3.5-13:

$$\Delta\text{SOC}(t) = 0.28 \times \text{SOC}_{\text{agric}} \times [1 - \exp^{(-0.12 \times t)}]$$

where $\Delta\text{SOC}(t)$ is the change of SOC over time, t is the time (years) since breaking, and $\text{SOC}_{\text{agric}}$ is the 0- to 30-cm SOC from the National Soil Database within CanSIS for the soil profile under an agricultural land use (cropland). Thus, the total losses of SOC in grassland converted to cropland were calculated using an IPCC Tier 2 approach:

Equation A3.5-14:

$$\Delta C_{GL-CL} = \sum_{1951-2005} \sum_{ALLSLC} \sum_t (\Delta SOC_t \times AREA_{GL-CL})$$

where:

ΔC_{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
ΔSOC_t	=	rate of carbon change at a particular time (t) after breaking, Mg C/ha per year
$AREA_{GL-CL}$	=	area of grassland converted to cropland, ha

Losses of Soil Organic N and N₂O Emissions

From the data shown in Table A3-37 of Canada's National Inventory Report (Environment Canada, 2006), 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. Thus, the emissions of N₂O in grassland converted to cropland were calculated using an IPCC Tier 2 approach as:

Equation A3.5-15:

$$N_2O_{GL-CL} = \sum_{1951-2005} \sum_{ALLSLC} \sum_t (\Delta SOC_t \times AREA_{GL-CL} \times 0.06 \times EF_{BASE}) \times \frac{44}{28}$$

where:

N_2O_{GL-CL}	=	emissions of N ₂ 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
ΔSOC_t	=	rate of carbon change at a particular time (t) after breaking, Mg C/ha per year
$AREA_{GL-CL}$	=	area of grassland converted to cropland, ha
0.06	=	conversion of carbon to nitrogen
EF_{BASE}	=	emission factor, defined as a function of P/PE at an ecodistrict level (refer to Section 6.4)
44/28	=	molecular weight ratio of N ₂ O to N ₂

Data Sources

For the Census years of 1981, 1986, 1991, 1996, and 2001, unimproved pasture areas at the SLC level were obtained from the "reconfigured" Census of Agriculture database. 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.

SOC_{agric} is the 0- to 30-cm soil for each SLC that contains grassland derived from the National Soil Database within CanSIS for the soil profile under an agricultural land use.

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 can not be larger than the uncertainty of the area of cropland or the area of grassland. Therefore, the uncertainty of the area of conversion was set to the lower of the uncertainty of the area of cropland and grassland. The factor scaling coefficient was assumed to be the same as for annual-perennial conversions (McConkey et al., 2007b).

A3.5.3.3 Forest Converted to Cropland

CO₂ and N₂O 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 change in soil carbon and N₂O emissions associated with the soil disturbance. The method for estimating emissions from biomass upon conversion is presented in Section A3.5.2.3. For SOC change, there is a need to differentiate between the eastern and the western parts of the country.

Eastern Canada

Eastern Canada, generally all land in the provinces of Ontario, Quebec, New Brunswick, Prince Edward Island, Nova Scotia, and Newfoundland and Labrador, was forested before its land use changed to agriculture. There are many observations that compare SOC for land under forest with adjacent land under agricultural purposes in eastern Canada. The mean loss of carbon was 20.3% for a depth of approximately 30 cm shown in Table A3-38 of Canada's National Inventory Report (Environment Canada, 2006). This value is comparable with soil database in CanSIS (Table A3.5-8), indicating that, on average, SOC for the uppermost 30 cm of soil under agriculture was 20.5% less than under forest.

Table A3.5-8: 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		
	Forested Land ¹	Cropland ¹	Difference
	Mg C/ha		%
Eastern Canada			
Coarse	85 (26)	68 (42)	-19
Medium	99 (38)	77 (35)	-22
Fine	99 (58)	78 (36)	-21
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 A3.5-8) 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 for two locations in Ontario (-----

Figure A3.5-13). In the first years after deforestation, there is an increase in soil organic matter, as litter and aboveground and belowground 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.

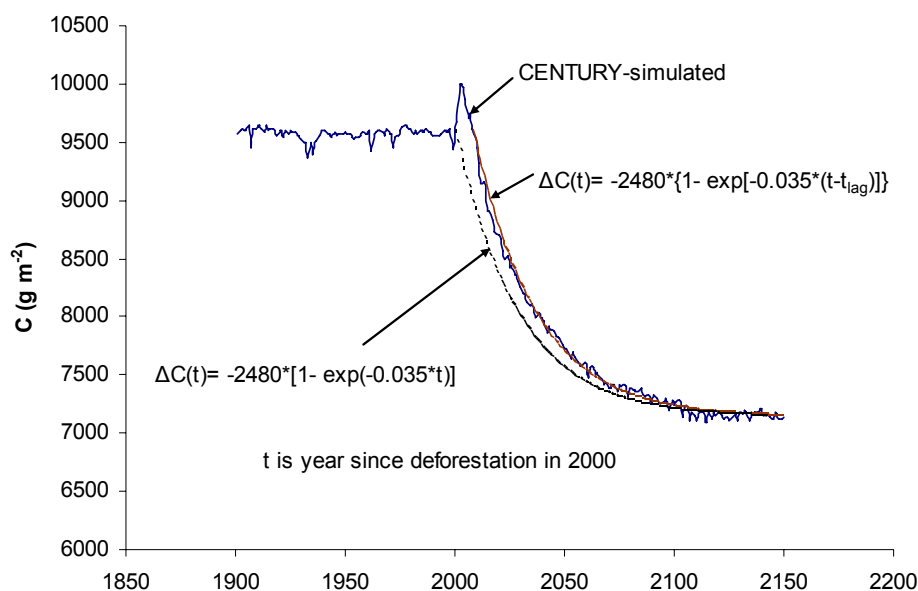


Figure A3.5-13: CENTURY-Simulated SOC Following Deforestation of Long-Term Deciduous Forest to Cropland

Neglecting the initial SOC increase, these SOC dynamics were described by the following equation:

Equation A3.5-16:

$$\Delta\text{SOC}(t) = \Delta\text{SOC}_{\text{Dmax}} \times [1 - \exp^{(-k_D \times (t - t_{\text{lag}}))}]$$

where $\Delta\text{SOC}(t)$ is the change in SOC over time, $\Delta\text{SOC}_{\text{Dmax}}$ is the maximum ultimate change in SOC from deforestation to agriculture, k_D is the rate constant for describing the decomposition, t is the time since deforestation, and t_{lag} is the time lag before ΔSOC becomes negative. For the example shown in Figure A3.5-13, 25% of carbon is lost 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 soil carbon starts to decline immediately upon deforestation: i.e., the fitted SOC loss (i.e., Equation A3.5-16) is used to estimate SOC loss with time lag set to 0 after fitting. Fitting Equation A3.5-16 to the simulations shown in Figure A3.5-13 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 result of these assumptions is conservative with regard to carbon loss after deforestation, as it is, arguably, more likely to overestimate than to underestimate SOC loss from deforestation to agriculture.

It was decided to use the mean loss of 20.5% of SOC resulting from deforestation to agriculture for eastern Canada based on CanSIS information. It was assumed that the 20.5% value corresponded 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 agriculture than of SOC under long-term forest in areas where agriculture exists, we chose to estimate this loss from SOC under agriculture (i.e., $\text{loss} = 0.221/(1-0.221) \times \text{SOC}$ or $\text{loss} = 0.284 \times \text{SOC}$ under agriculture). Therefore, the final equation for estimating SOC loss for deforestation to agriculture in eastern Canada is:

Equation A3.5-17:

$$\Delta\text{SOC}(t) = 0.284 \times \text{SOC}_{\text{agric}} \times [1 - \exp^{(-0.0262 \times t)}]$$

where $\Delta\text{SOC}(t)$ is the change of SOC over time, $\text{SOC}_{\text{agric}}$ is the 0- to 30-cm SOC from CanSIS for a soil profile under an agricultural land use (cropland), k_D (–0.0262) is the rate constant for describing the decomposition, and t is the time since deforestation. Thus, the total amount of SOC lost from forest land converted to cropland is estimated to be:

Equation A3.5-18:

$$\Delta C_{FL-CL} = \sum_{ALLSLC} \sum_{t_1, t_2} \sum_{t_1+1, t_2} (\Delta SOC_t \times AREA_{FL-CL, t})$$

where ΔC_{FL-CL} is the total carbon loss in forest land converted to cropland annually since 1970 (t_1), t_2 is the most recent year, ΔSOC_t is defined in Equation A3.5-16, and $AREA_{FL-CL, t}$ is the area of forested land converted to cropland annually since 1970. Note that the SOC loss predicted by Equation A3.5-16 is in addition to carbon released from removal of carbon in above- and belowground tree biomass and from removal or decay of other above- and belowground coarse woody DOM that existed in the forest at the time of deforestation.

Based on the field observations shown in Table A3-38 of Canada's National Inventory Report (Environment Canada, 2006), average nitrogen change in eastern Canada was -5.2%, representing 0.4 Mg N/ha. For those comparisons where both nitrogen and carbon loss was 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 carbon loss. Thus, N_2O emissions from forest land converted to cropland are estimated as:

Equation A3.5-19:

$$N_2O_{FL-CL} = \sum_{1951-2005} \sum_{ALLSLC} \sum_t (\Delta SOC_t \times AREA_{FL-CL} \times 0.02 \times EF_{BASE}) \times \frac{44}{28}$$

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 forestland conversion
t	=	time after forestland conversion, years
ΔSOC_t	=	rate of carbon change at a particular time (t) after forestland conversion, Mg C/ha per year
$AREA_{FL-CL}$	=	area of forestland converted to cropland, ha
0.02	=	conversion of carbon to nitrogen
EF_{BASE}	=	emission factor, defined as a function of P/PE at an ecodistrict level (refer to Section 6.4)
44/28	=	molecular weight ratio of N_2O to N_2

Western Canada

Much of the current agricultural soil in western Canada (Manitoba, Saskatchewan, Alberta, and British Columbia) 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 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 agriculture (Table A3.5-8). 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 as 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 this 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. In fact, frequently, SOC was found to be greater under forages than under forest. Fuller and Anderson (1993) determined that after 40–50 years under forest, SOC was about 40% less than under native grass at an upland site and about 15% less at a lowland site in central Saskatchewan. Similarly, for afforestation of pasture, Paul *et al.* (2002) reported that, on average, there is a slight loss in SOC, whereas there is generally a gain when afforesting land in annual crops.

For western Canada, no loss of SOC over the long term was assumed from deforestation to agriculture. Therefore, the carbon loss from deforestation in western Canada would be from losses of carbon in above- and belowground tree biomass and coarse woody DOM that existed in the forest at the time of deforestation. Similarly, average nitrogen change in western Canada for sites at least 50 years from breaking was +52% (Environment Canada, 2006), reflecting substantial added nitrogen in agricultural systems compared with the situation in forests. However, recognizing the uncertainty about actual carbon–nitrogen dynamics for deforestation, for purposes of N₂O accounting, forest land converted to cropland was assumed not to be a source of N₂O.

Data Sources

The approach used to estimate the area of forest land converted to cropland is described in Section A3.5.2.2. 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 factor scaling coefficient was assumed to be the same as for annual-perennial conversions (McConkey *et al.*, 2007b). The uncertainty of C change in each reporting zone was estimated differently for eastern and western Canada because of differences in C change estimation methods. For western Canada, an uncertainty of C change was estimated although the mean value of factor was zero. The assumption was that the uncertainty of C change after FL-CL in western Canada would follow a similar pattern as that for eastern Canada.

A3.5.4 Grasslands

Agricultural grassland is defined as “unimproved pasture” used for grazing domestic livestock in geographical areas where grassland would not naturally revert to 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 burning, adding new plant species into the grassland, and the amount, duration, and timing of grazing by domestic livestock.

A3.5.4.1 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 of 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 identified as “low” for “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.

A3.5.4.2 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 one-half of range in Canada was in poor condition. They also noted that range management systems had improved over past several decades, and 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. However, there is no

clear relationship between range condition and SOC. Henderson *et al.* (2004) compared ungrazed enclosures rated in excellent condition with adjacent grazed pastures in poor to good condition. They found no consistent effect of range conditions on SOC. Dormaar and Willms (1990) found significantly more SOC in range in poor than in good condition because range in poor condition was dominated by grass species that provide greater root input of carbon to the soil.

Invasion of grassland with tame grass species is an important problem for Canadian grassland (Prairie Farm Rehabilitation Administration, 2000) because of negative effects on biodiversity (Bai *et al.*, 2001). Soils that have been cultivated and then seeded to tame grasses have lower SOC than undisturbed soil remaining in native range (Dormaar *et al.*, 1995; Christian and Wilson, 1999). However, SOC is not affected by invasion of tame grasses into native range (Henderson and Naeth, 2005) or intentionally seeded directly into native range without prior cultivation of the native range (Broersma *et al.*, 2000).

According to the IPCC Good Practice Guidance for LULUCF (IPCC, 2003) grassland in temperate/boreal regions in degraded conditions has 95% of the SOC of that in non-degraded conditions, indicating opportunity to change SOC by changing conditions of the grass. 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 well grazed (Lynch *et al.*, 2005). In a modelling study, Lynch *et al.* (2005) estimated a negligible 0.060–0.180 Mg/ha increase in SOC over 30 years from improved grazing management of rangeland compared with the traditional season-long grazing regime in southern Saskatchewan. 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. Studies have shown increased SOC from grazing compared with no grazing (Dormaar *et al.*, 1994; Wienhold *et al.*, 2001), no effect (Willms *et al.*, 2002), and decreased SOC (Bauer *et al.*, 1987; Dormaar *et al.*, 1997). Dormaar *et al.* (1977) showed that there was no consistent effect of grazing, but that the apparent effect depended greatly on season of sampling and timing of sampling relative to grazing pressure. Grazing has not been shown to affect annual CO₂ fluxes (LeCain *et al.*, 2002).

Reeder and Schuman (2002) showed that SOC was greater for heavy grazing pressure than for moderate grazing pressure. Schuman *et al.* (1999) and Frank *et al.* (1995) found similar results, but later sampling at those same sites showed that SOC for heavy grazing was not greater than that for moderate grazing (Wienhold *et al.*, 2001; Ganjegunte *et al.*, 2005). Naeth *et al.* (1991) found that there was no effect of grazing on total SOC but that

early-season (before July) grazing was more detrimental to carbon inputs to soil than late-season (after July) grazing. Manley *et al.* (1995) found no effect of grazing regime, including rotational grazing, on SOC.

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 belowground 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 total 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 reason to conclude that fire suppression is producing significant decreases in SOC. Annual CO₂ fluxes indicate that grazed grassland with no burning does not appear to be either a source or sink of CO₂ 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 semiarid 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.

A3.5.5 Wetlands

A3.5.5.1 Peatlands

Approximately 14 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 18 kha, the difference being peatlands that are no longer under production. 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 Association⁵²).

General Approach and Methods

Only CO₂ emissions from lands 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. 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 A3.5-20:

Equation A3.5-20:

$$\text{CO}_2\text{-C}_{\text{L_Peat}} = \text{CO}_2\text{-C}_{\text{BIOMASS}} + \text{CO}_2\text{-C}_{\text{DOM residual}} + \text{CO}_2\text{-C}_{\text{SOILS drained}} + \text{CO}_2\text{-C}_{\text{SOILS extraction}} + \text{CO}_2\text{-C}_{\text{SOILS stockpiles}}$$

where:

$\text{CO}_2\text{-C}_{\text{L_Peat}}$	=	total carbon emissions as CO ₂ from land converted to wetlands (for peat extraction)
$\text{CO}_2\text{-C}_{\text{BIOMASS}}$	=	carbon emissions as CO ₂ from the loss of C to forest products upon forest clearing
$\text{CO}_2\text{-C}_{\text{DOM residual}}$	=	carbon emissions as 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 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 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 CO ₂ from the oxidation of stockpiled peat on productive peatlands converted for no more than 20 years

Pre-conversion biomass (or biomass cleared) is estimated at an average 20 t C/ha. Upon clearing, all biomass carbon is transferred to forest products or dead organic matter; 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 A3.5-21.

⁵² Available online at: <http://www.peatmoss.com/pm-harvest.php>.

Equation A3.5-21:

$$\text{CO}_2\text{-C}_{\text{Peat}} = \text{CO}_2\text{-C}_{\text{DOM residual}} + \text{CO}_2\text{-C}_{\text{SOILS extraction}} + \text{CO}_2\text{-C}_{\text{SOILS stockpiles}} + \text{CO}_2\text{-C}_{\text{SOILS abandoned}} + \text{CO}_2\text{-C}_{\text{SOILS restored}}$$

where:

$\text{CO}_2\text{-C}_{\text{Peat}}$	=	total carbon emissions as CO_2 from wetlands remaining wetlands (peatlands)
$\text{CO}_2\text{-C}_{\text{DOM residual}}$	=	carbon emissions as CO_2 from the decay of biomass cleared on previous years
$\text{CO}_2\text{-C}_{\text{SOILS extraction}}$	=	carbon emissions as 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 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 CO_2 resulting from the net ecosystem production on abandoned peatlands
$\text{CO}_2\text{-C}_{\text{SOILS restored}}$	=	carbon emissions/removals as 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 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 peatfields (to prevent desiccation). In the initial years of restoration, straw decomposition may further increase CO_2 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_2 respiration, and gross ecosystem production is zero during the non-growing season. Table A3.5–9 lists the main parameter values applied in estimate development. Uncertainty estimates were obtained from expert judgement.

Table A3.5-9: Parameters and Emission Factors for Estimating CO₂-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 ₂ -C/m ² per year	351	75
Emission factor on productive fields	g CO ₂ -C/m ² per year	1019	75
Exponential decay constant, stockpiles		0.05	75
Annual decrease in emission factor, abandoned fields			
Vacuum-harvested	g CO ₂ -C/m ² per year	15	75
Block-cut	g CO ₂ -C/m ² per year	35	75
Emission factor, restored peatlands			
First year	g CO ₂ -C/m ² per year	1753	75
>Five years	g CO ₂ -C/m ² per year	-84	75

Data Sources

Little information on the area of peat production is available in Canada. 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 assumed to be 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 pre-conversion biomass carbon density (20 t C/ha) was assumed.

A3.5.5.2 Flooded Lands

General Approach and Methods

Following IPCC Good Practice Guidance for LULUCF (IPCC, 2003), emissions from land converted to wetlands (creation of flooded lands, namely reservoirs) were estimated for all known reservoirs flooded for 10 years or less. Only CO₂ emissions are reported. An IPCC Tier 2 method was used, whereby country-specific CO₂ 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 estimation methodologies were used to account for GHG fluxes from flooded lands, depending on land conversion practices. When there was evidence of forest clearing and/or burning prior to flooding, immediate and residual emissions from all carbon pools were estimated as in all forest conversion events since 1970, with the CBM-CFS3 (see Section A3.5.2.1 above). Note that emissions from forest clearing for infrastructure development are reported under forest conversion to settlements.

In the absence of such evidence, it was assumed that all vegetation was simply flooded.

The estimation of CO₂ emissions from the surface of reservoirs is described below. The proportion of the area flooded that was previously forested was used to attribute emissions to either “forest land converted to wetlands” or “other land converted to wetlands.”

Since 1993, measurements of CO₂ 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 CO₂, CH₄, or N₂O (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. The emission curve for the Montane Cordillera (reporting zone 14) was developed from 16 reservoirs and a total of 16 measurements (Figure A3.5-14). For the Taiga/Boreal/Hudson Plains regions (reporting zones 4, 5, 8, and 10), the emission curve was developed from nine reservoirs and a total of 17 measurements (Figure A3.5-14). It is important to note that each of these measurements (data points in Figure A3.5-14) 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 A3.5-22:

$$\text{CO}_2 \text{ rate } L_{\text{reservoir}} = b_0 + b_1 \times \ln(t)$$

where:

CO ₂ rate L _{reservoir}	=	rate of CO ₂ emissions from land converted to wetlands (reservoirs), mg/m ² per day
b ₀ , b ₁	=	curve parameters, unitless
t	=	time since flooding, years

The relations between diffuse CO₂ 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.

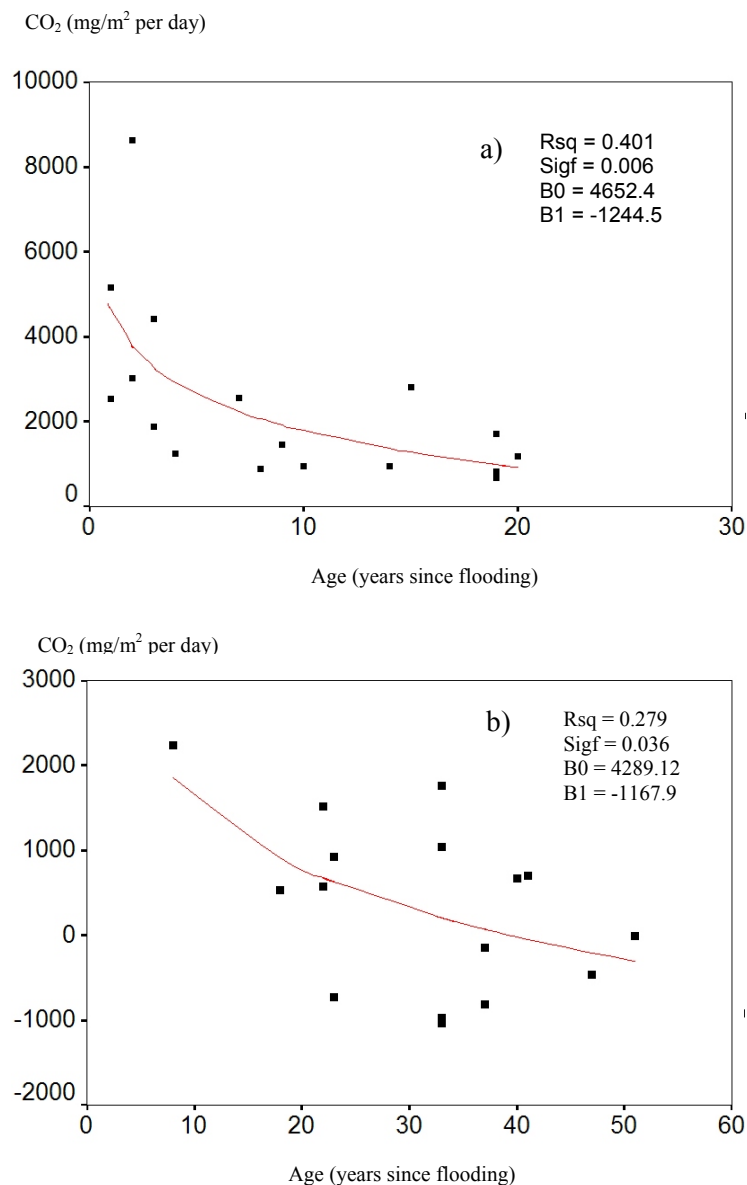


Figure A3.5-14: Logarithmic Curve Fits for (a) Taiga/Boreal Reservoirs and (b) Cordillera Reservoirs

Note: Curve parameters are provided, as well as the coefficients of determination and their significance.

Total CO₂ emissions from the surface of reservoirs were estimated as the sum of all emissions from reservoirs flooded for 10 years or less:

Equation A3.5-23:

$$\text{CO}_2 \text{ L_reservoirs} = \sum_{\text{reservoirs}} (\text{CO}_2 \text{ rate L_reservoir} \times \text{A}_{\text{reservoir}} \times \text{Days}_{\text{ice free}} \times 10^{-8})$$

where:

$\text{CO}_2 \text{ L_reservoirs}$	=	emissions from lands converted to flooded lands (reservoirs), Gg CO_2 /year
$\text{CO}_2 \text{ rate L_reservoir}$	=	rate of CO_2 emissions for each reservoir, mg/m^2 per day
$\text{A}_{\text{reservoir}}$	=	reservoir area, ha
$\text{Days}_{\text{ice free}}$	=	number of days without ice, days

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).

Following the guidance in IPCC Good Practice Guidance (Section 3a.3 of IPCC (2003)), $\text{A}_{\text{reservoir}}$ was used as the best available estimate of the land-use change area.

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 i) information received on forest conversion due to reservoir impoundment in reporting zones 4 and 5 (see Section A3.5.2.2, Forest Conversion); and ii) 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 31 388 ha. The distribution of reservoir area is skewed, with 25% of the largest reservoirs representing over 95% of all reservoir area in Canada.

Since 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. In the 2007 submission corrections were made for the flooding year of a large reservoir (Laforge 2) where electricity generation began over a decade after flooding.

The trend in area flooded is characterized by two distinct periods (Figure A3.5-15). 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 2004, there was a small but consistent increase in new reservoir areas, with the occurrence of several small to medium-scale flooding events. Three new reservoirs (Touloustouc, Peribonka, and Eastmain-1) have been recently created; since flooding for Peribonka and Eastmain-1 reservoirs was not completed in 2005 and accounting of reservoir emissions for Touloustouc started in 2006, the 2007 submission only includes emissions from forest clearing for these three sites.

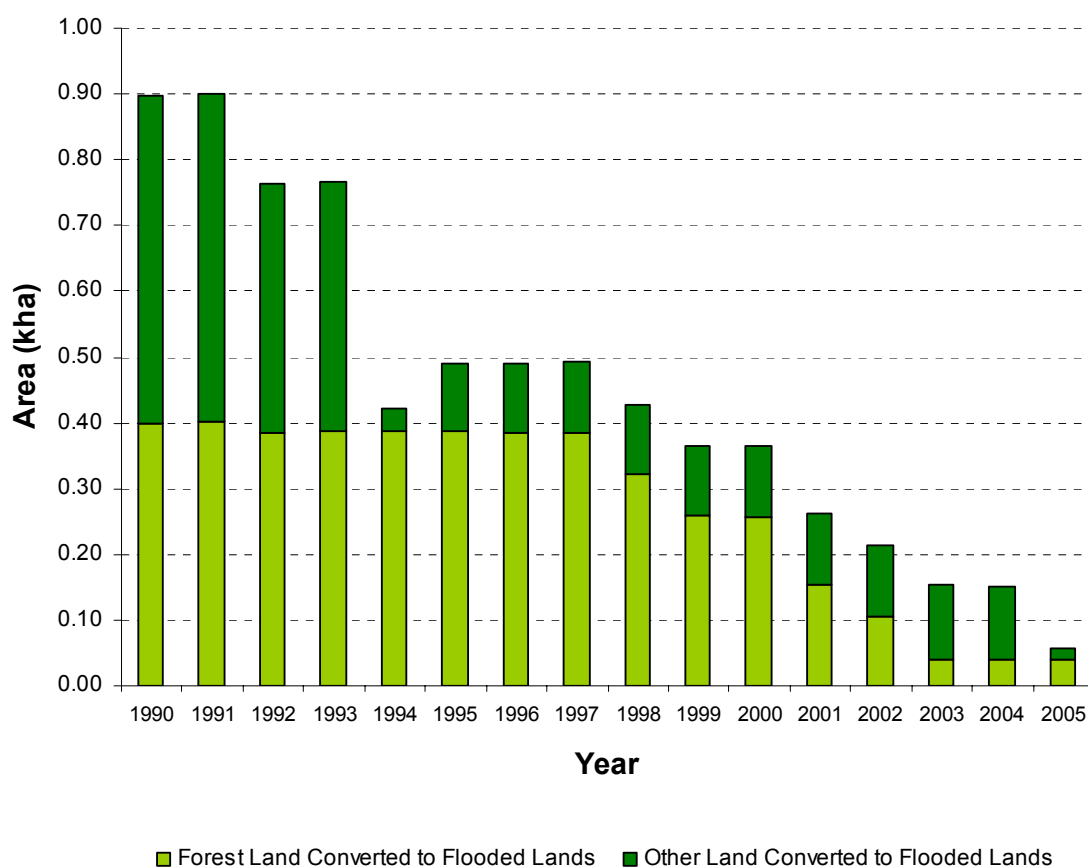


Figure A3.5-15: Cumulative Areas in the Category “Lands Converted to Wetlands (Flooded Lands)”

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 is 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:

1. 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 CO₂ 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.
2. Seasonal variability. Some reservoirs display marked seasonal variability in CO₂ 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.
3. The omission of potentially important CO₂ emission pathways, e.g., degassing.

Planned Improvements

Planned improvements include refining the methodology to further minimize the potential double-counting of carbon emissions; improving, in partnership with industry, the activity data on reservoirs; and including flooded lands other than hydroelectric reservoirs as appropriate.

A3.5.6 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 computing every year over 1990-2005 an average growth of 0.05 t biomass/ha/yr applied to 1796 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.

A3.5.6.1 General Approach and Methods

The Canadian northern regions (Arctic and sub-Arctic) cover nearly half of Canada's landmass and include five land categories (*sensu* IPCC, 2003) except cropland. This assessment covered an area of about 359 million hectares and included reporting zones 1, 2, 3, 17, and 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:

1. Map non-forest land-use change in Canada's Arctic/sub-Arctic prior to and including 1990 and between 1990 and 2000.
2. Estimate annual GHG emissions (aboveground 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.⁵³ All 23 frames were located in the western Arctic and sub-Arctic regions.

The Land Use Change Mapping System for Canada's North was devised (Butson and Fraser, 2005), which 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.

To develop an estimate for above ground biomass a series of aboveground biomass maps in 2000 were developed for the main land-use change areas, using relationships between aboveground biomass and remote sensing data constructed from and calibrated with

⁵³ 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.

ground measurements (Figure A3.5-16). These maps were used to determine CO₂ emissions from the clearing of aboveground biomass. The dominant land cover types in the two study areas are rock, lichen, low–high shrub, grass, and sparse woodland.

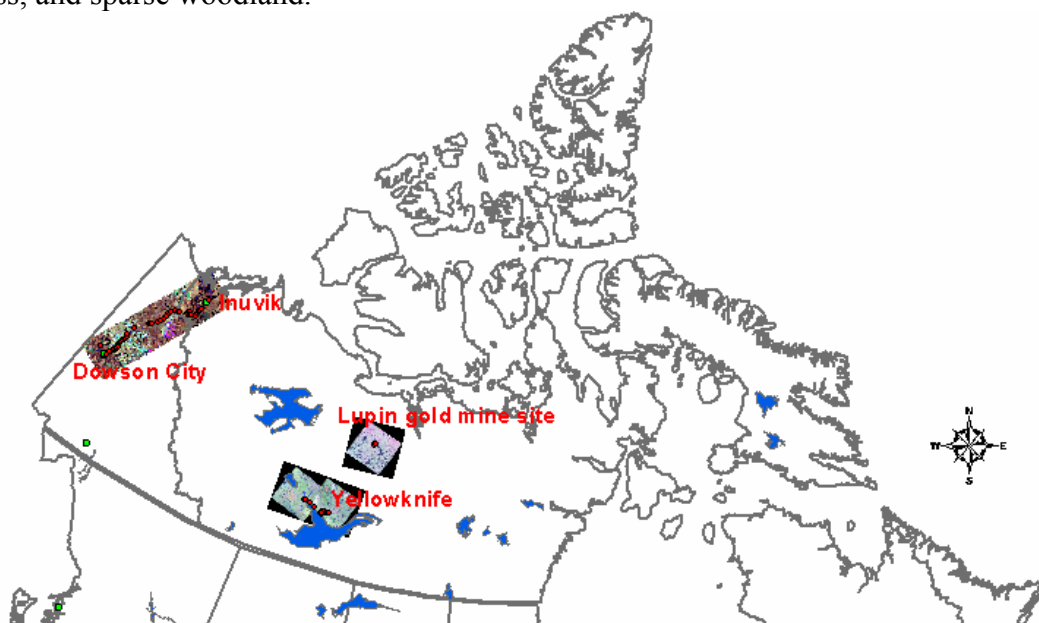


Figure A3.5-16: Study Areas for the Determination of Aboveground Biomass

Multiple regressions were conducted between $\ln(\text{aboveground biomass})$ 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 pre-conversion 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 pre-conversion biomass carbon was deemed emitted upon clearing.

For 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 3t C/ha). For this region there was an average rate of land use change of 116 ha/yr for the period 1990-2005.

When only the aboveground biomass component is considered, land-use change activities over Canada's north released an estimated 153 kt CO₂ eq./year in the 1990-2005 period. .

A3.5.6.2 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 aboveground 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 aboveground 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).

A3.5.7 Estimation of Delayed CO₂ 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 A3.5-1 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:

$$HE_{\text{Default}} = \text{RW} + \text{Firewood}$$

Stock Change:

$$HE_{\text{Stock Change}} = \text{RW} + \text{Firewood} - \text{Domestic Long-Lived Commodity} + \text{Inherited Emissions from Long-Lived Commodity Consumption}$$

Production:

$$HE_{\text{Production}} = \text{Firewood} - \text{Long-Lived Commodity Production} + \text{Inherited Emissions from Long-Lived Commodity Production}$$

Atmospheric Flow:

$$HE_{\text{Atm. Flow}} = \text{Firewood} + \text{Processing Wastes} + \text{Inherited Emissions from Long-Lived Commodity Consumption}$$

where:

HE	=	carbon emitted outside of the 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, CO₂ emissions outside of managed forests in 2005, resulting from either domestically consumed or domestically produced HWP, vary from 177Mt (IPCC default) to 120 (atmospheric flow), 136 (production), or 163 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 semiprocessed 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 LULUCF (IPCC, 2003) and the 2006 IPCC Guidelines (IPCC, 2006). Work has been initiated in 2007 to update the Forest Product Sector module of the Carbon Budget Model.

Box A3.5-1: 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 CO₂ 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 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.

A3.6 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:

- CH₄ emissions from solid waste disposal on land;
- CH₄ and N₂O emissions from wastewater treatment; and
- CO₂, CH₄, and N₂O emissions from waste incineration.

A3.6.1 CH₄ Emissions from Solid Waste Disposal on Land**A3.6.1.1 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 CH₄ generation from landfills using the following first-order decay equation (IPCC/OECD/IEA, 1997):

Equation A3.6-1:

$$Q_{T,x} = kM_x L_0 e^{-k(T-x)}$$

where:

$Q_{T,x}$	=	the amount of methane generated in the current year (T) by the waste M_x , kt CH ₄ /year
x	=	the year of waste input
M_x	=	the amount of waste disposed in year x , Mt
k	=	methane generation rate constant, /year
L_0	=	methane generation potential, kg CH ₄ /t waste
T	=	current year

Equation A3.6-2:

$$Q_T = \sum Q_{T,x}$$

where:

Q_T	=	the amount of methane generated in the current year (T), kt CH ₄ /year.
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The Scholl Canyon model assumes that CH₄ production is highest in the early phase, followed by a slow steady decline in annual production rates, as shown in Figure A3.6.1. The Canadian model assumes that the initial lag time where anaerobic conditions are established is negligible, as shown in Figure A3.6-1.

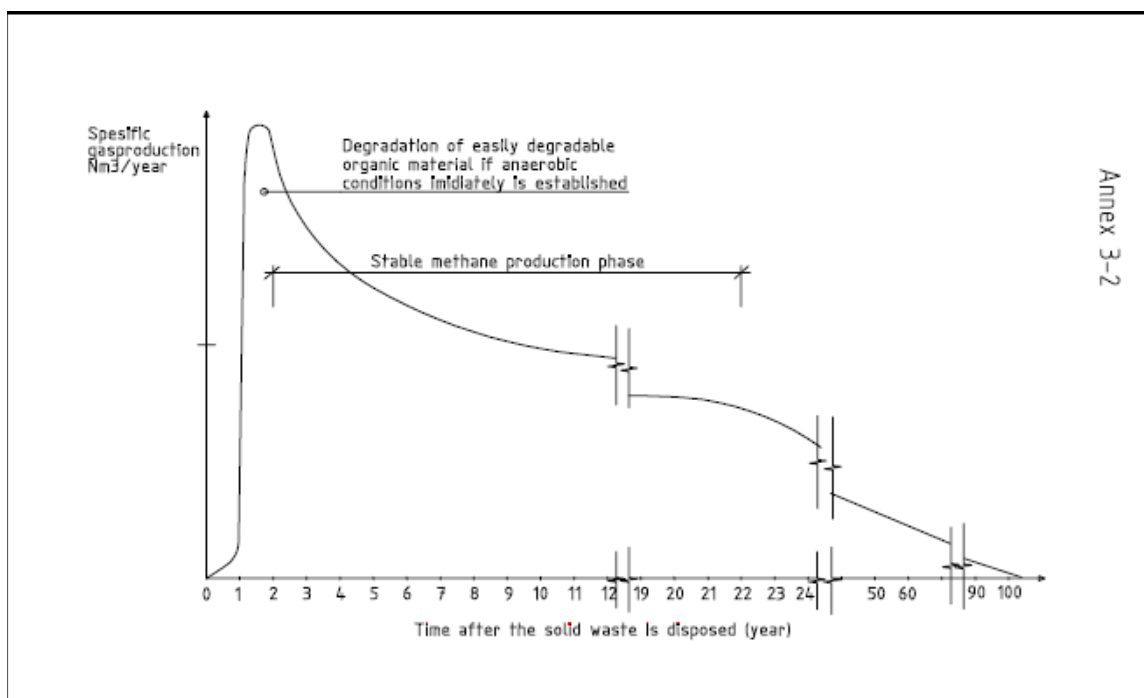


Figure A3.6-1: Scholl Canyon Model Representation of Landfill Degradation (Jensen & Pipatti, 2003)¹

¹ Figure shown as published without modification.

In order to estimate CH₄ 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 G_i for every section of waste landfilled in past years is taken, the captured gas quantities subtracted, and the CH₄ 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 to 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, 2004a, 2007). MSW disposal values for the subsequent odd years (1999, 2001, and 2003) are obtained by taking an average of the corresponding even years. Disposal, with respect to the Statistics Canada data, refers to the combination of waste incinerated and 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, 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, 2004a, 2007) MSW landfill 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 A3.6-1 shows the polynomial coefficients generated by the multiple linear regression method for each of the provinces.

Table A3.6-1: 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 ₁	-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 ₂	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 ₃	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 ₄	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 ₅	-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 ₆	-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 ₇	-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 ₈	-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 ₉	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 ₁₀	-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 ₁₁	-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 ₁₂	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 ₁₃	-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 A3.6-3:

$$M_X = (C_{13} * X^{13}) + (C_{12} * X^{12}) + (C_{11} * X^{11}) + (C_{10} * X^{10}) + (C_9 * X^9) + (C_8 * X^8) + (C_7 * X^7) + (C_6 * X^6) + (C_5 * X^5) + (C_4 * X^4) + (C_3 * X^3) + (C_2 * X^2) + (C_1 * X) + C$$

where:

M_X	=	MSW landfilled in year X, t
C_i	=	coefficient of the <i>i</i> th order (see table A3.6-1)
X	=	year of interest

Statistics Canada MSW disposal data are unavailable for Prince Edward Island and the Northwest, Nunavut and Yukon Territories. Thus, MSW landfill values for this province and territories for the period 1991–2005 are obtained by trending historical landfill data with the provincial populations for 1971–2005 (Statistics Canada, 2006). Three sources of landfill data are used to estimate the MSW landfill amounts for 1991 to 2005. The first set of data was provided by Levelton for 1971–1990 (Levelton, 1991). The second set of landfill data was provided by the Hazardous Waste Branch of Environment Canada for 1992 (Environment Canada, 1996). The third set of landfill data involves multiplying the 1992 percentage of waste landfilled for P.E.I. and the Northwest, Nunavut and Yukon Territories (Environment Canada, 1996) by the surplus of waste landfilled provided by Statistics Canada for 1998, 2000, 2002 and 2004 (Statistics Canada, 2000, 2003, 2004a, 2007). 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 A3.6-2 shows the amount of MSW landfilled for the period 1990–2005.

Table A3.6-2: MSW Landfilled for 1990–2005

Year	Waste Landfilled											
	NL	PE	NS	NB	QC	ON	MB	SK	AB	BC	NT & NU	YK
	<i>(t)</i>											
1990 ¹	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	68,831	540,341	489,539	4,073,027	6,287,557	741,706	720,035	1,790,701	1,990,162	37,230	18,977
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	39,275	20,582
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	40,590	19,849
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	41,757	20,679
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	42,585	21,717
1997	393,651	80,156	447,861	446,225	4,539,872	6,659,708	813,373	746,914	2,027,558	2,021,350	42,670	22,168
1998	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	80,521	357,703	387,656	4,799,511	6,283,801	875,695	741,743	2,006,801	1,843,849	42,635	21,046
2000 ²	373,020	92,586	308,311	349,685	5,030,113	6,604,076 ³	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	43,845	20,329
2002 ²	356,595	82,280	304,309	358,318	5,085,567	6,505,705 ³	818,566	719,801	2,246,704	1,867,362	38,830	18,920
2003	367,700	82,480	309,104	366,047	5,290,543	6,346,012	839,021	734,066	2,346,984	1,993,321	45,877	20,825
2004 ²	378,804	91,318	313,899	373,776	5,495,519	6,186,319 ³	859,475	748,331	2,447,264	2,119,281	43,095	20,998
2005	375,542	84,067	306,272	373,734	5,807,178	5,964,694	864,443	747,396	2,551,536	2,117,746	47,171	21,280

Notes:

1 Levelton (1991) data.

2 Statistics Canada disposal data (Statistics Canada, 2000, 2003, 2004a, 2007).

3 Exported MSW subtracted from the Statistics Canada disposal data (Pope, 2006, 2007).

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 1991–2005.

Wood Waste Landfills

The amount of wood waste landfilled in the years 1970 through to 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 and 2005. This interpolation method is selected as it is most suitable for the data distribution.

The breakdown in the amount of wood residue disposed (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 breakdown in wood waste disposal is estimated at 80% for solid wood operations and 20% for pulp and paper mills.

The breakdown in the amount of wood residue landfilled for the solid wood operations and the pulp and paper industries is estimated based on the Wood Residue Data Base (NRCan, 1997). The portion of wood waste landfilled in private landfills is estimated at 15% for solid wood operations and 86% for pulp and paper mills. The portion of wood waste landfilled in private versus public landfills is calculated to avoid double counting since emissions from public landfills are already accounted for in the emissions from municipal solid waste landfills. This portion is assumed to be also true for the years 1970–2005. Table A3.6-3 shows the amount of wood waste disposed of and landfilled for the period 1990–2005.

Table A3.6-3: Wood Waste Generated and Landfilled in Canada for 1990–2005

Year	Wood Waste Disposed of		Wood Waste Landfilled		Total
	Pulp & Paper	Solid Wood Industry	Pulp & Paper	Solid Wood Industry	
	<i>(bone dry tonnes)</i>				
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

CH₄ Generation Rate Constant (k)

The CH₄ generation rate constant *k* represents the first-order rate at which CH₄ 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).

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 USEPA (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. USEPA 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 A3.6-4 shows the mean annual precipitation and decay values assigned for each of the provincial landfill sites chosen by Levelton (1991).

Table A3.6-4: Mean Annual Precipitation and MSW Landfill k Value Estimates for Provincial Landfill Sites

Region	Mean Annual Precipitation (mm)	Kinetic Rate Constant k (/year)
Newfoundland and Labrador		
Carbonear	NA	NA
Corner Brook	1270.8	0.048
St. John's	1513.7	0.055
Average	1392.3	0.052
Prince Edward Island		
Charlottetown	1173.3	0.045
Summerside	1078.0	0.042
Average	1125.7	0.044
Nova Scotia		
Dartmouth	NA	NA
Halifax	1452.2	0.054
Lunenburg	NA	NA
New Glasgow	NA	NA
Sydney	1504.9	0.055
Truro	1202.1	0.046
Average	1386.4	0.056
New Brunswick		
Bathurst	1058.6	0.042
Campbellton	NA	NA
Edmundston	NA	NA
Fredericton	1143.3	0.044
Moncton	1143.5	0.044
Saint John	1390.3	0.052
Average	1184.0	0.046
Quebec		
Montréal	1064.6	0.042
Quebec	1230.3	0.047
Rimouski	915.0	0.037
Saint-Étienne	NA	NA
Saint Tite-des-Caps	NA	NA
St. Cecile	NA	NA
St. Sophie	NA	NA
Average	1070.0	0.042

Region	Mean Annual Precipitation (mm)	Kinetic Rate Constant k (/year)
Ontario		
Barrie	938.5	0.038
Belleville	891.6	0.037
Brantford	892.3	0.037
Brockville	983.4	0.040
Cornwall	1002.0	0.040
Guelph	923.2	0.038
Hamilton	910.1	0.037
Kingston	968.4	0.039
Kitchener	NA	NA
London	987.1	0.040
North Bay	1007.7	0.040
Oshawa	877.9	0.036
Ottawa-Hull	NA	NA
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
Average	902.0	0.037
Manitoba		
Brandon	472.0	0.024
Portage la Prairie	514.5	0.025
Thompson	517.4	0.026
Winnipeg	513.7	0.025
Average	504.4	0.025
Saskatchewan		
Moose Jaw	365.1	0.021
Prince Albert	424.3	0.023
Regina	388.1	0.022
Saskatoon	350.0	0.021
Swift Current	377.1	0.021
Yorkton	450.9	0.024
Average	392.6	0.022

Region	Mean Annual Precipitation (mm)	Kinetic Rate Constant k (/year)
Alberta		
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
Average	426.4	0.023
British Columbia		
Campbell River	1451.5	0.054
Chilliwack	1501.3	0.055
Courtney	NA	NA
Kamloops	305.1	0.019
Matsqui	NA	NA
Port Alberni	1910.7	0.067
Prince Rupert	2593.6	0.088
Vancouver	1199.0	0.046
Vernon	409.9	0.022
Victoria	883.3	0.036
Average	1280.7	0.048
Yukon		
Whitehorse	267.4	0.018
Average	267.4	0.018
Northwest Territories & Nunavut		
Yellowknife	280.7	0.018
Average	280.7	0.018

Note:

NA = Not available

MSW Landfills

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 A3.6-5.

Table A3.6-5: MSW Landfill k Value Estimates for Each Province

k Value											
NL	PE	NS	NB	QC	ON	MB	SK	AB	BC	YT	NT & NU
(/year)											
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 methane emissions recommended by the National Council for Air and Stream Improvement, Inc., a k value of 0.03/year was assumed to represent the methane generation rate constant for all of the wood waste landfills in Canada (NCASI, 2003).

CH₄ Generation Potential (L₀)

MSW Landfills

The CH₄ generation potential (L₀) represents the amount of CH₄ that could be theoretically produced per tonne of waste landfilled. The following equation, as presented in the IPCC Guidelines, is used to calculate the CH₄ generation potential for MSW landfills (IPCC/OECD/IEA, 1997):

Equation A3.6-4:

$$L_0 = MCF \times DOC \times DOC_F \times F \times \frac{16}{12} \times 1000 \frac{kgCH_4}{tCH_4}$$

where:

L ₀	=	CH ₄ generation potential, kg CH ₄ / t waste
MCF	=	CH ₄ correction factor, fraction
DOC	=	degradable organic carbon, t C/t waste
DOC _F	=	fraction of DOC dissimilated
F	=	fraction of CH ₄ in landfill gas
16/12	=	stoichiometric factor to convert CH ₄ to carbon

The CH₄ correction factor (MCF) accounts for the proportion of managed to unmanaged solid waste disposal sites. Unmanaged solid waste disposal sites produce less CH₄, 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 A3.6-6 (IPCC/OECD/IEA, 1997).

Table A3.6-6: Solid Waste Disposal Site CH₄ 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 CH₄ in landfill gas (F) ranges between 0.4 and 0.6. It can vary based on certain factors, including waste composition and potential air dilution effects that can lower the actual concentration of CH₄ in the landfill gas. The average value 0.5 is chosen for the fraction of CH₄ in landfill gas.

The fraction of degradable organic carbon dissimilated (DOC_F) represents the amount of organic carbon that is ultimately degraded and released from the solid waste disposal site. DOC_F accounts for the fact that some of the organic carbon does not degrade or degrades very slowly. The IPCC DOC_F default value for landfill sites excluding lignin is used in the calculation for the CH₄ generation potential (IPCC/OECD/IEA, 1997).

The fraction of degradable organic carbon (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 A3.6-5:

$$\% \text{ DOC (by wet weight)} = (0.4 \times A) + (0.17 \times B) + (0.15 \times C) + (0.3 \times D)$$

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

Provincial waste consumption data and CH₄ generation potentials for 1990–2003 are shown in Table A3.6-7 (Thompson *et al.*, 2006). For cases where audit data are not available, a default value of 117 kg/t of waste is used (ORTECH Corporation, 1994).

Table A3.6-7: Canadian CH₄ Generation Potential (L₀) Values Derived from Waste Audit Data for 1990–2003¹

Location	Paper and Textiles	Garden and Park Waste	Food Waste	Wood and Straw Waste	DOC	CH ₄ Generation Potential (L ₀) (kg/t of waste)
(% by wet weight)						
Vancouver, BC	40.6	17.5	11.7	0.3	21.2	108.8
AB	35.0	11.0	12.0	6.0	19.5	100.0
Regina, SK	33.2	17.0	30.7	NA	20.8	106.8
Winnipeg, MB	31.0	6.6	26.1	2.3	18.1	92.4
ON	27.0	13.0	25.0	2.9	17.6	90.3
QC	59.0	NA	2.7	2.9	24.9	127.8
NB	----	----	----	----	----	----
PE	----	----	----	----	----	----
NS	27.7	15.4	25.3	NA	17.5	89.8
NL	37.0	NA	30.0	NA	19.9	102.2
NT & NU	----	----	----	----	----	----
YT	----	----	----	----	----	----

Notes:

1 Data source: Thompson *et al.* (2006).

NA = Unavailable categorical information.

---- = Unavailable provincial data.

The L₀ from waste disposed prior to 1990, is derived from the amount of organic waste diverted per province (Statistics Canada, 2002). The 1990–2003 L₀ values are increased by the percentage currently diverted per province in order to calculate the 1941–1989 L₀ values. For cases where provincial diversion data are not available, a default value of 165 kg/t of waste is used (EPA, 1990). It is assumed that the same L₀ evaluated for 1990–2003 is valid for 2004 and 2005 since the waste diversion rates should not have changed significantly since the Thompson study.

Provincial waste consumption data and CH₄ generation potentials are shown in Table A3.6-8 (Thompson *et al.*, 2006).

Table A3.6-8: CH₄ Generation Potential (L₀) from 1941 to Present¹

Province/ Territory	2002 Organic Waste Diversion (%)	L ₀ Value Following 1990 (kg/t of waste)	L ₀ Value Prior to 1990 (kg/t of waste)
BC	23.3	108.8	134.1
AB	16.7	100.0	116.7
SK	4.3	106.8	111.3
MB	4.9	92.4	96.5
ON	16.4	90.3	105.1
QC	13.7	127.8	145.3
NB	19.8	117.0 ²	140.2
PE	NA	117.0 ²	165.0 ²
NS	29.7	89.8	116.5
NL	NA	102.2	165.0 ²
NT & NU	NA	117.0 ²	165.0 ²
YT	NA	117.0 ²	165.0 ²

Notes :

1 Data source: Thompson *et al.* (2006)

2 Default value.

NA = Unavailable categorical information.

Wood Waste Landfills

Equation A3.6-3, as presented in the IPCC Guidelines, is used to calculate the CH₄ 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 IPCC default value for the fraction of CH₄ in landfill gas (F) ranges between 0.4 and 0.6. The value 0.5 is chosen for the fraction of CH₄ in landfill gas.

The fraction of degradable organic carbon dissimilated (DOC_F) represents the amount of organic carbon that is ultimately degraded and released from the solid waste disposal sites. DOC_F accounts for the fact that some of the organic carbon does not degrade or degrades very slowly. The IPCC Guidelines provide 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 CH₄ generation potential to better represent the high lignin content in wood waste (IPCC/OECD/IEA, 1997).

The fraction of degradable organic carbon (DOC) represents the amount of organic carbon that is accessible to biochemical decomposition. Equation A3.6-4 is used to calculate the national wood waste DOC value, assuming 100% wood or straw composition (IPCC/OECD/IEA, 1997).

Based on these considerations, an L_0 of 80 kg CH_4/t of wood waste is calculated from Equation A3.6-3.

Captured Landfill Gas

At many large MSW landfill facilities, landfill gas is captured to be flared or utilized or both. Due to the relatively high concentration of CH_4 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_4 emissions from landfills, the amount of captured CH_4 is subtracted from the CH_4 generated as estimated by the Scholl Canyon model, and then this value is added to the portion of methane emitted from the flaring operation. Greenhouse gas emissions affiliated with the use of landfill gas for energy recovery will be accounted for in the Energy Sector. The net CH_4 emissions calculation is shown in the following equation:

Equation A3.6-6:

$$\text{CH}_{4(\text{NET})} = \text{CH}_{4(\text{generated})} - \text{CH}_{4(\text{captured})} + \text{CH}_{4(\text{emitted-F})}$$

where:

$\text{CH}_{4(\text{NET})}$	=	net CH_4 emissions from MSW landfills, t
$\text{CH}_{4(\text{generated})}$	=	CH_4 emissions generated from MSW landfills, t
$\text{CH}_{4(\text{captured})}$	=	CH_4 emissions captured from MSW landfills, t
$\text{CH}_{4(\text{emitted-F})}$	=	CH_4 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_4 emitted. This value is obtained from Table 2.4-3 of Chapter 2.4 of EPA AP 42 (EPA, 1995). The amount of CH_4 emitted from flaring of landfill gas is calculated as follows:

Equation A3.6-7:

$$\text{CH}_{4(\text{emitted-F})} = \text{CH}_{4(\text{flared})} * (1 - \text{Eff}_{(\text{flare-control})})$$

where:

$\text{CH}_{4(\text{emitted-F})}$	=	CH_4 emissions emitted from flaring of MSW CH_4 gas, t/year
$\text{CH}_{4(\text{flared})}$	=	CH_4 gas flared, t/year
$\text{Eff}_{(\text{flare-control})}$	=	flare emission control efficiency, fraction

The quantities of CH_4 gas collected from 1983 to 1996 were obtained from ad hoc surveys conducted by Environment Canada (Perkin, 1998), and for the years 1997 to 2003, were collected directly from individual landfill operators biennially by Environment Canada's National Office of Pollution Prevention (Environment Canada, 2003a). CH_4 gas capture data for 2005 was obtained through a study prepared for Environment Canada (Environment Canada, 2007). Since the CH_4 capture data are

collected every odd year, for the purposes of the national GHG inventory, the CH₄ capture data for the subsequent even years are averaged from the odd years from 1997. Table A3.6-9 shows the amount of CH₄ captured and flared from 1990 to 2005¹.

Table A3.6-9: Estimated MSW CH₄ Captured, Flared and Emitted for 1990–2005

Year	CH ₄ Generated	CH ₄ Captured	CH ₄ Flared	CH ₄ Emitted from Flare	CH ₄ Emitted
	(t)	(t)	(t)	(t)	(t)
1990	1 118 264	192 661	23 614	71	925 674
1991	1 142 990	195 641	27 175	82	947 430
1992	1 167 844	204 782	35 291	106	963 168
1993	1 192 678	209 390	44 461	133	983 422
1994	1 217 364	223 362	56 729	170	994 172
1995	1 241 757	243 442	69 355	208	998 523
1996	1 265 708	264 551	78 672	236	1 001 393
1997	1 289 044	267 803	81 001	243	1 021 484
1998	1 307 661	271 817	90 797	272	1 036 117
1999	1 327 893	275 830	100 593	302	1 052 365
2000	1 349 893	294 287	117 904	352	1 055 960
2001	1 370 981	312 743	135 214	406	1 058 643
2002	1 391 244	312 561	137 063	411	1 079 095
2003	1 412 476	312 378	139 342	418	1 100 516
2004	1 434 652	312 950	146 918	442	1 122 143
2005	1 457 118	313 523	154 493	463	1 144 058

Note:

- 1 The following LFG capture facilities did not provide data by February, 2007. Thus, data provided in the 2003 inventory was assumed to be held constant for the 2005 inventory: Highway 101 Landfill (N.S), Bestan inc. (QC), Eastview Road Landfill Site (ON), Aurora Landfill (ON), and Cottonwood Landfill (B.C).

A3.6.1.2 Data Sources

Waste disposal data are collected from a biennial waste survey conducted by Statistics Canada (2000, 2003, 2004a, 2007). 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 to 2003 were collected directly from individual landfill operators biennially by Environment Canada's National Office of Pollution Prevention (Environment Canada, 2003a). CH₄ gas capture data for 2005 was obtained through a study prepared for Environment Canada (Environment Canada, 2007).

A3.6.2 CH₄ Emissions from Wastewater Treatment

A3.6.2.1 Methodology

Municipal Wastewater Treatment

The IPCC default method for calculating CH₄ 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 CH₄ generation rate from the anaerobic decomposition of organic matter in wastewater is 0.22 kg CH₄/kg BOD₅ (the five-day biochemical oxygen demand), and the daily per capita BOD₅ loading rate is 0.050 kg BOD₅/person per day. Based on these two assumptions, it is estimated that 4.015 kg CH₄/person per year could potentially be emitted from anaerobically treated wastewater. The derivation of the CH₄ emission factor is shown below.

Equation A3.6-8:

$$\begin{aligned} \text{EF}_{\text{CH}_4} (\text{kg CH}_4/\text{capita per year}) &= (\text{per capita BOD}_5 \text{ loading rate}) \times (\text{CH}_4 \text{ generation rate}) \\ &= \left(\frac{0.05 \text{ kg BOD}_5}{\text{capita} \cdot \text{day}} \right) \times \left(365 \frac{\text{days}}{\text{Year}} \right) \times \left(0.22 \frac{\text{kg CH}_4}{\text{kg BOD}_5} \right) \\ &= \left(4.015 \frac{\text{kg CH}_4}{\text{capita} \cdot \text{Year}} \right) \end{aligned}$$

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, 2006). This method of estimation is consistent with the IPCC surrogate method (IPCC, 2000). The percentage of wastewater treated for 2000–2005 is estimated by applying a growth function to the 1983–1999 water use database values using the provincial populations for 1983–2005 (Statistics Canada, 2006). 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, 2006) and the fraction of wastewater that is anaerobically treated.

Equation A3.6-9:

$$CH_{4(x)} = EF_{CH_4} \times P_x \times \text{Frac}_{AN(x)}$$

where:

$CH_{4(x)}$	=	CH ₄ emissions from wastewater treatment for province x, t/year
EF_{CH_4}	=	CH ₄ emission factor for wastewater treatment, t/capita/year
P_x	=	population of province x
$\text{Frac}_{AN(x)}$	=	fraction of wastewater treated anaerobically for province x

CH₄ emissions are also calculated using the IPCC check method for CH₄ emissions from domestic wastewater treatment (IPCC, 2000). The check method calculation is shown below:

Equation A3.6-10:

$$WM = P \times D \times SBF \times EF \times FTA \times 365 \times 10^{-12}$$

where:

WM	=	annual CH ₄ emission per country, from domestic wastewater, Tg
P	=	population of country
D	=	organic load in biochemical oxygen demand per person, g BOD/person/day: 60 g BOD/person per day was used (Table 6.5 of the IPCC Guidelines; IPCC/OECD/IEA, 1997)
SBF	=	fraction of BOD that readily settles: default = 0.5
EF	=	emission factor, g CH ₄ /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 IPCC Guidelines method (IPCC, 2000). Canada falls into this category. However, due 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 A3.6-11:

$$FT_i = \sum_x \frac{\%AN_{x,i} \times P_{x,i}}{P_{tot,i}}$$

where:

FT_i	=	fraction of BOD in sludge that degrades anaerobically for year i
$\%AN_{x,i}$	=	percentage of the population served by anaerobic wastewater treatment for province x in year i
$P_{x,i}$	=	population of province x for year i
$P_{tot,i}$	=	population of Canada for year i

The difference in CH₄ 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 CH₄/g BOD. The emission factor used in the method developed by ORTECH Corporation (1994) (0.22 g CH₄/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 A3.6-10 shows the percentage of wastewater treated anaerobically (waste stabilization ponds) for 1983–2005. 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 A3.6-10: 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	100	46.4
1986	2.3	13.6	16.9	37.1	8.5	2.2	11.1	20.9	20.6	8.4	100	43.0
1989	3.8	11.2	9.6	41.5	13.0	3.1	11.2	19.7	13.4	8.8	100	83.7
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	7.5	34.9	17.2	3.0	9.7	21.9	0.0	6.1	99.5	93.2
2005	42.0	10.6	7.4	34.9	17.7	3.1	9.6	21.9	0.0	5.9	99.6	94.1

Industrial Wastewater Treatment

A top-down modified IPCC Guidelines approach, as described in Figure 5.4 of the IPCC Good Practice Guidance, (IPCC, 2000), is used for the calculation of CH₄ emissions from industrial wastewater handling. CH₄ from Industrial wastewater is not currently a key source category, thus, “Box 1” of the decision tree in Figure 5.4 is the chosen methodology for calculation of CH₄ emissions.

The IPCC default value of 0.25 kg CH₄/kg COD (chemical oxygen demand) is used in the estimation of CH₄ 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, 1996). The volume of industrial wastewater treated for 1997–2005 is forecasted by applying a growth function to the 1986, 1991, and 1996 water use database 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 (1986, 1991, and 1996) and the forecasted data (1997–2005). 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 A3.6-11 shows the polynomial coefficients generated by the multiple linear regression method for each of the industry groups.

Table A3.6-11: Multiple Linear Regression Polynomial Coefficients Used in Estimating the Amount of Industrial Wastewater Treated for 1987–1990 and 1992–1995

	C	C ₁	C ₂	C ₃	C ₄	C ₅	C ₆
Food	5.05E+07	0	0	0	-4.75E-05	3.80E-08	-7.93E-12
Beverages	-4.11E+06	0	0	0	3.86E-06	-3.09E-09	6.43E-13
Rubber Products	1.02E+06	0	0	0	-9.58E-07	7.67E-10	-1.60E-13
Plastic Products	2.50E+05	0	0	0	-2.35E-07	1.88E-10	-3.92E-14
Total Textiles	-1.73E+07	0	0	0	1.64E-05	-1.31E-08	2.74E-12
Paper & Allied Products	-7.56E+07	0	0	0	7.17E-05	-5.76E-08	1.20E-11
Petroleum & Coal Products	-5.54E+06	0	0	0	5.23E-06	-4.19E-09	8.75E-13
Chemical Products	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 A3.6-12:

$$V_X = (C_6 * X^6) + (C_5 * X^5) + (C_4 * X^4) + (C_3 * X^3) + (C_2 * X^2) + (C_1 * X) + C$$

where:

V_X	=	volume of industrial wastewater treated in year X, million cubic metres
C_i	=	coefficient of the i th order
X	=	year of interest

Table A3.6-12 shows the amount of industrial wastewater treated per industry group for 1986–2005.

Table A3.6-12: Volume of Wastewater Treated per Industry Type for 1986–2005

Year	Volume of Wastewater Treated							
	Food	Beverages	Rubber Products	Plastic Products	Total Textile	Paper & Allied Products	Petroleum & Coal Products	Chemicals & Chemical Products
<i>(million cubic metres)</i>								
1986	352	15	5	7	25	2286	33	208
1987	295.3	20.1	4.2	6.7	36.2	2287.0	36.7	199.0
1988	251.0	24.4	3.6	6.5	42.5	2260.2	38.8	194.9
1989	214.6	28.0	3.2	6.3	46.6	2226.3	40.2	192.8
1990	185.2	30.9	3.0	6.2	48.8	2186.5	40.9	192.6
1991	147.5	33.9	2.3	6	58.3	2214.3	44	183.9
1992	144.8	35.3	2.8	6.0	48.2	2093.6	40.8	196.5
1993	132.3	36.8	2.8	5.9	46.1	2042.8	40.0	200.2
1994	123.9	37.9	2.9	5.9	43.0	1990.5	39.0	204.9
1995	118.9	38.7	3.1	5.9	39.2	1938.0	37.7	210.1
1996	128.6	38.4	3.6	5.9	28.3	1847.5	34.4	220.9
1997	125.1	39.4	3.9	5.9	24.5	1781.8	32.7	229.1
1998	121.7	39.8	4.1	5.9	23.1	1756.2	32.1	232.5
1999	118.4	40.0	4.2	5.9	22.3	1741.0	31.7	234.6
2000	115.2	40.2	4.2	5.9	21.7	1728.9	31.4	236.2
2001	112.1	40.4	4.3	5.9	21.1	1716.9	31.1	237.9
2002	109.1	40.6	4.4	5.9	20.4	1702.6	30.8	239.9
2003	106.1	40.9	4.5	5.8	19.5	1682.9	30.3	242.8
2004	103.3	41.5	4.7	5.8	18.1	1651.7	29.5	247.4
2005	100.5	42.4	5.2	5.8	15.8	1597.0	28.2	256.0

CH₄ 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 CH₄/kg COD (IPCC, 2000) and the fraction of wastewater that was treated anaerobically. Although one slaughterhouse in Quebec reported to employ anaerobic digestion, where the collected biogas was combusted for energy generation purposes, it is assumed that there is no anaerobic treatment of industrial wastewater in Canada based on communications with the Ministère de l'Environnement du Québec and the British Columbia Ministry of Environment (Hicke, 2006; F. Flynn, Service de l'assainissement

des eaux, Direction des politiques du secteur industriel, Ministère de l'Environnement du Québec, personal communication, March 2006). 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 A3.6-12 are selected from the total group of industry waste streams provided in the Environment Canada report (Environment Canada, 1986, 1991, 1996) due to the availability of COD values for a select number of industry groups (IPCC, 2000). Table A3.6-13 shows the industry sectors included within the Environment Canada surveys (Environment Canada, 1986, 1991, and 1996) and the corresponding IPCC default COD values that are chosen to represent the industry sectors (IPCC, 2000).

Table A3.6-13: COD Values Used in CH₄ Emission Estimates per Industry Type

Industry Group (Environment Canada, 1986, 1991, 1996)	IPCC Industry Type (IPCC, 2000)	IPCC Degradable Organic Component – COD (IPCC, 2000) (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

Note:

N/A = Not available

CH₄ emissions for industrial wastewater treatment are calculated on a national level as follows:

Equation A3.6-13:

$$CH_{4(IndustryType)} = V_{(IndustryType)} \times COD_{(IndustryType)} \times EF_{CH_4} \times Frac_{(Anaerobic)}$$

where:

CH _{4(IndustryType)}	=	CH ₄ emissions generated per industry type, t/year
V _(IndustryType)	=	volume of wastewater treated, L/year
COD _(IndustryType)	=	chemical oxygen demand per industry type, kg/L
EF _{CH₄}	=	CH ₄ emission factor: IPCC default value = 0.00025 t CH ₄ /kg COD
Frac _(Anaerobic)	=	fraction of anaerobically treated wastewater

A3.6.2.2 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 year's 1986, 1991, and 1996 (Environment Canada, 1986, 1991 and 1996).

A3.6.3 N₂O Emissions from Wastewater Treatment

A3.6.3.1 Methodology

The N₂O 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 N₂O-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), as shown in Table A3.6-14. Data is provided for the years 1991, 1996, and 2001 to 2005. Protein consumption data for missing years is estimated by applying a multiple linear regression application to the Statistics Canada data.

Table A3.6-14: Canadian Protein Consumption

Year	Protein Consumption (g/capita/day)
1990	70.26
1991 ¹	68.48
1992	70.77
1993	71.06
1994	71.37
1995	71.70
1996 ¹	71.22
1997	72.41
1998	72.79
1999	73.17
2000	73.57
2001 ¹	75.94
2002 ¹	75.44
2003 ¹	74.43
2004 ¹	75.10
2005 ¹	74.47

Note:

1 Data Source: Statistics Canada (2005). The data have been adjusted for retail, household, cooking and plate loss

An emission factor is calculated as follows:

Equation A3.6-14:

$$EF_{N_2O} = PC \times EF_{N_2O-N} \times \text{Frac}_{NPR} \times \frac{44}{28}$$

Emissions are calculated by multiplying the emission factor by the population of the respective provinces (Statistics Canada, 2006).

Equation A3.6-15:

$$N_2O_s = EF_{N_2O} \times NR_{PEOPLE}$$

where:

EF_{N_2O}	=	emission factor: kg N ₂ O/capita/year
PC	=	annual per capita protein consumption kg/capita/ year (Statistics Canada, 2005)
EF_{N_2O-N}	=	emission factor: default 0.01 (0.002–0.12) kg N ₂ O-N/kg sewage nitrogen Produced
Frac_{NPR}	=	fraction of nitrogen in protein: default = 0.16 kg N/kg protein
44/28	=	stoichiometric factor to convert nitrogen to N ₂ O..
$N_2O_{(s)}$	=	N ₂ O emissions from human sewage, kg N ₂ O/year
NR_{PEOPLE}	=	number of people in country

A3.6.3.2 *Data Sources*

The Canadian protein consumption is obtained from the annual food statistics publication (Statistics Canada, 2005).

The provincial populations are obtained from the annual demographic statistics catalogue No. 91-213-XIB (Statistics Canada, 2006).

A3.6.4 **CO₂ Emissions from Municipal Waste Incineration**

A3.6.4.1 *Methodology*

The IPCC decision tree in Figure 5.5 for CO₂ emissions from waste incineration defines good practice in adapting the methods in the IPCC Guidelines (IPCC, 2000). Country-specific carbon contents are not available, thus, “Box 2” of the decision tree in Figure 5.5 is the chosen methodology for calculation of CO₂ emissions.

The following steps detail the methodology for the estimation of CO₂ emissions from waste incineration.

1. *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, 1996). The amount of MSW incinerated for the years 1999, 2000, and 2001 was estimated based on a study 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 2002-2005, a trend extrapolation using the A.J. Chandler & Associates Ltd. and Environment Canada MSW incineration values for all relevant provinces except for Quebec and Ontario where only the former is used. In the province of Ontario, there was a closure of one of the incineration plants at the end of 2001. Therefore, the amount of waste incinerated in Ontario for the period 2002–2005 is estimated by trending the A.J. Chandler & Associates Ltd. incineration values for 1999–2001 with population (Statistics Canada, 2006), assuming that the Ontario incineration plant was closed for this period.

MSW incineration estimates for the period 1990–2005 are shown in Table A3.6-15.

Table A3.6-15: Estimated MSW Incinerated (by Province) for 1990–2005

Year	MSW Incinerated					
	NL	PE	NS	QC	ON	BC
			(t)			
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	¹ 165,943	251,783
2003	0	32,859	40,218	311,118	¹ 180,165	251,408
2004	0	33,121	39,044	314,660	¹ 193,507	250,956
2005	0	33,239	38,675	317,982	¹ 205,611	250,452

Note:

1 Ontario incineration plant closed as of 2001 year end.

2. *Developing Emission Factors*: Provincial CO₂ emission factors are developed based on a study performed by the Hazardous Waste Branch of Environment Canada (Environment Canada, 1996). The CO₂ emission factors are founded on the assumption that carbon contained in waste undergoes complete oxidation to CO₂.

The provincial breakdown in the type of waste incinerated for 1992 was estimated by the Hazardous Waste Branch of Environment Canada (Environment Canada, 1996). The quantity of waste incinerated was divided into three categories: paper, plastics and organics. Consistent with the IPCC Guidelines, only CO₂ 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 emissions 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; Environment Canada, 1995a; Environment Canada, 1995b). Table A3.6-16 shows the averaged breakdown in organic composition.

Table A3.6-16: 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 A3.6-16:

$$WasteType_{Fossil-Origin} = M_{Total} \times (1 - \%Organic_{comp})$$

where:

$WasteType_{Fossil-Origin}$	=	amount of fossil fuel based waste incinerated, t (1992 data provided by Environment Canada)
M_{Total}	=	amount of waste incinerated, t (1992 data provided by Environment Canada)
$\%Organic_{Comp}$	=	% organic composition per waste type (Environment Canada, 1994; Environment Canada, 1995a; Environment Canada, 1995b)

The amount of fossil fuel-based carbon is converted to tonnes of CO₂ per tonne of waste by multiplying by the ratio of the molecular mass of CO₂ to that of carbon. The derivation of the CO₂ emission factor is shown in the following equations:

Equation A3.6-17:

$$C_{Avail(y)} = (WasteType_{Fossil-Origin}) \times (1 - \%Moisture) \times \%C_{wastetype}$$

where:

$C_{Avail(y)}$	=	available carbon per waste type for province y, t
$WasteType_{Fossil-Origin}$	=	amount of fossil fuel based waste incinerated, t (1992 data provided by Environment Canada)
$\%Moisture$	=	% moisture content per waste type (Tchobanoglous et al., 1993)
$\%C_{Waste Type}$	=	% Carbon content per waste type (dry basis) (Tchobanoglous et al., 1993)

Equation A3.6-18:

$$EF_{CO_2-1992(y)} = \left(\frac{\sum C_{avail(y)}}{M_{Inc(y)}} \right) \times \frac{44}{12}$$

where:

$EF_{CO_2-1992(y)}$	=	1992 CO ₂ emission factor for incineration for province y, t CO ₂ /t waste incinerated
$C_{Avail(y)}$	=	available carbon per waste type for province y, t
$M_{Inc(y)}$	=	total mass waste incinerated in 1992 for province y, t
44/12	=	stoichimetric factor to convert carbon to CO ₂ .

3. *Calculating CO₂ Emissions*: Emissions were calculated on a provincial level by multiplying the amount of waste incinerated by the appropriate emission factors.

Equation A3.6-19:

$$CO_{2(x)} = EF_{CO_2-1992} \times (M_{Inc(x)/ province})$$

where:

$CO_{2(x)}$	=	CO ₂ emissions from waste incineration in year x, t/province/year
EF_{CO_2-1992}	=	1992 provincial CO ₂ emission factor for incineration, t CO ₂ /t incinerated
$M_{Inc(x)}$	=	mass waste incinerated per province in year x, t/year

A3.6.4.2 Data Sources

The amount of MSW incinerated in the year 1992 was estimated by the Hazardous Waste Branch of Environment Canada (Environment Canada, 1996). 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, 2003c).

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).

A3.6.5 N₂O Emissions from Waste Incineration**A3.6.5.1 Methodology****Municipal Solid Waste Incineration**

Emissions of N₂O from MSW incineration are estimated using the assumption that the IPCC five stokers facility factors are most representative. The average N₂O emission factor over the range given as IPCC default values for MSW five stokers 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 A3.6-20:

$$N_2O_{MSW} = M_{MSW} \times EF_{N_2O-MSW}$$

where:

N_2O_{MSW}	=	N_2O emissions from municipal solid waste incineration, t/year
M_{MSW}	=	mass of municipal solid waste incinerated, t/year
EF_{N_2O-MSW}	=	MSW N_2O emission factor (0.148 kg N_2O /t MSW incinerated / 1000 kg/t)

Sewage Sludge Incineration

Emissions of N_2O from sewage sludge incineration are estimated using the IPCC default emission factor for fluidized beds, 0.8 kg/t of dry 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 A3.6-21:

$$N_2O_{SS} = M_{SS} \times EF_{N_2O-SS}$$

where:

N_2O_{SS}	=	N_2O emissions from sewage sludge incineration, t/year
M_{SS}	=	mass of dry sewage sludge incinerated, t/year
EF_{N_2O-SS}	=	sewage sludge N_2O emission factor (0.8 kg N_2O /t dry sludge incinerated / 1000 kg/t)

A3.6.5.2 Data Sources

Data sources for MSW incineration are described in section A.3.6.4.2.

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, 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 by A.J. Chandler & Associates Ltd. for Environment Canada (Environment Canada, 2003c).

A3.6.6 CH₄ Emissions from Waste Incineration

A3.6.6.1 Methodology

CH₄ emissions from the incineration of MSW are assumed to be negligible. However, waste incineration of the biosolids resulting from municipal wastewater treatment does produce CH₄ emissions. The IPCC does not provide a methodology for CH₄ emissions from waste incineration, but recommends that national experts use existing published methods (IPCC, 2000).

Emissions of CH₄ 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.

CH₄ emissions from sewage sludge incineration are dependent on the amount of dried solids incinerated. To calculate the CH₄ 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 (W. Fettes, 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 2002–2005, 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 1990–2005 are shown in Table A3.6-17.

Table A3.6-17: Estimated Sewage Sludge Incinerated for 1990–2005

Year	Sewage Sludge Incinerated				National Total
	QC	ON	SK	AB	
	<i>(t, dry basis)</i>				
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 ¹	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

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, due 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 land applied. 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.

CH₄ emissions are calculated as follows:

Equation A3.6-22:

$$CH_{4(s)} = S_{Inc} \times EF_{CH_4-FB}$$

where:

CH _{4(s)}	=	CH ₄ emissions from waste incineration, t/year
S _{Inc}	=	sewage sludge incinerated, dry t/year
EF _{CH₄-FB}	=	CH ₄ emission factor for fluidized bed incinerators: 1.6 t CH ₄ /kt sewage sludge incinerated / 1000 kg/t

A3.6.6.2 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, 1994, personal communication). 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 by A.J. Chandler & Associates Ltd. for Environment Canada (Environment Canada, 2003c).

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Annex 4 Comparison of Sectoral and Reference Approaches

This annex covers the results of the Reference Approach (RA) to estimating Canada's CO₂ emissions, a comparison of its results to those estimated by the Sectoral Approach, and the methodology of the RA. The relevant information on the national energy balance, which is the main data source for both the RA and SA methods, is also covered.

A4.1 Comparison of Reference Approach to Sectoral Approach

Results from the RA were compared with the SA as a check of combustion-related emissions. The check was performed for all years from 1990 to 2005 and is an integral part of reporting to the UNFCCC.

In the CRF reporting software, the RA is directly compared with the SA's fuel combustion total. This comparison produces a significant discrepancy, since the SA total for combustion does not include fossil fuel-derived CO₂ from flaring activities, industrial processes, and non-energy use of fossil fuels. This can be seen in Table A4-1. When the RA and SA are directly compared, there is a 3.1–10.9% variation in kt CO₂ eq emissions and 8.4–13.1% variation in energy (PJ) of fuel consumed, with the RA values being consistently higher than the SA values. This comparison can be seen in Table A4-1. To ensure that energy information is comparable, the apparent energy consumption output should exclude non-energy fuel use and feedstock (as presented in CRF Table 1.A.(c) Comparison of CO₂ Emissions from Fuel Combustion) for it to be comparable with the energy consumption from the SA.

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 industrial processes, while CO₂ emissions resulting from non-energy use of fossil fuels in the oil and gas industries (e.g., natural gas used for flaring or hydrogen production) are reported in the Fugitive Emissions from Oil and Natural Gas tables of the CRF. Due to these discrepancies, the predefined comparison of emissions used in the CRF reporting Table 1.A.(c) is not appropriate for Canada, since emissions comparison between the reference approach and the sectoral approach are not comparing similar emission sources. However, this can be rectified by incorporating the non-combustion emissions into the comparison.

The Canadian reporting procedure does follow the IPCC Guidelines (IPCC/OECD/IEA, 1997). When the RA energy amount is corrected to exclude non-energy feedstock use of fuels, the variation between the sectoral and adjusted RA varies between –1.7 and +3.0%. Correcting the RA for emissions by subtracting the industrial process and fugitive emissions calculated for comparison with the SA, the totals match within –3.3% to +4.5%. 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
Energy - PJ																
Reference Approach Value	7,378	7,121	7,343	7,339	7,585	7,724	8,002	8,152	8,273	8,479	8,758	8,801	8,866	9,234	9,275	9,226
Sectoral Approach Value	6,523	6,396	6,632	6,638	6,854	7,022	7,209	7,345	7,467	7,722	8,077	7,948	8,116	8,478	8,320	8,337
Difference	13.1%	11.3%	10.7%	10.6%	10.7%	10.0%	11.0%	11.0%	10.8%	9.8%	8.4%	10.7%	9.2%	8.9%	11.5%	10.7%
Adjusted Reference Approach Excluding Non-Energy Use and Feedstocks	6,720	6,458	6,660	6,619	6,857	6,968	7,205	7,318	7,465	7,657	7,986	7,955	7,981	8,347	8,264	8,266
Adjusted Difference	3.0%	1.0%	0.4%	-0.3%	0.0%	-0.8%	-0.1%	-0.4%	0.0%	-0.8%	-1.1%	0.1%	-1.7%	-1.6%	-0.7%	-0.9%
Emissions - kt CO₂eq																
Reference Approach Value	463,422	444,545	455,689	448,561	464,290	468,901	482,192	490,372	497,970	508,294	526,994	529,314	528,115	553,055	548,838	548,916
Sectoral Approach Value	417,796	408,239	421,640	418,587	431,231	442,668	454,008	465,164	472,242	488,301	510,952	505,084	512,400	532,043	526,440	527,752
Difference	10.9%	8.9%	8.1%	7.2%	7.7%	5.9%	6.2%	5.4%	5.4%	4.1%	3.1%	4.8%	3.1%	3.9%	4.3%	4.0%
Non-energy Use and Feedstock Emissions																
Ammonia Production	3,924	3,869	4,154	4,497	4,463	5,300	5,389	5,167	5,237	5,269	5,309	5,011	4,719	5,038	5,477	5,002
Iron and Steel Production	7,060	8,317	8,502	8,184	7,539	7,884	7,747	7,552	7,688	7,893	7,896	7,282	7,116	7,044	8,164	7,010
Aluminium Production	2,715	3,147	3,273	3,908	3,771	3,643	3,863	3,929	3,977	3,949	3,899	4,202	4,419	4,581	4,224	4,842
Other & Undifferentiated Production	8,317	8,728	8,210	8,252	8,969	8,707	9,633	9,972	9,191	9,667	9,697	10,144	9,911	10,903	13,000	12,613
Hydrogen Production from Refineries	526	787	805	800	383	402	744	764	621	355	869	1,006	1,030	1,145	973	1,085
Fugitive Flaring	4,352	4,214	4,309	4,623	4,723	4,988	5,296	5,491	6,994	5,260	5,341	4,926	5,360	5,542	5,366	5,404
Total Non-Energy Use of Fuel and Feedstock	26,894	29,063	29,253	30,266	29,848	30,924	32,672	32,874	33,708	32,394	33,011	32,570	32,555	34,252	37,204	35,955
Adjusted Reference Approach Excluding Non-Energy Use and Feedstocks	436,528	415,482	426,436	418,295	434,442	437,977	449,520	457,498	464,263	475,900	493,982	496,744	495,560	518,803	511,634	512,961
Sectoral Approach Value	417,796	408,239	421,640	418,587	431,231	442,668	454,008	465,164	472,242	488,301	510,952	505,084	512,400	532,043	526,440	527,752
Adjusted Difference	4.5%	1.8%	1.1%	-0.1%	0.7%	-1.1%	-1.0%	-1.6%	-1.7%	-2.5%	-3.3%	-1.7%	-3.3%	-2.5%	-2.8%	-2.8%

Energy conversion factors used to convert fossil fuel data in physical units to common energy units (PJ) and from Higher Heating Value (HHV) to Lower Heating Value (LHV) will also have an impact on the comparison of energy and emission information between the two approaches. In Canada, like the United States, HHV is used to record the energy content of fuels, and this has been used for energy data reporting in the CRF for the RA and SA. Canada developed country-specific higher heating energy conversion and carbon emission factors for the majority of the fossil fuels except for crude oil, lubricants, solid biomass, and liquid biomass, where default IPCC carbon emission factors were used along with the OECD's conversion factor of 95% for solid and liquid fuels LHV to HHV.

To elaborate on the method of developing HHV conversion factors, a table has been included (Table A4-2) to illustrate the method and data sources used for the reference approach. The energy conversion factors are taken directly from Statistics Canada *Annual Report on Energy Supply and Demand Catalogue #57-003(RES)*, with the exception of NGLs, LPG, gasoline, gas/diesel oil, natural gas, petroleum coke, still gas, and other bituminous coal, where the factors are based upon the proportion of their components.

Table A4-2: Reference Approach Conversion Factors for Canada

Fuel Types			Energy Conversion factor - GHV			Carbon emission factor - GHV (t C/TJ)		
			2005 Value	Unit	Reference	2005 Value	Derivation	Reference
Liquid Fossil	Primary Fuels	Crude Oil	39.28	TJ/ML	Ref. 4	19.00	20.00 x 95%	Ref. 1
		Orimulsion	N/A	-	-	N/A	-	-
		Natural Gas Liquids	20.85 ¹	TJ/ML	Ref. 4	16.07 ¹	-	Ref. 2
	Secondary Fuels	Gasoline	35.00 ²	TJ/ML	Ref. 4	18.36 ²	-	Ref. 3
		Jet Kerosene	37.40	TJ/ML	Ref. 4	19.32	-	Ref. 3
		Other Kerosene	37.68	TJ/ML	Ref. 4	18.45	-	Ref. 3
		Shale Oil	N/A	-	-	N/A	-	-
		Gas/Diesel Oil	38.37 ³	TJ/ML	Ref. 4	19.53 ³	-	Ref. 3
		Residual Fuel Oil	42.50	TJ/ML	Ref. 4	20.18	-	Ref. 3
		LPG	26.38 ⁴	TJ/ML	Ref. 4	16.48 ⁴	-	Ref. 2
		Ethane	17.22	TJ/ML	Ref. 4	15.61	-	Ref. 2
		Naphtha	35.17	TJ/ML	Ref. 4	19.33	-	Ref. 3
		Bitumen	44.46	TJ/ML	Ref. 4	20.90	22.00 x 95%	Ref. 1
		Lubricants	39.16	TJ/ML	Ref. 4	19.66	-	Ref. 3
		Petroleum Coke	45.35 ⁵	TJ/ML	Ref. 4	22.36	-	Ref. 2
		Refinery Feedstocks	35.17	TJ/ML	Ref. 4	19.33	-	Ref. 3
		Still Gas	37.97 ⁶	TJ/GL	Ref. 4	13.30	-	Ref. 3
		Other Oil	39.82	TJ/ML	Ref. 4	19.84	-	Ref. 3
Solid Fossil	Primary Fuels	Anthracite	27.70	TJ/kt	Ref. 4	23.50	-	Ref. 2
		Coking Coal	N/A	-	-	N/A	-	-
		Other Bituminous Coal	29.18 ⁷	TJ/kt	Ref. 4	21.85 ⁵	-	Ref. 2
		Sub-Bituminous Coal	19.15	TJ/kt	Ref. 4	24.68	-	Ref. 2
		Lignite	15.00	TJ/kt	Ref. 4	25.73	-	Ref. 2
		Oil Shale	N/A	-	-	N/A	-	-
		Peat	N/A	-	-	N/A	-	-
	Secondary Fuels	BKB & Patent Fuel	N/A	-	-	N/A	-	-
		Coke	28.83	TJ/kt	Ref. 4	23.46	-	Ref. 3
Gaseous Fossil		Natural Gas	38.21 ⁸	TJ/GL	Ref. 4	13.86 ⁶	-	Ref. 2
Biomass		Solid Biomass	16.77 ⁹	TJ/kt	Ref. 4	25.51 ⁷	29.90 x 95%	Ref. 1
		Liquid Biomass	24.12	TJ/kt	Ref. 5	17.06	-	Ref. 5
		Gas Biomass	N/A	-	-	N/A	-	-

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_key.html.

Notes:

- 1 Composite value is based on proportions of propane, butane, and ethane in Canada for the specific inventory year.
 - 2 Composite value is based on proportions of motor gasoline and aviation gasoline in Canada for the specific inventory year.
 - 3 Composite value is based on proportions of diesel fuel oil and light fuel oil in Canada for the specific inventory year.
 - 4 Composite value is based on proportions of refinery propane and butane in Canada for the specific inventory year.
 - 5 Composite value is based on proportions of refinery petroleum coke and upgrader petroleum coke
 - 6 Composite value is based on proportions of refinery still gas and upgrader still gas
 - 7 Composite value is based on provincial (domestic and imported) proportions for the specific inventory year.
 - 8 Composite value is based on proportions of marketable natural gas and producer-consumed gas.
 - 9 Composite value is based upon IPCC default values for solid and liquid biomass.
- N/A = Not applicable; BKB = Charcoal briquettes

A4.2 Reference Approach Methodology

The RA for the most part follows the IPCC-designated method with the use of HHVs. In Canada, like the United States, HHV is used to record the energy content of fuels. Fuel quantities are recorded from the RESD and entered in their physical units (typically megalitres, thousands of cubic metres, kilotonnes, etc.) with the exception of international bunkers. The data for international bunkers is determined by the Transportation Group within the GHG Division of Environment Canada. For primary fuels (crude oil, natural gas liquids, all coal, and natural gas) the production data is adjusted to account for any imports, exports, international bunkers, stock variation, and other adjustments to determine the apparent consumption of the fuel. The apparent consumption of the 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 three sources: the RESD; *Canada's Greenhouse Gas Emissions: Estimates for 1990* (Jaques, 1992); the *1998 Fossil Fuel and Derivative Factors* (McCann, 2000), and Measurement Canada. Emission factors and oxidation percentages for liquid fuels are from Jaques (1992). Factors for coal and natural gas fuels are from McCann (2000), with the use of default IPCC oxidation fractions. Some of the carbon emission factors take oxidation fractions into consideration. In these cases, the oxidation rate in the CRF table for the RA has been listed as 1 so as not to double-count the oxidation fractions.

When necessary, the carbon emission factors (t C/TJ) are derived using the IPCC default (IPCC/OECD/IEA, 1997) and LHVs that are converted to HHVs using the OECD conversion factor of 95% for solid and liquid fuels. The IPCC default was used in the case of crude oil, bitumen (asphalt), and solid biomass. The carbon emission factor and energy content for liquid biomass is from Measurement Canada.

To adjust the RA for comparison with the SA, the stored carbon value must be calculated. The stored carbon is calculated for the following fuels: propane; ethane; butane; naphtha; bitumen; lubricants; natural gas; other products; refinery feedstocks; NGLs; and LPGs. The stored carbon amounts are subtracted from the appropriate fuel and the remaining carbon for that fuel is then used to determine the adjusted CO₂ emissions. The fuels used in the RA are listed below with specific details for that fuel type.

A4.2.1 Crude Oil

The crude oil used in the RA includes pentanes plus, condensate, crude bitumen, and synthetic crude, as well as conventional crude.

A4.2.2 Natural Gas Liquids (NGLs)

NGLs are accommodated by representing them as a virtual composite mixture of ethane, propane, and butane. The energy conversion factor (TJ/unit) and the carbon emission factor (t C/TJ) are dependent on the annual proportions of each fuel and are generated for each year based on those data.

A4.2.3 Gasoline

This category is a combination of motor gasoline and aviation gasoline, with the former dominating the total. The energy conversion factor and carbon emission factor are based on the proportions of each fuel for each year and have been weighted accordingly.

A4.2.4 Gas/Diesel Oil

Gas/diesel oil includes diesel fuel oil and light fuel oil. A weighted average carbon emission factor and energy conversion factor have been calculated for each year to accommodate the differences in annual consumption levels of these two fuels and their different energy and carbon contents.

A4.2.5 Other Kerosene

Other kerosene includes kerosene and stove oil. A weighted average carbon emission factor and energy conversion factor have been calculated for each year to accommodate the differences in annual consumption levels of these two fuels and their different energy and carbon contents.

A4.2.6 Jet Kerosene

Jet kerosene includes aviation turbo fuel. A weighted average carbon emission factor and energy conversion factor have been calculated for each year to accommodate the differences in annual consumption levels of these two fuels and their different energy and carbon contents. Fuel from international bunkers has been removed.

A4.2.7 Coke Oven Gas and Coal Coke

Coke oven gas and coal coke are produced from coal. There is no apparent consumption of coke oven gas; therefore, this section only includes emissions from the consumption of coal coke.

A4.2.8 Petroleum Coke

Petroleum coke includes petroleum coke from upgraders and refineries. A weighted energy conversion factor and carbon emission factor were developed for petroleum coke to take this into consideration. As the factors are dependant upon annual consumption amounts, the factors are calculated for each year.

A4.2.9 Liquefied Petroleum Gas (LPG)

LPG is accommodated by representing it as a virtual composite mixture of propane and butane produced by the refineries. The energy conversion factor (TJ/unit) and carbon emission factor (t C/TJ) are dependent upon the annual consumption proportions; therefore, these factors are calculated for each year.

A4.2.10 Bitumen

All calculations are made using default IPCC values for the carbon emission factors and RESD energy conversion factor.

A4.2.11 Other Oils

This category includes stored carbon due to other products from Table 1-A(d) of the CRF. According to Statistics Canada, other products includes: waxes; paraffin; and unfinished products.

A4.2.12 Other Bituminous and Sub-Bituminous Coal

Other bituminous represents both Canadian bituminous and imported bituminous. The carbon and energy contents of Canadian bituminous vary by province. Factors for imported bituminous also vary depending on where the bituminous coal has been mined. The energy conversion factor and carbon emission factor have been weighted according to the provincial bituminous coal consumption values and their associated carbon and energy content values.

Sub-bituminous coal is both imported and produced domestically. The energy conversion factor and carbon emission factor are the same for both imported and domestic sub-bituminous coal.

A4.2.13 Natural Gas

There are two types of natural gas consumed in Canada: marketable natural gas and producer consumed natural gas. Marketable natural gas and producer-consumed natural

gas have different energy and carbon contents. The energy conversion factor and carbon emission factor for natural gas have been generated to take this into consideration. The production includes marketable (for commercial sales) production plus field flared and waste, gathering uses, and plant uses. The last three items are shown as producer consumption.

A4.2.14 Biomass

Solid biomass includes Canadian industrial and residential wood combustion and spent pulping liquor combustion. For solid biomass, all calculations are made using default IPCC values for the carbon emission factors. The energy content has been weighted to take into consideration the different energy contents of solid wood and spent pulping liquor. This is updated on an annual basis to take the annual consumption of both fuels into consideration.

Liquid biomass includes ethanol used in the transportation sector. Both the energy conversion factor and carbon emission factor are country-specific and provided by Measurement Canada.

A4.3 National Energy Balance

Canada's statistical agency, Statistics Canada, provides Environment Canada with a large portion of the underlying activity data to estimate greenhouse gas emissions for the Energy and the Industrial Processes sector. 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*' (*RESD*). 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 (IMDB).

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 census from industry, federal agencies (such as the National Energy Board and Alberta Energy Utilities Board), from 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 *Alberta Energy Utilities Boards* is highly accurate since it is tied to oil and gas exploitation permits and through federal and provincial royalty schemes.

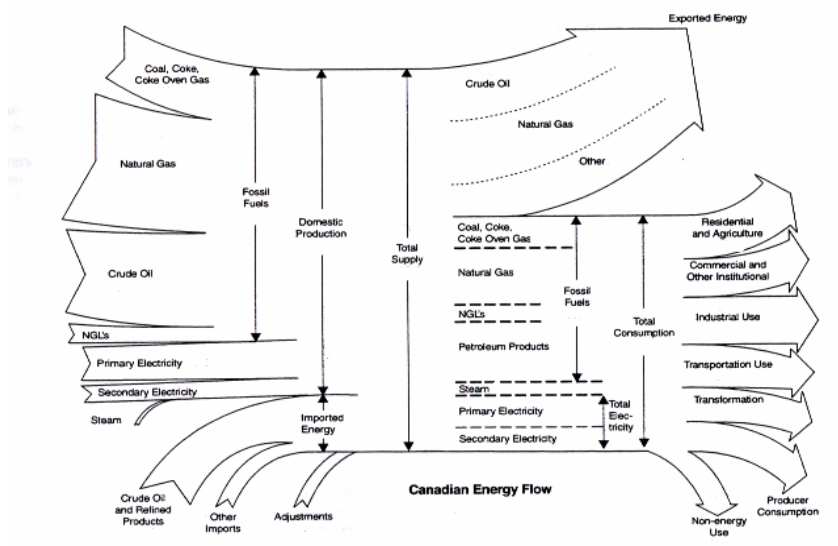


Figure A4-1: Sample of an Energy Balance Flow Diagram for Canada

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.

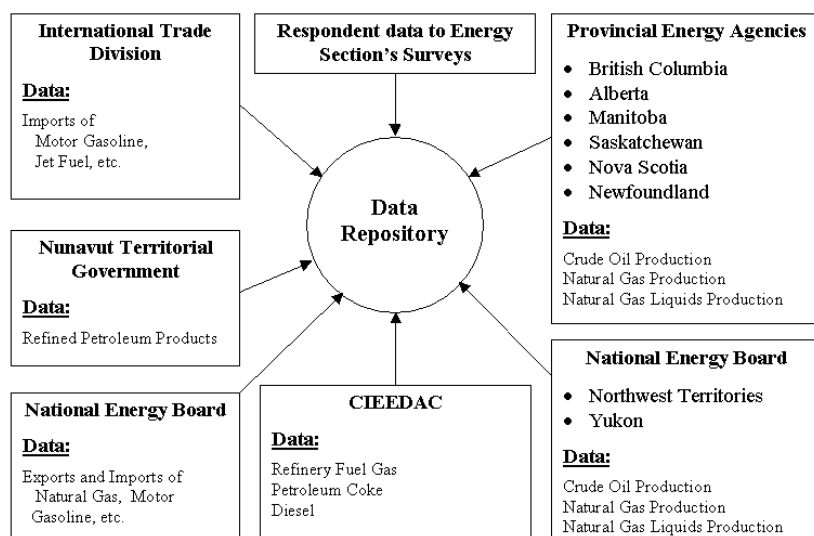


Figure A4-2: Fossil Fuel and Energy Data Input

The energy balance consists of information on crude oil, natural gas, coal, refined petroleum products, 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 emissions forecasting and reporting to the United Nations Framework Convention on Climate Change. As such, MCED has established partnerships with various federal government departments, provincial energy ministries, industrial associations, and centre 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 to review the industrial consumption of energy product and the energy balance prior to its official release. Canadian industrial members also participate in the review of industrial data through the *Canadian Industrial Program for Energy Conservation (CIPEC)* group. The *Canadian Industrial Energy End Use Data Analysis Centre (CIEEDAC)* also participates in the review of refinery data and the industrial energy statistics.

Due the complexity of energy data, a *Working Group on Energy Statistics (WGES)* was established to provide advice, direction, and recommendations. The WGES consists of members from Statistics Canada, Environment Canada and Natural Resources Canada 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

IPCC/OECD/IEA (1997), *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, Intergovernmental Panel on Climate Change, Organisation for Economic Co-operation and Development, and International Energy Agency. Available online at: <http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm>.

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McCann, T.J. (2000), *1998 Fossil Fuel and Derivative Factors*, Report prepared for Environment Canada by T.J. McCann and Associates Ltd.

Statistics Canada, *Report on Energy Supply–Demand in Canada (Annual)*, Catalogue No. 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 due to reasons explained in the CRF 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 due to their relatively small contributions.

A5.1.1 Fuel Combustion

Emissions from the combustion of waste fuels for the production of energy at industrial facilities are not included. An appropriate data collection mechanism has not yet been identified for this emission source. Further emission factor research is needed to ensure that there is no double-counting of GHG emissions from the non-energy use of fossil fuels (reported under the Industrial Processes Sector).

A5.1.2 Emissions from Combustion of Landfill Gas

Emissions from the combustion of captured landfill gas used as a fuel source to generate heat or electricity are currently not included in the Energy Sector. In future, these will be estimated and reported in the appropriate category indicated by the IPCC Guidelines (IPCC/OECD/IEA, 1997).

A5.1.3 Fuel Combustion - Transportation

Due to lack of reliable data illustrating historic biodiesel consumption for transport purposes in Canada, emissions from biodiesel (1.AA.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 (though, as indicated in section 3.4.2.3 of chapter 3, emissions from ethanol fuel use is inventoried). Additionally, all emissions from multilateral operations (1.C2) are reported within their respective civilian source categories (Aviation & Navigation) due to security limitations which 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 not affecting 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 CO₂ emissions; however, as CO₂ is also a necessary component in the process reactions, it is most commonly recovered for re-use. Hence, the quantity of recovered CO₂ is estimated in this year's inventory for years 1990 to 2001, but the net amount of non-recovered CO₂ coming from soda ash production is not estimated and is considered to be minimal.

A5.2.2 Chemical Production

N₂O 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 N₂O; however, more research is required to determine its significance.

Similarly, there are insufficient data available to estimate CH₄ emissions from chemical manufacturing processes in Canada, although they are thought to be insignificant.

Process-related CO₂ emissions from adipic acid production are not inventoried (i.e. not estimated) and are considered negligible.

A5.2.3 Metal Production

CH₄ emissions associated with the production of metals are not estimated and are thought to be insignificant. For instance, CH₄ emissions coming from coke production in the iron and steel industry are not estimated, but they are believed to be negligible.

A5.2.4 Production and Consumption of Halocarbons and SF₆

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 SF₆ are reported as “Not Estimated” (NE) because there is currently no information on SF₆ exports in bulk and in product, and destruction of SF₆.

A5.2.5 Other and Undifferentiated Production

CO₂ emissions from the non-energy use (NEU) of hydrocarbons are estimated using two types of emission factors (EFs): one using the national carbon content only, and the second using the national carbon content and IPCC default fraction 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 in a short term only.

Hence, CO₂ emission from the combustion of waste fuel made with NEU of hydrocarbon and using the first type of EF are included in the NIR. However, CO₂ emissions from the combustion of waste fuels made from NEU of hydrocarbon, and using the second type of EF (i.e., with IPCC default fraction of carbon stored) need to be researched further in order 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).

A5.3 Solvent and Other Product Use

In this sector, only N₂O 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, 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 smaller animal categories, such as ranched deer, wild boar, elk, llamas, alpacas, rabbit, and ostrich have not yet been included. IPCC default emission factors are unavailable for these categories and they have relatively low populations.

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. AAFC and Statistics Canada conducted a Farm Environmental Management Survey (FEMS) in 2001, which found that, in that year, 2.2% of crop residues on an area basis were burned, the majority in Manitoba and Saskatchewan (Korol, 2004). Expert opinion suggests that, on a national basis, field burning of crop residues has declined since the early 1990s. Due to the paucity of the data and the absence of data collection mechanisms, no time series is available.

A5.4.3 Rice Production

CH₄ emissions from rice production are not currently inventoried, as rice production is believed to be very small in Canada. An appropriate data collection method for this source has not been established.

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, dead organic matter, and soil) in managed forests resulting from

growth and mortality, fire and insect disturbances, and management activities. Emissions of CO₂, CH₄, CO, and N₂O are estimated. Emissions of NO_x are not estimated. CO emissions occur during biomass burning only; they are reported as CO₂ 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.

A5.5.2 Cropland

Estimates of cropland remaining cropland include soil and partial biomass estimates. Estimates for mineral soils capture the major land management changes (crop mixture, tillage practices and summer fallow). 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 only CO₂ emissions from all pools due to forest and grassland conversion to cropland. Non-CO₂ emissions (CH₄, CO, N₂O) from biomass burning are also reported; NO_x estimates have not been estimated. GHG emissions and removals from the conversion of wetlands and settlements to cropland have not been estimated due to 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 on grasslands that would allow the implementation of the IPCC methodology. Moreover, there is no indication that these lands have been losing or gaining soil organic carbon as a result of human activity. Moreover, according to the definitions, the conversion of forest land and cropland to grassland is not occurring (NO). Emissions from the conversion of wetlands to grassland have not been estimated (NE).

A5.5.4 Wetlands

GHG emissions in land converted to flooded land, land converted to (managed) peatland, and (managed) peatland remaining peatland have been prepared but cannot be reported separately in the CRF tables. CO₂ estimates were developed in all categories; non-CO₂ (CH₄, CO, and N₂O) estimates associated with biomass burning are reported in forest land converted to flooded land. Emissions of NO_x 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 un-managed wetlands and grassland (tundra).

A5.5.5 Settlements

The current estimates in the land converted to settlements category include forest loss to settlements and the conversion of tundra (reported under grassland) to settlements in the Canadian north. Non-CO₂ emissions (CH₄, CO, and N₂O) are reported only when biomass burning has occurred in the course of conversion activities. Emissions of NO_x have not been estimated. Emissions and removals from the conversion of cropland, agricultural grassland, wetlands, and other land to settlements have not been estimated. More complete estimates are under preparation. CO₂ estimates in settlements remaining settlements include only net carbon sequestration in the aboveground biomass of urban trees.

A5.6 Waste

This category is for the most part complete, with the exception of the following.

A5.6.1 Domestic and Commercial Wastewater

N₂O emissions from domestic and commercial wastewater without human sewage/wastewater is given the notation IE in the CRF tables and is reported in the human sewage subsector. CH₄ recovery from the wastewater treatment operations entered under the Waste Water (w/o human sewage) subcategory of the CRF, is reported as NE. Recovery of CH₄ from these operations has not been confirmed but is not expected to occur. CH₄ and N₂O emissions from the Sludge subcategory are reported as NE as the data required to evaluate the quantities captured from specific sites are not available at this time. Methane recovery from covered anaerobic digesters is expected but has not been quantified as of yet.

A5.6.2 Industrial Wastewater

Confirmation of industrial waste water 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 slaughter house 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 and chemical products, petroleum products, textiles, and plastic. Since the slaughter house mentioned above captures and combusts the methane generated from the anaerobic digestion, it is assumed that the methane emissions are negligible on a national scale and therefore, the notation Not Occuring (NO) was reported. Gas collection is occurring for

this facility; however; quantitative data are currently not available so the methane recovery is reported as NE. 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.

A5.6.3 Waste Incineration

CH₄ emissions from MSW incineration are considered as negligible and have not been estimated. Approximately less than five percent of all MSW is incinerated in Canada. Therefore, CH₄ emissions from this source are not expected to contribute significantly to the national inventory and are reported as NE. We expect, through future facility level activity data improvement studies and the derivation of reliable emission factors that are presently lacking for this source, to be able to quantify the emissions or at least confirm that the quantities are in the trace range.

References

IPCC (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/lulucf/gpoglulucf_unedit.html.

IPCC/OECD/IEA (1997), *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, Intergovernmental Panel on Climate Change, Organisation for Economic Co-operation and Development, and International Energy Agency. 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 the QA/QC plan, a QA/QC co-ordinator position was staffed in 2006. The quality management framework has been reviewed and redesigned and new QA/QC plan and procedures were developed. Continuous improvement is at the foundation of the QA/QC plan; and as such, the plan and procedures are intended to be reviewed and revised, when necessary, to reflect new information as the program develops.

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 and to publication. In addition, the plan encompasses a quality management cycle that spans several years, ensuring that all inventory categories are subject to a suite of QA/QC procedures.

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; benchmarking of inventory processes through verification; and processes to ensure 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 and QA activities will be performed every year on a rolling schedule so that all categories (beginning with the key categories and those with a Tier 2 estimation method, followed by non-key categories) will be subject to QC and QA. In addition, all proposed significant methodological changes must undergo QA and be approved by the QA/QC co-ordinator.

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 co-ordination 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. However, the development of the 2007 inventory submission has been highly atypical with significant delays in the receipt of activity data. Risk mitigation and contingency planning for such events will be a key focus of QA/QC activities in the preparing for the 2008 submission.

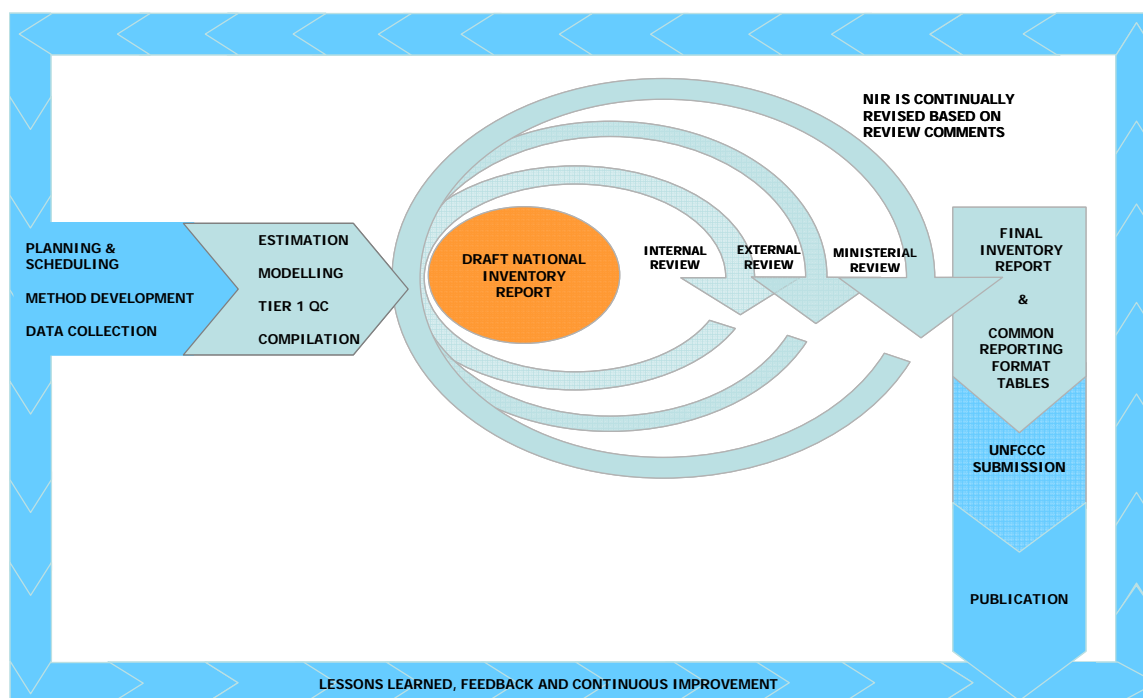


Figure A6-1: Typical Inventory Process

In April and May each year, review meetings are held both internally and with partners in order to capture lessons-learned during the previous inventory cycle. These meetings are both the final step in the cycle and also the initial step in preparing for the next inventory cycle to allow for continual improvement in the process.

In May and June an evaluation is conducted based on the results of: the lessons-learned review of the previous inventory cycle, QA/QC follow ups, the UNFCCC review report,

and the improvement plan. Based on these outcomes, methodologies, emission factors and procedures are reviewed, developed and/or refined.

From May to September, QA reviews of methodologies and emission factors are started for categories where a change in methodology or emission factor is proposed. Also, performed in this period is implementation of the (approved) methodology or emission factor improvements for categories that are included in such a schedule. During this time, the required data starts to be collected while the new inventory development schedule is prepared. By the end of October, methodologies are finalized and the data collection process is near completion.

Between November and January, draft estimates and the NIR are prepared by inventory experts. Emissions are calculated by inventory experts (dedicated to a specific Sector) who conduct QC checks concurrently. QC checks and estimates are signed-off by functional managers before the report and national totals are prepared. This process involves key category assessment, recalculations, uncertainty work, QA/QC, and documentation preparation.

Over February and March, the compiled inventory is reviewed internally, and components are (subject to availability and time considerations) 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 national inventory is archived and the NIR is then edited, translated and published.

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 (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 trends 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 emissions estimates are performed, focussing 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

In addition to general Tier 1 QC checks, Tier 2 QC is performed on a case-by-case basis starting with key categories (for which typically higher tier methodologies are used) and categories where a significant change in method or data occur. Tier 2 QC procedures are specific to the categories and require more in-depth technical expertise.

Tier 2 QC is done in addition to Tier 1 QC and the focus is on: categories that apply a Tier 2 or Tier 3 method in compiling the emissions; categories where “significant data or methodological changes have occurred”; and/or key categories.

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 emissions expert working group 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 governments. 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 data exists from the GHG Emissions Reporting Program of facility level GHG data; analysis is undertaken to perform bottom-up versus top-down comparisons.

A6.6 Key QA/QC Achievements in the 2007 Inventory Submission

In the 2006 calendar year, a QA/QC co-ordinator role was staffed in line with the strategic priority of the GHGD to review and redesign the quality framework. This review has had several key outcomes including the development and implementation of an enhanced QA/QC plan and procedures.

Elements of the QA/QC plan and procedures include:

- Embedding documentation of QC procedures into the inventory development process to ensure real-time recording of QC activities;
- Establishment of the Prioritization and Planning Committee to centralize inventory decision making particularly on approaches to QA and Planned Improvements;
- Development and implementation of a more efficient electronic archiving structure and electronic records management system; and
- Development and implementation of a rolling 5 year schedule to ensure complete coverage of all inventory categories with Tier 1 QC, Tier 2 QC and QA.

For the 2007 submission, Tier 1 QC procedures were implemented and the results documented for the 56 key categories and 3 non-key categories by the experts who prepared these category estimates. Cross-cutting checks on the NIR and CRF were also performed prior to submission.

References

IPCC (2000), Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories,

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 at least the Tier 1 method, as provided in the IPCC Good Practice Guidance (IPCC, 2000). Alternatively, Annex I Parties may use the Tier 2 method in the IPCC Good Practice Guidance (IPCC, 2000) to address technical limitations in the Tier 1 method. Uncertainty in the data used for all source and sink categories should also be qualitatively discussed in a transparent manner in the NIR, in particular for those sources that were identified as key sources.

Canada performed an uncertainty assessment of its 1990 estimates in 1994 (McCann, 1994). In 2003–2004, Canada embarked on a comprehensive study to quantify uncertainty 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, 2004). At the time of the study, the IPCC report on Good Practice Guidance for LULUCF (IPCC, 2003) was still under preparation; therefore, the LULUCF Sector was excluded from the assessment.

The overall trend uncertainty for the 2001 GHG inventory, which was not performed in the original phase due to computational limitations, was performed in the subsequent phase (ICF, 2005) and is reported in Table A7-1. Also performed in the subsequent phase was a sensitivity study of the overall inventory uncertainty to identify source categories that contribute the most to the uncertainty.

Since the 2003 NIR submission (Environment Canada, 2003), which contained emission estimates for the year 2001, updates to the methods and the activity data were made for certain source categories. Where available or relevant, updated quantitative uncertainty estimates for these categories are reported in the chapters 3 to 8 of this report and highlighted in Section A7.4 of this Annex.

In this annex, a picture of the overall uncertainty as assessed for the Canadian national GHG inventory of 1990–2001 (as reported in the 2003 NIR) is provided, followed by

sections describing the scope of the ICF (2004, 2005) uncertainty study. A summary of sector uncertainty results for 2001 is discussed in the final section, in tabular and narrative formats, together with highlights on updates to uncertainty assessments.

A7.2 Overall Inventory Uncertainty for 2001 (reported in NIR 2003)

Table A7-1 shows the overall level uncertainty picture for Canada's 2001 GHG inventory year (reported in NIR 2003) for each gas and for the overall inventory in CO₂ eq, with and without the incorporation of the uncertainty associated with the GWP of the component gases. 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 without consideration of the uncertainty within the GWPs. With GWP uncertainty considered, the overall uncertainty falls within a range of -5% to +10%. This compares with other Annex I Parties' reported uncertainties and reflects the range of uncertainties that such countries would see in their inventories.

In regards to the particular gases, N₂O 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%. CO₂ 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 use of IPCC default uncertainty ranges in certain categories (e.g., uncertainty associated with national cement production, with a value of 35%) is believed to have generated a larger uncertainty range for the overall inventory. In the coming years, the overall uncertainty estimates should be improved further once national uncertainty ranges for certain emission variables are obtained.

Further results of the study, on a sectoral and category basis, are detailed in Tables A7-5 to A7-15 in Section A7.4.

Table A7-1: Quantitative Tier 2 Uncertainty Assessment of Overall National Inventory GHG Emissions and Trends for 2001 by Gas

Gas	Base Year Emissions (1990) ¹	Year t Emissions (2001) ¹	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	
	<i>Gg CO₂ eq</i>	<i>Gg CO₂ eq</i>	<i>% Below (2.5th percentile)</i>	<i>% Above (97.5th percentile)</i>	<i>%</i>	<i>Lower % (2.5th percentile)</i>	<i>Upper % (97.5th percentile)</i>
CO ₂	472 000	566 000	-4	0	20	18	24
CH ₄	73 000	93 000	-5	35	27	0	75
N ₂ 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 ₆	2 870	2 020	-1	1	-30	-30	-29
Total GHG Emissions (without GWP Uncertainty)	608 000	720 000	-3	6	19	12	27
Total GHG Emissions (with GWP Uncertainty)	610 000	720 000	-5	10	19	12	28

Sources:

ICF (2004, 2005).

Notes:

1 As reported in NIR 2003.

Excludes LULUCF Sector.

NA = Not applicable.

A7.3 *Scope of 2004/2005 Uncertainty Study*

The source categories assessed include key categories and various other source categories selected in accordance with an agreed-upon uncertainty model. This ensured that the important sources were included while avoiding overrepresentation of smaller sources with similar activity or emission factor uncertainty data.

A Tier 2 approach was adopted (IPCC, 2000), since i) the probability distributions underlying the estimates are non-Gaussian distributions, ii) the inventory estimation methodology is complex and includes several input variables, iii) the uncertainty surrounding the input variables is large, and iv) the variables are correlated between and/or within source categories. Tier 1 uncertainty analysis was not conducted due to time and resource constraints, but it will be performed in the future.

Level uncertainty estimates were developed through Tier 2 for each inventory source category based on the 2001 estimates (excluding LULUCF) and for the GHG inventory overall. Also developed were trend uncertainty estimates between 1990 and 2001. The Monte Carlo stochastic simulation technique was used for individual source categories.

The uncertainty ranges were developed for the 2.5th and 97.5th percentiles (95% confidence interval) for source categories. It is assumed that uncertainty ranges for many source categories included in the ICF (2004, 2005) study can be used for the current GHG inventory estimates, provided that the methods for obtaining activity data and methodology to develop estimates have not changed. For trend uncertainty estimates, the assumption has been 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.

As a planned future improvement, a Tier 1 uncertainty analysis would be conducted for compatibility with other countries and to meet a requirement of the IPCC Good Practice Guidance. Also, as some methodologies have been subject to improvements in the last four years, a Tier 1 study of uncertainty would show the most recent uncertainty picture for the inventory.

A7.3.1 General Concepts

Emission estimate uncertainty is composed of i) model uncertainty and ii) parameter uncertainty. Model uncertainty refers to the uncertainty associated with the estimation methodology (i.e., the mathematical equations or inventory estimation models, such as $\text{Emissions} = \text{Activity Data} \times \text{Emission Factor}$). Model uncertainty results in biased inventory estimates. It can be detected through QA and reduced by developing an appropriate, alternative inventory estimation model.

Parameter uncertainty refers to the uncertainty associated with variables such as activity data, emission factors, and constants used as inputs to the inventory estimation models. Parameter uncertainty can be further divided into i) random (or statistical) uncertainty

and ii) systematic uncertainty (or bias). While random uncertainty can be estimated statistically, systematic uncertainty can be quantified only through research and analysis. Both random and systematic uncertainty can be quantified through expert elicitation. Although random uncertainty cannot be removed, efforts can be undertaken to minimize it.

Canada's 2001 GHG inventory has been shown to possess all three types of uncertainties mentioned above. While random parameter uncertainty is present in all cases, systematic parameter and model uncertainties have also been found in some categories (e.g., PFCs from aluminium production). See also Section A7.4 below.

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 point estimates, uncertainty ranges associated with the inventory estimates of the input variables were obtained from various best available data sources, consistent with the guidelines provided in the IPCC Good Practice Guidance (IPCC, 2000). The two main sources of uncertainty data were:

1. published references, survey data, sample statistics, and other unpublished reports; and
2. expert elicitations.

The important published references that were used in developing uncertainty for the input variables included McCann (2000), SGA (2000), IPCC Good Practice Guidance (IPCC, 2000), the IPCC Guidelines (IPCC/OECD/IEA, 1997), and the 2003 NIR (Environment Canada, 2003):

- McCann (2000) developed CO₂ emission factors for fossil fuel combustion, by fossil fuel type, for 1998 and the associated uncertainty ranges for 95% confidence intervals. McCann (2000) recommended CO₂ emission factors for coal (with the exception of anthracite), natural gas, and NGLs. These emission factors were used in the development of the 2001 inventory estimates. Therefore, for purposes of this study, uncertainty estimates developed by McCann (2000) were adopted.
- For marketed refined petroleum products, the CO₂ emission factors used in the 2001 inventory estimation differed from the emission factors reported by McCann (2000). However, based on the recommendation of Dr. John Nyboer of CIEEDAC, the uncertainty associated with the inventory estimates was developed based on the emission factors and the associated uncertainty ranges recommended by McCann (2000).
- SGA (2000) developed the CH₄ and N₂O emission factors and uncertainty

estimates for fossil fuel combustion. These CH₄ and N₂O emission factor estimates are used in the inventory estimation for stationary and mobile fuel combustion source categories. Consequently, for this uncertainty analysis, the uncertainty ranges developed by SGA (2000) for CH₄ and N₂O were adopted for generating uncertainty estimates for the stationary and mobile fuel combustion source categories.

- 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 of uncertainty in the input variables were developed based on a review of i) the inventory estimation methodology and the data source used for the 2003 NIR and ii) the recommended estimation methodology and the methodological details provided in the IPCC Guidelines (IPCC/OECD/IEA, 1997) and the input data selection discussions provided in the IPCC Good Practice Guidance (IPCC, 2000) for that source category, as appropriate.

For many other variables, uncertainty data to characterize the input variables were obtained through expert elicitations. Two sets of expert elicitations were conducted: i) detailed expert elicitation and ii) less detailed expert elicitation. Both sets of elicitations were administered using elicitation protocols and differed in terms of the time commitments provided by the experts. The detailed expert elicitation protocol was structured similarly to the well-known Stanford/SRI International protocol (Morgan and Henrion, 1990; IPCC, 2000). A pre-elicitation template was used, since it was not possible to obtain significant time commitments from the experts to complete the process.

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. Gary Smalldridge from Statistics Canada, Jeff Gienow and Oliver Bussler from SaskPower, Dr John Nyboer from Canadian Industrial Energy End-Use Data and Analysis Centre (CIEEDAC), were among the experts consulted, to name a few. The exhaustive list of all the experts can be found in the ICF, 2004 report.

For uncertainty assessment of 1990 emissions, the data obtained from expert elicitations were limited. This was due to the long time that had passed since 1990 and the unavailability of appropriate records to which the experts could refer. Therefore, the uncertainty for the majority of source categories considered in this study for 1990 has been assumed to be equal to their uncertainty in 2001. The applicability of the uncertainty characteristics of 2001 estimates to the 1990 estimates needs to be further evaluated. Hence, the trend uncertainty results provided here (which use the uncertainty of 1990 as well as the uncertainty of 2001 estimates) should be considered preliminary and with caution.

Tables A7-2 and A7-3 show examples of uncertainty assessments obtained through the expert elicitation process and through source document research. Table A7-3 provides more detailed information on the uncertainty, such as the central value for the variable, the shape of the probability distribution function, the uncertainty range, and the confidence interval for which the range is quoted.

Table A7-2: Sample Input Parameter Uncertainty Estimates Obtained from Expert Elicitation — Activity Data for Quantity of Fuel Consumed

Fuel Consumption Uncertainty Estimates (2001) – in % around the mean value																				
Stationary and Mobile Fuel Combustion	Natural Gas	Still Gas	Motor Gasoline	Kerosene & Stove Oil	Diesel Fuel Oil	Light Fuel Oil	Heavy Fuel Oil	Petroleum Coke	Aviation Gasoline	Aviation Turbo Fuel	NGL – Propane	NGL – Butane	NGL – Ethane	Canadian Bituminous	Sub-Bituminous	Lignite	Anthracite	U.S. (Imported) Bituminous	Coke	Coke Oven Gas
1.A.1 Energy Industries																				
1.A.1 a. Electricity Generation	1				1	1	1	1						1	1	1		1	1	1
1.A.1 b. Petroleum Refining (Upstream & Downstream Oil and Gas Industries)	1	2		1	1	1	1	1			1	1								
1.A.2 Manufacturing Industries and Construction																				
1.A.2 a. Iron and Steel	1				3		1	1						1			1		1	1
1.A.2 b. Non-Ferrous Metals	1				3		1	1						1			1		1	
1.A.2 c. Chemicals	1				3	2	1	1					1							
1.A.2 d. Pulp, Paper and Print	1				3	2	1									1		1		
1.A.4 Other Sectors																				
1.A.4 a. Commercial/Institutional	3		2	1	3	2	2		1	1	3			1						
1.A.4 b. Residential	1			1		1	1				1			1	1	1				
1.A.4 c. Agriculture/Forestry/Fisheries	1		2	1	3	1	1				1									
Fuel consumed by all other sectors	Assumed ±3% for all fuels as default value																			

Source: ICF (2004).

Table A7-3: Sample Input Parameter Uncertainty Estimates Obtained from Expert Elicitation and Source Reference Research — Emission Factor Data for Stationary Fuel Combustion

Source/Sub-Source Category	CO ₂ Emission Factors (2001 Inventory Estimate)	Probability Distribution	Uncertainty Range Relative to 2001 Inventory Estimate		Confidence Interval (%)	Data Source
			Low (%)	High (%)		
Coal <i>g/kg</i>						
Lignite ¹	1 420.22	Normal	−6	4	95	J. Gienow and O. Bussler, SaskPower
Anthracite ²	2 390.00	Normal	−5	5	95	Assumed
U.S. Bituminous ³	2 387.08	Normal	−3	3	95	McCann (2000)
Canadian Bituminous ³	1 973.13	Normal	−3	3	95	McCann (2000)
Sub-Bituminous ³	1 747.44	Normal	−3	3	95	McCann (2000)
Coke ²	2 480.00	Normal	−5	5	90	Assumed
Coke Oven Gas ²	1 600.00	Normal	−10	10	90	Assumed
Natural Gas <i>g/m³</i>						
Non-Energy	1 266.97	Normal	−5	5	95	Assumed
Interprovincial ⁴	1 891.00	Normal	−3	3	95	McCann (2000)
Petroleum Refineries for Hydrogen ⁴	1 892.00	Normal	−3	3	95	McCann (2000)
Liquid <i>g/L</i>						
Petroleum Coke	4 200.00	Normal	−37	−25	95	McCann (2000)
Propane (Non-Energy Use)	303.00	Normal	−5	5	95	Assumed
Butane (Non-Energy Use)	349.00	Normal	−5	5	95	Assumed
Ethane (Non-Energy Use)	197.00	Normal	−5	5	95	Assumed
Petrochemical Feedstocks ⁵	2 500.00	Normal	−15	15	90	Assumed
Naphthas	2 500.00	Normal	−10	10	95	Assumed
Lubricants ⁵	2 820.00	Normal	−10	10	90	Assumed
Other Products ⁵	1 835.00	Normal	−20	20	90	Assumed

Source:
ICF (2004).

Notes:

- 1 Emission factor range for Saskatchewan for energy use applied.
- 2 Same as for energy use.
- 3 These uncertainty ranges may be different from those used for energy use, as energy use emission factors were provincial.
- 4 Same as for energy use — natural gas in industry.
- 5 The uncertainty around the emission factor is assumed to be larger, as petrochemical feedstock is not a unique product, but compares general products. Hence, a 90% confidence interval is assumed.

A7.3.3 Level of Aggregation Adopted for Uncertainty Analysis

Theoretically, the ideal level of disaggregation for an uncertainty analysis should be the level at which the inventory estimation was performed, if the uncertainty input data can be reliably obtained for the variables at that level of disaggregation. However, from a practical implementation perspective, the appropriate level of disaggregation is also determined by budget and time constraints.

For each category, the appropriate level of disaggregation was determined in consultation between the GHG Division and the consultant. It was generally conducted at the level at which it was believed that the uncertainty data associated with the inventory input variables could be obtained reliably. Table A7-4 reports the level of disaggregation adopted for performing the uncertainty analysis under this project. For identification of key categories among the categories shown in this table, the readers should refer to Tables A7-5 to A7-15 at the end of the annex (key sources in these tables are indicated by the symbol KS).

Table A7-4: Level of Aggregation Adopted for the Uncertainty Analysis, by Key Source Category (2001 Inventory Submitted in 2003)¹

Source Category	IPCC Source Category	Direct GHG	Criteria for Identification ²	Level of Aggregation
1-A-1-a	Fuel Combustion – Public Electricity and Heat Production	CO ₂	Level, Trend, and Quality	Provincial level for coal and national level for others
1-A-1-b	Fuel Combustion – Petroleum Refining	CO ₂	Level, Trend, and Quality	Provincial level for coal (coal is not used as refinery fuel) and national level for others
1-A-1-c	Fuel Combustion – Manufacture of Solid Fuels and Other Energy Industries	CO ₂	Level, Trend, and Quality	Provincial level for coal and national level for others
1-A-2	Fuel Combustion – Manufacturing Industries and Construction	CO ₂	Level and Trend	Provincial level for coal and national level for others
1-A-3-a	Fuel Combustion – Civil Aviation	CO ₂	Level	National, by fuel type
1-A-3-b	Fuel Combustion – Road Transportation	CO ₂	Level, Trend, and Quality	National, by vehicle category and fuel type
1-A-3-b	Fuel Combustion – Road Transportation	N ₂ O	Level, Trend, and Quality	National, by vehicle category and fuel type
1-A-3-c	Fuel Combustion – Railways	CO ₂	Level and Trend	National, by fuel type
1-A-3-e	Fuel Combustion – Other Transport	CO ₂	Level	National, by fuel type
1-A-3-f	Fuel Combustion – Pipeline Transport	CO ₂	Level, Trend, and Quality	National, by fuel type
1-A-4	Fuel Combustion – Other Sectors	CO ₂	Level and Trend	Provincial level for coal and national level for others
1-B-1-a	Fugitive Emissions – Coal Mining	CH ₄	Level	National, by mine type
1-B-2-(a+b)	Fugitive Emissions – Oil and Natural Gas	CH ₄	Level, Trend, and Quality	National, by economic activity
1-B-2-c	Fugitive Emissions – Oil and Natural Gas – Venting and Flaring	CO ₂	Level, Trend, and Quality	National
1-B-2-c	Fugitive Emissions – Oil and Natural Gas – Venting and Flaring	CH ₄	Quality	National
2-A-1	Industrial Processes – Cement Production	CO ₂	Level and Quality	National
2-B-1	Industrial Processes – Ammonia Production	CO ₂	Level	National
2-B-3	Industrial Processes – Adipic Acid Production	N ₂ O	Level, Trend, and Quality	National
2-C-1	Industrial Processes – Iron and Steel Production	CO ₂	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 ₆	Level and Quality	National
2-F	Industrial Processes – Other (Undifferentiated Production)	CO ₂	Level	National, by feedstock fuel type
4-A	Agriculture – Enteric Fermentation	CH ₄	Level	National, by cattle type
4-B	Agriculture – Manure Management	CH ₄	Level	National, by cattle type
4-D	Agriculture – Agricultural Soils	N ₂ O	Level	National with subsector details
6-A	Waste – Solid Waste Disposal on Land	CH ₄	Level and Quality	National, by waste category

Notes:

1 This table was adapted based on Table A1-1 of the 2003 NIR.

2 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 Tier 2 approach to uncertainty estimation, also known as the Monte Carlo stochastic simulation technique, was adopted in performing sensitivity analysis of the level uncertainty.

Development of uncertainty importance of level uncertainty estimates was performed through ICF (2005), with probabilistic sensitivity analysis to identify the key input variables that significantly influence the uncertainty in the output variables.

There are several measures for estimating the uncertainty importance of input variables (i.e., the degree of sensitivity of output variables to the variation in the input variables) used in the inventory estimation. However, rank correlation coefficients were considered to be the appropriate measure of uncertainty importance:

- A value of 0% rank order correlation coefficient indicates that there is no relationship between the rank ordered input and the corresponding output variable; the variation in the output variable is independent of (or non-responsive to) the variation in the input variable.
- A value of 100% indicates that the variation in the output variable is fully responsive to the variation in the input variable.

The rank correlation values (“r”) generated through this sensitivity analysis are reported in the following section. They represent the magnitude of influence (or importance) of uncertainty in each of the specified categories to the uncertainty in the overall inventory GHG emissions.

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 Tables A7-5 to A7-15.

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, as a percentage, to identify the key source categories that significantly influence the uncertainty in the total overall inventory emissions. Finally, for the trend uncertainty, the values shown in the tables provide a picture of trend uncertainty in 2001.

Note that the uncertainty range as presented in these tables does not include the uncertainty associated with the GWP for the corresponding emission values.

Also, some uncertainty estimates for the source categories appear to be the same for the base year 1990 and for 2001, due to the rounding effects; however, the percent trend values and the uncertainty ranges shown are valid.

The sensitivity analysis of the overall uncertainty in the total inventory emissions indicates that:

- The uncertainty associated with the N₂O emissions 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 47%), although CO₂ 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 CH₄ emissions from stationary source fossil fuel combustion (r = 37%), N₂O from agricultural soils (r = 36%), CH₄ from the Waste Sector (r = 31%), and CO₂ from stationary source fuel combustion (r = 30%).

Further analysis reveals that the respective uncertainties associated with the overall inventory emissions, by gas, were found to be most influenced by source category uncertainties associated with the following sectors:

- In the case of uncertainty associated with the overall CO₂ emissions, the key uncertainty-important source categories include stationary fuel combustion, followed by mobile sources, industrial processes, and fugitive emissions.
- In the case of uncertainty associated with the overall CH₄ emissions, the key uncertainty-important source categories include stationary fuel combustion, followed by the Waste Sector and fugitive emissions.
- In the case of uncertainty associated with the overall N₂O emissions, the principal uncertainty-important source categories include mobile sources, followed by agricultural soils and stationary fuel combustion.
- In the case of PFC emissions, the CF₄ from industrial sources is the primary uncertainty-important source category, followed by C₂F₆ from industrial processes.
- In the case of HFC emissions, the halocarbons use source category is the key uncertainty-important source category, as it was the only source of HFC emissions in Canada in 2001.
- Similarly, SF₆ from industrial processes is the only uncertainty-important source category that contributed to SF₆ emissions in Canada in 2001.

As mentioned before, the trend uncertainty estimates were developed by assigning the same or similar uncertainty characteristics associated with the 2001 input variables for both 1990 and 2001, which means that these estimates should be viewed with caution.

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 3–8.

Table A7-5: Tier 2 Uncertainty Reporting — CO₂ Energy (Stationary Combustion)

IPCC Source Category	Gas	Base Year Emissions (1990)	Year t Emissions (2001)	Uncertainty in Year t Emissions as % of Emissions in the Category		Uncertainty Introduced on National Total in Year t (2001)	% Change in Emissions between 2001 and 1990	Range of Likely % Change between 2001 and 1990		Comments
		Gg CO ₂ eq	Gg CO ₂ eq	% Below (2.5th percentile)	% Above (97.5th percentile)	%	%	Lower % (2.5th percentile)	Upper % (97.5th percentile)	
1.A Stationary Combustion	CO ₂	276 000	335 000	-4	1	30	21	20	23	
Liquid Fuels	CO ₂	73 000	74 000	-15	2					
Solid Fuels	CO ₂	86 000	111 000	-3	3					
Gaseous Fuels	CO ₂	117 000	150 000	-2	2					
1.A.1. Energy Industries	CO ₂	144 000	201 000	-6	2					
Liquid Fuels	CO ₂	35 000	42 000	-24	5					
Solid Fuels	CO ₂	78 700	104 000	-3	4					
Gaseous Fuels	CO ₂	30 200	54 900	-5	5					
1.A.1.a. Public Electricity and Heat Production (KS)	CO ₂	94 700	136 000	-3	3		44	45	50	
1.A.1.a.i – Electricity Generation – Utilities	CO ₂	91 900	127 000	-3	3					
1.A.1.a.ii – Electricity Generation – Industry	CO ₂	2 210	4 600	-8	3					
1.A.1.a.iii – Heat/Steam Generation	CO ₂	690	5 000	-2	2					
1.A.1.b. Petroleum Refining (KS)	CO ₂	26 000	29 000	-35	7		11	7	10	
1.A.1.c. Manufacture of Solid Fuels and Other Energy Industries (KS)	CO ₂	23 600	35 500	-8	8		50	45	60	
1.A.2. Manufacturing Industries and Construction (KS)	CO ₂	62 100	59 700	-3	2					
Liquid Fuels	CO ₂	15 500	12 700	-9	1					
Solid Fuels	CO ₂	7 170	7 030	-4	5					
Gaseous Fuels	CO ₂	39 500	39 900	-3	3					
1.A.2.a. Iron and Steel	CO ₂	6 420	5 830	-5	5		-9	-15	-4	
1.A.2.b. Non-Ferrous Metals	CO ₂	3 210	3 480	-6	-1		8	18	22	
1.A.2.c. Chemicals	CO ₂	7 060	6 440	-3	2		-9	-10	-8	
1.A.2.d. Pulp, Paper and Print	CO ₂	13 400	9 500	-4	4		-29	-29	-27	
1.A.2.e. Food Processing, Beverages and Tobacco	CO ₂	IE	IE	-	-					See Note 1

IPCC Source Category	Gas	Base Year Emissions (1990)	Year t Emissions (2001)	Uncertainty in Year t Emissions as % of Emissions in the Category		Uncertainty Introduced on National Total in Year t (2001)	% Change in Emissions between 2001 and 1990	Range of Likely % Change between 2001 and 1990		Comments
		<i>Gg CO₂ eq</i>	<i>Gg CO₂ eq</i>	<i>% Below (2.5th percentile)</i>	<i>% Above (97.5th percentile)</i>	<i>%</i>	<i>%</i>	<i>Lower % (2.5th percentile)</i>	<i>Upper % (97.5th percentile)</i>	
1.A.2.f. Other	CO ₂	32 000	34 400	-3	2					
1.A.2.f.i Cement	CO ₂	3 370	3 270	9	16		-3	8	16	
1.A.2.f.ii Mining	CO ₂	6 150	10 200	-3	3		65	60	70	
1.A.2.f.iii Construction	CO ₂	1 860	998	-3	2		-46	-50	-45	
1.A.2.f.iv Other Manufacturing	CO ₂	20 600	20 000	-6	1		-3	-11	-4	
1.A.4 Other Sectors (KS)	CO ₂	69 400	74 300	-3	2					
Liquid Fuels	CO ₂	22 200	19 200	-5	1					
Solid Fuels	CO ₂	191	144	-5	1					
Gaseous Fuels	CO ₂	47 000	54 900	-3	3					
1.A.4 a. Commercial/Institutional	CO ₂	25 700	32 700	-3	3		27	23	30	
1.A.4.b. Residential	CO ₂	41 300	39 400	-3	2		-5	-6	-3	
1.A.4.c. Agriculture/Forestry/Fisheries	CO ₂	2 400	2 190	-3	1		-9	-9	-7	

Notes:

1 Emissions from Food Processing, Beverages and Tobacco are included in Other Manufacturing (1.A.2.f.iv)

KS = Key source

IE = Included elsewhere

Table A7-6: Tier 2 Uncertainty Reporting — CH₄ Energy (Stationary Combustion)

IPCC Source Category	Gas	Base Year Emissions (1990)	Year t Emissions (2001)	Uncertainty in Year t Emissions as % of Emissions in the Category		Uncertainty Introduced on National Total in Year t (2001)	% Change in Emissions between 2001 and 1990	Range of Likely % Change between 2001 and 1990		Comments
		<i>Gg CO₂ eq</i>	<i>Gg CO₂ eq</i>	<i>% Below (2.5th percentile)</i>	<i>% Above (97.5th percentile)</i>	<i>%</i>	<i>%</i>	<i>Lower % (2.5th percentile)</i>	<i>Upper % (97.5th percentile)</i>	
1.A Stationary Combustion	CH ₄	4 000	5 000	-24	700	37	25	-2	45	See Note 1
Liquid Fuels	CH ₄	30	20	1	490					
Solid Fuels	CH ₄	30	40	-24	210					
Gaseous Fuels	CH ₄	2 000	3 000	0	230					
Biomass	CH ₄	2 000	2 000	-95	1 500					
1.A.1. Energy Industries	CH ₄	2 000	3 000	1	230					See Note 1
Liquid Fuels	CH ₄	10	10	14	850					
Solid Fuels	CH ₄	20	30	-18	19					
Gaseous Fuels	CH ₄	2 000	3 000	0	230					See Note 2
Biomass	CH ₄	—	—	—	—					
1.A.1.a. Public Electricity and Heat Production (KS)	CH ₄	38	100	-20	40		175	100	200	
1.A.1.a.i. – Electricity Generation – Utilities	CH ₄	37	100	-23	35					
1.A.1.a.ii – Electricity Generation – Industry	CH ₄	1	2	-28	220					
1.A.1.a.iii – Heat/Steam Generation	CH ₄	0	1	24	1 900					
1.A.1.b. Petroleum Refining (KS)	CH ₄	8	9	-50	900		13	-26	50	
1.A.1.c. Manufacture of Solid Fuels and Other Energy Industries (KS)	CH ₄	2 000	2 000	0	240		50	40	55	

IPCC Source Category	Gas	Base Year Emissions (1990)	Year t Emissions (2001)	Uncertainty in Year t Emissions as % of Emissions in the Category		Uncertainty Introduced on National Total in Year t (2001)	% Change in Emissions between 2001 and 1990	Range of Likely % Change between 2001 and 1990		Comments
		Gg CO ₂ eq	Gg CO ₂ eq	% Below (2.5th percentile)	% Above (97.5th percentile)	%	%	Lower % (2.5th percentile)	Upper % (97.5th percentile)	
1.A.2 Manufacturing Industries and Construction (KS)	CH ₄	40	40	-35	380					See Note 1
Liquid Fuels	CH ₄	10	8	-18	230					
Solid Fuels	CH ₄	5	4	-70	350					
Gaseous Fuels	CH ₄	16	16	-40	40					
Biomass	CH ₄	7	10	-95	1 400					
<i>1.A.2.a. Iron and Steel</i>	CH ₄	5	5	-70	320		-6	-90	550	
<i>1.A.2.b. Non-Ferrous Metals</i>	CH ₄	1	2	-19	95		19	10	27	
<i>1.A.2.c. Chemicals</i>	CH ₄	3	3	-35	40		-7	-9	-1	
<i>1.A.2.d. Pulp, Paper and Print</i>	CH ₄	20	20	-60	900		0	-28	35	
<i>1.A.2.e. Food Processing, Beverages and Tobacco</i>	CH ₄	IE	IE	-	-					See Note 3
<i>1.A.2.f. Other</i>	CH ₄	10	10	-28	120					
1.A.2.f.i Cement	CH ₄	1	2	-35	500		6	-7	27	
1.A.2.f.ii Mining	CH ₄	3	4	-28	160		60	18	160	
1.A.2.f.iii Construction	CH ₄	1	1	-35	190		-45	-60	-40	
1.A.2.f.iv Other Manufacturing	CH ₄	10	8	-30	70		-11	-14	5	
1.A.4 Other Sectors (KS)	CH ₄	2 000	2 000	-90	1 500					See Note 1
Liquid Fuels	CH ₄	5	5	-40	280					
Solid Fuels	CH ₄	8	7	-75	1 100					
Gaseous Fuels	CH ₄	20	20	-40	40					
Biomass	CH ₄	2 000	2 000	-95	1 500					
<i>1.A.4 a. Commercial/Institutional</i>	CH ₄	10	10	-28	160		30	30	190	
<i>1.A.4.b. Residential</i>	CH ₄	2 000	2 000	-90	1 500		-6	-15	3	
<i>1.A.4.c. Agriculture/Forestry/Fisheries</i>	CH ₄	1	1	-28	230		0	-4	21	

Notes:

1 Refer to Chapter 3 of the NIR for a discussion of the uncertainty associated with CH₄ emission factors.

2 Need to reassess the uncertainty assumption for non-marketable natural gas emission factor – Refer to Chapter 3 of the NIR for additional details.

3 Emissions from Food Processing, Beverages and Tobacco are included in Other Manufacturing (1.A.2.f.iv).

KS = Key source

IE = Included elsewhere

Table A7-7: Tier 2 Uncertainty Reporting — N₂O Energy (Stationary Combustion)

IPCC Source Category	Gas	Base Year Emissions (1990)	Year t Emissions (2001)	Uncertainty in Year t Emissions as % of Emissions in the Category		Uncertainty Introduced on National Total in Year t (2001)	% Change in Emissions between 2001 and 1990	Range of Likely % Change between 2001 and 1990		Comments
		Gg CO ₂ eq	Gg CO ₂ eq	% Below (2.5th percentile)	% Above (97.5th percentile)	%	%	Lower % (2.5th percentile)	Upper % (97.5th percentile)	
1.A. Stationary Combustion	N ₂ O	2 000	2 000	-11	650	24	20	-45	190	See Note 1
Liquid Fuels	N ₂ O	400	400	-12	800					
Solid Fuels	N ₂ O	500	600	-60	1 000					
Gaseous Fuels	N ₂ O	700	1000	-65	950					
Biomass	N ₂ O	400	400	-85	1 200					
1.A.1. Energy Industries	N ₂ O	900	1 000	-23	800					See Note 1
Liquid Fuels	N ₂ O	200	200	0	1 100					
Solid Fuels	N ₂ O	400	600	-70	1 100					
Gaseous Fuels	N ₂ O	300	500	-80	1 200					
Biomass	N ₂ O	—	—	—	—					
1.A.1.a. Public Electricity and Heat Production (KS)	N ₂ O	500	800	-35	900		40	-75	950	
1.A.1.a.i – Electricity Generation – Utilities	N ₂ O	500	700	-50	900					
1.A.1.a.ii – Electricity Generation – Industry	N ₂ O	20	28	-70	1 000					
1.A.1.a.iii – Heat/Steam Generation	N ₂ O	4	8	170	12 000					
1.A.1.b. Petroleum Refining (KS)	N ₂ O	90	90	-28	1 000		5	-40	40	
1.A.1.c. Manufacture of Solid Fuels and Other Energy Industries (KS)	N ₂ O	200	300	-90	1 500		50	35	80	
1.A.2 Manufacturing Industries and Construction (KS)	N ₂ O	400	400	-55	850					See Note 1
Liquid Fuels	N ₂ O	100	100	-45	650					
Solid Fuels	N ₂ O	50	50	-75	550					
Gaseous Fuels	N ₂ O	200	200	-95	1 500					
Biomass	N ₂ O	40	60	-95	1 500					
1.A.2.a. Iron and Steel	N ₂ O	60	50	-85	650		-6	-90	650	
1.A.2.b. Non-Ferrous Metals	N ₂ O	10	20	-55	850		21	-60	240	
1.A.2.c. Chemicals	N ₂ O	40	40	-85	1 300		-7	-11	9	
1.A.2.d. Pulp, Paper and Print	N ₂ O	100	100	-60	900		-6	-29	30	

IPCC Source Category	Gas	Base Year Emissions (1990)	Year t Emissions (2001)	Uncertainty in Year t Emissions as % of Emissions in the Category		Uncertainty Introduced on National Total in Year t (2001)	% Change in Emissions between 2001 and 1990	Range of Likely % Change between 2001 and 1990		Comments
		Gg CO ₂ eq	Gg CO ₂ eq	% Below (2.5th percentile)	% Above (97.5th percentile)	%	%	Lower % (2.5th percentile)	Upper % (97.5th percentile)	
1.A.2.e. Food Processing, Beverages and Tobacco	N ₂ O	IE	IE	–	–					See Note 2
1.A.2.f. Other	N ₂ O	200	200	–65	1 000					
1.A.2.f.i Cement	N ₂ O	10	10	–55	850		2	–80	550	
1.A.2.f.ii Mining	N ₂ O	40	80	–70	1 000		110	3	280	
1.A.2.f.iii	N ₂ O	20	8	–75	1 100		–55	–65	–35	
Construction										
1.A.2.f.iv Other Manufacturing	N ₂ O	100	100	–75	1 200		–9	–30	17	
1.A.4 Other Sectors (KS)	N ₂ O	700	700	–65	1 000					See Note 1
Liquid Fuels	N ₂ O	90	100	–35	850					
Solid Fuels	N ₂ O	1	1	–75	1 100					
Gaseous Fuels	N ₂ O	300	300	–95	1 400					
Biomass	N ₂ O	300	300	–95	1 400					
1.A.4 a. Commercial/Institutional	N ₂ O	200	200	–70	1 000		40	22	110	
1.A.4.b. Residential	N ₂ O	500	500	–75	1 100		–3	–24	10	
1.A.4.c. Agriculture/Forestry/Fisheries	N ₂ O	20	20	–70	1 000		5	–12	19	

Notes:

1 Refer to Chapter 3 of the NIR for a discussion of the uncertainty associated with N₂O emission factors.

2 Emissions from Food Processing, Beverages and Tobacco are included in Other Manufacturing (1.A.2.f.iv)

KS = Key source

Table A7-8: Tier 2 Uncertainty Reporting — CO₂ Energy (Transport)

IPCC Source Category	Gas	Base Year Emissions (1990)	Year t Emissions (2001)	Uncertainty in Year t Emissions as % of emissions in the Category		Uncertainty Introduced on National Total in Year t (2001)	% Change in Emissions between 2001 and 1990	Range of likely % Change between 2001 and 1990		Comments
		Gg CO ₂ eq	Gg CO ₂ eq	% Below (2.5th percentile)	% Above (97.5th percentile)	%	%	Lower % (2.5th percentile)	Upper % (97.5th percentile)	
1.A.3 Transport	CO ₂	146 000	178 000	—	—	12				
Total Mobile Sources (Total Transport excluding Pipelines)	CO ₂	139 000	168 000	—4	0					
Total Non-Rail Surface Transport Vehicles (On-Road & Off-Road)	CO ₂	118 000	145 200	—4	0					
1.A.3.a. Civil Aviation (KS)	CO ₂	10 410	11 800	—1	1		13	12	15	See Note 1
1.A.3.b. Road Transportation (KS)	CO ₂	103 000	127 000	—8	—3		24	20	28	See Note 2
On-Road Gasoline Vehicles (Cars + Trucks + Heavy Duty + Motorcycles)	CO ₂	75 200	87 000	—7	—3		16	12	19	See Note 3
On-Road Diesel Vehicles (Cars + Trucks + Heavy Duty)	CO ₂	25 500	39 400	—13	—1		55	45	70	See Note 3
On-Road Natural Gas Vehicles	CO ₂	84	118	—4	4		40	35	45	
On-Road Propane Vehicles	CO ₂	2 080	979	—2	2		—55	—55	—50	
1.A.3.c. Railways (KS)	CO ₂	6 320	5 820	—5	3		—8	—13	—5	
1.A.3.d. Navigation (KS)	CO ₂	4 730	5 180	—3	3		9	6	13	
1.A.3.e. Other Transportation (KS)	CO ₂			—	—					
1.A.3.e.i Off-Road	CO ₂	15 100	17 700	4	45		17	—5	50	See Note 4
Off-Road — Gasoline	CO ₂	5 000	5 000	—1	110					
Off-Road — Diesel	CO ₂	10 000	13 000	—5	35					
1.A.3.e.ii. Pipeline (Transport) (KS)	CO ₂	6 700	9 970	—3	3	2	50	45	50	
Liquid Fuels	CO ₂	43	33	—6	3					
Gaseous Fuels	CO ₂	6 660	9 930	—3	3					

- Notes:
- 1 Aviation methodology has been greatly enhanced. Fuel sold to Canadian airlines has now been allocated to either international or domestic use based upon supplemental t-km activity data.
 - 2 An updated MGEM model (MGEM07) is now used which employs much higher-resolution data in comparison to the model that was used when this uncertainty assessment was developed. The relationships are now uniform through the time series, and the structure allows for both more data resolution and future relationship enhancement for activity data.
 - 3 It is the practitioner responsible for the transportation sector estimates who feels that the uncertainty attributed to activity data, whether fuel consumption or, more specifically, vehicle populations, is flawed in its construction and solicitation. This, however, has minimal effects in a fuel-constrained model.
 - 4 In unison with the M-GEM model update, Off-Road values would be commensurately improved. Some data previously truncated are now carried at full resolution.
- KS = Key source

Table A7-9: Tier 2 Uncertainty Reporting – CH₄ Energy (Transport)

IPCC Source Category	Gas	Base Year Emissions (1990)	Year t Emissions (2001)	Uncertainty in Year t Emissions as % of Emissions in the Category		Uncertainty Introduced on National Total in Year t (2001)	% Change in Emissions between 2001 and 1990	Range of Likely % Change between 2001 and 1990		Comments
		Gg CO ₂ eq	Gg CO ₂ eq	% Below (2.5th percentile)	% Above (97.5th percentile)	%	%	Lower % (2.5th percentile)	Upper % (97.5th percentile)	
1.A.3 Transport	CH ₄	600	700	–	–	5				
Total Mobile Sources (Total Transport excluding Pipelines)	CH ₄	500	400	–24	700					
Total Non-Rail Surface Transport Vehicles (On-Road & Off-Road)	CH ₄	500	400	–29	700					
1.A.3.a. Civil Aviation (KS)	CH ₄	10	10	–75	900		–12	–35	13	See Note 1
1.A.3.b. Road Transportation (KS)	CH ₄	350	290	–19	18		–17	–24	–8	See Note 2
On-Road Gasoline Vehicles (Cars + Trucks + Heavy Duty + Motorcycles)	CH ₄	280	210	–22	16		–25	–30	–18	See Note 3
On-Road Diesel Vehicles (Cars + Trucks + Heavy Duty)	CH ₄	30	40	–65	55		55	45	70	See Note 3
On-Road Natural Gas Vehicles	CH ₄	20	30	–50	120		40	35	45	
On-Road Propane Vehicles	CH ₄	20	10	–50	120		–53	–55	–50	
1.A.3.c. Railways (KS)	CH ₄	7	7	–60	60		–8	–12	–4	
1.A.3.d. Navigation (KS)	CH ₄	7	8	–40	190		11	6	15	
1.A.3.e. Other Transportation (KS)	CH ₄	300	300	–	–					
1.A.3.e.i Off-Road	CH ₄	100	100	–80	2 300		–3	–35	60	See Note 4
Off-Road – Gasoline	CH ₄	100	100	–90	2 600					
Off-Road – Diesel	CH ₄	10	10	–90	1 700					
1.A.3.e.ii. Pipeline (Transport) (KS)	CH ₄	140	210	–15	–15		50	45	50	
Liquid Fuels	CH ₄	0	0	–	–					
Gaseous Fuels	CH ₄	100	200	–	–					

- Notes:
- 1 Aviation methodology has been greatly enhanced. Fuel sold to Canadian airlines has now been allocated to either international or domestic use based upon supplemental t-km activity data.
 - 2 An updated MGEM model (MGEM07) is now used which employs much higher-resolution data in comparison to the model that was used when this uncertainty assessment was developed. The relationships are now uniform through the time series, and the structure allows for both more data resolution and future relationship enhancement for activity data.
 - 3 It is the practitioner responsible for the transportation sector estimates who feels that the uncertainty attributed to activity data, whether fuel consumption or, more specifically, vehicle populations, is flawed in its construction and solicitation. This, however, has minimal effects in a fuel-constrained model.
 - 4 In unison with the M-GEM model update, Off-Road values would be commensurately improved. Some data previously truncated are now carried at full resolution.
- KS = Key source

Table A7-10: Tier 2 Uncertainty Reporting — N₂O Energy (Transport)

IPCC Source Category	Gas	Base Year Emissions (1990)	Year t Emissions (2001)	Uncertainty in Year t Emissions as % of Emissions in the Category		Uncertainty Introduced on National Total in Year t (2001)	% Change in Emissions between 2001 and 1990	Range of Likely % Change between 2001 and 1990		Comments
		Gg CO ₂ eq	Gg CO ₂ eq	% Below (2.5th percentile)	% Above (97.5th percentile)	%	%	Lower % (2.5th percentile)	Upper % (97.5th percentile)	Method changes or any other factors that would alter the estimated uncertainty from 2001
1.A.3 Transport	N ₂ O	6 000	9 000			47				
Total Mobile Sources (Total Transport excluding Pipelines)	N ₂ O	6 000	9 000	-28	410					
Total Non-Rail Surface Transport Vehicles (On-Road & Off-Road)	N ₂ O	5 000	7 000	-35	390					
1.A.3.a. Civil Aviation (KS)	N ₂ O	300	400	-90	1 500		13	-17	16	See Note 1
1.A.3.b. Road Transportation (KS)	N ₂ O	3 600	5 700	-35	35		57	40	75	See Note 2
On-Road Gasoline Vehicles (Cars + Trucks + Heavy Duty + Motorcycles)	N ₂ O	3 400	5 400	-35	30		58	40	80	See Note 3
On-Road Diesel Vehicles (Cars + Trucks + Heavy Duty)	N ₂ O	200	400	-70	260		53	35	65	See Note 3
On-Road Natural Gas Vehicles	N ₂ O	1	1	-95	1 400		40	35	45	
On-Road Propane Vehicles	N ₂ O	10	6	-95	1 500		-55	-55	-50	
1.A.3.c. Railways (KS)	N ₂ O	800	700	-95	1 500		-8	-12	-4	
1.A.3.d. Navigation (KS)	N ₂ O	300	300	-90	1 300		7	2	12	
1.A.3.e. Other Transportation (KS)	N ₂ O	1 000	2 000	-	-					
1.A.3.e.i Off-Road	N ₂ O	1 000	2 000	-90	1 800		27	-1	60	See Note 4
Off-Road – Gasoline	N ₂ O	30	30	-90	2 600					
Off-Road – Diesel	N ₂ O	1 000	2 000	-95	1 800					
1.A.3.e.ii. Pipeline (Transport) (KS)	N ₂ O	50	80			1	50	3	50	
Liquid Fuels	N ₂ O	0	0	-	-					
Gaseous Fuels	N ₂ O	50	80	-	-					

Notes:

- 1 Aviation methodology has been greatly enhanced. Fuel sold to Canadian airlines has now been allocated to either international or domestic use based upon supplemental t-km activity data.
 - 2 An updated MGEM model (MGEM07) is now used which employs much higher-resolution data in comparison to the model that was used when this uncertainty assessment was developed. The relationships are now uniform through the time series, and the structure allows for both more data resolution and future relationship enhancement for activity data.
 3. It is the practitioner responsible for the transportation sector estimates who feels that the uncertainty attributed to activity data, whether fuel consumption or, more specifically, vehicle populations, is flawed in its construction and solicitation. This, however, has minimal effects in a fuel-constrained model.
 - 4 In unison with the M-GEM model update, Off-Road values would be commensurately improved. Some data previously truncated are now carried at full resolution.
- KS = Key source

Table A7-11: Tier 2 Uncertainty Reporting — CO₂ Energy (Fugitives)

IPCC Source Category	Gas	Base Year Emissions (1990)	Year t Emissions (2001)	Uncertainty in Year t Emissions as % of Emissions in the Category		Uncertainty Introduced on National Total in Year t (2001)	% Change in Emissions between 2001 and 1990	Range of Likely % Change between 2001 and 1990		Comments
		(Gg CO ₂ eq)	(Gg CO ₂ eq)	% Below (2.5th percentile)	% Above (97.5th percentile)	%	%	Lower % (2.5th percentile)	Upper % (97.5th percentile)	
1.B Fugitive Emissions from Coal Mining/Handling and from Oil and Gas	CO ₂	9 800	15 000	-35	-13	6	55	-3	45	See Notes 1 and 2
<i>1.B.1.a Fugitive Emissions – Coal Mining</i>	CO ₂	–	–	–	–					
<i>1.B.2.(a+b) Fugitive Emissions – Oil and Natural Gas (KS)</i> ³	CO ₂	9 800	15 000	-35	-13		55	-3	45	See Notes 1 and 2
<i>1.B.2.a Oil</i>	CO ₂	30	80	-60	-40		190	-11	90	See Notes 1 and 2
1.B.2.a.ii Production	CO ₂	30	80	-60	-40					
1.B.2.a.iii Transport	CO ₂	0	0	-35	35					
<i>1.B.2.b. Natural Gas</i>	CO ₂	20	30	25	55		55	35	85	See Notes 1 and 2
1.B.2.b.ii Production/Processing	CO ₂	20	30	26	60					
1.B.2.b.iii Transmission	CO ₂	2	2	-5	70					
1.B.2.b.v Other Leakage	CO ₂	1	2	-40	35					
<i>1.B.2.c Fugitive Emissions – Oil and Natural Gas – Venting and Flaring (KS)</i>	CO ₂	9 800	15 000	-35	-13		55	-4	44	See Notes 1 and 2
Venting	CO ₂	4 500	7 800	-29	10					See Notes 1 and 2
Flaring	CO ₂	5 300	7 400	-50	-30					See Notes 1 and 2

Notes:

1 Uncertainty in year t emission as % of the category's emission has been taken from ICF (2005) study.

2 New uncertainty data have been obtained from a more recent study, see Energy Sector chapter for more details.

3 Overall uncertainty for Total GHG (CO₂ eq) Fugitive Emissions (oil and gas excluding coal) is -10% and +9% as per the ICF (2005) study.

KS = Key source

Table A7-12: Tier 2 Uncertainty Reporting — CH₄ Energy (Fugitives)

IPCC Source Category	Gas	Base Year Emissions (1990)	Year t Emissions (2001)	Uncertainty in Year t Emissions as % of Emissions in the Category		Uncertainty Introduced on National Total in Year t (2001)	% Change in Emissions between 2001 and 1990	Range of Likely % Change between 2001 and 1990 as per ICF Study		Comments
		Gg CO ₂ eq	Gg CO ₂ eq	% Below (2.5th percentile)	% Above (97.5th percentile)	%	%	Lower % (2.5th percentile)	Upper % (97.5th percentile)	Method changes or any other factors that would alter the estimated uncertainty from 2001
1.B Fugitive Emissions from Coal Mining/ Handling and from Oil and Gas	CH ₄	28 000	39 000	-7	16	15	40	23	65	See Notes 1 and 2
1.B.1.a Fugitive Emissions – Coal Mining (KS)	CH ₄	2 000	1 000	-30	130		-50	-70	22	See Notes 1 and 2
1.B.1.a.i Underground Mines	CH ₄	1 000	300	-50	50					
1.B.1.a.ii Surface Mines	CH ₄	700	700	-40	180					
1.B.2.(a+b) Fugitive Emissions – Oil and Natural Gas (KS)	CH ₄	26 000	38 000	-7	15		45	28	75	See Notes 1 and 2
1.B.2.a Oil	CH ₄	8 500	14 000	-29	13		65	29	150	
1.B.2.a.ii Production	CH ₄	8 500	14 000	-29	13					
1.B.2.a.iii Transport	CH ₄	32	35	-35	35					
1.B.2.b Natural Gas	CH ₄	17 000	24 000	1	28		40	19	70	See Notes 1 and 2
1.B.2.b.ii Production/ Processing	CH ₄	8 600	13 000	-9	21					
1.B.2.b.iii Transmission	CH ₄	4 000	6 000	-7	65					
1.B.2.b.iv Distribution	CH ₄	3 000	3 000	-6	70					
1.B.2.b.v Other Leakage	CH ₄	1 500	1 800	-40	35					
1.B.2.c Fugitive Emissions – Oil and Natural Gas – Venting and Flaring (KS)	CH ₄	500	700	-95	-90		35	-90	-85	See Notes 1 and 2
Venting	CH ₄	0	0	-	-					See Notes 1 and 2
Flaring	CH ₄	500	700	-95	-90					See Notes 1 and 2

Notes:

1 Uncertainty in year t emission as % of the category's emission has been taken from ICF (2005) study.

2 New uncertainty data have been obtained from a more recent study, see Energy Sector chapter for more details.

KS = Key source

Table A7-13: Tier 2 Uncertainty Reporting — Industrial Processes, Solvent and Other Product Use

IPCC Source Category	Gas	Base Year Emissions (1990)	Year t Emissions (2001)	Uncertainty in Year t Emissions as % of Emissions in the Category		Uncertainty Introduced on National Total in Year t (2001)	% Change in Emissions between 2001 and 1990	Range of Likely % Change between 2001 and 1990		Comments
		<i>Gg CO₂ eq</i>	<i>Gg CO₂ eq</i>	<i>% Below (2.5th percentile)</i>	<i>% Above (97.5th percentile)</i>	<i>%</i>	<i>%</i>	<i>Lower % (2.5th percentile)</i>	<i>Upper % (97.5th percentile)</i>	
2.A. Mineral Products		8 200	8 700	-	-		6	-28	55	
2.A.1. Cement Production (KS)	CO ₂	5 900	6 500	-35	35		11	-35	85	See Note 1
2.A.2. Lime Production (KS)	CO ₂	2 000	2 000	-2	110		-5	-45	65	See Note 1
2.A.3. Limestone and Dolomite Use (KS)	CO ₂	370	340	-16	16		-9	-15	-2	
2.A.4. Soda Ash Use (KS)	CO ₂	68	64	-26	29		-6	-35	30	See Note 1
2.B. Chemical Industry		16 500	7 520	-	-		-55	-65	-40	
2.B.1. Ammonia Production (KS)	CO ₂	5 000	6 000	-23	55		18	-16	65	See Note 1
2.B.2. Nitric Acid Production (KS)	N ₂ O	780	800	-15	-16		2	-18	28	See Note 1
2.B.3. Adipic Acid Production (KS)	N ₂ 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 (KS)	CO ₂	7 590	7 920	-5	5		4	3	6	See Note 1
2.C.3. Aluminium Production (Total GHGs) (Breakdown of emissions)	-	8 600	10 000	-45	-30		20	-35	-19	See Note 1
	CO ₂ (KS)	2 600	4 160	-15	15		60	45	70	See Note 1
	CF ₄	5 000	6 000	-70	-60		4	-70	-60	See Note 1
	CO ₂ eq C ₂ F ₆	700	600	-70	-60		-8	-70	-60	See Note 1
	CO ₂ eq PFC (KS)	6 000	6 000	-70	-60		3	-70	-60	See Note 1
2.C.4. SF ₆ Used in Magnesium Foundries (KS)	SF ₆	2 870	2 020	-1	1		-30	-30	-29	
2.G. Other		9 200	11 700	-40	1		27	-30	50	See Note 1
Other and Undifferentiated Production (KS)	CO ₂	9 200	11 700	-40	1		27	-30	50	See Note 1

IPCC Source Category	Gas	Base Year Emissions (1990)	Year t Emissions (2001)	Uncertainty in Year t Emissions as % of Emissions in the Category		Uncertainty Introduced on National Total in Year t (2001)	% Change in Emissions between 2001 and 1990	Range of Likely % Change between 2001 and 1990		Comments
		<i>Gg CO₂ eq</i>	<i>Gg CO₂ eq</i>	<i>% Below (2.5th percentile)</i>	<i>% Above (97.5th percentile)</i>	<i>%</i>	<i>%</i>	<i>Lower % (2.5th percentile)</i>	<i>Upper % (97.5th percentile)</i>	
Total GHG Emissions from Industrial Processes	CO ₂ eq	52 900	48 900	-7	5	10	-9	-27	-12	See Note 1
Total CO ₂ Emissions – Industrial Processes	CO ₂	32 600	38 300	2	19		18	-3	27	See Note 1
Total N ₂ O Emissions – Industrial Processes	N ₂ O	11 500	1 600	-8	8		-85	-85	-85	
Total HFC Emissions from ODS Substitutes (KS)	HFC	0	900	-21	55	1	-	-	-	See Note 1
Total PFC Emissions – Industrial Processes	PFC	6 000	6 000	-70	-60		-	-	-	See Note 1
Total SF ₆ Emissions – Industrial Processes	SF ₆	2 870	1 910	-1	1		-30	-30	-29	See Note 1
3. Solvent and Other Product Use										
Total Emissions from Solvent Use (KS)	N ₂ O	420	470	-23	22		12	12	12	See Note 1

Notes:

1 For details on the applicability of the uncertainty ranges provided in the ICF study to the current emission estimates, please refer to section A.7.4.2 and category-specific uncertainty sections in Chapter 4.

KS = Key Source

ODS = Ozone-depleting substance

Table A7-14: Tier 2 Uncertainty Reporting — Agriculture

IPCC Source Category	Gas	Base Year Emissions (1990)	Year t Emissions (2001)	Uncertainty in Year t Emissions as % of Emissions in the Category		Uncertainty Introduced on National Total in Year t (2001)	% Change in Emissions between 2001 and 1990	Range of Likely % Change between 2001 and 1990		Comments
		<i>Gg CO₂ eq</i>	<i>Gg CO₂ eq</i>	<i>% Below (2.5th percentile)</i>	<i>% Above (97.5th percentile)</i>	<i>%</i>	<i>%</i>	<i>Lower % (2.5th percentile)</i>	<i>Upper % (97.5th percentile)</i>	See Note 1
4.A. Enteric Fermentation (KS)	CH ₄	16 000	18 800	-9	9	6	18	15	20	See Note 1
4.B. Manure Management	CH ₄ (KS)	4 600	5 500	-15	15	4	19	15	23	See Note 1
	N ₂ O (KS)	3 700	4 600	-30	35	5	25	-10	60	See Note 1
	CO ₂ eq	8 300	10 000	-16	18		22	6	40	
4.D. Agricultural Soils						36				
Direct Soil Emissions (KS)	N ₂ O	22 000	24 000	-25	35		11	7	16	See Note 1
Indirect Soil Emissions (KS)	N ₂ O	5 400	7 000	-60	120		28	24	35	See Note 1
Total (Direct and Indirect Soil Emissions)	N ₂ O	27 000	31 000	-25	40		15	11	20	See Note 1

Notes:

1 Revised uncertainty estimates have been obtained from more recent studies. See Agriculture Sector Chapter 6 for more details.

KS = Key source

Table A7-15: Tier 2 Uncertainty Reporting — Waste

IPCC Source Category	Gas	Base Year Emissions (1990)	Year t Emissions (2001)	Uncertainty in Year t Emissions as % of Emissions in the Category		Uncertainty Introduced on National Total in Year t (2001)	% Change in Emissions between 2001 and 1990	Range of Likely % Change between 2001 and 1990		Comments
		<i>Gg CO₂ eq</i>	<i>Gg CO₂ eq</i>	<i>% Below (2.5th percentile)</i>	<i>% Above (97.5th percentile)</i>	<i>%</i>	<i>%</i>	<i>Lower % (2.5th percentile)</i>	<i>Upper % (97.5th percentile)</i>	Method changes or any other factors that would alter the estimated uncertainty from 2001
6. Waste	CO ₂ eq	20 000	25 000			31				
6.A. Solid Waste Disposal on Land (KS)	CH ₄	19 000	23 000	-35	40		25	29	55	
Emissions from MSW Landfills	CH ₄	17 000	22 000	-40	35					See Note 1
Emissions from Wood Waste	CH ₄	2 000	2 000	-60	190					See Note 2
6.B. Wastewater Handling/Treatment (KS)	CO ₂ eq	1 000	1 000	-40	55		12	12	13	
Emissions from Wastewater Treatment	CH ₄	360	400	-40	45		13	12	13	See Note 2
	N ₂ O	900	1 000	-60	65		12	12	12	See Note 3
6.C. Waste Incineration (KS)	CO ₂ eq	300	300	-12	65		10	10	11	
Emissions from MSW Incineration	CO ₂	300	300	-3	85		12	11	12	See Note 4
Emissions from Sewage Sludge Incineration	N ₂ O	50	60	-80	85		11	11	12	See Note 5.
	CH ₄	10	7	-60	60		-25	-30	-19	See Note 6

Notes:

- 1 The accuracy of these values is subject to the following limitations: (1) the uncertainty values from the ICF (2004) study were calculated from the Monte Carlo method employing a much simplified CH₄ 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 (CH₄ volume capture, MSW landfilling rate per capita, Scholl Canyon constants [CH₄ generation potential, L₀, and the CH₄ 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 CH₄ captured to be 10% overestimated. The uncertainty about the quantity of CH₄ captured was overestimated due to a transcription error.
- 2 The input values for this category were IPCC default values or assumed values.
- 3 The wastewater input uncertainties were assumed values.
- 4 Uncertainties for all inputs were assumed.
- 5 Uncertainties for all inputs were assumed except for the N₂O emissions, which were based on IPCC estimates.
- 6 The uncertainty range for the CH₄ emission factor for fluidized beds in the 2001 inventory year was assumed. For simplicity, the multihearth incinerators were not included. Uncertainty about the quantity of sewage sludge incinerated was assumed based upon IPCC values.

KS = Key source

A7.4.1 Energy

Emissions evaluated for this sector include CO₂, CH₄, and N₂O from stationary combustion and from transport and CO₂ and CH₄ from fugitive emissions. Uncertainty values were obtained from the ICF (2004, 2005) study based upon data and models that were developed for the 2003 NIR submission year for the year 2001 inventory.

A7.4.1.1 Energy — Stationary Combustion

The overall uncertainty for CO₂ is found to have a range of -4% to +1%. The highest uncertainty range for CO₂ from major fuel types used in this subsector relates to liquid fuels (-15% to +2%). Estimates for uncertainty ranges for CH₄ and N₂O emissions in this subsector are -24% to +700% and -11% to +650%, respectively. Additional analysis of uncertainty is provided in Chapter 3.

A7.4.1.2 Energy — Transport

The ICF uncertainty range for CO₂ 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 CO₂ estimates directly follows the uncertainty existing in the fuel quantities consumed. Uncertainties for CH₄ and N₂O are in the ranges of -24% to +700% and -28% to +410%, respectively.

In the time since the ICF Uncertainty study was completed, some significant changes to Transport estimation methodology have been employed. Specifically, the methodology to allocate aviation fuels to domestic or international use has changed along with the method to allocate Transport fuels between On and Off Road. While the reduction of uncertainty accompanying these improvements has not yet been quantified, we feel the uncertainty indicated in the study is not representative of that embodied in the new methods. 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 transportation category uncertainties.

A7.4.1.3 Energy — Fugitive Emissions

This subsector includes CH₄ and CO₂ fugitive emissions occurring in the coal mining and oil and gas industry. It includes emissions associated with leaks, venting, and flaring in

the oil and gas operations, as well as in coal mining. The uncertainty ranges for emissions from venting and flaring activities in the oil and gas industry are –35% to –13% for CO₂ and –7% to +16% for CH₄. The uncertainties discussion presented in the chapter 3 of this report for the upstream oil and gas industry are based on results from a Tier 1 analysis conducted by Clearstone Engineering for CAPP (2005).

For the refining industry, the uncertainty analysis was conducted by Levelton Consulting for the CPPI (2004). The overall uncertainty estimate, based on a Tier 1 analysis, was found to be ±8.3%. A Tier 2 analysis was also conducted; in this case, overall uncertainties were estimated to be ±14%. Note that the uncertainty estimates presented in Table A7-11 and Table A7-12 for the overall fugitive category (1.B), the overall oil category (1.B.2.a), Oil Production (1.B.2.a.i), 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 analysis, the uncertainty for the 2001 GHG emissions from Industrial Processes, excluding halocarbons, ranged from –7% to +5%. There has been addition of new sources, improvements in calculation methods, and acquisition of new activity data for a number of categories since the completion of the ICF study. It is therefore expected that the uncertainty associated with the Industrial Processes Sector will be slightly different from the value provided by ICF. Because of similar reasons the uncertainty ranges provided for emission totals belonging to the gases are also believed to be different.

Major factors that have affected the results of the ICF uncertainty assessment are described in the following sections. Further details on the level of uncertainty for each category are provided in Chapter 4.

A7.4.2.1 Industrial Processes – Mineral Products

The uncertainty levels associated with the subsectors of cement and lime production would be lower than those shown in the ICF report because of the improvements made to the calculation methods. Inclusion of additional emissions coming from uses of limestone, which were not reported in the 1990–2001 inventory, also affects the uncertainty estimates provided by ICF. The uncertainty values associated with CO₂ emissions from soda ash use in the whole time series vary from ±10% to ±14%. (AMEC 2006). The uncertainty associated with emissions from magnesite use in the whole time series varies from ±4.9% to ±6.0% (AMEC, 2006).

A7.4.2.2 Industrial Processes – Chemical Industry

Improvements in GHG estimates have been made to the category of ammonia production. For instance, the value of ammonia production not involving steam methane reformation (SMR) and the urea export data used for estimating emissions have been updated for all years. The uncertainty associated with this category as compared to the ICF study have lowered as a result of these updates. The uncertainty range, provided in the ICF study, for the category of nitric acid production is no longer applicable, since the emission estimation methodology has been revised as a result of recent study (Cheminfo, 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 has helped reduce the uncertainty related to this category. Since there has not been any change in method or data source for adipic acid production, the uncertainty values presented in the ICF report are still applicable to its corresponding emission estimates.

A7.4.2.3 Industrial Processes – Metal Production

The shift from a Tier 1 to a Tier 2 approach, since the completion of the ICF study, for estimating CO₂ emissions from iron and steel production would have decreased the uncertainty for this category. The uncertainties in CO₂ and PFC emission estimates for aluminium production, provided in the ICF report, are no longer applicable due to an improvement in the calculation method. SF₆ from aluminium production is a category for which uncertainty has not been assessed by ICF. Since there has not been any change in data source for magnesium production, the uncertainty value presented in the ICF report is still applicable to the emission estimate in this submission. SF₆ from magnesium casting was not a category considered in the ICF study. However, according to the Cheminfo Services (2005) study, it has an uncertainty of $\pm 4\%$.

A7.4.2.4 Industrial Processes – Consumption of Halocarbons and SF₆

Owing to acquisition of more recent consumption data on both HFCs and PFCs and method improvements, the uncertainty ranges for HFC and PFC emissions of -22% to $+60\%$ and -28% to 70% , respectively, would be considered as highly conservative. Uncertainty for both the categories of SF₆ from electrical equipment and SF₆ from semiconductor manufacturing were not assessed by ICF. Nonetheless, the Cheminfo (2005) study provides an uncertainty range of -50 to $+19\%$ for the former category.

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 study. Revisions are due to changes in the CO₂ emission estimates for aluminium production, ammonia production and iron & 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 CO₂ emissions from natural gas used for hydrogen making to the Energy Sector categories. Although the uncertainty around the current emission estimate has not been re-assessed, the range provided in the ICF study are acceptable, but are considered as conservative.

A7.4.3 Solvent and Other Product Use

The time series for Solvent Use has been revised based on the N₂O sales information gathered during the Cheminfo 2006 study. Revised uncertainty estimates were also delivered as part of the report. For further details, see Chapter 5, section 5.2.3.

A7.4.4 Agriculture

Since the ICF 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 CH₄ sources and N₂O 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

So far, the LULUCF Sector has not been included in top-down uncertainty analyses such as the ICF study, since the most important uncertainty sources stemmed from model bias (omissions of carbon pools, lack of a unified land framework) and were not quantifiable. Quantitative uncertainty analyses have become possible due to the methodological improvements implemented since the 2006 submission; work is under way to develop formal uncertainty estimates in each of the LULUCF categories. Uncertainty values in Cropland remaining Cropland are reported in Chapter 7. Section A3.5 in Annex 3 presents preliminary assessments and expert-based, partial uncertainty estimates in, notably, wetlands and forest conversion.

All LULUCF categories do not equally contribute to the overall sectoral uncertainty. By virtue of the size of fluxes, uncertainties about forest land estimates and, to a lesser extent, cropland, dominate the sector and are prioritized. Cross-cutting estimates, such as forest conversion to other land categories, introduce a covariance factor between estimates in different land categories, which adds to the complexity of developing an aggregate uncertainty value.

A7.4.6 Waste

Emissions evaluated for this sector include CH₄ emissions from solid waste disposal on land, CH₄ and N₂O emissions from wastewater handling, and CO₂, CH₄, and N₂O emissions from waste incineration.

Uncertainty values were obtained from the ICF (2004, 2005) study 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 CH₄, since CO₂ emissions originate from the biodegradation of biomass and therefore are not included in the total emissions and since N₂O emissions are assumed to be negligible. The uncertainty associated with CH₄ 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 CH₄ generation potential and the CH₄ rate constant used in the Scholl Canyon model for the MSW landfill CH₄ generation estimates. As a result of the ICF Consultants 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 parameters to the model (Thompson *et al.*, 2005). In the absence of a quantitative statement based upon a follow-up Tier 2 uncertainty study, it is expected that the uncertainty of the CH₄ emissions from this source would be reduced by the introduction of these new values.

A7.4.6.2 Waste — Wastewater Handling

N₂O emissions were responsible for approximately 80% of the total emissions from this subsector. The overall level uncertainty associated with the Wastewater Handling subsector was estimated to be in the range of –40% to +55%.

Uncertainties for CH₄ and N₂O emissions were –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.

A7.4.6.3 Waste — Waste Incineration

The overall uncertainty associated with the Waste Incineration source category was estimated to be in the range of –12% to +65%. CO₂ contributed roughly 79% of the total emissions from this subsector. The uncertainties associated with CO₂, CH₄, and N₂O emissions were –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.

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Annex 8 Canada's Greenhouse Gas Emission Tables, 1990–2005

Annex 8 contains summary tables illustrating national GHG emissions by year, by gas, and by sector.

Table A8-1: Greenhouse Gas Category Description

Greenhouse Gas 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 are included)
Mining	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 operation
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.
	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 houses)
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 consumption of fossil fuels (including non-CO ₂ emissions from ethanol) by vehicles licensed to operate on roads
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 domestically
Others - Off Road	Emissions resulting from the consumption of fossil fuels (including non-CO ₂ 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
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 aluminium, iron and steel, magnesium production and casting
d. Consumption of Halocarbons and SF₆	Use of HFCs and/or PFCs in air conditioning units, refrigeration units, fire extinguishers, aerosol cans, solvents, foam blowing, semi-conductor manufacturing and electronics industry; use of SF ₆ in electrical equipment and semi-conductors
e. Other & Undifferentiated Production	Non-energy use of fossil fuels
SOLVENT & OTHER PRODUCT USE	Emissions resulting from the use of N ₂ O as anaesthetic and propellant
AGRICULTURE	Emissions resulting from:
a. Enteric Fermentation	Livestock enteric fermentation
b. Manure Management	Livestock waste management
c. Agriculture Soils	
Direct sources	Direct N ₂ O emissions from synthetic fertilizer, manure on cropland, crop residue, tillage, summer-fallow, irrigation and cultivation of organic soils
Manure on Pasture, Range and Paddock	Direct N ₂ O emissions from manure deposited on pasture, range and paddock
Indirect Sources	Indirect N ₂ 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 ₂) ; lands converted to cropland
c. Grassland	Managed grasslands, lands converted to grasslands (CO ₂)
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 1990–2005 Greenhouse Gas Emissions by Sector

Greenhouse Gas Categories	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
	<i>kt CO₂ equivalent</i>											
TOTAL¹	596 000	646 000	664 000	677 000	683 000	695 000	721 000	714 000	720 000	745 000	747 000	747 000
ENERGY	473 000	514 000	530 000	543 000	552 000	566 000	592 000	586 000	593 000	613 000	608 000	609 000
a. Stationary Combustion Sources	282 000	294 000	302 000	307 000	311 000	323 000	344 000	340 000	345 000	360 000	349 000	346 000
Electricity and Heat Generation	95 300	101 000	99 600	111 000	123 000	121 000	132 000	134 000	129 000	135 000	127 000	129 000
Fossil Fuel Industries	52 000	54 000	55 000	51 000	55 000	66 000	67 000	68 000	73 000	74 000	72 000	73 000
Petroleum Refining and Upgrading	16 000	14 000	15 000	14 000	13 000	13 000	14 000	16 000	19 000	19 000	18 000	18 000
Fossil Fuel Production	36 000	40 000	40 000	37 000	43 000	52 000	53 000	53 000	54 000	54 000	54 000	55 000
Mining & Oil and Gas Extraction	6 180	7 850	8 740	8 960	7 940	7 450	10 400	10 300	11 800	15 700	14 800	15 600
Manufacturing Industries	54 700	52 900	54 600	54 600	52 100	52 800	53 000	48 800	48 900	49 300	50 900	45 900
Iron and Steel	6 490	7 040	7 330	7 300	7 160	7 280	7 190	5 890	6 480	6 370	6 480	6 520
Non Ferrous Metals	3 180	3 090	3 480	3 170	3 490	3 250	3 190	3 460	3 210	3 200	3 230	3 190
Chemical	7 090	8 450	8 790	8 880	8 560	8 450	7 850	6 750	6 120	5 810	6 760	5 350
Pulp and Paper	13 600	11 700	12 200	12 000	11 000	11 100	11 000	9 780	9 200	8 990	9 310	7 340
Cement	3 690	3 670	3 500	3 560	3 630	3 920	3 890	3 850	4 090	4 080	4 210	4 580
Other Manufacturing	20 600	19 000	19 400	19 700	18 300	18 700	19 900	19 000	19 800	20 800	20 900	18 900
Construction	1 880	1 180	1 270	1 260	1 120	1 170	1 080	1 010	1 240	1 300	1 350	1 310
Commercial & Institutional	25 800	29 000	29 600	30 000	27 300	28 900	33 200	33 200	35 400	37 900	37 900	36 800
Residential	44 000	45 000	50 000	46 000	41 000	43 000	45 000	42 000	44 000	45 000	43 000	42 000
Agriculture & Forestry	2 420	2 790	2 960	2 950	2 610	2 690	2 570	2 210	2 110	2 210	2 100	1 950
b. Transportation²	150 000	160 000	170 000	170 000	180 000	180 000	180 000	180 000	180 000	190 000	190 000	200 000
Domestic Aviation	6 400	5 900	6 200	6 300	6 500	6 600	6 600	6 200	6 800	7 300	7 900	8 700
Road Transportation	101 000	112 000	111 000	115 000	118 000	121 000	122 000	124 000	126 000	129 000	133 000	135 000
Light Duty Gasoline Vehicles	47 200	45 700	44 500	44 500	43 100	43 900	43 300	43 000	43 100	42 600	42 400	41 200
Light Duty Gasoline Trucks	21 300	28 700	29 700	32 400	35 000	37 200	37 900	38 600	40 300	41 700	43 300	44 500
Heavy Duty Gasoline Vehicles	8 050	6 270	5 860	5 820	5 960	5 420	5 450	6 180	6 050	6 230	6 600	6 510
Motorcycles	151	125	121	127	150	146	163	187	212	233	252	260
Light Duty Diesel Vehicles	363	335	321	322	333	347	362	377	398	408	441	443
Light Duty Diesel Trucks	724	1 360	1 340	1 470	1 610	1 610	1 730	1 750	1 850	1 930	2 040	2 200
Heavy Duty Diesel Vehicles	21 200	27 100	26 600	28 700	30 500	31 200	32 100	33 200	33 500	35 000	37 400	39 000
Propane & Natural Gas Vehicles	2 200	2 100	2 000	1 800	1 800	1 500	1 100	1 100	840	820	860	720
Railways	7 000	6 000	6 000	6 000	6 000	7 000	7 000	7 000	6 000	6 000	6 000	6 000
Domestic Marine	5 100	4 400	4 500	4 500	5 200	5 000	5 100	5 500	5 500	6 200	6 700	6 500
Others	30 000	30 000	40 000	40 000	40 000	40 000	40 000	40 000	40 000	40 000	40 000	40 000
Off Road Gasoline	7 000	7 000	8 000	7 000	9 000	8 000	8 000	8 000	8 000	8 000	8 000	7 000
Off Road Diesel	20 000	20 000	20 000	20 000	20 000	20 000	20 000	20 000	20 000	20 000	20 000	20 000
Pipelines	6 900	12 000	12 500	12 600	12 500	12 600	11 300	10 300	10 900	9 110	8 520	10 100
c. Fugitive Sources	42 700	57 000	60 900	62 600	64 900	62 200	64 700	65 600	65 100	65 900	66 200	65 700
Coal Mining	2 000	2 000	2 000	2 000	1 000	1 000	900	1 000	700	700	700	700
Oil and Natural Gas	40 700	55 300	59 200	61 000	63 500	61 100	63 700	64 600	64 400	65 100	65 500	65 000
Oil	4 180	5 150	5 330	5 560	5 430	5 390	5 430	5 770	5 580	5 780	5 940	5 660
Natural Gas	12 900	16 500	18 100	17 600	19 100	18 700	19 400	19 600	19 700	20 100	20 400	20 800
Venting	19 300	28 600	30 400	32 300	31 900	31 700	33 500	34 200	33 600	33 700	33 700	33 000
Flaring	4 400	5 100	5 400	5 600	7 100	5 300	5 400	5 000	5 400	5 600	5 400	5 500
INDUSTRIAL PROCESSES	53 500	55 700	56 900	56 500	52 600	50 000	50 200	49 200	48 700	50 600	55 400	53 300
a. Mineral Products	8 300	8 800	8 400	9 000	9 100	9 500	9 600	9 000	9 000	9 100	9 500	9 500
Cement Production	5 400	6 100	5 800	6 200	6 400	6 600	6 700	6 500	6 700	6 800	7 100	7 200
Lime Production	1 700	1 800	1 800	1 800	1 800	1 900	1 900	1 600	1 700	1 600	1 800	1 700
Mineral Product Use ³	1 090	878	883	929	928	908	1 020	844	636	612	590	599
b. Chemical Industry	16 000	17 000	18 000	16 000	11 000	8 200	7 400	7 100	7 200	7 400	9 800	8 900
Ammonia Production	3 900	5 300	5 400	5 200	5 200	5 300	5 300	5 000	4 700	5 000	5 500	5 000
Nitric Acid Production	1 010	1 000	1 110	1 060	1 040	1 170	1 230	1 280	1 260	1 260	1 230	1 260
Adipic Acid Production	11 000	11 000	11 000	9 900	5 100	1 700	900	800	1 300	1 100	3 100	2 600
c. Metal Production	19 500	19 200	18 800	18 700	19 500	18 800	18 900	17 400	17 500	17 200	17 600	16 200
Iron and Steel Production	7 060	7 880	7 750	7 550	7 690	7 890	7 900	7 280	7 120	7 040	8 160	7 010
Aluminum Production	9 300	9 200	9 400	9 400	9 600	8 600	8 200	7 700	7 500	7 700	7 300	7 900
SF ₆ Used in Magnesium Smelters and Casters	3 110	2 110	1 640	1 670	2 210	2 270	2 780	2 360	2 940	2 480	2 190	1 300
d. Consumption of Halocarbons and SF₆	1 800	2 000	2 000	2 700	3 400	3 900	4 500	5 500	5 000	6 000	5 500	6 100
e. Other & Undifferentiated Production	8 300	8 700	9 600	10 000	9 200	9 700	9 700	10 000	9 900	11 000	13 000	13 000
SOLVENT & OTHER PRODUCT USE	170	210	210	230	210	220	240	210	170	220	210	180
AGRICULTURE	46 000	50 000	52 000	52 000	52 000	52 000	53 000	52 000	52 000	54 000	56 000	57 000
a. Enteric Fermentation	18 000	21 000	22 000	22 000	22 000	21 000	22 000	22 000	23 000	23 000	24 000	25 000
b. Manure Management	6 700	7 400	7 500	7 600	7 600	7 600	7 800	8 000	8 100	8 100	8 400	8 600
c. Agriculture Soils	21 000	22 000	23 000	23 000	23 000	23 000	23 000	22 000	22 000	23 000	24 000	23 000
Direct Sources	12 000	12 000	13 000	13 000	13 000	13 000	13 000	12 000	12 000	13 000	13 000	13 000
Pasture, Range and Paddock Manure	3 200	3 700	3 800	3 800	3 800	3 800	3 900	4 000	4 000	4 000	4 300	4 400
Indirect Sources	5 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000
WASTE	23 000	25 000	25 000	25 000	26 000	26 000	26 000	26 000	27 000	27 000	28 000	28 000
a. Solid Waste Disposal on Land	22 000	24 000	24 000	24 000	25 000	25 000	25 000	25 000	26 000	26 000	26 000	27 000
b. Wastewater Handling	780	810	840	840	850	900	880	910	910	910	930	930
c. Waste Incineration	400	350	340	280	270	240	250	250	220	230	230	240
Land Use, Land-use Change and Forestry	-120 000	150 000	-75 000	-120 000	95 000	-31 000	-110 000	-94 000	55 000	22 000	81 000	-17 000
a. Forest Land	-150 000	140 000	-93 000	-130 000	78 000	-46 000	-120 000	-110 000	43 000	11 000	70 000	-27 000
b. Cropland	14 000	7 300	6 900	6 000	5 400	4 600	3 700	2 800	2 300	1 400	1 200	520
c. Grassland	-	-	-	-	-	-	-	-	-	-	-	-
d. Wetlands	5 000	3 000	3 000	3 000	3 000	3 000	2 000	2 000	1 000	2 000	2 000	2 000
e. Settlements	9 000	9 000	8 000	8 000	8 000	8 000	8 000	8 000	8 000	8 000	8 000	8 000

Notes:

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

Table A8-3: 2005 Greenhouse Gas Emissions Summary for Canada**Greenhouse Gas Categories**

Greenhouse Gas Categories		Greenhouse Gases									
		CO ₂	CH ₄	CH ₄	N ₂ O	N ₂ O	HFCs	PFCs	SF ₆	TOTAL	
		Global Warming Potential Unit	kt	21 kt CO ₂ eq	kt	310 kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	
TOTAL ¹		583 000	5 200	110 000	140	44 000	4 800	3 100	2 500	747 000	
ENERGY		544 000	2 600	54 000	30	10 000	–	–	–	609 000	
a. Stationary Combustion Sources	Stationary Combustion Sources	338 000	200	5 000	8	3 000	–	–	–	346 000	
	Electricity and Heat Generation	128 000	5.1	110	2	700	–	–	–	129 000	
	Fossil Fuel Industries	70 400	100	3 000	2	500	–	–	–	73 000	
	Petroleum Refining and Upgrading	18 000	–	–	0.4	100	–	–	–	18 000	
	Fossil Fuel Production	52 000	100	3 000	1	400	–	–	–	55 000	
	Mining & Oil and Gas Extraction	15 500	0.3	6	0.4	100	–	–	–	15 600	
	Manufacturing Industries	45 400	3	60	2	500	–	–	–	45 900	
	Iron and Steel	6 460	0.2	5	0.2	60	–	–	–	6 520	
	Non Ferrous Metals	3 170	0.07	2	0.05	20	–	–	–	3 190	
	Chemical	5 320	0.11	2.3	0.09	30	–	–	–	5 350	
	Pulp and Paper	7 040	2	40	0.8	300	–	–	–	7 340	
	Cement	4 570	0.1	2	0.04	10	–	–	–	4 580	
	Other Manufacturing	18 800	0.4	8	0.4	100	–	–	–	18 900	
	Construction	1 300	0.02	0.5	0.03	10	–	–	–	1 310	
	Commercial & Institutional	36 600	0.6	10	0.7	200	–	–	–	36 800	
	Residential	39 500	90	2 000	2	500	–	–	–	42 000	
	Agriculture & Forestry	1 930	0.03	0.7	0.06	20	–	–	–	1 950	
	b. Transportation ²	Transportation ²	190 000	30	600	20	8 000	–	–	–	200 000
		Domestic Aviation	8 420	0.5	9	0.8	200	–	–	–	8 700
		Road Transportation	131 000	9.4	200	11	3 500	–	–	–	135 000
		Light Duty Gasoline Vehicles	39 800	3.2	66	4.1	1 300	–	–	–	41 200
		Light Duty Gasoline Trucks	42 800	3.2	67	5.3	1 600	–	–	–	44 500
		Heavy Duty Gasoline Vehicles	6 370	0.38	8.0	0.43	130	–	–	–	6 510
		Motorcycles	255	0.16	3.5	0.01	1.5	–	–	–	260
		Light Duty Diesel Vehicles	432	0.01	0.2	0.03	10	–	–	–	443
		Light Duty Diesel Trucks	2 150	0.05	1	0.2	50	–	–	–	2 200
		Heavy Duty Diesel Vehicles	38 600	2	40	1	400	–	–	–	39 000
Propane & Natural Gas Vehicles		706	0.7	10	0.01	4	–	–	–	720	
Railways		5 620	0.3	6	2	700	–	–	–	6 000	
Domestic Marine		6 070	0.4	9	1	400	–	–	–	6 500	
Others		38 000	20	400	9	3 000	–	–	–	40 000	
Off Road Gasoline		7 000	8	200	0.2	50	–	–	–	7 000	
Off Road Diesel		21 000	1	20	9	3 000	–	–	–	20 000	
Pipelines		9 850	9.8	210	0.3	80	–	–	–	10 100	
c. Fugitive Sources		Fugitive Sources	16 000	2 300	49 000	0.1	40	–	–	–	65 700
		Coal Mining	–	30	700	–	–	–	–	–	700
		Oil and Natural Gas	16 500	2 310	48 500	0.1	40	–	–	–	65 000
		Oil	170	260	5 460	0.1	30	–	–	–	5 660
		Natural Gas	61.0	989	20 800	–	–	–	–	–	20 800
		Venting	10 800	1 050	22 100	0.01	4.56	–	–	–	33 000
		Flaring	5 400	3.7	78	0.01	2	–	–	–	5 500
INDUSTRIAL PROCESSES		39 000	–	–	12.6	3 910	4 800	3 100	2 500	53 300	
a. Mineral Products		Mineral Products	9 500	–	–	–	–	–	–	–	9 500
		Cement Production	7 200	–	–	–	–	–	–	–	7 200
	Lime Production	1 700	–	–	–	–	–	–	–	1 700	
	Mineral Product Use ³	599	–	–	–	–	–	–	–	599	
b. Chemical Industry	Chemical Industry	5 000	–	–	12.6	3 910	–	–	–	8 900	
	Ammonia Production	5 000	–	–	–	–	–	–	–	5 000	
	Nitric Acid Production	–	–	–	4.08	1 260	–	–	–	1 260	
	Adipic Acid Production	–	–	–	8.5	2 600	–	–	–	2 600	
c. Metal Production	Metal Production	11 900	–	–	–	–	–	3 000	1 320	16 200	
	Iron and Steel Production	7 010	–	–	–	–	–	–	–	7 010	
	Aluminum Production	4 800	–	–	–	–	–	3 000	17.6	7 900	
	SF ₆ Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	1 300	1 300	
d. Consumption of Halocarbons and SF ₆	Consumption of Halocarbons and SF ₆	–	–	–	–	–	4 800	30	1 200	6 100	
	Other & Undifferentiated Production	13 000	–	–	–	–	–	–	–	13 000	
SOLVENT & OTHER PRODUCT USE		–	–	–	0.57	180	–	–	–	180	
AGRICULTURE		–	1 300	28 000	93	29 000	–	–	–	57 000	
a. Enteric Fermentation	Enteric Fermentation	–	1 200	25 000	–	–	–	–	–	25 000	
	Manure Management	–	150	3 200	17	5 400	–	–	–	8 600	
c. Agriculture Soils	Agriculture Soils	–	–	–	76	23 000	–	–	–	23 000	
	Direct Sources	–	–	–	41	13 000	–	–	–	13 000	
	Pasture, Range and Paddock Manure	–	–	–	14	4 400	–	–	–	4 400	
	Indirect Sources	–	–	–	20	6 000	–	–	–	6 000	
WASTE		190	1 300	27 000	2	700	–	–	–	28 000	
a. Solid Waste Disposal on Land	Solid Waste Disposal on Land	–	1 300	27 000	–	–	–	–	–	27 000	
	Wastewater Handling	–	12	250	2	700	–	–	–	930	
c. Waste Incineration	Waste Incineration	190	0.06	1	0.2	50	–	–	–	240	
Land Use, Land-use Change and Forestry		-26 000	260	5 400	11	3 400	–	–	–	-17 000	
a. Forest Land	Forest Land	-35 000	240	5 100	10	3 100	–	–	–	-27 000	
	Cropland	180	9	200	0.5	200	–	–	–	520	
c. Grassland	Grassland	–	–	–	–	–	–	–	–	–	
d. Wetlands	Wetlands	1 000	2	30	0.07	20	–	–	–	2 000	
e. Settlements	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 CO₂ emissions coming from the use of limestone & dolomite, soda ash, and magnesite.

Totals may not add up due to rounding.

Table A8-4: 2004 Greenhouse Gas Emissions Summary for Canada

Greenhouse Gas Categories		Greenhouse Gases								
Global Warming Potential	Unit	CO ₂	CH ₄	CH ₄	N ₂ O	N ₂ O	HFCs	PFCs	SF ₆	TOTAL
		kt	kt	21 kt CO ₂ eq	kt	310 kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq
TOTAL¹		583 000	5 200	110 000	140	45 000	4 700	3 100	3 000	747 000
ENERGY		543 000	2 600	55 000	30	10 000	—	—	—	608 000
a. Stationary Combustion Sources		342 000	200	5 000	8	3 000	—	—	—	349 000
Electricity and Heat Generation		126 000	4.7	100	2	700	—	—	—	127 000
Fossil Fuel Industries		69 200	100	2 000	1	500	—	—	—	72 000
Petroleum Refining and Upgrading		18 000	—	—	0.4	100	—	—	—	18 000
Fossil Fuel Production		51 100	100	2 000	1	300	—	—	—	54 000
Mining & Oil and Gas Extraction		14 700	0.3	6	0.3	100	—	—	—	14 800
Manufacturing Industries		50 300	3	60	2	500	—	—	—	50 900
Iron and Steel		6 420	0.2	5	0.2	60	—	—	—	6 480
Non Ferrous Metals		3 210	0.07	2	0.05	10	—	—	—	3 230
Chemical		6 720	0.14	2.9	0.1	40	—	—	—	6 760
Pulp and Paper		9 000	2	40	0.9	300	—	—	—	9 310
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		37 700	0.7	10	0.8	200	—	—	—	37 900
Residential		40 700	90	2 000	2	500	—	—	—	43 000
Agriculture & Forestry		2 080	0.04	0.7	0.06	20	—	—	—	2 100
b. Transportation²		185 000	30	600	20	8 000	—	—	—	190 000
Domestic Aviation		7 660	0.4	9	0.7	200	—	—	—	7 900
Road Transportation		129 000	9.6	200	12	3 700	—	—	—	133 000
Light Duty Gasoline Vehicles		40 900	3.5	72	4.6	1 400	—	—	—	42 400
Light Duty Gasoline Trucks		41 500	3.2	66	5.4	1 700	—	—	—	43 300
Heavy Duty Gasoline Vehicles		6 460	0.41	8.7	0.42	130	—	—	—	6 600
Motorcycles		247	0.16	3.4	0.00	1.5	—	—	—	252
Light Duty Diesel Vehicles		431	0.01	0.2	0.03	10	—	—	—	441
Light Duty Diesel Trucks		1 990	0.05	1	0.2	50	—	—	—	2 040
Heavy Duty Diesel Vehicles		37 000	2	40	1	300	—	—	—	37 400
Propane & Natural Gas Vehicles		842	0.7	20	0.02	5	—	—	—	860
Railways		5 350	0.3	6	2	700	—	—	—	6 000
Domestic Marine		6 250	0.5	10	1	400	—	—	—	6 700
Others		36 000	20	400	9	3 000	—	—	—	40 000
Off Road Gasoline		8 000	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		16 000	2 400	50 000	0.1	40	—	—	—	66 200
Coal Mining		—	30	700	—	—	—	—	—	700
Oil and Natural Gas		16 500	2 330	49 000	0.1	40	—	—	—	65 500
Oil		180	273	5 720	0.1	30	—	—	—	5 940
Natural Gas		57.2	968	20 300	—	—	—	—	—	20 400
Venting		10 900	1 090	22 900	0.02	4.66	—	—	—	33 700
Flaring		5 400	3.7	79	0.01	2	—	—	—	5 400
INDUSTRIAL PROCESSES		40 000	—	—	13.9	4 320	4 700	3 100	3 000	55 400
a. Mineral Products		9 500	—	—	—	—	—	—	—	9 500
Cement Production		7 100	—	—	—	—	—	—	—	7 100
Lime Production		1 800	—	—	—	—	—	—	—	1 800
Mineral Product Use ³		590	—	—	—	—	—	—	—	590
b. Chemical Industry		5 500	—	—	13.9	4 320	—	—	—	9 800
Ammonia Production		5 500	—	—	—	—	—	—	—	5 500
Nitric Acid Production		—	—	—	3.96	1 230	—	—	—	1 230
Adipic Acid Production		—	—	—	10	3 100	—	—	—	3 100
c. Metal Production		12 400	—	—	—	—	—	3 000	2 220	17 600
Iron and Steel Production		8 160	—	—	—	—	—	—	—	8 160
Aluminum Production		4 200	—	—	—	—	—	3 000	31.9	7 300
SF ₆ Used in Magnesium Smelters and Casters		—	—	—	—	—	—	—	2 190	2 190
d. Consumption of Halocarbons and SF₆		—	—	—	—	—	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	27 000	94	29 000	—	—	—	56 000
a. Enteric Fermentation		—	1 100	24 000	—	—	—	—	—	24 000
b. Manure Management		—	150	3 200	17	5 300	—	—	—	8 400
c. Agriculture Soils		—	—	—	77	24 000	—	—	—	24 000
Direct Sources		—	—	—	42	13 000	—	—	—	13 000
Pasture, Range and Paddock Manure		—	—	—	14	4 300	—	—	—	4 300
Indirect Sources		—	—	—	20	6 000	—	—	—	6 000
WASTE		180	1 300	27 000	2	700	—	—	—	28 000
a. Solid Waste Disposal on Land		—	1 300	26 000	—	—	—	—	—	26 000
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		61 000	580	12 000	24	7 600	—	—	—	81 000
a. Forest Land		51 000	560	12 000	24	7 400	—	—	—	70 000
b. Cropland		900	9	200	0.5	200	—	—	—	1 200
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 CO₂ emissions coming from the use of limestone & dolomite, soda ash, and magnesite.

Totals may not add up due to rounding.

Table A8-5: 2003 Greenhouse Gas Emissions Summary for Canada

Greenhouse Gas Categories		Greenhouse Gases								
	Global Warming Potential Unit	CO ₂	CH ₄	CH ₄	N ₂ O	N ₂ O	HFCs	PFCs	SF ₆	TOTAL
				21		310				
		kt	kt	kt CO ₂ eq	kt	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq
TOTAL¹		586 000	5 100	110 000	130	41 000	4 400	3 000	4 200	745 000
ENERGY		549 000	2 600	54 000	30	10 000	—	—	—	613 000
a. Stationary Combustion Sources		353 000	200	5 000	9	3 000	—	—	—	360 000
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	—	—	0.4	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		48 700	3	60	2	500	—	—	—	49 300
Iron and Steel		6 310	0.2	5	0.2	60	—	—	—	6 370
Non Ferrous Metals		3 180	0.07	1	0.05	10	—	—	—	3 200
Chemical		5 770	0.12	2.5	0.1	30	—	—	—	5 810
Pulp and Paper		8 680	2	40	0.9	300	—	—	—	8 990
Cement		4 060	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		37 700	0.7	10	0.8	200	—	—	—	37 900
Residential		42 900	90	2 000	2	500	—	—	—	45 000
Agriculture & Forestry		2 190	0.04	0.8	0.06	20	—	—	—	2 210
b. Transportation²		179 000	30	600	20	8 000	—	—	—	190 000
Domestic Aviation		7 060	0.4	9	0.6	200	—	—	—	7 300
Road Transportation		125 000	9.7	200	12	3 800	—	—	—	129 000
Light Duty Gasoline Vehicles		41 000	3.7	77	5.1	1 600	—	—	—	42 600
Light Duty Gasoline Trucks		39 900	3.1	66	5.5	1 700	—	—	—	41 700
Heavy Duty Gasoline Vehicles		6 100	0.42	8.8	0.38	120	—	—	—	6 230
Motorcycles		228	0.15	3.2	0.00	1.4	—	—	—	233
Light Duty Diesel Vehicles		398	0.01	0.2	0.03	10	—	—	—	408
Light Duty Diesel Trucks		1 880	0.05	1	0.1	50	—	—	—	1 930
Heavy Duty Diesel Vehicles		34 600	2	30	1	300	—	—	—	35 000
Propane & Natural Gas Vehicles		795	0.7	10	0.02	5	—	—	—	820
Railways		5 260	0.3	6	2	700	—	—	—	6 000
Domestic Marine		5 830	0.4	9	1	300	—	—	—	6 200
Others		36 000	20	400	8	3 000	—	—	—	40 000
Off Road Gasoline		8 000	9	200	0.2	50	—	—	—	8 000
Off Road Diesel		20 000	1	20	8	2 000	—	—	—	20 000
Pipelines		8 850	8.8	190	0.2	70	—	—	—	9 110
c. Fugitive Sources		17 000	2 300	49 000	0.1	40	—	—	—	65 900
Coal Mining		—	30	700	—	—	—	—	—	700
Oil and Natural Gas		16 700	2 300	48 400	0.1	40	—	—	—	65 100
Oil		170	266	5 580	0.1	40	—	—	—	5 780
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
INDUSTRIAL PROCESSES		37 000	—	—	7.58	2 350	4 400	3 000	4 200	50 600
a. Mineral Products		9 100	—	—	—	—	—	—	—	9 100
Cement Production		6 800	—	—	—	—	—	—	—	6 800
Lime Production		1 600	—	—	—	—	—	—	—	1 600
Mineral Product Use ³		612	—	—	—	—	—	—	—	612
b. Chemical Industry		5 000	—	—	7.58	2 350	—	—	—	7 400
Ammonia Production		5 000	—	—	—	—	—	—	—	5 000
Nitric Acid Production		—	—	—	4.08	1 260	—	—	—	1 260
Adipic Acid Production		—	—	—	3.5	1 100	—	—	—	1 100
c. Metal Production		11 600	—	—	—	—	—	3 000	2 550	17 200
Iron and Steel Production		7 040	—	—	—	—	—	—	—	7 040
Aluminum Production		4 600	—	—	—	—	—	3 000	70.4	7 700
SF ₆ Used in Magnesium Smelters and Casters		—	—	—	—	—	—	—	2 480	2 480
d. Consumption of Halocarbons and SF₆		—	—	—	—	—	4 400	30	1 600	6 000
e. Other & Undifferentiated Production		11 000	—	—	—	—	—	—	—	11 000
SOLVENT & OTHER PRODUCT USE		—	—	—	0.71	220	—	—	—	220
AGRICULTURE		—	1 200	26 000	90	28 000	—	—	—	54 000
a. Enteric Fermentation		—	1 100	23 000	—	—	—	—	—	23 000
b. Manure Management		—	150	3 100	16	5 000	—	—	—	8 100
c. Agriculture Soils		—	—	—	74	23 000	—	—	—	23 000
Direct Sources		—	—	—	41	13 000	—	—	—	13 000
Pasture, Range and Paddock Manure		—	—	—	13	4 000	—	—	—	4 000
Indirect Sources		—	—	—	20	6 000	—	—	—	6 000
WASTE		180	1 200	26 000	2	700	—	—	—	27 000
a. Solid Waste Disposal on Land		—	1 200	26 000	—	—	—	—	—	26 000
b. Wastewater Handling		—	12	240	2	700	—	—	—	910
c. Waste Incineration		180	0.05	1	0.1	50	—	—	—	230
Land Use, Land-use Change and Forestry		6 700	460	9 700	19	6 000	—	—	—	22 000
a. Forest Land		-3 900	450	9 400	19	5 800	—	—	—	11 000
b. Cropland		1 000	9	200	0.5	200	—	—	—	1 400
c. Grassland		—	—	—	—	—	—	—	—	—
d. Wetlands		2 000	0.7	20	0.03	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 CO₂ emissions coming from the use of limestone & dolomite, soda ash, and magnesite.

Totals may not add up due to rounding.

Table A8-6: 2002 Greenhouse Gas Emissions Summary for Canada

Greenhouse Gas Categories		Greenhouse Gases								
	Global Warming Potential Unit	CO ₂	CH ₄	CH ₄	N ₂ O	N ₂ O	HFCs	PFCs	SF ₆	TOTAL
				21		310				
		kt	kt	kt CO ₂ eq	kt	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq
TOTAL¹		564 000	5 000	110 000	130	40 000	3 900	3 000	4 000	720 000
ENERGY		529 000	2 600	54 000	30	10 000	—	—	—	593 000
a. Stationary Combustion Sources		338 000	200	5 000	8	3 000	—	—	—	345 000
Electricity and Heat Generation		128 000	4.7	99	2	700	—	—	—	129 000
Fossil Fuel Industries		70 100	100	2 000	1	500	—	—	—	73 000
Petroleum Refining and Upgrading		18 000	—	—	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	—	—	—	48 900
Iron and Steel		6 420	0.2	5	0.2	60	—	—	—	6 480
Non Ferrous Metals		3 200	0.07	1	0.05	10	—	—	—	3 210
Chemical		6 080	0.12	2.6	0.1	30	—	—	—	6 120
Pulp and Paper		8 890	2	40	0.9	300	—	—	—	9 200
Cement		4 080	0.08	2	0.04	10	—	—	—	4 090
Other Manufacturing		19 700	0.4	8	0.4	100	—	—	—	19 800
Construction		1 230	0.02	0.5	0.03	9	—	—	—	1 240
Commercial & Institutional		35 200	0.6	10	0.7	200	—	—	—	35 400
Residential		41 000	90	2 000	2	500	—	—	—	44 000
Agriculture & Forestry		2 090	0.03	0.7	0.06	20	—	—	—	2 110
b. Transportation²		174 000	30	700	20	7 000	—	—	—	180 000
Domestic Aviation		6 580	0.4	9	0.6	200	—	—	—	6 800
Road Transportation		122 000	10	210	13	4 000	—	—	—	126 000
Light Duty Gasoline Vehicles		41 300	4.0	83	5.7	1 800	—	—	—	43 100
Light Duty Gasoline Trucks		38 500	3.1	66	5.6	1 700	—	—	—	40 300
Heavy Duty Gasoline Vehicles		5 930	0.44	9.3	0.35	110	—	—	—	6 050
Motorcycles		208	0.14	3.0	0.00	1.3	—	—	—	212
Light Duty Diesel Vehicles		389	0.01	0.2	0.03	9	—	—	—	398
Light Duty Diesel Trucks		1 810	0.05	1	0.1	40	—	—	—	1 850
Heavy Duty Diesel Vehicles		33 200	2	30	1	300	—	—	—	33 500
Propane & Natural Gas Vehicles		824	0.7	20	0.02	5	—	—	—	840
Railways		5 280	0.3	6	2	700	—	—	—	6 000
Domestic Marine		5 150	0.4	8	1	400	—	—	—	5 500
Others		35 000	20	400	7	2 000	—	—	—	40 000
Off Road Gasoline		8 000	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
c. Fugitive Sources		17 000	2 300	48 000	0.1	40	—	—	—	65 100
Coal Mining		—	30	700	—	—	—	—	—	700
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
INDUSTRIAL PROCESSES		35 000	—	—	8.09	2 510	3 900	3 000	4 000	48 700
a. Mineral Products		9 000	—	—	—	—	—	—	—	9 000
Cement Production		6 700	—	—	—	—	—	—	—	6 700
Lime Production		1 700	—	—	—	—	—	—	—	1 700
Mineral Product Use ³		636	—	—	—	—	—	—	—	636
b. Chemical Industry		4 700	—	—	8.09	2 510	—	—	—	7 200
Ammonia Production		4 700	—	—	—	—	—	—	—	4 700
Nitric Acid Production		—	—	—	4.05	1 260	—	—	—	1 260
Adipic Acid Production		—	—	—	4.0	1 300	—	—	—	1 300
c. Metal Production		11 500	—	—	—	—	—	3 000	3 020	17 500
Iron and Steel Production		7 120	—	—	—	—	—	—	—	7 120
Aluminum Production		4 400	—	—	—	—	—	3 000	80.1	7 500
SF ₆ Used in Magnesium Smelters and Casters		—	—	—	—	—	—	—	2 940	2 940
d. Consumption of Halocarbons and SF₆		—	—	—	—	—	3 900	30	1 000	5 000
e. Other & Undifferentiated Production		9 900	—	—	—	—	—	—	—	9 900
SOLVENT & OTHER PRODUCT USE		—	—	—	0.54	170	—	—	—	170
AGRICULTURE		—	1 200	26 000	86	27 000	—	—	—	52 000
a. Enteric Fermentation		—	1 100	23 000	—	—	—	—	—	23 000
b. Manure Management		—	150	3 100	16	5 000	—	—	—	8 100
c. Agriculture Soils		—	—	—	70	22 000	—	—	—	22 000
Direct Sources		—	—	—	38	12 000	—	—	—	12 000
Pasture, Range and Paddock Manure		—	—	—	13	4 000	—	—	—	4 000
Indirect Sources		—	—	—	20	6 000	—	—	—	6 000
WASTE		180	1 200	26 000	2	700	—	—	—	27 000
a. Solid Waste Disposal on Land		—	1 200	26 000	—	—	—	—	—	26 000
b. Wastewater Handling		—	11	240	2	700	—	—	—	910
c. Waste Incineration		180	0.05	1	0.1	40	—	—	—	220
Land Use, Land-use Change and Forestry		36 000	550	12 000	23	7 200	—	—	—	55 000
a. Forest Land		25 000	540	11 000	23	7 000	—	—	—	43 000
b. Cropland		2 000	9	200	0.5	200	—	—	—	2 300
c. Grassland		—	—	—	—	—	—	—	—	—
d. Wetlands		1 000	0.03	0.6	0.00	0.3	—	—	—	1 000
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 CO₂ emissions coming from the use of limestone & dolomite, soda ash, and magnesite.

Totals may not add up due to rounding.

Table A8-7: 2001 Greenhouse Gas Emissions Summary for Canada

Greenhouse Gas Categories		Greenhouse Gases								
	Global Warming Potential Unit	CO ₂	CH ₄	CH ₄	N ₂ O	N ₂ O	HFCs	PFCs	SF ₆	TOTAL
				21		310				
		kt	kt	kt CO ₂ eq	kt	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq
TOTAL¹		557 000	5 000	110 000	130	40 000	3 500	3 500	4 400	714 000
ENERGY		521 000	2 600	55 000	30	10 000	—	—	—	586 000
a. Stationary Combustion Sources		333 000	200	5 000	8	3 000	—	—	—	340 000
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		48 200	3	60	2	500	—	—	—	48 800
Iron and Steel		5 830	0.2	5	0.2	50	—	—	—	5 890
Non Ferrous Metals		3 440	0.08	2	0.05	20	—	—	—	3 460
Chemical		6 710	0.14	2.9	0.1	40	—	—	—	6 750
Pulp and Paper		9 480	2	40	0.8	300	—	—	—	9 780
Cement		3 840	0.07	2	0.04	10	—	—	—	3 850
Other Manufacturing		18 900	0.4	8	0.4	100	—	—	—	19 000
Construction		1 010	0.02	0.4	0.03	8	—	—	—	1 010
Commercial & Institutional		33 000	0.6	10	0.7	200	—	—	—	33 200
Residential		39 400	90	2 000	2	500	—	—	—	42 000
Agriculture & Forestry		2 190	0.04	0.8	0.06	20	—	—	—	2 210
b. Transportation²		172 000	30	600	20	8 000	—	—	—	180 000
Domestic Aviation		6 000	0.4	9	0.5	200	—	—	—	6 200
Road Transportation		120 000	10	220	13	4 100	—	—	—	124 000
Light Duty Gasoline Vehicles		41 100	4.2	88	6.1	1 900	—	—	—	43 000
Light Duty Gasoline Trucks		36 800	3.1	65	5.6	1 700	—	—	—	38 600
Heavy Duty Gasoline Vehicles		6 070	0.48	10	0.34	100	—	—	—	6 180
Motorcycles		183	0.13	2.7	0.00	1.1	—	—	—	187
Light Duty Diesel Vehicles		368	0.01	0.2	0.03	9	—	—	—	377
Light Duty Diesel Trucks		1 710	0.04	0.9	0.1	40	—	—	—	1 750
Heavy Duty Diesel Vehicles		32 800	2	30	1	300	—	—	—	33 200
Propane & Natural Gas Vehicles		1 110	0.9	20	0.02	7	—	—	—	1 100
Railways		5 820	0.3	7	2	700	—	—	—	7 000
Domestic Marine		5 170	0.4	8	1	400	—	—	—	5 500
Others		35 000	20	400	8	2 000	—	—	—	40 000
Off Road Gasoline		7 000	9	200	0.2	50	—	—	—	8 000
Off Road Diesel		18 000	0.9	20	7	2 000	—	—	—	20 000
Pipelines		9 970	10	210	0.3	80	—	—	—	10 300
c. Fugitive Sources		16 000	2 400	49 000	0.1	40	—	—	—	65 600
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
INDUSTRIAL PROCESSES		36 000	—	—	6.74	2 090	3 500	3 500	4 400	49 200
a. Mineral Products		9 000	—	—	—	—	—	—	—	9 000
Cement Production		6 500	—	—	—	—	—	—	—	6 500
Lime Production		1 600	—	—	—	—	—	—	—	1 600
Mineral Product Use ³		844	—	—	—	—	—	—	—	844
b. Chemical Industry		5 000	—	—	6.74	2 090	—	—	—	7 100
Ammonia Production		5 000	—	—	—	—	—	—	—	5 000
Nitric Acid Production		—	—	—	4.14	1 280	—	—	—	1 280
Adipic Acid Production		—	—	—	2.6	800	—	—	—	800
c. Metal Production		11 500	—	—	—	—	—	3 500	2 400	17 400
Iron and Steel Production		7 280	—	—	—	—	—	—	—	7 280
Aluminum Production		4 200	—	—	—	—	—	3 500	43.9	7 700
SF ₆ Used in Magnesium Smelters and Casters		—	—	—	—	—	—	—	2 360	2 360
d. Consumption of Halocarbons and SF₆		—	—	—	—	—	3 500	30	2 000	5 500
e. Other & Undifferentiated Production		10 000	—	—	—	—	—	—	—	10 000
SOLVENT & OTHER PRODUCT USE		—	—	—	0.69	210	—	—	—	210
AGRICULTURE		—	1 200	25 000	87	27 000	—	—	—	52 000
a. Enteric Fermentation		—	1 100	22 000	—	—	—	—	—	22 000
b. Manure Management		—	150	3 000	16	4 900	—	—	—	8 000
c. Agriculture Soils		—	—	—	71	22 000	—	—	—	22 000
Direct Sources		—	—	—	39	12 000	—	—	—	12 000
Pasture, Range and Paddock Manure		—	—	—	13	4 000	—	—	—	4 000
Indirect Sources		—	—	—	20	6 000	—	—	—	6 000
WASTE		200	1 200	25 000	2	700	—	—	—	26 000
a. Solid Waste Disposal on Land		—	1 200	25 000	—	—	—	—	—	25 000
b. Wastewater Handling		—	11	240	2	700	—	—	—	910
c. Waste Incineration		200	0.04	0.9	0.2	50	—	—	—	250
Land Use, Land-use Change and Forestry		-98 000	130	2 800	5.7	1 800	—	—	—	-94 000
a. Forest Land		-110 000	120	2 500	5.0	1 600	—	—	—	-110 000
b. Cropland		2 500	9	200	0.5	200	—	—	—	2 800
c. Grassland		—	—	—	—	—	—	—	—	—
d. Wetlands		2 000	0.03	0.6	0.00	0.3	—	—	—	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 CO₂ emissions coming from the use of limestone & dolomite, soda ash, and magnesite.

Totals may not add up due to rounding.

Table A8-8: 2000 Greenhouse Gas Emissions Summary for Canada

Greenhouse Gas Categories		Greenhouse Gases								
		CO ₂	CH ₄	CH ₄	N ₂ O	N ₂ O	HFCs	PFCs	SF ₆	TOTAL
		Global Warming Potential Unit	kt	kt	kt CO ₂ eq	kt	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq
TOTAL ¹		564 000	4 900	100 000	130	42 000	3 000	4 300	4 300	721 000
ENERGY		527 000	2 600	54 000	30	10 000	—	—	—	592 000
a. Stationary Combustion Sources		337 000	200	5 000	8	3 000	—	—	—	344 000
Electricity and Heat Generation		131 000	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		52 400	3	60	2	500	—	—	—	53 000
Iron and Steel		7 120	0.3	5	0.2	60	—	—	—	7 190
Non Ferrous Metals		3 170	0.07	1	0.05	10	—	—	—	3 190
Chemical		7 810	0.16	3.3	0.1	40	—	—	—	7 850
Pulp and Paper		10 600	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		1 070	0.02	0.4	0.03	8	—	—	—	1 080
Commercial & Institutional		33 000	0.6	10	0.7	200	—	—	—	33 200
Residential		42 500	90	2 000	2	500	—	—	—	45 000
Agriculture & Forestry		2 550	0.04	0.9	0.06	20	—	—	—	2 570
b. Transportation ²		174 000	30	700	30	8 000	—	—	—	180 000
Domestic Aviation		6 380	0.4	9	0.6	200	—	—	—	6 600
Road Transportation		118 000	11	230	13	4 200	—	—	—	122 000
Light Duty Gasoline Vehicles		41 200	4.5	95	6.4	2 000	—	—	—	43 300
Light Duty Gasoline Trucks		36 100	3.3	69	5.6	1 700	—	—	—	37 900
Heavy Duty Gasoline Vehicles		5 360	0.50	11	0.26	79	—	—	—	5 450
Motorcycles		160	0.12	2.5	0.00	0.97	—	—	—	163
Light Duty Diesel Vehicles		353	0.01	0.2	0.03	8	—	—	—	362
Light Duty Diesel Trucks		1 690	0.04	0.9	0.1	40	—	—	—	1 730
Heavy Duty Diesel Vehicles		31 800	1	30	1	300	—	—	—	32 100
Propane & Natural Gas Vehicles		1 070	1	20	0.02	7	—	—	—	1 100
Railways		5 920	0.3	7	2	700	—	—	—	7 000
Domestic Marine		4 770	0.3	7	1	400	—	—	—	5 100
Others		39 000	20	400	9	3 000	—	—	—	40 000
Off Road Gasoline		8 000	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
c. Fugitive Sources		16 000	2 300	49 000	0.1	40	—	—	—	64 700
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
INDUSTRIAL PROCESSES		36 000	—	—	6.87	2 130	3 000	4 300	4 300	50 200
a. Mineral Products		9 600	—	—	—	—	—	—	—	9 600
Cement Production		6 700	—	—	—	—	—	—	—	6 700
Lime Production		1 900	—	—	—	—	—	—	—	1 900
Mineral Product Use ³		1 020	—	—	—	—	—	—	—	1 020
b. Chemical Industry		5 300	—	—	6.87	2 130	—	—	—	7 400
Ammonia Production		5 300	—	—	—	—	—	—	—	5 300
Nitric Acid Production		—	—	—	3.97	1 230	—	—	—	1 230
Adipic Acid Production		—	—	—	2.9	900	—	—	—	900
c. Metal Production		11 800	—	—	—	—	—	4 300	2 830	18 900
Iron and Steel Production		7 900	—	—	—	—	—	—	—	7 900
Aluminum Production		3 900	—	—	—	—	—	4 300	47.3	8 200
SF ₆ Used in Magnesium Smelters and Casters		—	—	—	—	—	—	—	2 780	2 780
d. Consumption of Halocarbons and SF ₆		—	—	—	—	—	3 000	30	1 500	4 500
e. Other & Undifferentiated Production		9 700	—	—	—	—	—	—	—	9 700
SOLVENT & OTHER PRODUCT USE		—	—	—	0.78	240	—	—	—	240
AGRICULTURE		—	1 200	25 000	90	28 000	—	—	—	53 000
a. Enteric Fermentation		—	1 000	22 000	—	—	—	—	—	22 000
b. Manure Management		—	140	2 900	16	4 800	—	—	—	7 800
c. Agriculture Soils		—	—	—	75	23 000	—	—	—	23 000
Direct Sources		—	—	—	42	13 000	—	—	—	13 000
Pasture, Range and Paddock Manure		—	—	—	13	3 900	—	—	—	3 900
Indirect Sources		—	—	—	20	6 000	—	—	—	6 000
WASTE		200	1 200	25 000	2	700	—	—	—	26 000
a. Solid Waste Disposal on Land		—	1 200	25 000	—	—	—	—	—	25 000
b. Wastewater Handling		—	11	240	2	600	—	—	—	880
c. Waste Incineration		200	0.04	0.8	0.2	50	—	—	—	250
Land Use, Land-use Change and Forestry		-110 000	50	1 100	2.2	680	—	—	—	-110 000
a. Forest Land		-120 000	37	770	1.5	480	—	—	—	-120 000
b. Cropland		3 400	9	200	0.5	200	—	—	—	3 700
c. Grassland		—	—	—	—	—	—	—	—	—
d. Wetlands		2 000	0.03	0.7	0.00	0.4	—	—	—	2 000
e. Settlements		8 000	4	90	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 CO₂ emissions coming from the use of limestone & dolomite, soda ash, and magnesite.

Totals may not add up due to rounding.

Table A8-9: 1999 Greenhouse Gas Emissions Summary for Canada**Greenhouse Gas Categories**

	Global Warming Potential Unit	Greenhouse Gases								TOTAL kt CO ₂ eq
		CO ₂	CH ₄	CH ₄ 21	N ₂ O	N ₂ O 310	HFCs	PFCs	SF ₆	
		kt	kt	kt CO ₂ eq	kt	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	
TOTAL¹		540 000	4 800	100 000	140	42 000	2 500	4 600	3 800	695 000
ENERGY		504 000	2 500	52 000	30	10 000	—	—	—	566 000
a. Stationary Combustion Sources		316 000	200	5 000	8	2 000	—	—	—	323 000
Electricity and Heat Generation		121 000	3.9	81	2	700	—	—	—	121 000
Fossil Fuel Industries		62 800	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	—	—	—	7 450
Manufacturing Industries		52 200	3	60	2	500	—	—	—	52 800
Iron and Steel		7 210	0.3	6	0.2	60	—	—	—	7 280
Non Ferrous Metals		3 240	0.06	1	0.05	10	—	—	—	3 250
Chemical		8 400	0.18	3.7	0.1	50	—	—	—	8 450
Pulp and Paper		10 800	2	40	0.9	300	—	—	—	11 100
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		28 700	0.5	10	0.6	200	—	—	—	28 900
Residential		40 500	90	2 000	2	500	—	—	—	43 000
Agriculture & Forestry		2 680	0.04	0.8	0.06	20	—	—	—	2 690
b. Transportation²		172 000	30	700	30	8 000	—	—	—	180 000
Domestic Aviation		6 400	0.4	9	0.6	200	—	—	—	6 600
Road Transportation		117 000	11	240	14	4 400	—	—	—	121 000
Light Duty Gasoline Vehicles		41 700	4.9	100	7.0	2 200	—	—	—	43 900
Light Duty Gasoline Trucks		35 300	3.3	69	5.8	1 800	—	—	—	37 200
Heavy Duty Gasoline Vehicles		5 340	0.53	11	0.23	72	—	—	—	5 420
Motorcycles		143	0.11	2.3	0.00	0.88	—	—	—	146
Light Duty Diesel Vehicles		339	0.01	0.2	0.03	8	—	—	—	347
Light Duty Diesel Trucks		1 570	0.04	0.8	0.1	40	—	—	—	1 610
Heavy Duty Diesel Vehicles		30 900	1	30	0.9	300	—	—	—	31 200
Propane & Natural Gas Vehicles		1 460	1	20	0.03	9	—	—	—	1 500
Railways		5 780	0.3	7	2	700	—	—	—	7 000
Domestic Marine		4 640	0.3	7	1	400	—	—	—	5 000
Others		39 000	20	500	8	2 000	—	—	—	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		12 200	12	260	0.3	100	—	—	—	12 600
c. Fugitive Sources		16 000	2 200	46 000	0.1	40	—	—	—	62 200
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
INDUSTRIAL PROCESSES		36 000	—	—	9.41	2 920	2 500	4 600	3 800	50 000
a. Mineral Products		9 500	—	—	—	—	—	—	—	9 500
Cement Production		6 600	—	—	—	—	—	—	—	6 600
Lime Production		1 900	—	—	—	—	—	—	—	1 900
Mineral Product Use ³		908	—	—	—	—	—	—	—	908
b. Chemical Industry		5 300	—	—	9.41	2 920	—	—	—	8 200
Ammonia Production		5 300	—	—	—	—	—	—	—	5 300
Nitric Acid Production		—	—	—	3.76	1 170	—	—	—	1 170
Adipic Acid Production		—	—	—	5.6	1 700	—	—	—	1 700
c. Metal Production		11 800	—	—	—	—	—	4 600	2 320	18 800
Iron and Steel Production		7 890	—	—	—	—	—	—	—	7 890
Aluminum Production		3 900	—	—	—	—	—	4 600	53.5	8 600
SF ₆ Used in Magnesium Smelters and Casters		—	—	—	—	—	—	—	2 270	2 270
d. Consumption of Halocarbons and SF₆		—	—	—	—	—	2 500	20	1 500	3 900
e. Other & Undifferentiated Production		9 700	—	—	—	—	—	—	—	9 700
SOLVENT & OTHER PRODUCT USE		—	—	—	0.70	220	—	—	—	220
AGRICULTURE		—	1 200	24 000	91	28 000	—	—	—	52 000
a. Enteric Fermentation		—	1 000	21 000	—	—	—	—	—	21 000
b. Manure Management		—	140	2 900	15	4 800	—	—	—	7 600
c. Agriculture Soils		—	—	—	75	23 000	—	—	—	23 000
Direct Sources		—	—	—	43	13 000	—	—	—	13 000
Pasture, Range and Paddock Manure		—	—	—	12	3 800	—	—	—	3 800
Indirect Sources		—	—	—	20	6 000	—	—	—	6 000
WASTE		200	1 200	25 000	2	700	—	—	—	26 000
a. Solid Waste Disposal on Land		—	1 200	25 000	—	—	—	—	—	25 000
b. Wastewater Handling		—	13	270	2	600	—	—	—	900
c. Waste Incineration		200	0.04	0.7	0.1	50	—	—	—	240
Land Use, Land-use Change and Forestry		-41 000	310	6 600	13	4 100	—	—	—	-31 000
a. Forest Land		-57 000	300	6 300	13	3 900	—	—	—	-46 000
b. Cropland		4 300	9	200	0.5	200	—	—	—	4 600
c. Grassland		—	—	—	—	—	—	—	—	—
d. Wetlands		3 000	2	40	0.07	20	—	—	—	3 000
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 CO₂ emissions coming from the use of limestone & dolomite, soda ash, and magnesite.

Totals may not add up due to rounding.

Table A8-10: 1998 Greenhouse Gas Emissions Summary for Canada

Greenhouse Gas Categories		Greenhouse Gases								
	Global Warming Potential	CO ₂	CH ₄	CH ₄	N ₂ O	N ₂ O	HFCs	PFCs	SF ₆	TOTAL
	Unit	kt	kt	kt CO ₂ eq	kt	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq
TOTAL¹		525 000	4 800	100 000	150	45 000	1 900	5 600	3 700	683 000
ENERGY		490 000	2 500	52 000	30	10 000	—	—	—	552 000
a. Stationary Combustion Sources		304 000	200	4 000	8	2 000	—	—	—	311 000
Electricity and Heat Generation		122 000	3.9	81	2	700	—	—	—	123 000
Fossil Fuel Industries		52 900	90	2 000	1	300	—	—	—	55 000
Petroleum Refining and Upgrading		13 000	—	—	0.3	80	—	—	—	13 000
Fossil Fuel Production		40 400	90	2 000	0.9	300	—	—	—	43 000
Mining & Oil and Gas Extraction		7 880	0.2	3	0.2	60	—	—	—	7 940
Manufacturing Industries		51 600	3	60	2	500	—	—	—	52 100
Iron and Steel		7 100	0.3	5	0.2	60	—	—	—	7 160
Non Ferrous Metals		3 470	0.07	2	0.05	20	—	—	—	3 490
Chemical		8 510	0.18	3.7	0.1	50	—	—	—	8 560
Pulp and Paper		10 700	2	40	0.8	300	—	—	—	11 000
Cement		3 610	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		27 200	0.5	10	0.6	200	—	—	—	27 300
Residential		38 700	90	2 000	2	500	—	—	—	41 000
Agriculture & Forestry		2 590	0.04	0.8	0.06	20	—	—	—	2 610
b. Transportation²		168 000	40	700	30	8 000	—	—	—	180 000
Domestic Aviation		6 300	0.4	9	0.6	200	—	—	—	6 500
Road Transportation		114 000	12	250	14	4 500	—	—	—	118 000
Light Duty Gasoline Vehicles		40 700	5.0	110	7.3	2 300	—	—	—	43 100
Light Duty Gasoline Trucks		33 100	3.2	67	5.8	1 800	—	—	—	35 000
Heavy Duty Gasoline Vehicles		5 880	0.66	14	0.22	69	—	—	—	5 960
Motorcycles		147	0.12	2.5	0.00	0.91	—	—	—	150
Light Duty Diesel Vehicles		325	0.01	0.2	0.02	8	—	—	—	333
Light Duty Diesel Trucks		1 580	0.04	0.8	0.1	40	—	—	—	1 610
Heavy Duty Diesel Vehicles		30 200	1	30	0.9	300	—	—	—	30 500
Propane & Natural Gas Vehicles		1 740	1	30	0.03	10	—	—	—	1 800
Railways		5 460	0.3	6	2	700	—	—	—	6 000
Domestic Marine		4 820	0.3	7	1	300	—	—	—	5 200
Others		38 000	20	500	7	2 000	—	—	—	40 000
Off Road Gasoline		8 000	10	200	0.2	50	—	—	—	9 000
Off Road Diesel		17 000	0.9	20	7	2 000	—	—	—	20 000
Pipelines		12 100	12	260	0.3	100	—	—	—	12 500
c. Fugitive Sources		17 000	2 300	47 000	0.1	40	—	—	—	64 900
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	906	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
INDUSTRIAL PROCESSES		35 000	—	—	19.7	6 100	1 900	5 600	3 700	52 600
a. Mineral Products		9 100	—	—	—	—	—	—	—	9 100
Cement Production		6 400	—	—	—	—	—	—	—	6 400
Lime Production		1 800	—	—	—	—	—	—	—	1 800
Mineral Product Use ³		928	—	—	—	—	—	—	—	928
b. Chemical Industry		5 200	—	—	19.7	6 100	—	—	—	11 000
Ammonia Production		5 200	—	—	—	—	—	—	—	5 200
Nitric Acid Production		—	—	—	3.34	1 040	—	—	—	1 040
Adipic Acid Production		—	—	—	16	5 100	—	—	—	5 100
c. Metal Production		11 700	—	—	—	—	—	5 600	2 260	19 500
Iron and Steel Production		7 690	—	—	—	—	—	—	—	7 690
Aluminum Production		4 000	—	—	—	—	—	5 600	59.1	9 600
SF ₆ Used in Magnesium Smelters and Casters		—	—	—	—	—	—	—	2 210	2 210
d. Consumption of Halocarbons and SF₆		—	—	—	—	—	1 900	20	1 500	3 400
e. Other & Undifferentiated Production		9 200	—	—	—	—	—	—	—	9 200
SOLVENT & OTHER PRODUCT USE		—	—	—	0.67	210	—	—	—	210
AGRICULTURE		—	1 200	24 000	90	28 000	—	—	—	52 000
a. Enteric Fermentation		—	1 000	22 000	—	—	—	—	—	22 000
b. Manure Management		—	140	2 900	15	4 700	—	—	—	7 600
c. Agriculture Soils		—	—	—	74	23 000	—	—	—	23 000
Direct Sources		—	—	—	42	13 000	—	—	—	13 000
Pasture, Range and Paddock Manure		—	—	—	12	3 800	—	—	—	3 800
Indirect Sources		—	—	—	20	6 000	—	—	—	6 000
WASTE		220	1 200	25 000	2	700	—	—	—	26 000
a. Solid Waste Disposal on Land		—	1 200	25 000	—	—	—	—	—	25 000
b. Wastewater Handling		—	11	220	2	600	—	—	—	850
c. Waste Incineration		220	0.04	0.8	0.2	50	—	—	—	270
Land Use, Land-use Change and Forestry		69 000	750	16 000	32	9 800	—	—	—	95 000
a. Forest Land		53 000	740	15 000	31	9 600	—	—	—	78 000
b. Cropland		5 000	9	200	0.5	200	—	—	—	5 400
c. Grassland		—	—	—	—	—	—	—	—	—
d. Wetlands		3 000	0.9	20	0.04	10	—	—	—	3 000
e. Settlements		8 000	5	90	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 CO₂ emissions coming from the use of limestone & dolomite, soda ash, and magnesite.

Totals may not add up due to rounding.

Table A8-11: 1997 Greenhouse Gas Emissions Summary for Canada
Greenhouse Gas Categories

Greenhouse Gas Categories				Greenhouse Gases						
	CO ₂	CH ₄	CH ₄	N ₂ O	N ₂ O	HFCs	PFCs	SF ₆	TOTAL	
	Global Warming Potential		21		310					
	Unit	kt	kt	kt CO ₂ eq	kt	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	
TOTAL ¹		517 000	4 800	100 000	160	50 000	1 400	5 500	3 000	
677 000										
ENERGY		481 000	2 400	51 000	30	10 000	—	—	543 000	
a. Stationary Combustion Sources		301 000	200	4 000	7	2 000	—	—	307 000	
Electricity and Heat Generation		111 000	3.2	67	2	600	—	—	111 000	
Fossil Fuel Industries		49 200	80	2 000	1	300	—	—	51 000	
Petroleum Refining and Upgrading		14 000	—	—	0.2	70	—	—	14 000	
Fossil Fuel Production		35 500	80	2 000	0.7	200	—	—	37 000	
Mining & Oil and Gas Extraction		8 890	0.2	4	0.2	60	—	—	8 960	
Manufacturing Industries		54 000	3	60	2	500	—	—	54 600	
Iron and Steel		7 230	0.3	5	0.2	60	—	—	7 300	
Non Ferrous Metals		3 150	0.06	1	0.05	10	—	—	3 170	
Chemical		8 820	0.18	3.9	0.2	50	—	—	8 880	
Pulp and Paper		11 700	2	40	0.9	300	—	—	12 000	
Cement		3 550	0.06	1	0.04	10	—	—	3 560	
Other Manufacturing		19 600	0.4	8	0.3	100	—	—	19 700	
Construction		1 250	0.02	0.4	0.03	10	—	—	1 260	
Commercial & Institutional		29 800	0.5	10	0.6	200	—	—	30 000	
Residential		43 900	90	2 000	2	500	—	—	46 000	
Agriculture & Forestry		2 920	0.04	0.9	0.07	20	—	—	2 950	
b. Transportation ²		164 000	30	700	30	8 000	—	—	170 000	
Domestic Aviation		6 160	0.4	9	0.6	200	—	—	6 300	
Road Transportation		110 000	12	260	15	4 600	—	—	115 000	
Light Duty Gasoline Vehicles		41 900	5.5	120	7.9	2 400	—	—	44 500	
Light Duty Gasoline Trucks		30 600	3.2	66	5.7	1 800	—	—	32 400	
Heavy Duty Gasoline Vehicles		5 750	0.71	15	0.18	56	—	—	5 820	
Motorcycles		124	0.11	2.3	0.00	0.77	—	—	127	
Light Duty Diesel Vehicles		314	0.01	0.2	0.02	7	—	—	322	
Light Duty Diesel Trucks		1 430	0.04	0.8	0.1	30	—	—	1 470	
Heavy Duty Diesel Vehicles		28 400	1	30	0.8	300	—	—	28 700	
Propane & Natural Gas Vehicles		1 800	1	30	0.04	10	—	—	1 800	
Railways		5 660	0.3	6	2	700	—	—	6 000	
Domestic Marine		4 210	0.3	6	1	300	—	—	4 500	
Others		38 000	20	500	8	2 000	—	—	40 000	
Off Road Gasoline		7 000	8	200	0.2	50	—	—	7 000	
Off Road Diesel		19 000	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		36 000	—	—	35.3	10 900	1 400	5 500	56 500	
a. Mineral Products		9 000	—	—	—	—	—	—	9 000	
Cement Production		6 200	—	—	—	—	—	—	6 200	
Lime Production		1 800	—	—	—	—	—	—	1 800	
Mineral Product Use ³		929	—	—	—	—	—	—	929	
b. Chemical Industry		5 200	—	—	35.3	10 900	—	—	16 000	
Ammonia Production		5 200	—	—	—	—	—	—	5 200	
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 ₆ Used in Magnesium Smelters and Casters		—	—	—	—	—	—	1 670	1 670	
d. Consumption of Halocarbons and SF ₆		—	—	—	—	—	1 400	20	1 300	
e. Other & Undifferentiated Production		10 000	—	—	—	—	—	—	10 000	
SOLVENT & OTHER PRODUCT USE		—	—	—	0.73	230	—	—	230	
AGRICULTURE		—	1 200	25 000	89	28 000	—	—	52 000	
a. Enteric Fermentation		—	1 000	22 000	—	—	—	—	22 000	
b. Manure Management		—	130	2 800	15	4 700	—	—	7 600	
c. Agriculture Soils		—	—	—	73	23 000	—	—	23 000	
Direct Sources		—	—	—	41	13 000	—	—	13 000	
Pasture, Range and Paddock Manure		—	—	—	12	3 800	—	—	3 800	
Indirect Sources		—	—	—	20	6 000	—	—	6 000	
WASTE		220	1 200	25 000	2	700	—	—	25 000	
a. Solid Waste Disposal on Land		—	1 200	24 000	—	—	—	—	24 000	
b. Wastewater Handling		—	11	220	2	600	—	—	840	
c. Waste Incineration		220	0.03	0.7	0.2	50	—	—	280	
Land Use, Land-use Change and Forestry		-120 000	69	1 400	3.0	930	—	—	-120 000	
a. Forest Land		-140 000	56	1 200	2.3	720	—	—	-130 000	
b. Cropland		5 700	9	200	0.5	200	—	—	6 000	
c. Grassland		—	—	—	—	—	—	—	—	
d. Wetlands		3 000	0.1	3	0.01	2	—	—	3 000	
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 CO₂ emissions coming from the use of limestone & dolomite, soda ash, and magnesite.

Totals may not add up due to rounding.

Table A8-12: 1996 Greenhouse Gas Emissions Summary for Canada

Greenhouse Gas Categories		Greenhouse Gases								
	Global Warming Potential	CO ₂	CH ₄	CH ₄	N ₂ O	N ₂ O	HFCs	PFCs	SF ₆	TOTAL
	Unit	kt	kt	kt CO ₂ eq	kt	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq
TOTAL¹		505 000	4 700	99 000	170	51 000	870	5 500	2 800	664 000
ENERGY		469 000	2 400	50 000	30	10 000	—	—	—	530 000
a. Stationary Combustion Sources		296 000	200	4 000	7	2 000	—	—	—	302 000
Electricity and Heat Generation		99 000	2.6	55	2	600	—	—	—	99 600
Fossil Fuel Industries		53 100	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		8 670	0.2	4	0.2	60	—	—	—	8 740
Manufacturing Industries		54 100	3	60	2	500	—	—	—	54 600
Iron and Steel		7 260	0.3	5	0.2	60	—	—	—	7 330
Non Ferrous Metals		3 460	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	0.04	10	—	—	—	3 500
Other Manufacturing		19 200	0.4	8	0.3	100	—	—	—	19 400
Construction		1 260	0.02	0.4	0.03	10	—	—	—	1 270
Commercial & Institutional		29 400	0.5	10	0.6	200	—	—	—	29 600
Residential		47 100	90	2 000	2	500	—	—	—	50 000
Agriculture & Forestry		2 940	0.04	0.9	0.07	20	—	—	—	2 960
b. Transportation²		158 000	40	700	30	8 000	—	—	—	170 000
Domestic Aviation		6 010	0.4	9	0.5	200	—	—	—	6 200
Road Transportation		106 000	12	260	15	4 600	—	—	—	111 000
Light Duty Gasoline Vehicles		41 900	5.8	120	8.1	2 500	—	—	—	44 500
Light Duty Gasoline Trucks		28 000	3.1	65	5.5	1 700	—	—	—	29 700
Heavy Duty Gasoline Vehicles		5 790	0.77	16	0.16	48	—	—	—	5 860
Motorcycles		118	0.11	2.3	0.00	0.74	—	—	—	121
Light Duty Diesel Vehicles		313	0.01	0.2	0.02	7	—	—	—	321
Light Duty Diesel Trucks		1 300	0.03	0.7	0.1	30	—	—	—	1 340
Heavy Duty Diesel Vehicles		26 400	1	30	0.8	200	—	—	—	26 600
Propane & Natural Gas Vehicles		1 940	1	30	0.04	10	—	—	—	2 000
Railways		5 590	0.3	6	2	700	—	—	—	6 000
Domestic Marine		4 150	0.3	6	1	300	—	—	—	4 500
Others		37 000	20	500	7	2 000	—	—	—	40 000
Off Road Gasoline		8 000	9	200	0.2	50	—	—	—	8 000
Off Road Diesel		17 000	0.9	20	7	2 000	—	—	—	20 000
Pipelines		12 200	12	250	0.3	100	—	—	—	12 500
c. Fugitive Sources		15 000	2 200	45 000	0.1	40	—	—	—	60 900
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
INDUSTRIAL PROCESSES		35 000	—	—	40.6	12 600	870	5 500	2 800	56 900
a. Mineral Products		8 400	—	—	—	—	—	—	—	8 400
Cement Production		5 800	—	—	—	—	—	—	—	5 800
Lime Production		1 800	—	—	—	—	—	—	—	1 800
Mineral Product Use ³		883	—	—	—	—	—	—	—	883
b. Chemical Industry		5 400	—	—	40.6	12 600	—	—	—	18 000
Ammonia Production		5 400	—	—	—	—	—	—	—	5 400
Nitric Acid Production		—	—	—	3.57	1 110	—	—	—	1 110
Adipic Acid Production		—	—	—	37	11 000	—	—	—	11 000
c. Metal Production		11 600	—	—	—	—	—	5 500	1 700	18 800
Iron and Steel Production		7 750	—	—	—	—	—	—	—	7 750
Aluminum Production		3 900	—	—	—	—	—	5 500	59.1	9 400
SF ₆ Used in Magnesium Smelters and Casters		—	—	—	—	—	—	—	1 640	1 640
d. Consumption of Halocarbons and SF₆		—	—	—	—	—	870	20	1 100	2 000
e. Other & Undifferentiated Production		9 600	—	—	—	—	—	—	—	9 600
SOLVENT & OTHER PRODUCT USE		—	—	—	0.68	210	—	—	—	210
AGRICULTURE		—	1 200	25 000	89	28 000	—	—	—	52 000
a. Enteric Fermentation		—	1 000	22 000	—	—	—	—	—	22 000
b. Manure Management		—	130	2 800	15	4 700	—	—	—	7 500
c. Agriculture Soils		—	—	—	74	23 000	—	—	—	23 000
Direct Sources		—	—	—	42	13 000	—	—	—	13 000
Pasture, Range and Paddock Manure		—	—	—	12	3 800	—	—	—	3 800
Indirect Sources		—	—	—	20	6 000	—	—	—	6 000
WASTE		230	1 100	24 000	2	700	—	—	—	25 000
a. Solid Waste Disposal on Land		—	1 100	24 000	—	—	—	—	—	24 000
b. Wastewater Handling		—	12	240	2	600	—	—	—	840
c. Waste Incineration		230	0.3	7	0.3	100	—	—	—	340
Land Use, Land-use Change and Forestry		-82 000	200	4 200	8.5	2 600	—	—	—	-75 000
a. Forest Land		-99 000	190	3 900	7.8	2 400	—	—	—	-93 000
b. Cropland		6 500	9	200	0.5	200	—	—	—	6 900
c. Grassland		—	—	—	—	—	—	—	—	—
d. Wetlands		3 000	0.06	1	0.00	0.5	—	—	—	3 000
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 CO₂ emissions coming from the use of limestone & dolomite, soda ash, and magnesite.

Totals may not add up due to rounding.

Table A8-13: 1995 Greenhouse Gas Emissions Summary for Canada

Greenhouse Gas Categories		Greenhouse Gases								
	Global Warming Potential	CO ₂	CH ₄	CH ₄	N ₂ O	N ₂ O	HFCs	PFCs	SF ₆	TOTAL
	Unit	kt	kt	kt CO ₂ eq	kt	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq
TOTAL¹		492 000	4 500	95 000	160	49 000	480	5 500	3 700	646 000
ENERGY		457 000	2 200	47 000	30	10 000	—	—	—	514 000
a. Stationary Combustion Sources		288 000	200	4 000	7	2 000	—	—	—	294 000
Electricity and Heat Generation		100 000	3.0	63	2	600	—	—	—	101 000
Fossil Fuel Industries		52 400	80	2 000	1	400	—	—	—	54 000
Petroleum Refining and Upgrading		14 000	—	—	0.4	100	—	—	—	14 000
Fossil Fuel Production		38 200	80	2 000	0.8	200	—	—	—	40 000
Mining & Oil and Gas Extraction		7 790	0.2	3	0.2	60	—	—	—	7 850
Manufacturing Industries		52 400	3	60	2	500	—	—	—	52 900
Iron and Steel		6 970	0.3	5	0.2	60	—	—	—	7 040
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		1 170	0.02	0.4	0.03	10	—	—	—	1 180
Commercial & Institutional		28 800	0.5	10	0.6	200	—	—	—	29 000
Residential		42 400	100	2 000	2	500	—	—	—	45 000
Agriculture & Forestry		2 770	0.04	0.9	0.07	20	—	—	—	2 790
b. Transportation²		155 000	30	700	30	8 000	—	—	—	160 000
Domestic Aviation		5 740	0.4	9	0.5	200	—	—	—	5 900
Road Transportation		107 000	13	280	15	4 600	—	—	—	112 000
Light Duty Gasoline Vehicles		43 000	6.3	130	8.4	2 600	—	—	—	45 700
Light Duty Gasoline Trucks		27 000	3.2	67	5.5	1 700	—	—	—	28 700
Heavy Duty Gasoline Vehicles		6 200	0.86	18	0.14	44	—	—	—	6 270
Motorcycles		122	0.12	2.5	0.00	0.77	—	—	—	125
Light Duty Diesel Vehicles		327	0.01	0.2	0.02	8	—	—	—	335
Light Duty Diesel Trucks		1 330	0.03	0.7	0.1	30	—	—	—	1 360
Heavy Duty Diesel Vehicles		26 900	1	30	0.8	200	—	—	—	27 100
Propane & Natural Gas Vehicles		2 060	1	30	0.04	10	—	—	—	2 100
Railways		5 710	0.3	6	2	700	—	—	—	6 000
Domestic Marine		4 060	0.3	6	1	300	—	—	—	4 400
Others		32 000	20	400	6	2 000	—	—	—	30 000
Off Road Gasoline		6 000	7	200	0.1	40	—	—	—	7 000
Off Road Diesel		14 000	0.8	20	6	2 000	—	—	—	20 000
Pipelines		11 700	12	240	0.3	100	—	—	—	12 000
c. Fugitive Sources		15 000	2 000	42 000	0.1	40	—	—	—	57 000
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
INDUSTRIAL PROCESSES		34 000	—	—	37.8	11 700	480	5 500	3 700	55 700
a. Mineral Products		8 800	—	—	—	—	—	—	—	8 800
Cement Production		6 100	—	—	—	—	—	—	—	6 100
Lime Production		1 800	—	—	—	—	—	—	—	1 800
Mineral Product Use ³		878	—	—	—	—	—	—	—	878
b. Chemical Industry		5 300	—	—	37.8	11 700	—	—	—	17 000
Ammonia Production		5 300	—	—	—	—	—	—	—	5 300
Nitric Acid Production		—	—	—	3.24	1 000	—	—	—	1 000
Adipic Acid Production		—	—	—	35	11 000	—	—	—	11 000
c. Metal Production		11 500	—	—	—	—	—	5 500	2 170	19 200
Iron and Steel Production		7 880	—	—	—	—	—	—	—	7 880
Aluminum Production		3 600	—	—	—	—	—	5 500	59.1	9 200
SF ₆ Used in Magnesium Smelters and Casters		—	—	—	—	—	—	—	2 110	2 110
d. Consumption of Halocarbons and SF₆		—	—	—	—	—	480	30	1 500	2 000
e. Other & Undifferentiated Production		8 700	—	—	—	—	—	—	—	8 700
SOLVENT & OTHER PRODUCT USE		—	—	—	0.67	210	—	—	—	210
AGRICULTURE		—	1 100	24 000	86	27 000	—	—	—	50 000
a. Enteric Fermentation		—	1 000	21 000	—	—	—	—	—	21 000
b. Manure Management		—	130	2 800	15	4 600	—	—	—	7 400
c. Agriculture Soils		—	—	—	71	22 000	—	—	—	22 000
Direct Sources		—	—	—	40	12 000	—	—	—	12 000
Pasture, Range and Paddock Manure		—	—	—	12	3 700	—	—	—	3 700
Indirect Sources		—	—	—	20	6 000	—	—	—	6 000
WASTE		240	1 100	24 000	2	700	—	—	—	25 000
a. Solid Waste Disposal on Land		—	1 100	24 000	—	—	—	—	—	24 000
b. Wastewater Handling		—	10	220	2	600	—	—	—	810
c. Waste Incineration		240	0.3	7	0.3	100	—	—	—	350
Land Use, Land-use Change and Forestry		120 000	960	20 000	41	13 000	—	—	—	150 000
a. Forest Land		100 000	950	20 000	40	12 000	—	—	—	140 000
b. Cropland		7 000	9	200	0.5	200	—	—	—	7 300
c. Grassland		—	—	—	—	—	—	—	—	—
d. Wetlands		3 000	0.04	0.8	0.00	0.5	—	—	—	3 000
e. Settlements		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 CO₂ emissions coming from the use of limestone & dolomite, soda ash, and magnesite.

Totals may not add up due to rounding.

Table A8-14: 1994 Greenhouse Gas Emissions Summary for Canada

Greenhouse Gas Categories		Greenhouse Gases								
	Global Warming Potential	CO ₂	CH ₄	CH ₄	N ₂ O	N ₂ O	HFCs	PFCs	SF ₆	TOTAL
	Unit	kt	kt	kt CO ₂ eq	kt	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq
TOTAL¹		478 000	4 300	91 000	160	49 000	—	6 000	4 200	628 000
ENERGY		445 000	2 100	45 000	30	10 000	—	—	—	499 000
a. Stationary Combustion Sources		280 000	200	4 000	7	2 000	—	—	—	287 000
Electricity and Heat Generation		95 700	2.6	54	2	600	—	—	—	96 300
Fossil Fuel Industries		50 800	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	—	—	—	7 480
Manufacturing Industries		51 700	3	60	2	500	—	—	—	52 200
Iron and Steel		7 380	0.3	6	0.2	60	—	—	—	7 450
Non Ferrous Metals		3 270	0.07	2	0.05	20	—	—	—	3 280
Chemical		8 480	0.18	3.7	0.1	50	—	—	—	8 530
Pulp and Paper		11 700	2	40	0.8	200	—	—	—	12 000
Cement		3 510	0.07	1	0.04	10	—	—	—	3 530
Other Manufacturing		17 300	0.4	7	0.3	100	—	—	—	17 400
Construction		1 390	0.02	0.5	0.03	10	—	—	—	1 400
Commercial & Institutional		27 300	0.5	10	0.6	200	—	—	—	27 500
Residential		43 700	100	2 000	2	500	—	—	—	46 000
Agriculture & Forestry		2 540	0.04	0.8	0.06	20	—	—	—	2 560
b. Transportation²		151 000	30	700	20	8 000	—	—	—	160 000
Domestic Aviation		5 290	0.4	8	0.5	100	—	—	—	5 400
Road Transportation		105 000	14	290	15	4 600	—	—	—	110 000
Light Duty Gasoline Vehicles		43 600	6.7	140	8.4	2 600	—	—	—	46 400
Light Duty Gasoline Trucks		26 200	3.3	70	5.3	1 700	—	—	—	27 900
Heavy Duty Gasoline Vehicles		6 680	0.96	20	0.16	50	—	—	—	6 750
Motorcycles		125	0.12	2.6	0.00	0.79	—	—	—	129
Light Duty Diesel Vehicles		339	0.01	0.2	0.03	8	—	—	—	347
Light Duty Diesel Trucks		1 150	0.03	0.6	0.09	30	—	—	—	1 180
Heavy Duty Diesel Vehicles		25 500	1	30	0.8	200	—	—	—	25 700
Propane & Natural Gas Vehicles		1 880	1	30	0.04	10	—	—	—	1 900
Railways		6 310	0.3	7	3	800	—	—	—	7 000
Domestic Marine		4 350	0.3	6	1	300	—	—	—	4 700
Others		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		33 000	—	—	38.5	11 900	—	6 000	4 200	54 900
a. Mineral Products		8 100	—	—	—	—	—	—	—	8 100
Cement Production		5 400	—	—	—	—	—	—	—	5 400
Lime Production		1 800	—	—	—	—	—	—	—	1 800
Mineral Product Use ³		842	—	—	—	—	—	—	—	842
b. Chemical Industry		4 500	—	—	38.5	11 900	—	—	—	16 000
Ammonia Production		4 500	—	—	—	—	—	—	—	4 500
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 ₆ Used in Magnesium Smelters and Casters		—	—	—	—	—	—	—	2 280	2 280
d. Consumption of Halocarbons and SF₆		—	—	—	—	—	—	—	1 800	1 800
e. Other & Undifferentiated Production		9 000	—	—	—	—	—	—	—	9 000
SOLVENT & OTHER PRODUCT USE		—	—	—	0.55	170	—	—	—	170
AGRICULTURE		—	1 100	23 000	84	26 000	—	—	—	49 000
a. Enteric Fermentation		—	950	20 000	—	—	—	—	—	20 000
b. Manure Management		—	130	2 600	14	4 400	—	—	—	7 000
c. Agriculture Soils		—	—	—	69	22 000	—	—	—	22 000
Direct Sources		—	—	—	40	12 000	—	—	—	12 000
Pasture, Range and Paddock Manure		—	—	—	11	3 500	—	—	—	3 500
Indirect Sources		—	—	—	20	6 000	—	—	—	6 000
WASTE		240	1 100	24 000	2	700	—	—	—	25 000
a. Solid Waste Disposal on Land		—	1 100	24 000	—	—	—	—	—	24 000
b. Wastewater Handling		—	11	220	2	600	—	—	—	810
c. Waste Incineration		240	0.3	6	0.3	100	—	—	—	350
Land Use, Land-use Change and Forestry		-91 000	290	6 000	12	3 800	—	—	—	-81 000
a. Forest Land		-110 000	270	5 700	11	3 500	—	—	—	-100 000
b. Cropland		8 400	10	200	0.5	200	—	—	—	8 800
c. Grassland		—	—	—	—	—	—	—	—	—
d. Wetlands		2 000	0.03	0.6	0.00	0.3	—	—	—	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 CO₂ emissions coming from the use of limestone & dolomite, soda ash, and magnesite.

Totals may not add up due to rounding.

Table A8-15: 1993 Greenhouse Gas Emissions Summary for Canada**Greenhouse Gas Categories**

Greenhouse Gas Categories			Greenhouse Gases								TOTAL
	Global Warming Potential	CO ₂	CH ₄	CH ₄	N ₂ O	N ₂ O	HFCs	PFCs	SF ₆		
	Unit	kt	kt	kt CO ₂ eq	kt	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	
TOTAL ¹		464 000	4 200	88 000	150	45 000	—	6 500	4 200	608 000	
ENERGY		432 000	2 000	43 000	30	9 000	—	—	—	484 000	
a.	Stationary Combustion Sources	275 000	200	4 000	7	2 000	—	—	—	281 000	
	Electricity and Heat Generation	93 300	2.5	53	2	600	—	—	—	93 900	
	Fossil Fuel Industries	50 300	80	2 000	1	300	—	—	—	52 000	
	Petroleum Refining and Upgrading	15 000	—	—	0.3	100	—	—	—	15 000	
	Fossil Fuel Production	35 100	80	2 000	0.7	200	—	—	—	37 000	
	Mining & Oil and Gas Extraction	7 360	0.2	3	0.2	50	—	—	—	7 410	
	Manufacturing Industries	48 600	3	50	1	500	—	—	—	49 100	
	Iron and Steel	6 590	0.3	5	0.2	60	—	—	—	6 660	
	Non Ferrous Metals	2 690	0.06	1	0.04	10	—	—	—	2 700	
	Chemical	7 260	0.15	3.2	0.1	40	—	—	—	7 300	
	Pulp and Paper	11 900	2	30	0.7	200	—	—	—	12 100	
	Cement	3 110	0.06	1	0.03	10	—	—	—	3 120	
	Other Manufacturing	17 100	0.4	7	0.3	100	—	—	—	17 200	
	Construction	1 380	0.02	0.5	0.03	10	—	—	—	1 390	
	Commercial & Institutional	27 900	0.5	10	0.6	200	—	—	—	28 100	
	Residential	42 900	100	2 000	2	500	—	—	—	46 000	
	Agriculture & Forestry	3 040	0.05	1	0.07	20	—	—	—	3 060	
b.	Transportation ²	144 000	30	700	20	7 000	—	—	—	150 000	
	Domestic Aviation	5 110	0.4	8	0.5	100	—	—	—	5 300	
	Road Transportation	99 700	14	290	14	4 300	—	—	—	104 000	
	Light Duty Gasoline Vehicles	43 800	7.0	150	8.1	2 500	—	—	—	46 500	
	Light Duty Gasoline Trucks	24 100	3.2	68	4.8	1 500	—	—	—	25 700	
	Heavy Duty Gasoline Vehicles	6 590	1.0	21	0.17	52	—	—	—	6 660	
	Motorcycles	132	0.13	2.7	0.00	0.83	—	—	—	135	
	Light Duty Diesel Vehicles	346	0.01	0.2	0.03	8	—	—	—	354	
	Light Duty Diesel Trucks	960	0.03	0.5	0.07	20	—	—	—	983	
	Heavy Duty Diesel Vehicles	21 800	1	20	0.6	200	—	—	—	22 000	
	Propane & Natural Gas Vehicles	1 990	1	30	0.04	10	—	—	—	2 000	
	Railways	6 090	0.3	7	2	800	—	—	—	7 000	
	Domestic Marine	4 180	0.3	6	1	300	—	—	—	4 500	
	Others	29 000	20	400	6	2 000	—	—	—	30 000	
	Off Road Gasoline	6 000	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	
c.	Fugitive Sources	13 000	1 800	38 000	0.1	30	—	—	—	51 300	
	Coal Mining	—	90	2 000	—	—	—	—	—	2 000	
	Oil and Natural Gas	13 200	1 730	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	8 440	794	16 700	—	—	—	—	—	25 100	
	Flaring	4 600	3.0	64	0.00	0.7	—	—	—	4 700	
INDUSTRIAL PROCESSES		32 000	—	—	32.7	10 100	—	6 500	4 200	52 900	
a.	Mineral Products	7 200	—	—	—	—	—	—	—	7 200	
	Cement Production	4 600	—	—	—	—	—	—	—	4 600	
	Lime Production	1 800	—	—	—	—	—	—	—	1 800	
	Mineral Product Use ³	855	—	—	—	—	—	—	—	855	
b.	Chemical Industry	4 500	—	—	32.7	10 100	—	—	—	15 000	
	Ammonia Production	4 500	—	—	—	—	—	—	—	4 500	
	Nitric Acid Production	—	—	—	3.40	1 050	—	—	—	1 050	
	Adipic Acid Production	—	—	—	29	9 100	—	—	—	9 100	
c.	Metal Production	12 100	—	—	—	—	—	6 500	2 270	20 800	
	Iron and Steel Production	8 180	—	—	—	—	—	—	—	8 180	
	Aluminum Production	3 900	—	—	—	—	—	6 500	59.1	10 000	
	SF ₆ Used in Magnesium Smelters and Casters	—	—	—	—	—	—	—	2 210	2 210	
d.	Consumption of Halocarbons and SF ₆	—	—	—	—	—	—	—	2 000	2 000	
e.	Other & Undifferentiated Production	8 300	—	—	—	—	—	—	—	8 300	
SOLVENT & OTHER PRODUCT USE		—	—	—	0.50	160	—	—	—	160	
AGRICULTURE		—	1 000	22 000	81	25 000	—	—	—	47 000	
a.	Enteric Fermentation	—	920	19 000	—	—	—	—	—	19 000	
b.	Manure Management	—	120	2 600	14	4 200	—	—	—	6 800	
c.	Agriculture Soils	—	—	—	67	21 000	—	—	—	21 000	
	Direct Sources	—	—	—	39	12 000	—	—	—	12 000	
	Pasture, Range and Paddock Manure	—	—	—	11	3 400	—	—	—	3 400	
	Indirect Sources	—	—	—	20	5 000	—	—	—	5 000	
WASTE		250	1 100	24 000	2	700	—	—	—	25 000	
a.	Solid Waste Disposal on Land	—	1 100	23 000	—	—	—	—	—	23 000	
b.	Wastewater Handling	—	10	220	2	600	—	—	—	800	
c.	Waste Incineration	250	0.3	7	0.3	100	—	—	—	360	
Land Use, Land-use Change and Forestry		-78 000	300	6 400	13	4 000	—	—	—	-67 000	
a.	Forest Land	-100 000	290	6 000	12	3 800	—	—	—	-90 000	
b.	Cropland	9 900	10	200	0.6	200	—	—	—	10 000	
c.	Grassland	—	—	—	—	—	—	—	—	—	
d.	Wetlands	4 000	0.2	5	0.01	3	—	—	—	4 000	
e.	Settlements	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 CO₂ emissions coming from the use of limestone & dolomite, soda ash, and magnesite.

Totals may not add up due to rounding.

Table A8-16: 1992 Greenhouse Gas Emissions Summary for Canada**Greenhouse Gas Categories**

Greenhouse Gas Categories		Greenhouse Gases								
		CO ₂	CH ₄	CH ₄	N ₂ O	N ₂ O	HFCs	PFCs	SF ₆	TOTAL
		Global Warming Potential Unit	kt	kt	kt CO ₂ eq	kt	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq
TOTAL ¹		466 000	4 100	86 000	150	45 000	—	6 600	4 200	607 000
ENERGY		434 000	1 900	41 000	30	9 000	—	—	—	483 000
a.	Stationary Combustion Sources	281 000	200	4 000	7	2 000	—	—	—	287 000
	Electricity and Heat Generation	102 000	2.3	49	2	600	—	—	—	103 000
	Fossil Fuel Industries	50 100	80	2 000	1	300	—	—	—	52 000
	Petroleum Refining and Upgrading	15 000	—	—	0.3	100	—	—	—	15 000
	Fossil Fuel Production	35 000	80	2 000	0.7	200	—	—	—	37 000
	Mining & Oil and Gas Extraction	4 850	0.1	2	0.1	30	—	—	—	4 890
	Manufacturing Industries	51 100	3	60	2	500	—	—	—	51 600
	Iron and Steel	6 650	0.3	5	0.2	60	—	—	—	6 720
	Non Ferrous Metals	2 780	0.06	1	0.04	10	—	—	—	2 800
	Chemical	7 400	0.15	3.2	0.1	40	—	—	—	7 450
	Pulp and Paper	11 900	2	40	0.8	200	—	—	—	12 200
	Cement	3 130	0.06	1	0.03	10	—	—	—	3 140
	Other Manufacturing	19 200	0.4	8	0.4	100	—	—	—	19 300
	Construction	1 740	0.03	0.6	0.06	20	—	—	—	1 760
	Commercial & Institutional	26 900	0.5	10	0.5	200	—	—	—	27 000
	Residential	41 000	90	2 000	2	500	—	—	—	43 000
	Agriculture & Forestry	3 250	0.05	1	0.08	20	—	—	—	3 270
b.	Transportation ²	141 000	30	700	20	7 000	—	—	—	150 000
	Domestic Aviation	5 360	0.4	9	0.5	200	—	—	—	5 500
	Road Transportation	97 300	14	300	12	3 700	—	—	—	101 000
	Light Duty Gasoline Vehicles	44 000	7.3	150	7.0	2 200	—	—	—	46 300
	Light Duty Gasoline Trucks	22 300	3.2	67	4.0	1 200	—	—	—	23 600
	Heavy Duty Gasoline Vehicles	6 770	1.0	22	0.18	55	—	—	—	6 850
	Motorcycles	135	0.13	2.8	0.00	0.85	—	—	—	139
	Light Duty Diesel Vehicles	345	0.01	0.2	0.03	8	—	—	—	353
	Light Duty Diesel Trucks	813	0.02	0.5	0.06	20	—	—	—	831
	Heavy Duty Diesel Vehicles	20 300	1	20	0.6	200	—	—	—	20 500
	Propane & Natural Gas Vehicles	2 630	2	30	0.05	20	—	—	—	2 700
	Railways	6 120	0.3	7	2	800	—	—	—	7 000
	Domestic Marine	4 780	0.3	7	1	300	—	—	—	5 100
	Others	27 000	20	300	5	2 000	—	—	—	30 000
	Off Road Gasoline	5 000	6	100	0.1	40	—	—	—	6 000
	Off Road Diesel	12 000	0.7	10	5	2 000	—	—	—	10 000
	Pipelines	9 610	9.6	200	0.3	80	—	—	—	9 890
c.	Fugitive Sources	12 000	1 700	36 000	0.1	30	—	—	—	48 600
	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
INDUSTRIAL PROCESSES		32 000	—	—	35.5	11 000	—	6 600	4 200	53 300
a.	Mineral Products	7 400	—	—	—	—	—	—	—	7 400
	Cement Production	4 500	—	—	—	—	—	—	—	4 500
	Lime Production	1 800	—	—	—	—	—	—	—	1 800
	Mineral Product Use ³	1 100	—	—	—	—	—	—	—	1 100
b.	Chemical Industry	4 200	—	—	35.5	11 000	—	—	—	15 000
	Ammonia Production	4 200	—	—	—	—	—	—	—	4 200
	Nitric Acid Production	—	—	—	3.41	1 060	—	—	—	1 060
	Adipic Acid Production	—	—	—	32	10 000	—	—	—	10 000
c.	Metal Production	11 800	—	—	—	—	—	6 600	2 460	20 800
	Iron and Steel Production	8 500	—	—	—	—	—	—	—	8 500
	Aluminum Production	3 300	—	—	—	—	—	6 600	59.1	9 900
	SF ₆ Used in Magnesium Smelters and Casters	—	—	—	—	—	—	—	2 400	2 400
d.	Consumption of Halocarbons and SF ₆	—	—	—	—	—	—	—	1 700	1 700
e.	Other & Undifferentiated Production	8 200	—	—	—	—	—	—	—	8 200
SOLVENT & OTHER PRODUCT USE		—	—	—	0.45	140	—	—	—	140
AGRICULTURE		—	1 000	22 000	79	24 000	—	—	—	46 000
a.	Enteric Fermentation	—	910	19 000	—	—	—	—	—	19 000
b.	Manure Management	—	130	2 600	14	4 200	—	—	—	6 900
c.	Agriculture Soils	—	—	—	65	20 000	—	—	—	20 000
	Direct Sources	—	—	—	37	11 000	—	—	—	11 000
	Pasture, Range and Paddock Manure	—	—	—	11	3 300	—	—	—	3 300
	Indirect Sources	—	—	—	20	5 000	—	—	—	5 000
WASTE		260	1 100	23 000	2	700	—	—	—	24 000
a.	Solid Waste Disposal on Land	—	1 100	23 000	—	—	—	—	—	23 000
b.	Wastewater Handling	—	10	220	2	600	—	—	—	790
c.	Waste Incineration	260	0.5	10	0.4	100	—	—	—	400
Land Use, Land-use Change and Forestry		-150 000	63	1 300	2.7	850	—	—	—	-150 000
a.	Forest Land	-180 000	45	940	1.9	590	—	—	—	-180 000
b.	Cropland	11 000	10	300	0.7	200	—	—	—	12 000
c.	Grassland	—	—	—	—	—	—	—	—	—
d.	Wetlands	4 000	0.8	20	0.03	10	—	—	—	4 000
e.	Settlements	9 000	4	90	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 CO₂ emissions coming from the use of limestone & dolomite, soda ash, and magnesite.

Totals may not add up due to rounding.

Table A8-17: 1991 Greenhouse Gas Emissions Summary for Canada**Greenhouse Gas Categories**

Greenhouse Gas Categories		Greenhouse Gases									TOTAL
		CO ₂	CH ₄	CH ₄	N ₂ O	N ₂ O	HFCs	PFCs	SF ₆		
		Global Warming Potential Unit	kt	kt	kt CO ₂ eq	kt	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	
TOTAL ¹		451 000	3 900	82 000	140	45 000	—	6 900	5 500	589 000	
ENERGY		419 000	1 800	38 000	30	9 000	—	—	—	465 000	
a.	Stationary Combustion Sources	271 000	200	4 000	7	2 000	—	—	—	277 000	
	Electricity and Heat Generation	96 000	1.7	36	2	500	—	—	—	96 600	
	Fossil Fuel Industries	47 800	70	2 000	1	300	—	—	—	50 000	
	Petroleum Refining and Upgrading	15 000	—	—	0.3	100	—	—	—	15 000	
	Fossil Fuel Production	32 800	70	2 000	0.7	200	—	—	—	35 000	
	Mining & Oil and Gas Extraction	5 030	0.1	2	0.1	30	—	—	—	5 070	
	Manufacturing Industries	51 700	3	60	2	500	—	—	—	52 300	
	Iron and Steel	6 380	0.3	5	0.2	60	—	—	—	6 450	
	Non Ferrous Metals	2 560	0.06	1	0.04	10	—	—	—	2 570	
	Chemical	7 430	0.15	3.2	0.1	40	—	—	—	7 480	
	Pulp and Paper	12 700	2	40	0.8	200	—	—	—	13 000	
	Cement	3 170	0.06	1	0.03	10	—	—	—	3 180	
	Other Manufacturing	19 500	0.4	8	0.4	100	—	—	—	19 600	
	Construction	1 620	0.03	0.6	0.05	20	—	—	—	1 630	
	Commercial & Institutional	26 300	0.5	10	0.5	200	—	—	—	26 500	
	Residential	39 800	90	2 000	2	500	—	—	—	42 000	
	Agriculture & Forestry	2 740	0.04	0.8	0.06	20	—	—	—	2 760	
b.	Transportation ²	137 000	30	600	20	6 000	—	—	—	140 000	
	Domestic Aviation	5 510	0.4	9	0.5	200	—	—	—	5 700	
	Road Transportation	95 300	14	300	11	3 500	—	—	—	99 100	
	Light Duty Gasoline Vehicles	43 700	7.3	150	6.7	2 100	—	—	—	46 000	
	Light Duty Gasoline Trucks	20 900	3.0	64	3.7	1 100	—	—	—	22 100	
	Heavy Duty Gasoline Vehicles	7 050	1.1	24	0.19	59	—	—	—	7 140	
	Motorcycles	139	0.14	2.9	0.00	0.88	—	—	—	142	
	Light Duty Diesel Vehicles	346	0.01	0.2	0.02	8	—	—	—	353	
	Light Duty Diesel Trucks	740	0.02	0.4	0.05	20	—	—	—	757	
	Heavy Duty Diesel Vehicles	20 200	1	20	0.6	200	—	—	—	20 400	
	Propane & Natural Gas Vehicles	2 280	1	30	0.04	10	—	—	—	2 300	
	Railways	5 850	0.3	7	2	700	—	—	—	7 000	
	Domestic Marine	4 930	0.4	7	1	300	—	—	—	5 300	
	Others	26 000	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	—	—	—	7 650	
c.	Fugitive Sources	11 000	1 600	33 000	0.1	30	—	—	—	44 500	
	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	6 680	654	13 700	—	—	—	—	—	20 400	
	Flaring	4 200	2.5	53	0.00	0.4	—	—	—	4 300	
INDUSTRIAL PROCESSES		31 000	—	—	35.7	11 100	—	6 900	5 500	54 900	
a.	Mineral Products	7 300	—	—	—	—	—	—	—	7 300	
	Cement Production	4 400	—	—	—	—	—	—	—	4 400	
	Lime Production	1 800	—	—	—	—	—	—	—	1 800	
	Mineral Product Use ³	1 090	—	—	—	—	—	—	—	1 090	
b.	Chemical Industry	3 900	—	—	35.7	11 100	—	—	—	15 000	
	Ammonia Production	3 900	—	—	—	—	—	—	—	3 900	
	Nitric Acid Production	—	—	—	3.41	1 060	—	—	—	1 060	
	Adipic Acid Production	—	—	—	32	10 000	—	—	—	10 000	
c.	Metal Production	11 500	—	—	—	—	—	6 900	3 650	22 100	
	Iron and Steel Production	8 320	—	—	—	—	—	—	—	8 320	
	Aluminum Production	3 100	—	—	—	—	—	6 900	59.1	10 000	
	SF ₆ Used in Magnesium Smelters and Casters	—	—	—	—	—	—	—	3 590	3 590	
d.	Consumption of Halocarbons and SF ₆	—	—	—	—	—	—	—	1 900	1 900	
e.	Other & Undifferentiated Production	8 700	—	—	—	—	—	—	—	8 700	
SOLVENT & OTHER PRODUCT USE		—	—	—	0.54	170	—	—	—	170	
AGRICULTURE		—	1 000	21 000	78	24 000	—	—	—	45 000	
a.	Enteric Fermentation	—	890	19 000	—	—	—	—	—	19 000	
b.	Manure Management	—	120	2 600	13	4 100	—	—	—	6 700	
c.	Agriculture Soils	—	—	—	65	20 000	—	—	—	20 000	
	Direct Sources	—	—	—	37	12 000	—	—	—	12 000	
	Pasture, Range and Paddock Manure	—	—	—	10	3 200	—	—	—	3 200	
	Indirect Sources	—	—	—	20	5 000	—	—	—	5 000	
WASTE		250	1 100	23 000	2	700	—	—	—	24 000	
a.	Solid Waste Disposal on Land	—	1 100	23 000	—	—	—	—	—	23 000	
b.	Wastewater Handling	—	9.8	210	2	500	—	—	—	750	
c.	Waste Incineration	250	0.5	10	0.4	100	—	—	—	390	
Land Use, Land-use Change and Forestry		-110 000	230	4 900	10	3 100	—	—	—	-97 000	
a.	Forest Land	-130 000	220	4 500	9.1	2 800	—	—	—	-120 000	
b.	Cropland	12 000	10	300	0.7	200	—	—	—	13 000	
c.	Grassland	—	—	—	—	—	—	—	—	—	
d.	Wetlands	5 000	0.5	10	0.02	7	—	—	—	5 000	
e.	Settlements	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 CO₂ emissions coming from the use of limestone & dolomite, soda ash, and magnesite.

Totals may not add up due to rounding.

Table A8-18: 1990 Greenhouse Gas Emissions Summary for Canada

Greenhouse Gas Categories		Greenhouse Gases								TOTAL
Global Warming Potential	Unit	CO ₂	CH ₄	CH ₄	N ₂ O	N ₂ O	HFCs	PFCs	SF ₆	
		kt	kt	kt CO ₂ eq	kt	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq
TOTAL¹		459 000	3 800	80 000	150	46 000	–	6 500	5 000	596 000
ENERGY		428 000	1 700	37 000	30	8 000	–	–	–	473 000
a. Stationary Combustion Sources		276 000	200	4 000	7	2 000	–	–	–	282 000
Electricity and Heat Generation		94 700	1.8	38	2	500	–	–	–	95 300
Fossil Fuel Industries		49 600	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		6 140	0.1	3	0.1	40	–	–	–	6 180
Manufacturing Industries		54 200	3	60	2	500	–	–	–	54 700
Iron and Steel		6 420	0.2	5	0.2	60	–	–	–	6 490
Non Ferrous Metals		3 170	0.07	1	0.05	10	–	–	–	3 180
Chemical		7 050	0.15	3.0	0.1	40	–	–	–	7 090
Pulp and Paper		13 400	2	40	0.8	200	–	–	–	13 600
Cement		3 680	0.07	1	0.04	10	–	–	–	3 690
Other Manufacturing		20 500	0.4	9	0.4	100	–	–	–	20 600
Construction		1 860	0.03	0.7	0.05	20	–	–	–	1 880
Commercial & Institutional		25 700	0.5	10	0.5	200	–	–	–	25 800
Residential		41 300	100	2 000	2	500	–	–	–	44 000
Agriculture & Forestry		2 400	0.04	0.8	0.05	20	–	–	–	2 420
b. Transportation²		142 000	30	700	20	6 000	–	–	–	150 000
Domestic Aviation		6 220	0.5	10	0.6	200	–	–	–	6 400
Road Transportation		97 700	15	310	10	3 200	–	–	–	101 000
Light Duty Gasoline Vehicles		45 100	7.8	160	6.2	1 900	–	–	–	47 200
Light Duty Gasoline Trucks		20 200	3.1	66	3.2	1 000	–	–	–	21 300
Heavy Duty Gasoline Vehicles		7 950	1.3	27	0.22	69	–	–	–	8 050
Motorcycles		147	0.14	3.0	0.00	0.93	–	–	–	151
Light Duty Diesel Vehicles		355	0.01	0.2	0.03	8	–	–	–	363
Light Duty Diesel Trucks		708	0.02	0.4	0.05	20	–	–	–	724
Heavy Duty Diesel Vehicles		21 000	1	20	0.6	200	–	–	–	21 200
Propane & Natural Gas Vehicles		2 170	1	30	0.04	10	–	–	–	2 200
Railways		6 310	0.3	7	3	800	–	–	–	7 000
Domestic Marine		4 730	0.3	7	1	300	–	–	–	5 100
Others		27 000	20	300	6	2 000	–	–	–	30 000
Off Road Gasoline		7 000	8	200	0.1	40	–	–	–	7 000
Off Road Diesel		14 000	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		30 000	–	–	37.8	11 700	–	6 500	5 000	53 500
a. Mineral Products		8 300	–	–	–	–	–	–	–	8 300
Cement Production		5 400	–	–	–	–	–	–	–	5 400
Lime Production		1 700	–	–	–	–	–	–	–	1 700
Mineral Product Use ³		1 090	–	–	–	–	–	–	–	1 090
b. Chemical Industry		3 900	–	–	37.8	11 700	–	–	–	16 000
Ammonia Production		3 900	–	–	–	–	–	–	–	3 900
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 ₆ Used in Magnesium Smelters and Casters		–	–	–	–	–	–	–	3 110	3 110
d. Consumption of Halocarbons and SF₆		–	–	–	–	–	–	–	1 800	1 800
e. Other & Undifferentiated Production		8 300	–	–	–	–	–	–	–	8 300
SOLVENT & OTHER PRODUCT USE		–	–	–	0.56	170	–	–	–	170
AGRICULTURE		–	1 000	21 000	80	25 000	–	–	–	46 000
a. Enteric Fermentation		–	880	18 000	–	–	–	–	–	18 000
b. Manure Management		–	120	2 600	13	4 100	–	–	–	6 700
c. Agriculture Soils		–	–	–	67	21 000	–	–	–	21 000
Direct Sources		–	–	–	39	12 000	–	–	–	12 000
Pasture, Range and Paddock Manure		–	–	–	10	3 200	–	–	–	3 200
Indirect Sources		–	–	–	20	5 000	–	–	–	5 000
WASTE		270	1 100	22 000	2	700	–	–	–	23 000
a. Solid Waste Disposal on Land		–	1 000	22 000	–	–	–	–	–	22 000
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		-130 000	150	3 200	6.4	2 000	–	–	–	-120 000
a. Forest Land		-160 000	130	2 700	5.5	1 700	–	–	–	-150 000
b. Cropland		14 000	20	300	0.8	200	–	–	–	14 000
c. Grassland		–	–	–	–	–	–	–	–	–
d. Wetlands		5 000	0.4	7	0.01	5	–	–	–	5 000
e. Settlements		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 CO₂ emissions coming from the use of limestone & dolomite, soda ash, and magnesite.

Totals may not add up due to rounding.

Annex 9 Electricity Intensity Tables

This annex presents detailed GHG information related to the generation of electricity by public utilities by generation source 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 sources 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 the level of refinement to discuss the impacts of the distribution infrastructure. GHG emission estimates and electricity generation values are based on activities that occur at the plant only.

The analysis in this section uses fuel consumption and electricity production data published by Statistics Canada. Fuel consumption data is available from the Report on Energy Supply-Demand in Canada (RESO), (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 RESO and the data within the reports may differ slightly due to revision. The EPGTD is assumed to contain the most up-to-date data and unless otherwise stated, the data presented in this section is 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.

A9.1 Methodology and Limitations

GHG emissions resulting from electricity generation by public utilities is presented in this annex. Detailed data on industrial contributions to the electricity grid are available however, fuel consumption data associated with this electricity production is not currently available in the EPGTD. However, the contribution of industry generated electricity to the Canadian total is on average less than 9% and 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. Information on emissions and trends from the entire Electricity and Heat generation sector is presented in Canada's Greenhouse Gas Emission Tables, 1990–2005 (Annex 8) and the Provincial/Territorial Greenhouse Gas Emission Tables, 1990–2005 (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. Net electricity generation presented herein is from the EPGTD. For the period of 1990 to 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 demand at peak times, since some fuel will be consumed even when not producing power for the grid.

A9.2 National Trends

Public utility generated electricity has increased by 31% since 1990 while GHG emissions associated with this sector have increased by 32% over the same period. GHG intensity is up slightly from 217 g CO₂ eq/kWh in 1990 to 220 g CO₂ eq/kWh in 2005. GHG intensity is at its lowest level since 1997, largely due to increasing hydro and nuclear generation offsetting the GHG impact of “Other” fossil fuels (e.g. petroleum coke, still gas, coke oven gas) in the generation mix.

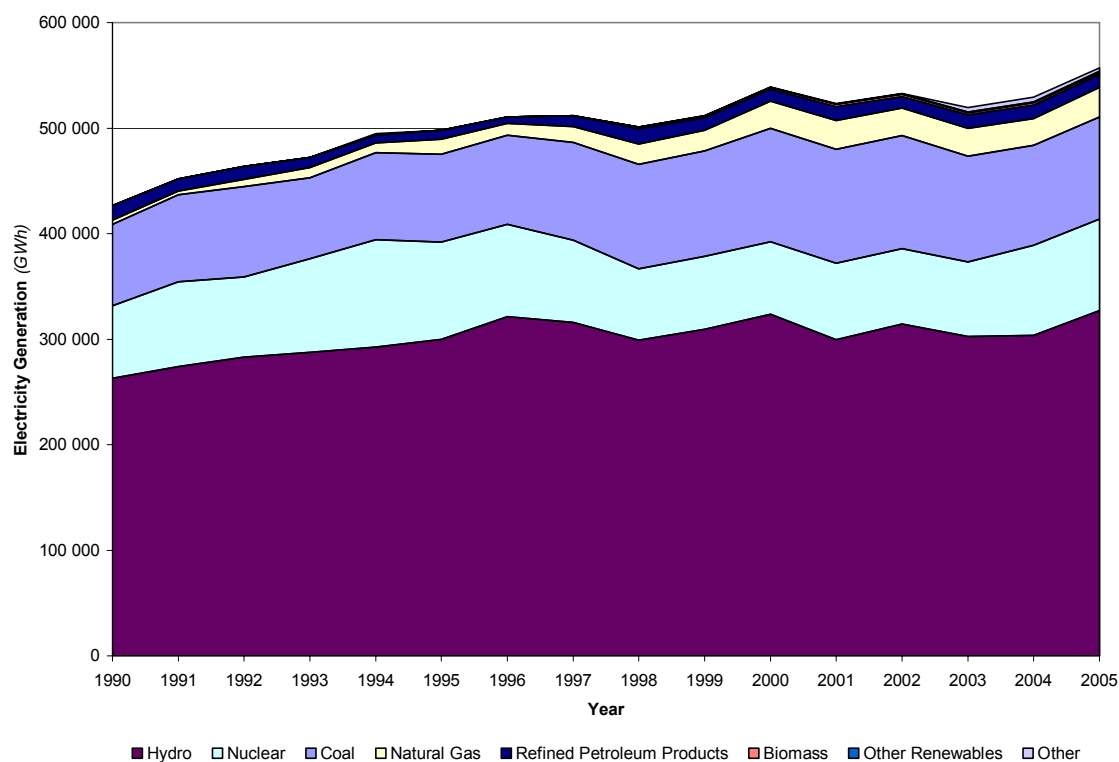


Figure A9-1: Utility Generated Electricity by Source

As is illustrated in Figure 9-1, hydroelectric resources still supply the majority of Canada's electricity, contributing 59% of total generation in 2005; down from 62% in 1990. Hydroelectric generation is essentially free of direct GHG emissions except for methane emissions that result from the flooding of lands to build reservoirs⁵⁴. Hydro resources are primarily concentrated in Labrador, Quebec, British Columbia and Manitoba and in most cases provide the base load. 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 electricity⁵⁵, contributing approximately 16% of total generation in 2005, as well as in 1990. Nuclear generation peaked in 1996 with 102,000 GWh, then declined in the subsequent years due to reactor maintenance and shutdowns (due to safety concerns). In 2005, nuclear power stations generated a total of 86,800 GWh, the majority (90%) in the province of Ontario. Nuclear power plants also operate in Quebec and in New Brunswick.

Coal provided slightly more than 17% of the electricity generated in Canada in 2005, totalling 96,600 GWh in 2005, an increase of 26% or 20,000 GWh from 1990. Coal-fired generation is responsible for about 79% 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 9-2 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 96 Mt of GHG emissions, a 17 Mt increase over 1990.

The use of natural gas for electricity generation has increased significantly since 1990 and it now surpasses refined petroleum products (RPPs) in its contribution to total supply. In 2005 its share was 5% - more than five times that of 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 (BC) and Saskatchewan. In Quebec and the Atlantic region, gas has only been available 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, 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 KWh are about half of those from coal, any displacement of coal by natural gas results in fewer GHG emissions. Total GHG emissions from natural gas in 2005 were 14 Mt, an increase of 11 Mt from 1990.

⁵⁴ Methane emissions from reservoirs are not included in the GHG totals for electricity though they are included in the LULUCF, Wetlands category of the GHG inventory.

⁵⁵ The inventory analysis does not consider emissions related to uranium mining, processing or disposal of waste fuel.

RPPs like heavy fuel oil and diesel were used to generate 11,900 GWh of electricity in 2005, a 15% decrease from 1990. RPP-fired generation made up 2.1% of Canada's total electricity production for 2005. RPPs are used for electricity generation primarily in Nova Scotia and New Brunswick, where they made up 14% and 37%, of their respective supply mixes in 2005, although these percentages vary from year to year depending on the price of RPP's relative to the price of coal. The remainder of RPP generation is located in Alberta and Quebec. GHG emissions from RPP generation in 2005 were 12.3 Mt, about 8% higher than their level in 1990.

Biomass sources, in particular wood and wood wastes, contributed 1.3% of the electricity supply in 2005, mainly 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.

A9.3 Regional Discussion

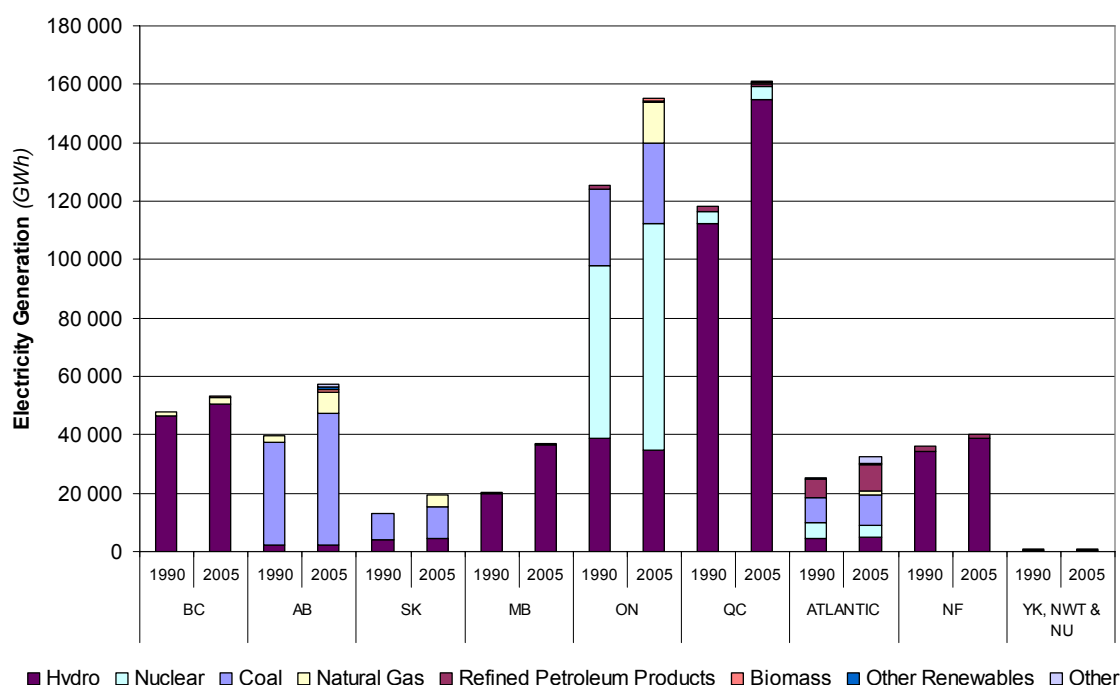


Figure A9-2: Electricity Generation By Region and Source 1990 & 2005

Figure 9-2 provides a breakdown of electricity generation by region and by source for the years 1990 and 2005.⁵⁶ Coal-fired sources predominate in Alberta and Saskatchewan. Hydro provides the majority of electricity generation in the provinces of Quebec, British Columbia, Manitoba and Newfoundland & Labrador. In Ontario and the Atlantic region, the electricity generation mix is fairly diverse, with nuclear power providing the greatest

⁵⁶ Due to their relatively small contribution to Canadian supply, the Atlantic provinces have been grouped together as have the Territories.

percentage of supply in Ontario. In terms of total generation, Quebec and Ontario have by far the highest generation totals – combined they produce 57% of Canada's electricity supply. They are followed by Alberta and BC with about 57,300 GWh and 53,400 GWh, respectively, then Newfoundland with 40,300 GWh.

Generation has increased in all provinces, although in BC the increase was minimal. Since 1990, generation in Alberta, Saskatchewan and Manitoba grew by over 35%. In Manitoba this growth was based on new hydro development at Churchill Falls, while in Alberta and Saskatchewan the increase was due to expanded use of coal and natural gas. The Atlantic region's 27% growth was also primarily brought about through increased use of fossil fuels – a combination of coal, RPP's 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 & tidal) continue to provide at least three quarters of the electricity in Canada. In the last 5 years the contribution of "Other Renewables" (mostly new wind installations), has increased almost 500% and will likely increase further in 2006 and 2007 due to federal and provincial incentive programs and increased public acceptance. However, this electricity source contributes minimally to the overall supply mix (0.3% in 2005).

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 only 8% between 2000 and 2005. Natural gas based generation was lower in 2002, 2003 and 2004 due in part to higher natural gas prices. 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, RPP and 'Other' fuel generation. With increasing oil costs, it appears that 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 for public utilities to pass on rising fuel costs. These financial impacts may have the impact of spurring investment in increasing efficiency and cogeneration at existing facilities in order to maximize power output.

A9.4 GHG Emissions Intensities

The quantity of GHG emissions per MWh for a specific fuel (or for a specific fuel and generation type) is known as the emission intensity and can be measured in tonnes of CO₂ equivalent emissions per GWh (t CO₂ eq/GWh). Emissions 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 emissions intensity and varies for different types of coal, though usually it is in the range of 1,000 t CO₂ eq/GWh. The intensity of RPPs also varies for

fuel type and technology, ranging from 600 to 800 t CO₂ eq/GWh, and reflects the variability of this category. Natural gas generators tend to generate at around 500 t CO₂ eq/GWh, though for cogeneration plants the value could be substantially lower.

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, though it has been decreasing due to increased use of natural gas, biomass and other renewable sources of energy. The Atlantic region, which has a mix of RPP's, coal, and nuclear has a GHG intensity that is somewhat lower than Alberta, whereas Quebec, Manitoba and BC, where generation is dominated by hydro have the lowest GHG intensities. Ontario lies somewhere between the two extremes with its mix of hydro, nuclear and fossil fuels and is very close to the Canadian average.

Table A9-1: Electricity Generation and Greenhouse Gas Emission Details for Canada¹

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Greenhouse Gas Emissions^a																
<i>kt CO₂ equivalent</i>																
Coal	78,763	82,428	85,428	78,177	81,662	82,998	84,835	91,375	97,044	96,681	104,770	103,365	101,949	101,260	92,862	96,022
Refined Petroleum Products ²	10,948	8,925	10,137	7,414	5,789	6,514	5,126	7,720	11,486	9,111	8,345	10,156	8,123	9,867	9,708	9,514
Natural Gas	2,626	2,140	4,407	5,472	5,544	7,001	5,575	7,444	9,641	9,735	12,906	13,863	12,698	13,575	12,576	14,058
Nuclear																
Hydro ³																
Biomass ⁴																
Other Renewables																
Other	40	24	23	0	28	13	15	105	43	44	119	373	425	3,841	3,985	2,683
Overall Total	92,377	93,518	99,996	91,062	93,023	96,525	95,551	106,644	118,214	115,571	126,141	127,757	123,195	128,543	119,131	122,277
Electricity Generation^b																
<i>GWh</i>																
Coal	76,975	82,494	85,505	77,059	82,306	83,351	84,548	92,555	99,236	99,591	107,680	107,779	106,913	100,391	94,872	96,620
Refined Petroleum Products	13,925	11,472	12,194	9,379	7,376	8,418	6,282	10,109	14,537	11,749	10,807	13,252	10,793	12,561	12,799	11,887
Natural Gas	3,969	3,413	6,821	9,545	9,191	14,189	10,777	15,099	18,904	19,688	25,881	27,280	26,389	26,244	25,340	27,947
Nuclear	68,761	80,122	76,019	88,639	101,710	92,306	87,510	77,857	67,467	69,331	68,675	72,353	71,251	70,653	85,240	86,830
Hydro	262,920	274,179	283,041	287,447	292,664	299,738	321,414	315,959	299,123	309,334	323,468	299,604	314,555	302,437	303,591	327,171
Biomass ⁴	14	24	0	125	337	IE	IE	IE	1,703	1,743	1,911	2,116	2,182	2,137	1,995	1,794
Other Renewables ⁵	26	32	58	33	34	33	32	82	84	278	264	366	435	704	970	1,578
Other ⁶	83	14.4	0	0	1,201	21	14	126	61	56	167	424	488	4,193	4,556	3,175
Overall Total	426,673	451,750	463,639	472,229	494,821	498,056	510,577	511,788	501,114	511,770	538,853	523,175	533,006	519,319	529,363	557,002
Greenhouse Gas Intensity																
<i>g CO₂ eq / kWh</i>																
Coal	1,023	999	999	1,015	992	996	1,003	987	978	971	973	959	954	1,009	979	994
Refined Petroleum Products	786	778	831	790	785	774	816	764	790	775	772	766	753	785	759	800
Natural Gas	662	627	646	573	603	493	517	493	510	494	499	508	481	517	496	503
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	484	1,677	-	-	23	583	1,043	834	716	775	713	880	872	916	875	845
Overall Total	217	207	216	193	188	194	187	208	236	226	234	244	231	248	225	220

Sources:

a Electric Power Generation, Transmission and Distribution, Catalogue No. 57-202-XIB, Statistics Canada

b Report on Energy Supply-Demand in Canada, Catalogue No. 57-003-XIB, Statistics Canada

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 other fuels

IE - Generation data is Included Elsewhere

Table A9-2: Electricity Generation and Greenhouse Gas Emission Details for Newfoundland and Labrador¹

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Greenhouse Gas Emissions^a <i>kt CO₂ equivalent</i>																
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Refined Petroleum Products ²	1,610	1,277	1,474	1,338	714	1,248	1,157	1,208	1,014	803	797	1,645	1,822	1,515	1,273	1,240
Natural Gas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro ³	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass ⁴	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Overall Total	1,610	1,277	1,474	1,338	714	1,248	1,157	1,208	1,014	803	797	1,645	1,822	1,515	1,273	1,240
Electricity Generation^b <i>GWh</i>																
Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Refined Petroleum Products	1,964	1,511	1,782	1,632	850	1,603	1,467	1,571	1,307	957	1,017	2,145	2,434	2,000	1,696	1,365
Natural Gas	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
Hydro	34,322	34,917	34,375	38,675	37,089	35,783	34,834	39,651	43,143	39,920	41,764	37,430	40,113	38,350	38,102	38,950
Biomass	14	22	0	24	25	21	14	0	0	0	0	0	0	0	0	0
Other Renewables ⁵	0.1	0	24	0	0	0	0	0	0	0	0	0	0	0	0	0
Other ⁶	0	0	0	0.3	0	0	0	0	0	0	0	0	0	0	0	0
Overall Total	36,300	36,450	36,180	40,331	37,965	37,407	36,315	41,221	44,450	40,877	42,780	39,575	42,546	40,351	39,798	40,314
Greenhouse Gas Intensity <i>g CO₂ eq/kWh</i>																
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Refined Petroleum Products	820	845	827	820	840	779	789	769	775	840	784	767	749	757	750	909
Natural Gas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Overall Total	44	35	41	33	19	33	32	29	23	20	19	42	43	38	32	31

Sources:

a Electric Power Generation, Transmission and Distribution, Catalogue No. 57-202-XIB, Statistics Canada.

b Report on Energy Supply-Demand in Canada, Catalogue No. 57-003-XIB, Statistics Canada.

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 other fuels.

Table A9-3: Electricity Generation and Greenhouse Gas Emission Details for Prince Edward Island¹

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Greenhouse Gas Emissions^a																
<i>kt CO₂ equivalent</i>																
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Refined Petroleum Products ²	100	90	50	73	57	37	24	30	10	18	55	50	29	42	18	12
Natural Gas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro ³	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass ⁴	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Overall Total	100	90	50	73	57	37	24	30	10	18	55	50	29	42	18	12
Electricity Generation^b																
<i>GWh</i>																
Coal	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
Natural Gas	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
Hydro	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
Other Renewables ⁵	0	0	0	0	0	0	0	0	0	0	0	5	19	20	35	40
Other ⁶	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Overall Total	81	71	34	59	40	22	9	21	3	8	48	49	39	63	48	46
Greenhouse Gas Intensity																
<i>g CO₂ eq/kWh</i>																
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Refined Petroleum Products	1,246	1,260	1,477	1,234	1,431	1,713	2,771	1,452	3,903	2,242	1,138	1,147	1,529	978	1,832	2,754
Natural Gas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Overall Total	1,246	1,260	1,477	1,234	1,431	1,713	2,771	1,452	3,903	2,242	1,138	1,014	742	669	373	252

Sources:

a Electric Power Generation, Transmission and Distribution, Catalogue No. 57-202-XIB, Statistics Canada.

b Report on Energy Supply-Demand in Canada, Catalogue No. 57-003-XIB, Statistics Canada.

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 other fuels.

Table A9-4: Electricity Generation and Greenhouse Gas Emission Details for Nova Scotia¹

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Greenhouse Gas Emissions^a																
	<i>kt CO₂ equivalent</i>															
Coal	5,046	5,278	5,387	5,535	6,105	5,842	6,507	6,860	5,886	6,533	7,593	7,655	6,108	5,461	5,847	5,993
Refined Petroleum Products ²	1,751	1,679	1,949	1,719	977	1,015	543	643	1,881	1,496	1,193	817	262	1,308	1,382	1,280
Natural Gas	0	0	0	0	0	0	0	0	0	0	0	0	883	64	52	106
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro ³	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass ⁴	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	0	0	0	0	0	0	0	0	0	0	0	0	0	1,497	2,668	2,031
Overall Total	6,796	6,957	7,336	7,254	7,082	6,857	7,050	7,503	7,767	8,029	8,786	8,472	7,253	8,329	9,950	9,410
Electricity Generation^b																
	<i>GWh</i>															
Coal	7,639	5,867	6,007	6,313	7,156	7,018	7,835	8,250	7,269	7,806	8,787	9,617	7,943	6,744	6,205	6,655
Refined Petroleum Products	300	2,120	2,459	2,153	1,189	1,274	623	778	2,121	1,880	1,470	1,042	447	1,959	1,859	1,693
Natural Gas	0	0	0	0	0	0	0	0	0	0	0	0	2,254	144	103	208
Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydro	1,119	998	845	849	982	871	1,084	919	871	962	887	678	1,000	1,052	865	1,036
Biomass	0	0	34	33	20	0	185	179	149	169	197	215	262	219	185	182
Other Renewables ⁵	26	32	34	33	34	33	32	20	29	84	0	32	31	33	29	113
Other ⁶	0	0	0	0	20	0	0	0	0	0	0	0	0	1,994	3,112	2,322
Overall Total	9,084	9,016	9,378	9,381	9,402	9,196	9,760	10,147	10,440	10,900	11,340	11,584	11,937	12,145	12,357	12,209
Greenhouse Gas Intensity																
	<i>g CO₂ eq/kWh</i>															
Coal	661	900	897	877	853	832	830	832	810	837	864	796	769	810	942	901
Refined Petroleum Products	5,834	792	793	798	822	796	870	826	887	796	812	784	586	668	743	756
Natural Gas	-	-	-	-	-	-	-	-	-	-	-	-	392	443	505	513
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	0	-	-	-	-	-	-	-	-	751	857	875
Overall Total	748	772	782	773	753	746	722	739	744	737	775	731	608	686	805	771

Sources:

a Electric Power Generation, Transmission and Distribution, Catalogue No. 57-202-XIB, Statistics Canada.

b Report on Energy Supply-Demand in Canada, Catalogue No. 57-003-XIB, Statistics Canada.

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 other fuels.

Table A9-5: Electricity Generation and Greenhouse Gas Emission Details for New Brunswick¹

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Greenhouse Gas Emissions^a																
<i>kt CO₂ equivalent</i>																
Coal	1,136	943	1,028	1,187	2,680	3,036	3,151	3,029	3,236	3,130	2,816	3,180	2,745	3,099	2,768	2,591
Refined Petroleum Products ²	4,593	4,212	4,866	3,746	3,214	3,472	2,599	5,013	5,881	4,714	5,452	6,539	5,216	4,272	4,916	4,915
Natural Gas	0	0	0	0	0	0	0	0	0	0	0	0	311	621	679	486
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro ³	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass ⁴	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	40	24	23	0	28	0	0	0	0	0	0	0	0	0	0	0
Overall Total	5,769	5,178	5,917	4,933	5,922	6,508	5,750	8,042	9,117	7,845	8,268	9,719	8,273	7,992	8,363	7,992
Electricity Generation^b																
<i>GWh</i>																
Coal	997	1,057	1,175	1,384	3,034	3,486	3,562	3,560	3,791	3,682	3,888	3,962	3,656	3,891	3,299	3,592
Refined Petroleum Products	6,098	5,553	6,382	4,780	4,193	4,301	3,162	6,499	7,642	6,023	7,020	8,163	6,365	5,111	6,430	7,473
Natural Gas	0	0	0	0	0	0	0	0	0	0	0	0	591	1,128	1,744	1,035
Nuclear	5,338	5,440	4,833	5,323	5,238	1,579	4,591	3,444	3,773	4,083	3,959	4,520	3,757	4,742	4,299	4,378
Hydro	3,459	2,935	2,941	2,990	2,718	2,637	3,440	2,304	2,777	3,302	3,222	2,066	2,190	3,156	2,954	3,817
Biomass	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Renewables ⁵	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other ⁶	83	14	NR	0	17	0	0	0	0	392	125	39	159	149	901	0
Overall Total	15,976	14,999	15,331	14,477	15,201	12,003	14,755	15,806	17,984	17,482	18,216	18,750	16,718	18,178	19,626	20,295
Greenhouse Gas Intensity																
<i>g CO₂ eq/kWh</i>																
Coal	1,139	891	875	858	884	871	885	851	854	850	724	803	751	796	839	721
Refined Petroleum Products	753	758	762	784	766	807	822	771	770	783	777	801	820	836	765	658
Natural Gas	-	-	-	-	-	-	-	-	-	-	-	-	527	551	389	469
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	483	1,717	-	-	1,615	-	-	-	-	0	0	0	0	0	0	-
Overall Total	361	345	386	341	390	542	390	509	507	449	454	518	495	440	426	394

Sources:

a Electric Power Generation, Transmission and Distribution, Catalogue No. 57-202-XIB, Statistics Canada.

b Report on Energy Supply-Demand in Canada, Catalogue No. 57-003-XIB, Statistics Canada.

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 other fuels.

NR - Generation data was Not Reported

Table A9-6: Electricity Generation and Greenhouse Gas Emission Details for Quebec¹

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Greenhouse Gas Emissions^a <i>kt CO₂ equivalent</i>																
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Refined Petroleum Products ²	1,353	373	791	144	310	187	175	201	1,300	891	291	316	189	1,478	1,254	1,249
Natural Gas	69	69	69	69	77	77	77	77	71	59	67	63	63	63	63	211
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro ³	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass ⁴	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Overall Total	1,422	442	860	213	387	264	252	277	1,371	949	358	379	251	1,541	1,317	1,460
Electricity Generation^b <i>GWh</i>																
Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Refined Petroleum Products	1,732	402	1,015	160	233	365	190	217	1,696	1,157	337	386	275	2,069	1,837	910
Natural Gas	104	103	110	109	83	258	204	218	194	192	196	183	123	229	107	188
Nuclear	4,070	3,910	4,600	4,807	5,406	4,511	5,243	4,204	3,814	3,775	4,886	4,705	4,530	3,548	4,878	4,483
Hydro	112,159	120,899	124,361	130,142	136,902	148,296	146,711	141,750	130,303	143,120	153,385	144,839	150,629	152,185	146,157	154,678
Biomass	0	0	0	0	0	0	418	610	636	592	619	770	815	817	662	288
Other Renewables ⁵	0	0	0	0	0	0	0	0	4	121	173	190	173	170	187	416
Other ⁶	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Overall Total	118,064	125,314	130,086	135,219	142,625	153,430	152,765	146,999	136,647	148,957	159,597	151,073	156,545	159,018	153,828	160,963
Greenhouse Gas Intensity <i>g CO₂ eq/kWh</i>																
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Refined Petroleum Products	781	928	780	900	1,330	513	922	923	767	770	864	817	686	714	682	1,372
Natural Gas	663	670	625	631	920	297	376	352	366	305	343	344	509	276	589	1,123
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Overall Total	12.0	3.5	6.6	1.6	2.7	1.7	1.6	1.9	10.0	6.4	2.2	2.5	1.6	9.7	8.6	9.1

Sources:

a Electric Power Generation, Transmission and Distribution, Catalogue No. 57-202-XIB, Statistics Canada.

b Report on Energy Supply-Demand in Canada, Catalogue No. 57-003-XIB, Statistics Canada.

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 other fuels.

Table A9-7: Electricity Generation and Greenhouse Gas Emission Details for Ontario¹

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Greenhouse Gas Emissions^a																
<i>kt CO₂ equivalent</i>																
Coal	24,720	26,161	25,374	16,496	13,520	14,248	16,419	20,585	27,154	28,233	36,159	33,301	33,107	32,869	24,463	27,601
Refined Petroleum Products ²	1,120	905	675	104	214	252	219	320	1,090	990	346	602	435	1,063	677	664
Natural Gas	0	0	741	1,162	1,607	2,936	2,735	3,460	3,687	4,848	4,613	5,303	5,385	5,629	4,806	5,910
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro ³	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass ⁴	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	0	0	0	0	0	13	15	105	43	44	21	0	45	14	0	0
Overall Total	25,841	27,066	26,789	17,763	15,341	17,449	19,388	24,471	31,975	34,115	41,140	39,205	38,973	39,575	29,946	34,176
Electricity Generation^b																
<i>GWh</i>																
Coal	26,136	30,354	28,537	20,470	16,739	16,154	17,656	26,506	33,075	33,380	40,468	36,246	35,968	30,315	25,725	27,437
Refined Petroleum Products	1,323	1,126	753	569	194	239	224	255	796	1,283	418	701	551	1,621	738	799
Natural Gas	0	1	1,170	804	2,976	6,623	6,343	6,329	8,677	10,935	10,582	11,567	11,982	15,001	10,523	13,683
Nuclear	59,353	70,773	66,586	78,509	91,066	86,216	77,676	70,209	59,879	61,473	59,829	63,128	62,964	62,362	76,063	77,969
Hydro	38,673	35,958	38,785	39,275	37,571	37,461	40,305	38,695	34,405	36,018	36,567	35,812	37,095	34,744	38,083	34,551
Biomass	0	0	0	106	300	IE	IE	IE	311	312	316	498	574	665	539	562
Other Renewables ⁵	0	0	0	0	0	0	0	0	0	1	1	1	3	5	25	26
Other ⁶	0	0	0	0	0	389	1,101	608	690	551	521	501	524	487	335	285
Overall Total	125,485	138,211	135,832	139,731	148,845	147,081	143,305	142,601	137,835	143,954	148,701	148,454	149,661	145,199	152,031	155,312
Greenhouse Gas Intensity																
<i>g CO₂ eq/kWh</i>																
Coal	946	862	889	806	808	882	930	777	821	846	894	919	920	1,084	951	1,006
Refined Petroleum Products	846	804	896	183	1,100	1,058	977	1,255	1,368	772	829	858	790	656	918	832
Natural Gas	563	552	633	1,446	540	443	431	547	425	443	436	458	449	375	457	432
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	32	13	174	63	79	41	0	86	30	0	0
Overall Total	206	196	197	127	103	119	135	172	232	237	277	264	260	273	197	220

Sources:

a Electric Power Generation, Transmission and Distribution, Catalogue No. 57-202-XIB, Statistics Canada.

b Report on Energy Supply-Demand in Canada, Catalogue No. 57-003-XIB, Statistics Canada.

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 other fuels.

IE - Generation data is Included Elsewhere.

Table A9-8: Electricity Generation and Greenhouse Gas Emission Details for Manitoba¹

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Greenhouse Gas Emissions^a																
	<i>kt CO₂ equivalent</i>															
Coal	455	351	351	275	276	177	281	224	944	522	971	463	375	603	315	485
Refined Petroleum Products ²	52	47	46	27	32	20	42	16	14	14	11	16	13	17	10	11
Natural Gas	0	0	3	0	0	0	1	0	0	0	0	0	82	154	58	8
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro ³	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass ⁴	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Overall Total	507	399	400	302	308	198	324	240	958	536	982	480	471	773	382	504
Electricity Generation^b																
	<i>GWh</i>															
Coal	303	227	228	188	182	120	186	183	846	464	870	443	378	697	280	414
Refined Petroleum Products	42	38	39	22	35	24	44	13	14	13	11	20	16	10	10	19
Natural Gas	0	0	3	0	0	1	1	0	0	0	0	0	121	102	76	14
Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydro	19,827	22,554	26,433	26,891	28,146	29,013	30,866	33,391	30,781	28,138	31,536	32,899	28,821	20,246	27,219	36,440
Biomass	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Renewables ⁵	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	53
Other ⁶	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Overall Total	20,172	22,819	26,703	27,102	28,364	29,158	31,096	33,587	31,641	28,615	32,417	33,362	29,336	21,054	27,585	36,940
Greenhouse Gas Intensity																
	<i>g CO₂ eq/kWh</i>															
Coal	1,504	1,552	1,541	1,462	1,513	1,478	1,512	1,224	1,116	1,126	1,116	1,045	993	866	1,123	1,170
Refined Petroleum Products	1,223	1,237	1,183	1,186	900	847	945	1,214	1,004	1,068	971	817	848	1,701	973	606
Natural Gas	828	867	860	872	-	792	892	-	-	-	-	-	680	1,506	758	574
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Overall Total	25	17	15	11	11	7	10	7	30	19	30	14	16	37	14	14

Sources:

a Electric Power Generation, Transmission and Distribution, Catalogue No. 57-202-XIB, Statistics Canada.

b Report on Energy Supply-Demand in Canada, Catalogue No. 57-003-XIB, Statistics Canada.

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 other fuels.

Table A9-9: Electricity Generation and Greenhouse Gas Emission Details for Saskatchewan¹

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Greenhouse Gas Emissions^a																
<i>kt CO₂ equivalent</i>																
Coal	10,072	10,276	11,552	12,103	13,109	13,404	13,538	14,010	14,081	13,980	13,198	13,566	13,569	13,587	14,298	13,428
Refined Petroleum Products ²	7	7	6	6	6	15	17	30	21	19	19	16	16	24	21	26
Natural Gas	182	224	490	190	50	326	338	680	907	805	1,301	1,475	1,523	2,539	2,360	2,538
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro ³	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass ⁴	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Overall Total	10,261	10,508	12,048	12,299	13,165	13,746	13,893	14,720	15,009	14,804	14,517	15,056	15,108	16,150	16,679	15,992
Electricity Generation^b																
<i>GWh</i>																
Coal	8,672	8,654	9,994	10,498	11,551	11,286	11,210	11,422	11,798	11,525	11,606	11,516	11,654	11,580	12,116	10,760
Refined Petroleum Products	6	7	2	3	8	12	8	29	11	20	21	22	23	31	23	37
Natural Gas	242	302	665	250	74	487	499	907	1,267	1,341	2,439	2,669	2,721	4,123	3,874	3,999
Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydro	4,215	4,214	3,059	4,051	3,393	4,118	4,376	3,986	3,442	3,689	3,046	2,391	2,836	3,416	2,746	4,573
Biomass	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Renewables ⁵	0	0	0	0	0	0	0	0	0	0	0	3	43	58	74	92
Other ⁶	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Overall Total	13,134	13,176	13,719	14,802	15,025	15,903	16,093	16,344	16,518	16,576	17,113	16,601	17,277	19,209	18,833	19,460
Greenhouse Gas Intensity																
<i>g CO₂ eq/kWh</i>																
Coal	1,161	1,188	1,156	1,153	1,135	1,188	1,208	1,227	1,194	1,213	1,137	1,178	1,164	1,173	1,180	1,248
Refined Petroleum Products	1,193	986	2,541	2,440	771	1,265	1,969	1,027	1,990	933	878	714	706	779	915	709
Natural Gas	755	743	737	758	676	670	677	749	716	600	533	552	560	616	609	635
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Overall Total	781	797	878	831	876	864	863	901	909	893	848	907	874	841	886	822

Sources:

a Electric Power Generation, Transmission and Distribution, Catalogue No. 57-202-XIB, Statistics Canada.

b Report on Energy Supply-Demand in Canada, Catalogue No. 57-003-XIB, Statistics Canada.

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 other fuels.

Table A9-10: Electricity Generation and Greenhouse Gas Emission Details for Alberta¹

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Greenhouse Gas Emissions^a																
<i>kt CO₂ equivalent</i>																
Coal	37,334	39,420	41,737	42,582	45,972	46,290	44,938	46,666	45,742	44,282	44,034	45,199	46,045	45,641	45,171	45,925
Refined Petroleum Products ²	12	14	15	18	18	15	43	8	26	22	30	27	25	38	42	33
Natural Gas	1,668	1,463	2,256	2,184	2,106	1,487	2,167	2,582	3,599	3,349	5,170	4,724	3,783	3,813	3,772	3,909
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro ³	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass ⁴	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	0	0	0	0	0	0	0	0	0	0	98	373	380	2,330	1,317	652
Overall Total	39,013	40,896	44,007	44,784	48,095	47,793	47,148	49,256	49,367	47,654	49,332	50,324	50,233	51,822	50,302	50,519
Electricity Generation^b																
<i>GWh</i>																
Coal	35,253	36,606	38,941	39,360	42,733	43,747	41,761	43,199	42,353	41,492	41,566	44,561	45,957	42,433	45,473	45,073
Refined Petroleum Products	15	15	15	18	16	12	36	8	29	29	26	31	27	34	46	40
Natural Gas	2,317	2,320	3,329	3,473	3,507	2,393	3,209	4,166	6,079	5,792	9,354	9,086	7,618	6,769	6,906	7,312
Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydro	2,060	2,030	1,562	1,808	1,806	2,190	2,261	1,837	2,047	2,166	1,756	1,434	1,719	1,745	1,876	2,242
Biomass	0	0	0	0	0	0	0	0	278	284	293	414	488	461	305	850
Other Renewables ⁵	0	0	0	0.2	0	0	0	62	51	72	89	134	164	417	621	837
Other ⁶	0	0	0	0	1,159	1,055	252	318	49	39	86	305	308	1,977	1,176	937
Overall Total	39,645	40,971	43,847	44,660	49,221	49,397	47,518	49,590	50,885	49,872	53,170	55,964	56,281	53,835	56,403	57,290
Greenhouse Gas Intensity																
<i>g CO₂ eq/kWh</i>																
Coal	1,059	1,077	1,072	1,082	1,076	1,058	1,076	1,080	1,080	1,067	1,059	1,014	1,002	1,076	993	1,019
Refined Petroleum Products	826	917	1,000	980	1,144	1,323	1,213	982	903	766	1,175	892	920	1,102	899	823
Natural Gas	720	630	678	629	601	621	675	620	592	578	553	520	497	563	546	535
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	0	0	0	0	0	0	1,147	1,223	1,234	1,179	1,120	696
Overall Total	984	998	1,004	1,003	977	968	992	993	970	956	928	899	893	963	892	882

Sources:

a Electric Power Generation, Transmission and Distribution, Catalogue No. 57-202-XIB, Statistics Canada.

b Report on Energy Supply-Demand in Canada, Catalogue No. 57-003-XIB, Statistics Canada.

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 other fuels.

Table A9-11: Electricity Generation and Greenhouse Gas Emission Details for British Columbia¹

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Greenhouse Gas Emissions^a <i>kt CO₂ equivalent</i>																
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Refined Petroleum Products ²	88	85	77	63	71	32	76	33	33	35	36	36	31	26	20	13
Natural Gas	707	384	849	1,866	1,704	2,174	258	646	1,376	674	1,755	2,298	668	693	786	889
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro ³	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass ⁴	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other ⁵	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Overall Total	795	469	926	1,929	1,775	2,206	334	679	1,410	709	1,791	2,334	700	719	807	902
Electricity Generation^b <i>GWh</i>																
Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Refined Petroleum Products	98	91	84	64	98	29	82	42	39	45	40	50	50	51	45	26
Natural Gas	1,258	662	1,506	3,414	3,024	4,165	447	1,212	2,645	1,579	3,346	4,797	1,659	1,797	2,233	2,381
Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydro	46,438	49,052	50,025	42,238	43,625	38,879	56,956	52,922	50,862	51,524	50,798	41,547	49,648	47,037	45,024	50,305
Biomass	0	0	0	0	604	505	462	449	414	646	547	594	562	598	716	638
Other Renewables ⁵	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other ⁶	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Overall Total	47,794	49,805	51,615	45,716	47,351	43,578	57,947	54,625	53,960	53,794	54,731	46,989	51,919	49,483	48,018	53,350
Greenhouse Gas Intensity <i>g CO₂ eq/kWh</i>																
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Refined Petroleum Products	901	925	917	978	724	1,114	932	787	850	763	894	717	633	518	454	503
Natural Gas	562	580	564	547	563	522	577	533	520	427	525	479	403	385	352	373
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Overall Total	17	9	18	42	37	51	6	12	26	13	33	50	13	15	17	17

Sources:

a Electric Power Generation, Transmission and Distribution, Catalogue No. 57-202-XIB, Statistics Canada.

b Report on Energy Supply-Demand in Canada, Catalogue No. 57-003-XIB, Statistics Canada.

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 other fuels.

Table A9-12: Electricity Generation and Greenhouse Gas Emission Details for Yukon, Northwest Territories, and Nunavut¹

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Greenhouse Gas Emissions^a <i>kt CO₂ equivalent</i>																
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Refined Petroleum Products ²	92	78	66	62	62	77	80	79	76	38	40	45	29	30	33	25
Natural Gas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro ³	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass ⁴	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Overall Total	92	78	66	62	62	77	80	79	76	38	40	45	29	30	33	25
Electricity Generation^b <i>GWh</i>																
Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Refined Petroleum Products	289	293	291	286	329	393	429	343	261	228	232	263	241	279	269	241.638
Natural Gas	0	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0
Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydro	649	623	655	528	432	489	583	504	491	495	507	509	506	505	564	580
Biomass	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Renewables ⁵	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
Other ⁶	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Overall Total	938	916	947	814	761	881	1,012	847	753	735	739	774	747	784	834	822
Greenhouse Gas Intensity <i>g CO₂ eq/kWh</i>																
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Refined Petroleum Products	317	266	226	216	187	195	187	231	291	167	173	173	121	106	124	103
Natural Gas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Renewables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Overall Total	98	85	69	76	81	87	79	94	101	52	54	59	39	38	40	30

Sources:

a Electric Power Generation, Transmission and Distribution, Catalogue No. 57-202-XIB, Statistics Canada.

b Report on Energy Supply-Demand in Canada, Catalogue No. 57-003-XIB, Statistics Canada.

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 other fuels.

References

Statistics Canada, *Report on Energy Supply–Demand in Canada* (Annual), Catalogue No. 57-003-XIB.

Statistics Canada, *Electric Power Generation, Transmission and Distribution* (Annual), Catalogue No. 57-202-XIB.

Annex 10 Provincial/Territorial Analysis

The following discussion describes GHG emission trends for each of the provinces and territories in Canada for both the long term (1990–2005) and the short term (2003–2005). 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 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.

All emission references are from the 1990–2005 national GHG inventory and are given in units of CO₂ equivalent unless otherwise stated. All energy quantities, GDP, and heating degree day (HDD) values originate from Statistics Canada (2007), although GDP information is further enhanced by Informetrica (2006). All values provided within these graphs are presented in kilotonnes CO₂ equivalent.

HDDs are an indicator of the necessity for space heating in a region. The number of HDDs is calculated for each day by subtracting the day's mean temperature from a base temperature (usually 18°C). The daily totals are accumulated for each month, and the monthly totals are accumulated for the “heating year” from January to December. The amount of energy consumed for heating is closely correlated to these HDDs. Only one value is given per province/territory per year, and, although real, this value is a weighted average of many weather stations in a province/territory and therefore may not be completely indicative of local conditions; it does, nonetheless, give a relative indication of year-to-year regional heating requirements. Furthermore, as this is a function of weather and climate, a trend may not be indicative of the region's performance with respect to emission mitigation actions.

A10.1 Newfoundland and Labrador

Table A10-1: Trends in GHG Emissions and GHG Intensity, Newfoundland and Labrador

	1990	1995	2000	2003	2005
Total GHG Emissions (Mt)	9.87	8.63	9.07	11.3	10.5
Growth Since 1990	N/A	-12.6%	-8.1%	14.3%	6.5%
Annual Change	N/A	13.3%	-2.9%	-5.8%	0.8%
GDP Expense – Annual Change	N/A	1.3%	6.3%	2.3%	-0.9%
GHG Intensity (Mt/\$B GDP)	1.03	0.90	0.81	0.87	0.81
Annual Change	N/A	11.8%	-8.7%	-7.9%	1.7%

Note:

N/A = Not Applicable

In 2005, Newfoundland and Labrador represented 1.6% of Canada's population and generated 1.4% of the GHG emissions and 1.2% of Canada's total GDP. Combined, these parameters registered GHG emissions of 20.4 t per person and 807 kt per billion dollars GDP (Table A10-1). Since 1990, socioeconomic indicators show a 36% increase in total GDP, while population and HDDs show decreases of 11% and 7.6%, respectively.

In 2005, emissions from the Energy and Waste sectors account for 90% and 8.8%, respectively, of their total regional contribution. Within the Energy Sector, stationary sources comprise 51% of emissions, while transportation is responsible for 41%.

A10.1.1 Long-Term Trends (1990–2005)

Over the long term (1990–2005), Newfoundland and Labrador's GHG emissions increased 6.5%, from 9.9 to 10.5 Mt. Energy Sector sources were responsible for both the greatest growth and the greatest decline in emissions. Increases due to fugitive emissions resulting from oil and natural gas production (0.8 Mt), fossil fuel industries (0.5 Mt), off-road diesel use (0.4 Mt), LDGTs (0.3 Mt) and HDDVs (0.1 Mt) were offset by reductions in residential heating (0.4 Mt), mining industries (confidential), electricity and heat generation (confidential), manufacturing industries (0.2 Mt), and light duty gasoline vehicles (0.2 Mt).

The 580% increase in energy production (primary) since 1990 has been a major driver of 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.

Methane emissions from Agriculture has increased by 5%, mainly because of increases in dairy (6%) and beef cattle population (20%), and partially offset by a decrease of 25% from manure management mainly because of an 85% reduction in swine population between 1990 and 2005. Nitrous oxide emissions have decreased by 17% due mainly to reductions in emissions from manure management as well as indirect soil emissions over the same period.

Long-term emission trends in Newfoundland and Labrador are illustrated in Figure A10-1.

A10.1.2 Short-Term Trends (2003–2005)

Over the short term, GHG emissions decreased by 6.9%, primarily as a result of a decline in emissions from the electricity and heat generation industries (confidential), residential heating (0.2 Mt), off-road diesel use (0.2 Mt), and fugitive emissions from oil and natural gas production (0.1 Mt). The greatest increase occurred in domestic marine fuel use (0.2 Mt).

Short-term emission trends in Newfoundland and Labrador are illustrated in Figure A10-2.

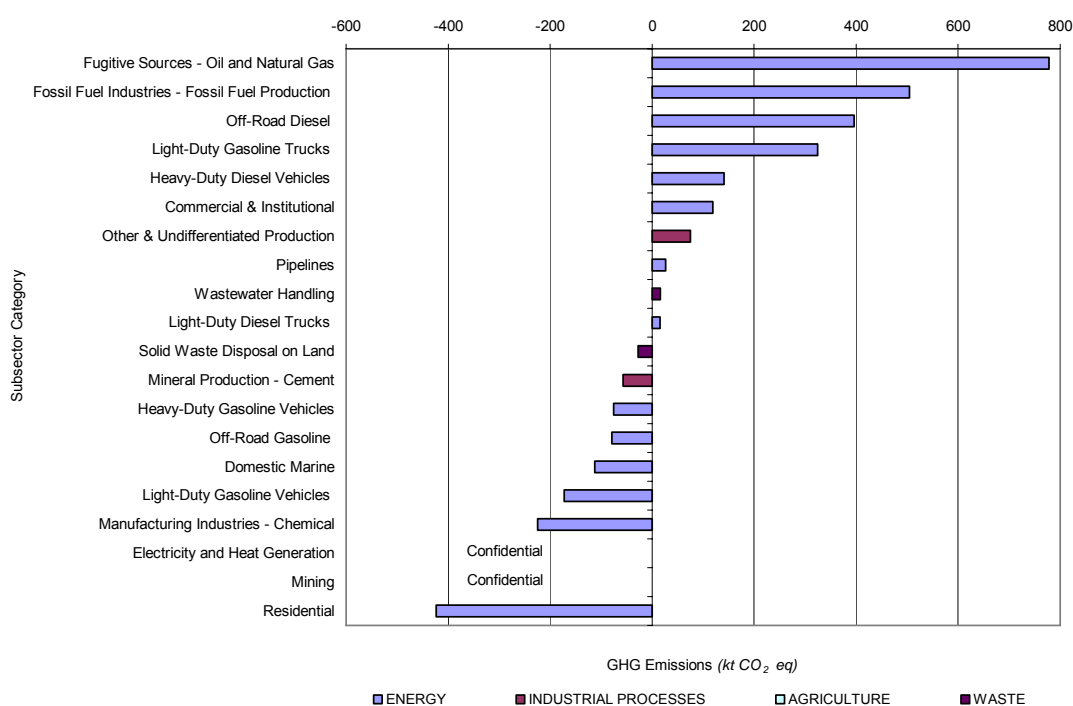


Figure A10-1: Newfoundland and Labrador Long-Term Emission Trends, 1990–2005

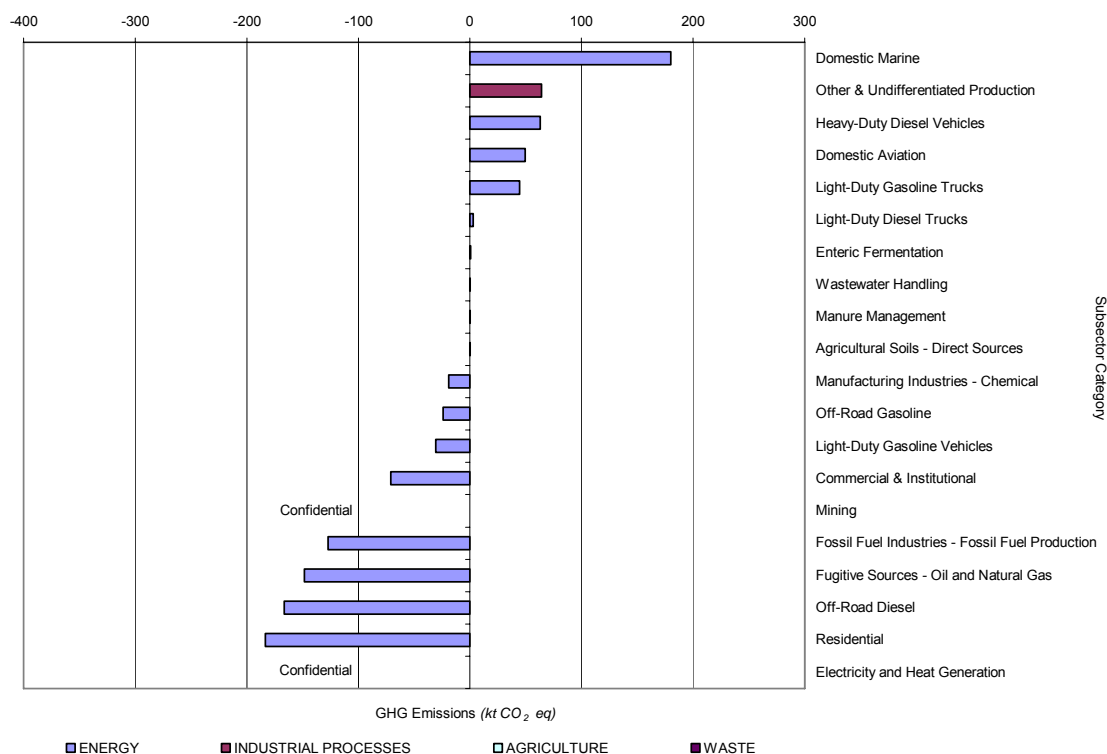


Figure A10-2: Newfoundland and Labrador Short-Term Emission Trends, 2003–2005

A10.2 Prince Edward Island

Table A10-2: Trends in GHG Emissions and GHG Intensity, Prince Edward Island

	1990	1995	2000	2003	2005
Total GHG Emissions (Mt)	2.07	2.00	2.29	2.30	2.28
Growth Since 1990	N/A	-3.5%	10.4%	11.1%	10.2%
Annual Change	N/A	-1.4%	7.0%	4.6%	-1.4%
GDP Expense – Annual Change	N/A	6.6%	3.5%	3.6%	1.5%
GHG Intensity (Mt/\$B GDP)	0.94	0.81	0.80	0.74	0.70
Annual Change	N/A	-7.5%	3.3%	0.9%	-2.8%

Note:

N/A = Not applicable

In 2005, Prince Edward Island, with 0.4% of Canada's population (138 100), contributed 2.3 Mt (0.3%) and \$3.3 billion (0.3%) towards Canada's GHG and GDP totals, respectively. These values are up 5.8%, 10%, and 48%, respectively, since 1990, while GHG emissions decreased 0.8% and GDP increased 4.2% since 2003 (Table A10-2).

In 2005, the Energy, Agriculture, and Waste sectors are responsible for over 99% of the province's total emissions, with a relatively larger portion coming from agricultural sources and a relatively smaller portion from the Energy Sector compared with the other Atlantic provinces (23% and 69%, respectively).

A10.2.1 Long-Term Trends (1990–2005)

The Energy Sector showed an overall long-term increase of 7.6% (0.2 Mt), due to a 19% (0.1 Mt) increase in road transport-related emissions, and specifically 109% (0.1 Mt) from LDGTs, and 134% (0.1 Mt) from off-road sources (gasoline, diesel and pipelines). However, these increases were offset somewhat by decreases of 32% in the residential sector (0.1 Mt), electricity and heat generation industries (confidential), and 64% from heavy duty gasoline vehicle emissions (< 0.1 Mt)).

Methane emissions from Agriculture has decreased by 7% mainly because of reductions in dairy and beef cattle population, partially offset by an increase in swine population between 1990 and 2005. N₂O emissions have increased by 28% due mainly to increases from direct (43%) and indirect (28%) soil emissions, partially offset by decreases in emissions from animal manure management systems and manure on pasture, range and paddock over the same period.

Long-term emission trends in Prince Edward Island are illustrated in Figure A10-3.

A10.2.2 Short-Term Trends (2003–2005)

Overall, GHG emissions decreased by 0.8% between 2003 and 2005. This slight decrease was primarily due to decreases in emissions from electricity and heat generation, residential heating and the commercial & institutional subsector. The small increase in GHG emissions from LDGTs and the domestic marine subsector were offset by the decreases.

The short-term trend between 2003 and 2005 showed no noticeable change in N₂O and CH₄ emissions from enteric fermentation, manure management, and agricultural soils.

Short-term emission trends in Prince Edward Island are illustrated in Figure A10-4.

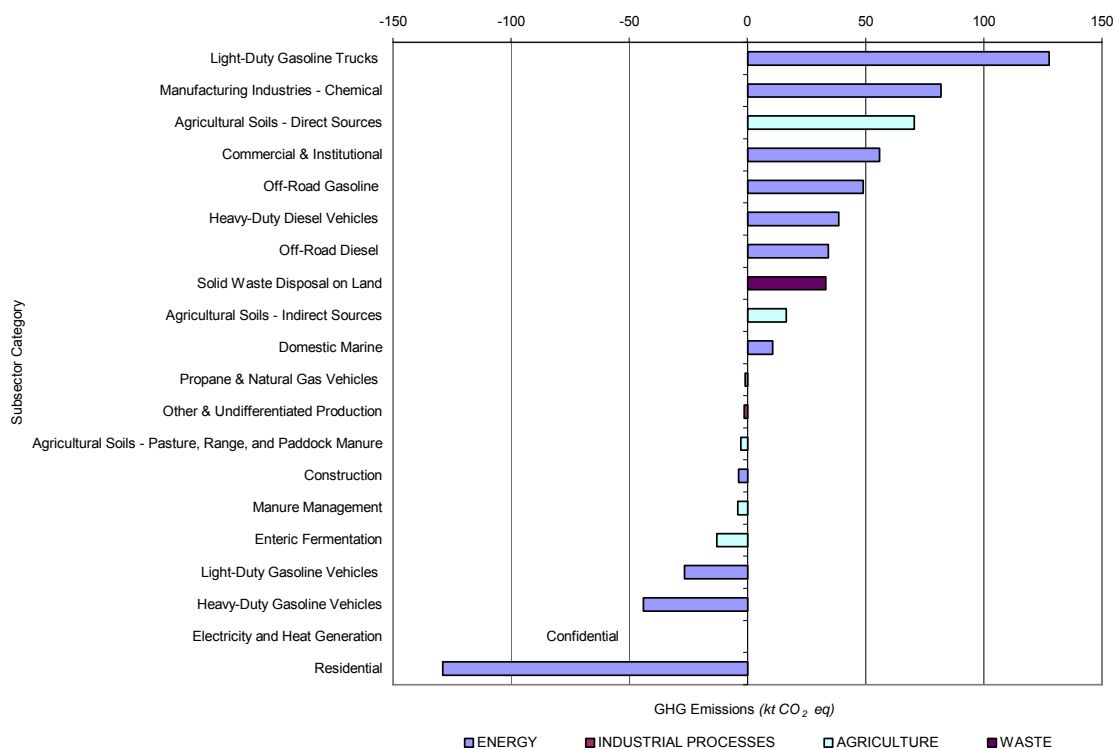


Figure A10-3: Prince Edward Island Long-Term Emission Trends, 1990–2005

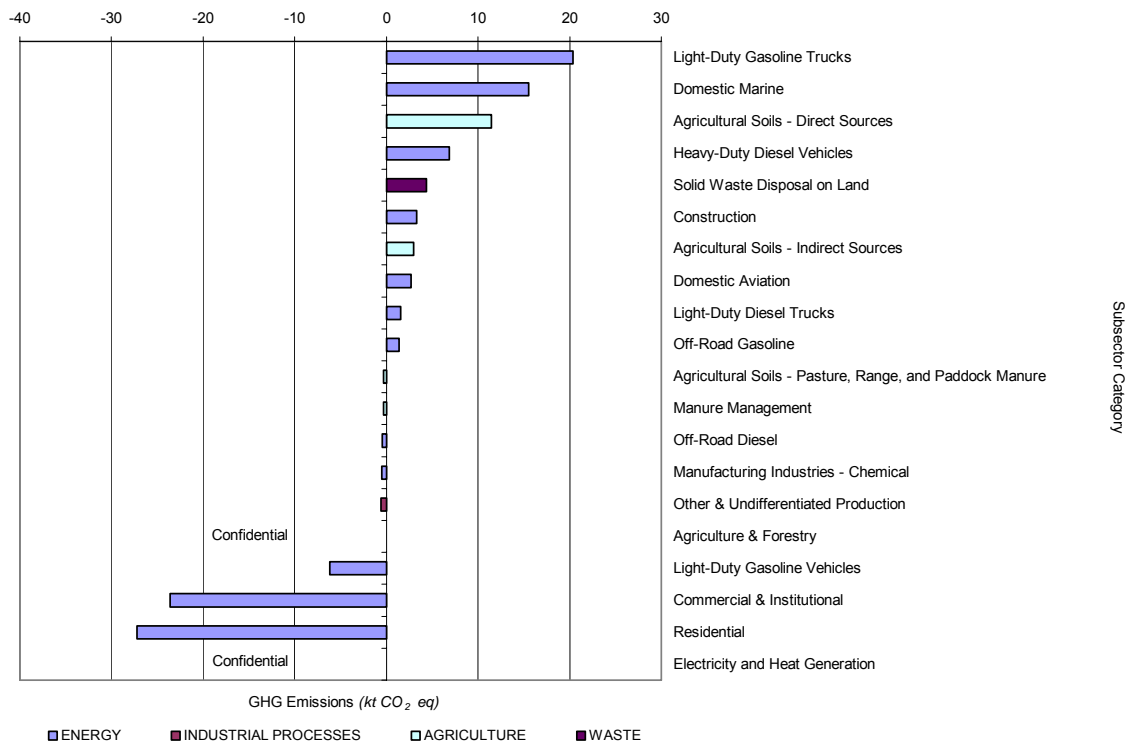


Figure A10-4: Prince Edward Island Short-Term Emission Trends, 2003–2005

A10.3 Nova Scotia

Table A10-3: Trends in GHG Emissions and GHG Intensity, Nova Scotia

	1990	1995	2000	2003	2005
Total GHG Emissions (Mt)	19.5	19.1	21.4	21.9	22.7
Growth Since 1990	N/A	-2.2%	9.4%	12.0%	16.2%
Annual Change	N/A	-0.8%	5.4%	11.0%	-2.2%
GDP Expense – Annual Change	N/A	2.0%	3.4%	0.6%	1.1%
GHG Intensity (Mt/\$B GDP)	1.13	1.07	1.02	0.97	0.96
Annual Change	N/A	-2.7%	1.9%	10.3%	-3.3%

Note:

N/A = Not applicable

In 2005, Nova Scotia generated 22.7 Mt or 3.1% of Canada's total GHG emissions (Table A10-3). Nova Scotians represent 2.9% of the population and contribute 2.2% to the total GDP. Since 1990, GHG emissions, population, and GDP output increased 16%, 3.1%, and 37%, respectively, while HDDs decreased by 0.1% from 1990 and 0.2% from 2003.

The Energy Sector accounted for 93% of provincial GHG emissions in 2005, with the Waste and Agriculture sectors contributing 4% and 2%, respectively.

A10.3.1 Long-Term Trends (1990–2005)

Energy-related emissions increased 19% between 1990 and 2005, while emissions from the Waste Sector decreased by 24%. In Nova Scotia, the dominant Energy subsectors are electricity and heat generation, commercial & institutional industries, and fossil fuel production. LDGTs, HDDVs domestic marine and domestic aviation have all exhibited growth since 1990 and are the primary contributors to GHG increases from the transport subsector. The contributions from light duty gasoline vehicles and HDGVs have decreased by 20% and 44%, respectively, since 1990, while those from LDGTs, HDDVs, domestic marine and domestic aviation have shown constant growth over the same period.

Fugitive emissions from coal mining have all but been eliminated but have been replaced with those from the oil and gas industry, as the primary energy production source in this province shifts from coal to petroleum.

CH₄ emissions from enteric fermentation and manure management have decreased by about 10% because of reductions of dairy, beef and swine population, while N₂O emissions from manure management and agricultural soils have increased by 6% due mainly to an increase in synthetic fertilizer nitrogen consumption between 1990 and 2005.

Long-term emission trends in Nova Scotia are illustrated in Figure A10-5.

A10.3.2 Short-Term Trends (2003–2005)

Between 2003 and 2005, total GHG emissions in Nova Scotia increased by 3.7%, primarily as a result of increased electricity and heat production (confidential) and commercial & institutional use (57%). During the same period, residential and fossil fuel production emissions declined by 38% and 14%, respectively. The short-term trend between 2003 and 2005 showed negligible changes in N₂O or CH₄ emissions from the Agriculture Sector.

Short-term emission trends in Nova Scotia are illustrated in Figure A10-6.

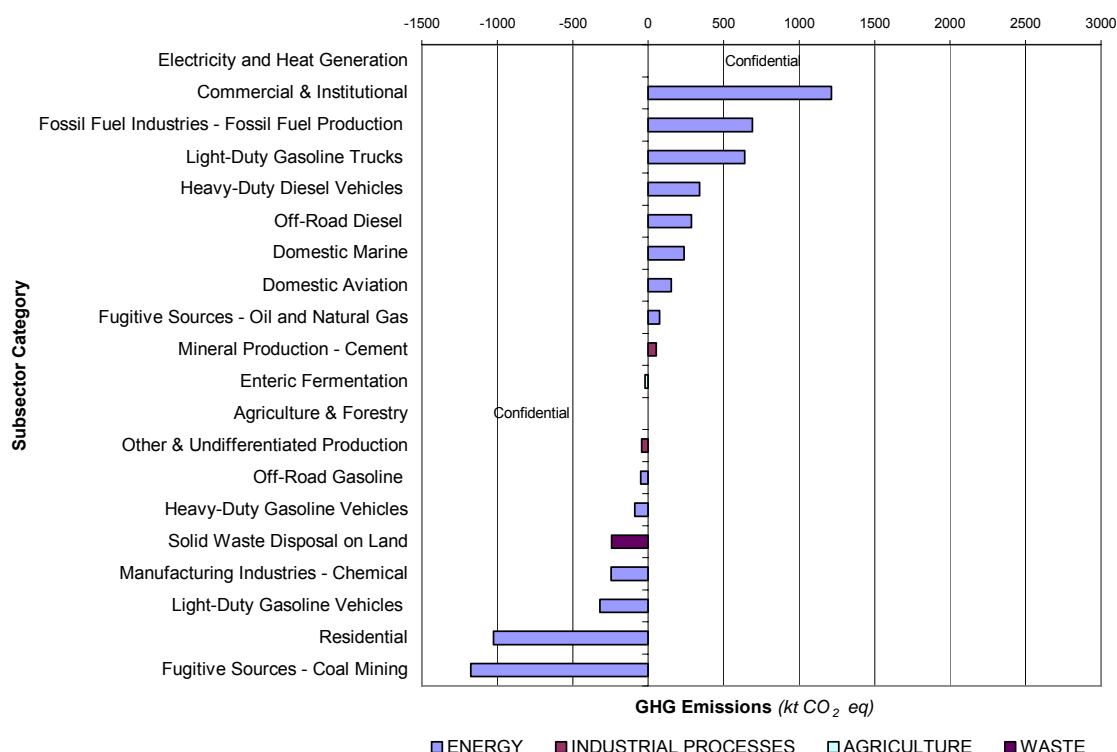


Figure A10-5: Nova Scotia Long-Term Emission Trends, 1990–2005

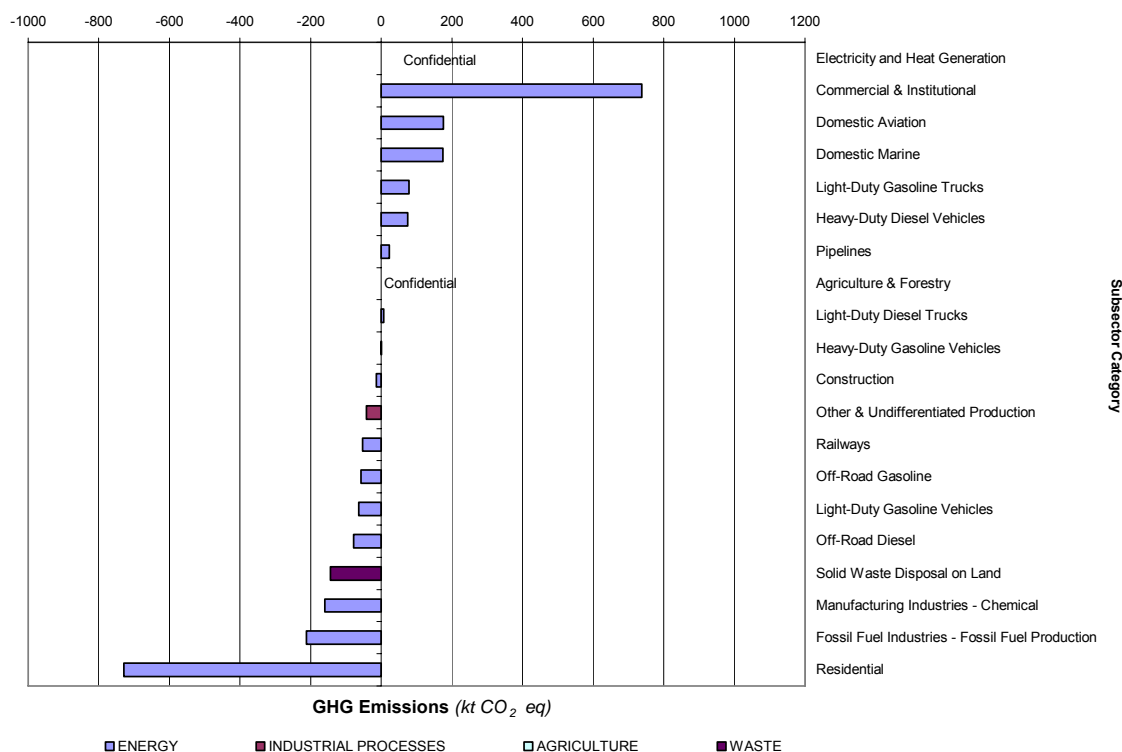


Figure A10-6: Nova Scotia Short-Term Emission Trends, 2003–2005

A10.4 New Brunswick

Table A10-4: Trends in GHG Emissions and GHG Intensity, New Brunswick

	1990	1995	2000	2003	2005
Total GHG Emissions (Mt)	16.2	17.3	20.4	21.1	21.3
Growth Since 1990	N/A	6.4%	25.9%	30.0%	31.3%
Annual Change	N/A	3.0%	6.0%	-1.5%	-1.4%
GDP Expense – Annual Change	N/A	3.2%	4.3%	-0.5%	0.4%
GHG Intensity (Mt/\$B GDP)	1.16	1.16	1.16	1.15	1.12
Annual Change	N/A	-0.2%	1.7%	-0.9%	-1.9%

Note:

N/A = Not applicable

In 2005, New Brunswick contributed 21.3 Mt or 2.9% of Canada's total GHG emissions (Table A10-4), which represents an increase of 31% since 1990. With 2.3% of Canada's population, New Brunswick's GDP contribution increased 36% between 1990 and 2005, representing 1.8% of the national total in 2005. Total HDDs were up 2.8% compared with 1990. In 2005, GHG emissions were 28.3 t per person, up 29% from 1990.

In 2005, the Energy Sector represents 92% of total provincial GHG emissions, with the Waste, Agriculture, and Industrial Processes sectors contributing 4.9%, 2.3%, and 1.1%, respectively.

A10.4.1 Long-Term Trends (1990–2005)

The 5.1 Mt growth in emissions over the long term was primarily driven by Energy Sector contributions from electricity and heat generation (confidential), fossil fuel production (166%), and transport (36%). Transportation emissions growth is a result of increases from HDDVs (74%), LDGTs (83%), and off-road diesel use (71%).

Agricultural N₂O emissions from manure management and agricultural soils have increased by 18% because of increase in synthetic nitrogen fertilizer consumption between 1990 and 2005, while CH₄ emissions declined slightly because of reductions in dairy and beef cattle population, and this decrease in cattle population was partially offset by increases in swine and poultry population over this period.

Long-term emission trends in New Brunswick are illustrated in Figure A10-7.

A10.4.2 Short-Term Trends (2003–2005)

The short-term 12% increase in emissions is primarily attributed to the commercial & institutional subsector (79% increase from 2003) and a 30% decrease in emissions from manufacturing industries.

Short-term emission trends in New Brunswick are illustrated in Figure A10-8.

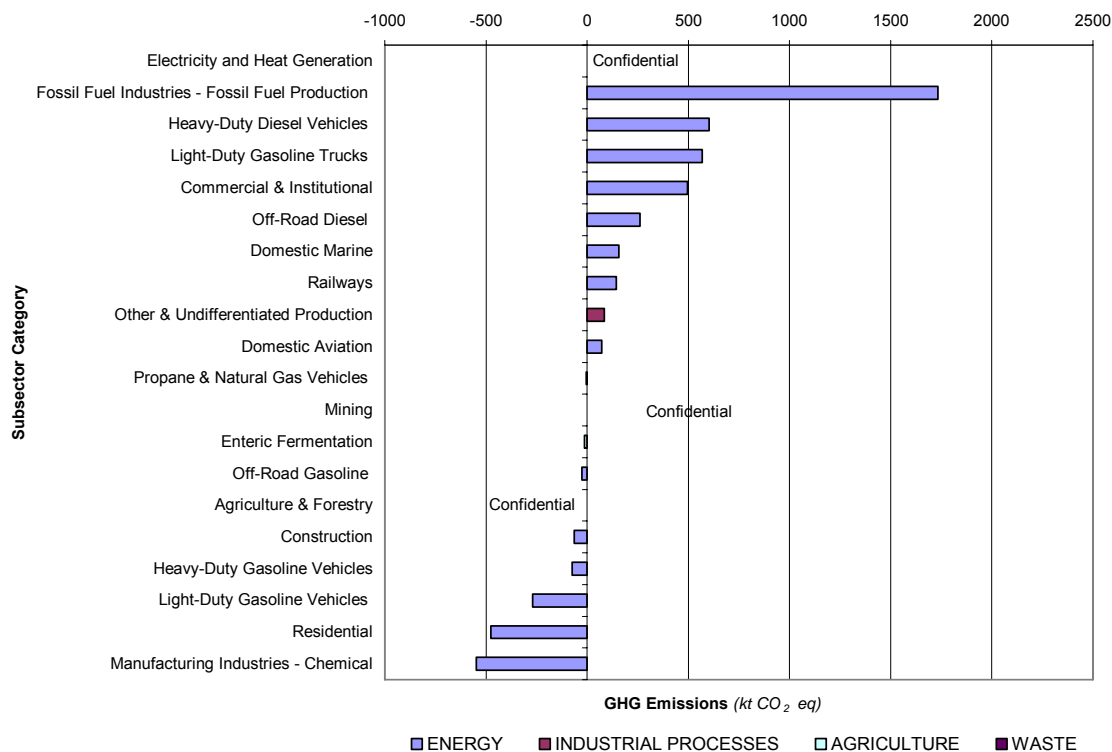


Figure A10-7: New Brunswick Long-Term Emission Trends, 1990–2005

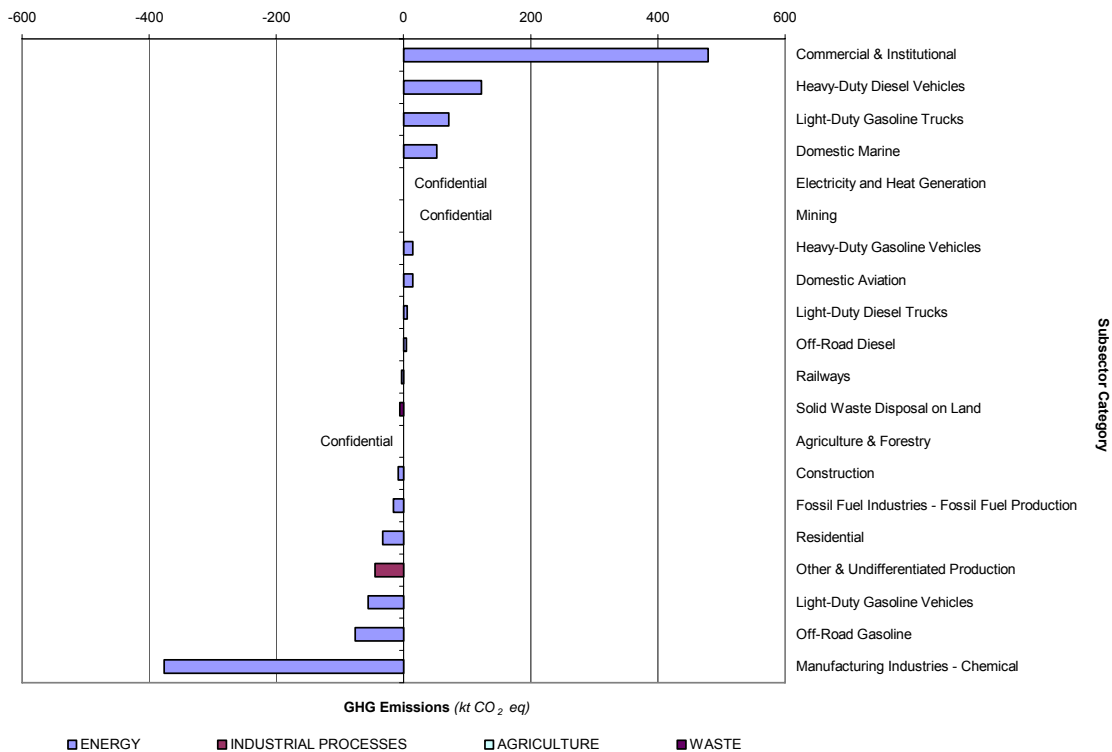


Figure A10-8: New Brunswick Short-Term Emission Trends, 2003–2005

A10.5 Quebec

Table A10-5: Trends in GHG Emissions and GHG Intensity, Quebec

	1990	1995	2000	2003	2005
Total GHG Emissions (Mt)	85.3	82.7	85.7	91.2	89.4
Growth Since 1990	N/A	-3.0%	0.4%	6.9%	4.8%
Annual Change	N/A	-1.0%	1.1%	5.6%	-2.2%
GDP Expense – Annual Change	N/A	1.0%	5.2%	0.7%	2.9%
GHG Intensity (Mt/\$B GDP)	0.52	0.49	0.42	0.42	0.39
Annual Change	N/A	-1.9%	-3.9%	4.9%	-5.0%

Note:

N/A = Not applicable

The province of Quebec represents 23.5% (7.6 million) of the country's population and accounted for 21.4% (\$230.4 billion) and 12.1% (89.4 Mt) of Canada's GDP and GHG totals, respectively, in 2005 (Table A10-5). GHG emissions per capita, at 11.8 t GHGs per person, and economic GHG intensity, at 0.39 Mt per billion dollars GDP, were both lower than the Canadian average. Since 1990, Quebec's GHG emissions have increased 4.8%, while the population increased by 7.7% and the province's economic output jumped 42%. HDDs in 2005 were 3.5% greater than in 1990.

Because of Quebec's abundant hydro-generated electricity and small petroleum industry, the contribution to total emissions from the electricity and heat generation subsector and the fossil fuel industries subsector are fairly low, at 2% and 4% each, respectively. The Energy, Industrial Processes, Agriculture, and Waste sectors comprise 72%, 11%, 8%, and 9%, respectively, of the regional total. Transportation sources and manufacturing industry emissions contributed 56% and 15%, respectively, to the Energy Sector, while 68% of industrial process emissions are released during aluminium production and magnesium production. CH₄ emissions from solid waste disposal on land accounted for 95% of the regional waste total in 2005.

A10.5.1 Long-Term Trends (1990–2005)

The province of Quebec is by far Canada's primary producer of aluminium and magnesium, with lower-level activities in Ontario and British Columbia. In 2005, Quebec accounted for 86% of Canada's process emissions associated with primary aluminium production. Between 1990 and 2005, the aluminium production subsector experienced an emission decrease of 13%, 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, which indicates efficiency achievements for the industry in regards to its combustion activities. Over the years, Norsk Hydro has invested in research and development projects with an objective of finding a substitute for SF₆ and eventually eliminating the use of SF₆ as cover gas at its

plant (Laperrière, 2004). This research and use of substitute gas mixtures contributed to significant reductions (97%) in its SF₆ emissions between 1990 and 2005.

Emissions from the Energy Sector increased 10% between 1990 and 2005. Transport emissions increased 25% during the same period, with LDGTs and HDDV emissions increasing 104% and 91%, respectively. Commercial and institutional energy emissions also increased by 60% from 1990 levels. CH₄ emissions from the Waste Sector increased by 17% between 1990 and 2005.

There was very little change in N₂O and CH₄ emissions from the Agriculture Sector between 1990 and 2005, due mainly to the fact that a reduction in emissions from dairy cows, dairy heifers and crop production was offset by an increase in emissions from beef cattle and swine.

Long-term emission trends in Quebec are illustrated in Figure A10-9.

A10.5.2 Short-Term Trends (2003–2005)

In the short term, a 2.0% decrease between 2003 and 2005 is largely attributable to decreases in emissions from commercial and institutional energy (14%), residential (11%) and mining (55%). From 2003 to 2005 emissions arising from the magnesium industry declined by 94%. The emission decrease was not only due to the replacement of SF₆ with other gases, as described above, but also due to lower production in anticipation of plant closures. Increases in emissions came mainly from the transportation and aluminium subsectors.

Short-term emission trends in Quebec are illustrated in Figure A10-10.

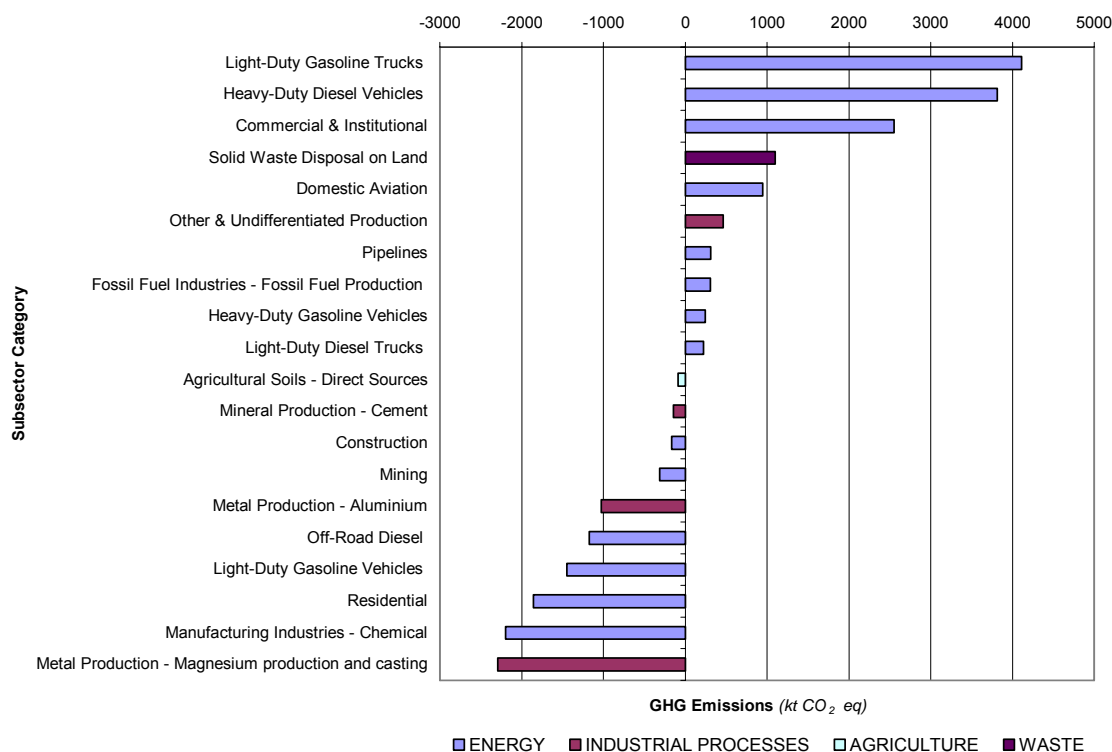


Figure A10-9: Quebec Long-Term Emission Trends, 1990–2005

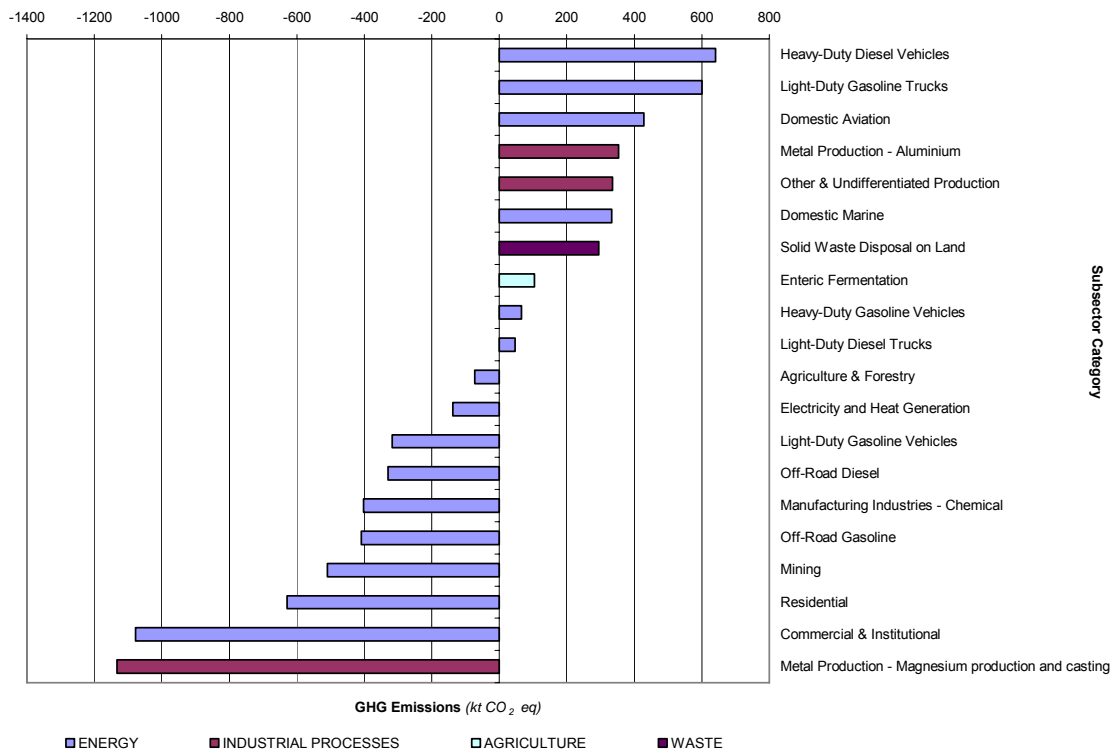


Figure A10-10: Quebec Short-Term Emission Trends, 2003–2005

A10.6 Ontario

Table A10-6: Trends in GHG Emissions and GHG Intensity, Ontario

	1990	1995	2000	2003	2005
Total GHG Emissions (Mt)	175	175	201	203	201
Growth Since 1990	N/A	0.1%	14.7%	16.0%	14.7%
Annual Change	N/A	2.5%	4.9%	2.2%	0.8%
GDP Expense – Annual Change	N/A	4.0%	6.2%	3.1%	3.5%
GHG Intensity (Mt/\$B GDP)	0.60	0.56	0.51	0.47	0.44
Annual Change	N/A	-1.4%	-1.2%	-0.9%	-2.6%

Note:

N/A = Not applicable

In 2005, Canada's most populated province — 12.5 million, or 38.9% of the total — generated 27.2% (201 Mt) of total GHG emissions (Table A10-6) and 42.7% of the country's GDP (\$459.0 billion). Between 1990 and 2005, Ontario's emissions increased 25.8 Mt (14.7%), while GDP and population increased 57% and 22%, respectively. In the short term (2003–2005), total emission output decreased by 1.1% or 2.1 Mt, with a 5.0% decrease in HDDs.

Over 90% of Ontario's GHG emissions are attributable to the Energy (82%) and Industrial Processes (9.4%) sectors, with the Agriculture (5.0%) and Waste (3.5%) Sectors making up the majority of the remainder.

A10.6.1 Long-Term Trends (1990–2005)

Between 1990 and 2005, increases in GHG emissions from LDGTs (9.4 Mt), electricity and heat generation (8.9 Mt), HDDVs (5.4 Mt), commercial and institutional sources (4.8 Mt) and cement's industrial process emissions (1.3 Mt), were offset by a 75% reduction (8.0 Mt) in adipic acid industrial process emissions, a 14% reduction (3.1 Mt) in manufacturing industries, and a 13% reduction (2.6 Mt) in light duty gasoline vehicle emissions. The substantial process emission reduction in the adipic acid industry, between 1990 and 2005, resulted from the installation of a catalytic emission abatement system in 1997.

In the Agriculture Sector, CH₄ emissions from enteric fermentation remained relatively unchanged between 1990 and 2005. There was a 7% decrease in N₂O emissions from soils over this period, likely due to lower synthetic fertilizer nitrogen consumption and lower crop production.

Long-term emission trends in Ontario are illustrated in Figure A10-11.

A10.6.2 Short-Term Trends (2003–2005)

The majority of the short-term reductions are realized in the Energy Sector, the bulk of which are a result of decreases in the electricity and heat generation subsector (5.7 Mt)

and manufacturing industries (1.0 Mt). Short-term emissions growth is led by the adipic acid production industry (1.6 Mt), and the transport subsector; LDGTs (1.3 Mt), HDDVs (1.0 Mt), and off-road diesel vehicles (1.0 Mt). The 2004 and 2005 levels of N₂O emitted by the adipic acid industry were significantly higher than the 2003 level because of poor performance of the emission abatement unit.

The short-term trend in Agriculture showed a 4% decrease in N₂O emissions, due mainly to a lower consumption of synthetic fertilizer nitrogen.

Short-term emission trends in Ontario are illustrated in Figure A10-12.

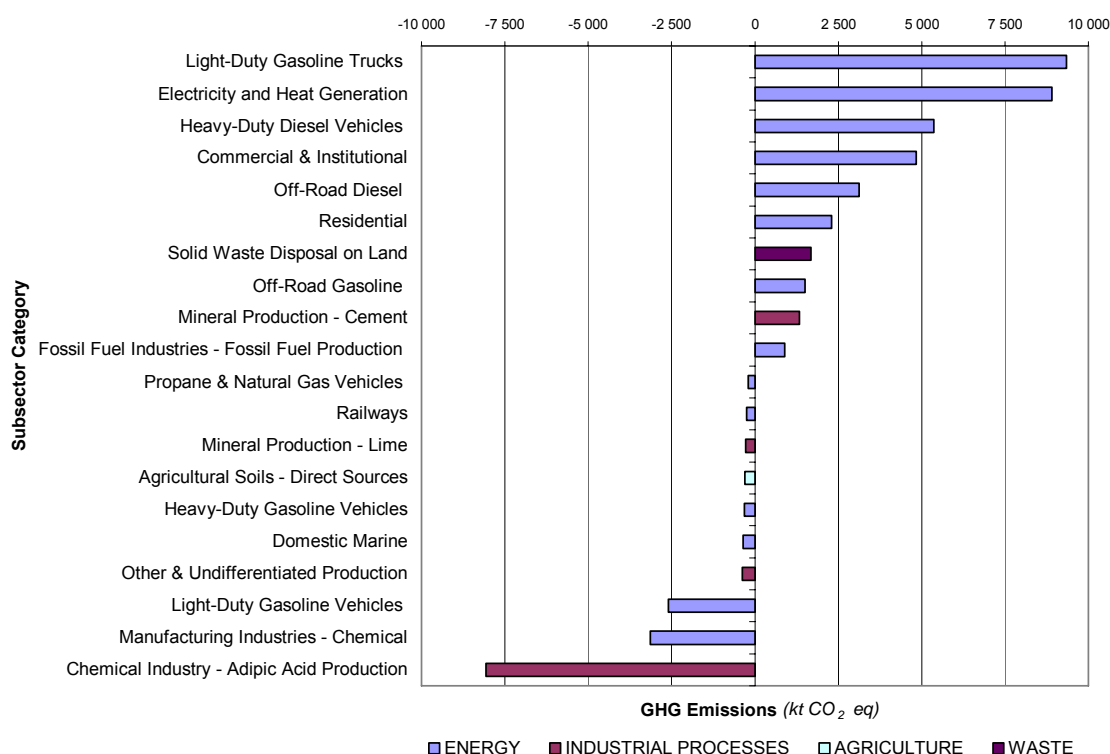


Figure A10-11: Ontario Long-Term Emission Trends, 1990–2005

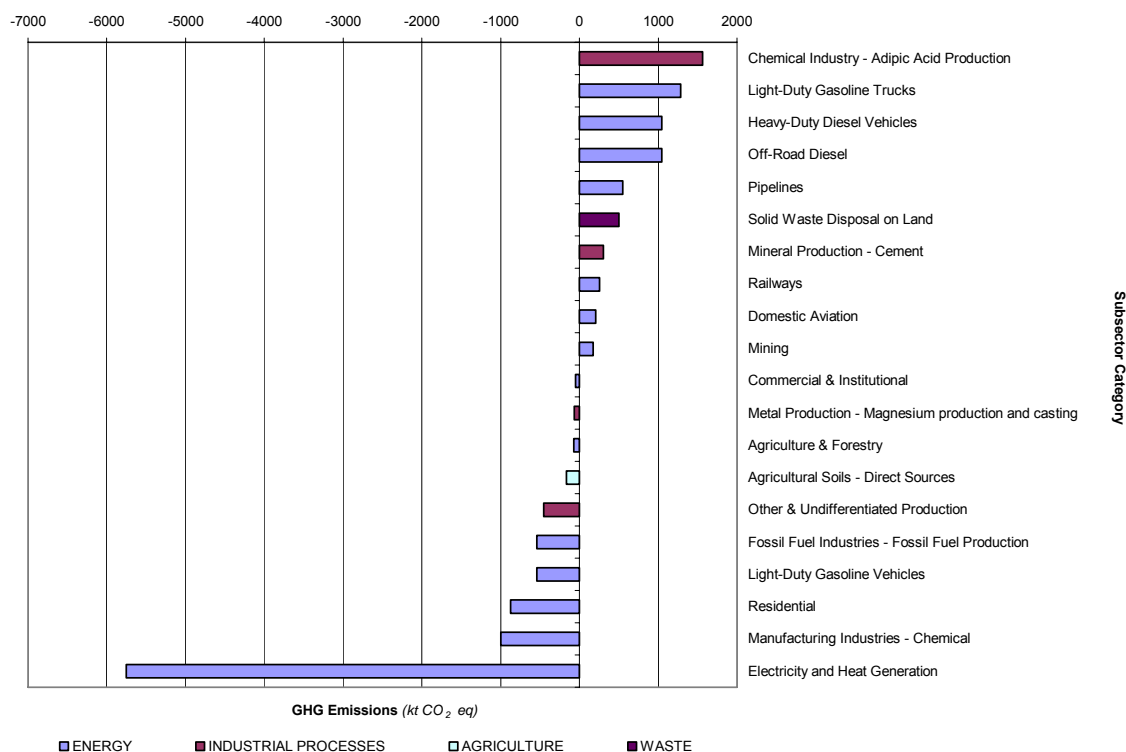


Figure A10-12: Ontario Short-Term Emission Trends, 2003–2005

A10.7 Manitoba

Table A10-7: Trends in GHG Emissions and GHG Intensity, Manitoba

	1990	1995	2000	2003	2005
Total GHG Emissions (Mt)	18.0	19.0	20.2	20.1	20.3
Growth Since 1990	N/A	5.8%	12.4%	11.6%	13.0%
Annual Change	N/A	4.7%	3.3%	3.1%	-0.2%
GDP Expense – Annual Change	N/A	1.1%	4.3%	0.3%	3.3%
GHG Intensity (Mt/\$B GDP)	0.70	0.74	0.67	0.63	0.60
Annual Change	N/A	3.6%	-0.9%	2.8%	-3.3%

Note:

N/A = Not applicable

In 2005, Manitoba's GHG emissions were up 13% (2.3 Mt) with respect to 1990, and up 1.2% (0.2 Mt) since 2003 (Table A10-7). Over the long term, the province's annual GDP and population increased 32.6% and 6.5%, respectively, contributing 17.3 t of GHGs per person and 600 kt GHGs per billion dollars GDP in 2005.

A10.7.1 Long-Term Trends (1990–2005)

Manitoba's economic structure gives its GHG inventory the lowest percentage of emissions from the Energy Sector (63%) and the highest percentage from the Agriculture

Sector (30%). The overall contributions from the Energy Sector have been fairly stable over the long term, with increases from LDGTs (0.8 Mt) and HDDVs (0.7 Mt) being offset by reductions from LDGVs (0.5 Mt), the residential and railway subsectors.

Agricultural emissions from all sources increased significantly between 1990 and 2005. CH₄ emissions from enteric fermentation and manure management increased by 66%, due mainly to increases in beef cattle and swine populations. N₂O emissions from manure management and agricultural soils increased by 17%, due mainly to increases in nitrogen fertilizer consumption, animal manure on pasture, and animal manure applied as fertilizers on cropland.

Long-term emission trends in Manitoba are illustrated in Figure A10-13.

A10.7.2 Short-Term Trends (2003–2005)

From 2003 to 2005, emissions increased primarily from off-road diesel vehicles (35%), manufacturing industries (26%) and enteric fermentation (12%). Short-term decreases in emissions were related to direct emissions from agricultural soils (23%) and electricity and heat generation (confidential). There was a 12% decrease in N₂O emissions from the Agriculture Sector due mainly to reductions of synthetic nitrogen fertilizer consumption.

Short-term emission trends in Manitoba are illustrated in Figure A10-14.

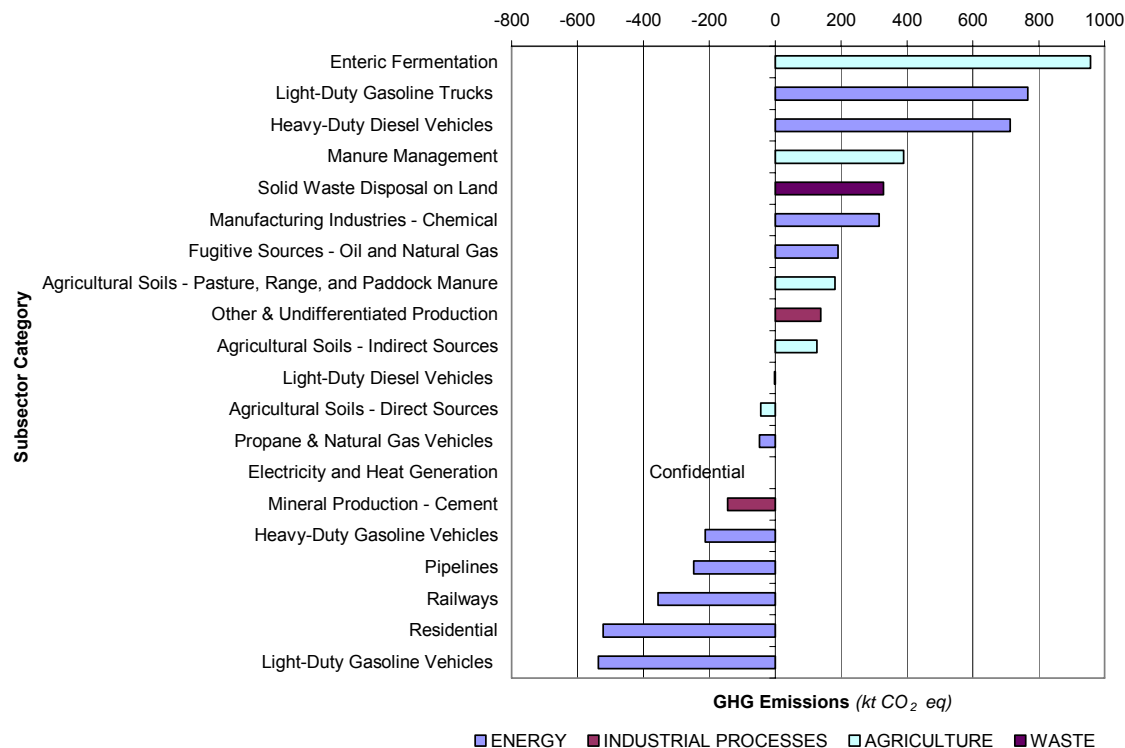


Figure A10-13: Manitoba Long-Term Emission Trends, 1990–2005

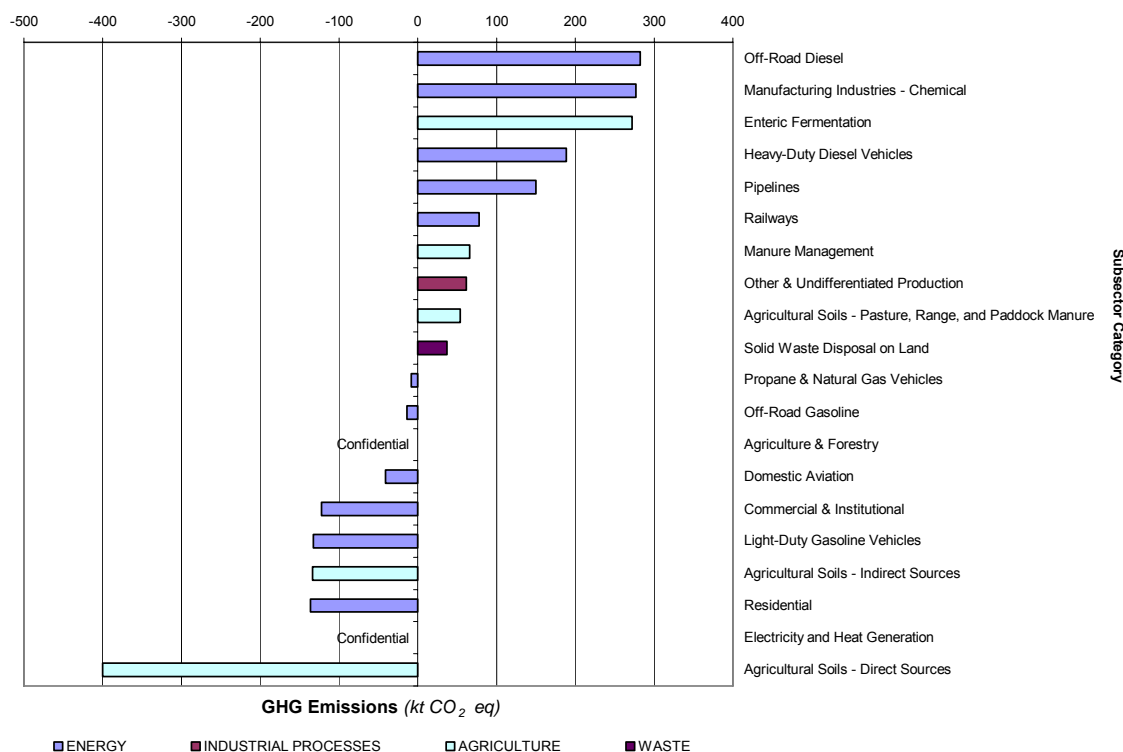


Figure A10-14: Manitoba Short-Term Emission Trends, 2003–2005

A10.8 Saskatchewan

Table A10-8: Trends in GHG Emissions and GHG Intensity, Saskatchewan

	1990	1995	2000	2003	2005
Total GHG Emissions (Mt)	44.1	58.7	65.6	68.3	70.9
Growth Since 1990	N/A	33.2%	48.8%	55.1%	60.9%
Annual Change	N/A	3.6%	2.2%	3.4%	0.2%
GDP Expense – Annual Change	N/A	0.3%	2.4%	2.9%	2.6%
GHG Intensity (Mt/\$B GDP)	1.90	2.39	2.25	2.36	2.31
Annual Change	N/A	3.3%	-0.2%	0.5%	-2.4%

Note:

N/A = Not applicable

Saskatchewan generated 70.9 Mt GHGs in 2005 (9.6% of Canada's total), a 61% increase over the 1990 base year and a 3.7% increase compared with 2003 (Table A10-8). GDP output increased 32.4% between 1990 and 2005, while population declined by 1.3%. In 2005, these measures translated to over 71 t GHGs per person and 2.3 Mt GHGs per billion dollars GDP. The annual HDDs observed in 2005 were 0.1% greater than in 1990 and down 4.0% from 2003.

Saskatchewan's emission contribution per sector represents the natural westerly transition across Canada's central provinces — that is, an increasing portion of energy-related emissions, accounting for 81% of the province's emission sources.

A10.8.1 Long-Term Trends (1990–2005)

Long-term growth trends show Energy subsectors as strong contributors, specifically fugitive emissions from oil and natural gas, emissions from electricity and heat generation, fossil fuel production, LDGTs and HDDVs. Coal-generated capacity has remained the predominant source of electricity, at about 54%, while the demand for electricity from low-GHG-intensive natural gas, hydro and wind resources continues to increase.

Combustion and fugitive emissions from fossil fuel production sources increased by 39% (1.7 Mt) and by 184% (11.1 Mt), respectively, between 1990 and 2005. Transport emissions from LDGTs and HDDVs increased by 130% and 85%, respectively over the long term.

Agricultural emissions from enteric fermentation, manure management, and agricultural soils grew by 68%, 63% and 43%, respectively between 1990 and 2005, due mainly to increases in beef cattle and swine populations as well as synthetic nitrogen fertilizer consumption.

Long-term emission trends in Saskatchewan are illustrated in Figure A10-15.

A10.8.2 Short-Term Trends (2003–2005)

Over the short term emissions increased by 3.7%, with Energy sector emissions from fossil fuel production, pipelines and diesel vehicles (off-road and HDDVs) and enteric fermentation showing the greatest increases. Small decreases were observed in the commercial & institutional, and manufacturing industries however they were not significant enough to offset the increases. There was a 4% increase in N₂O and CH₄ from the Agriculture Sector between 2004 and 2005, due mainly to increases in beef cattle and swine population.

Short-term emission trends in Saskatchewan are illustrated in Figure A10-16.

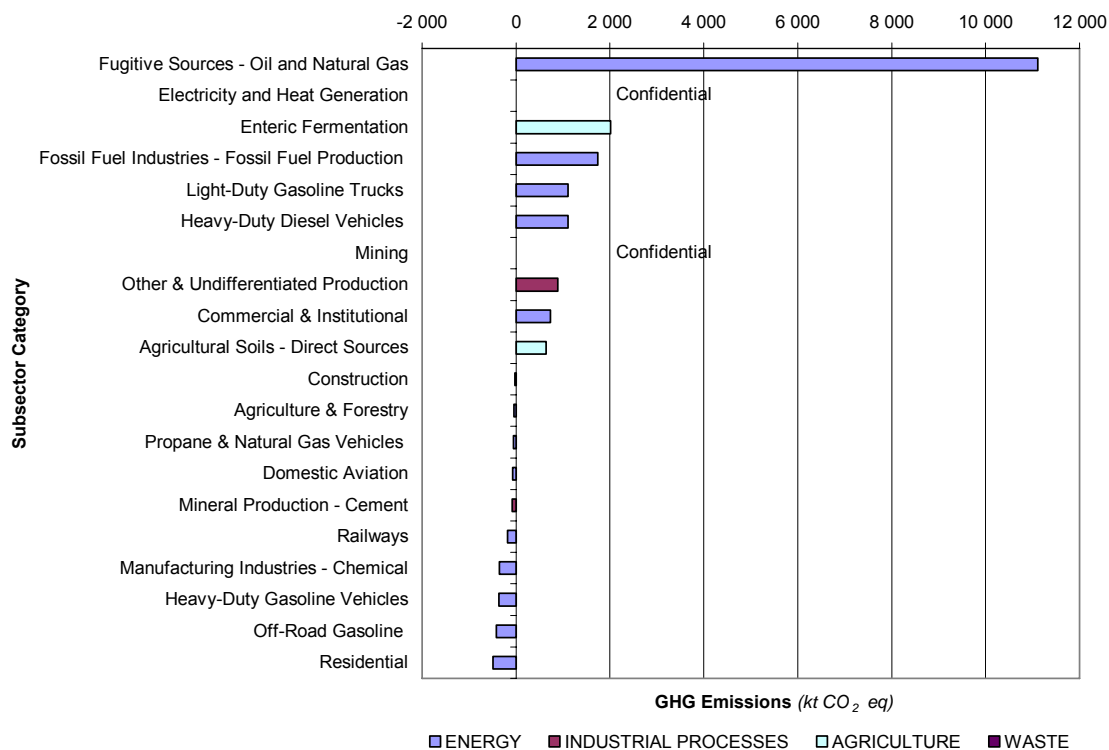


Figure A10-15: Saskatchewan Long-Term Emission Trends, 1990–2005

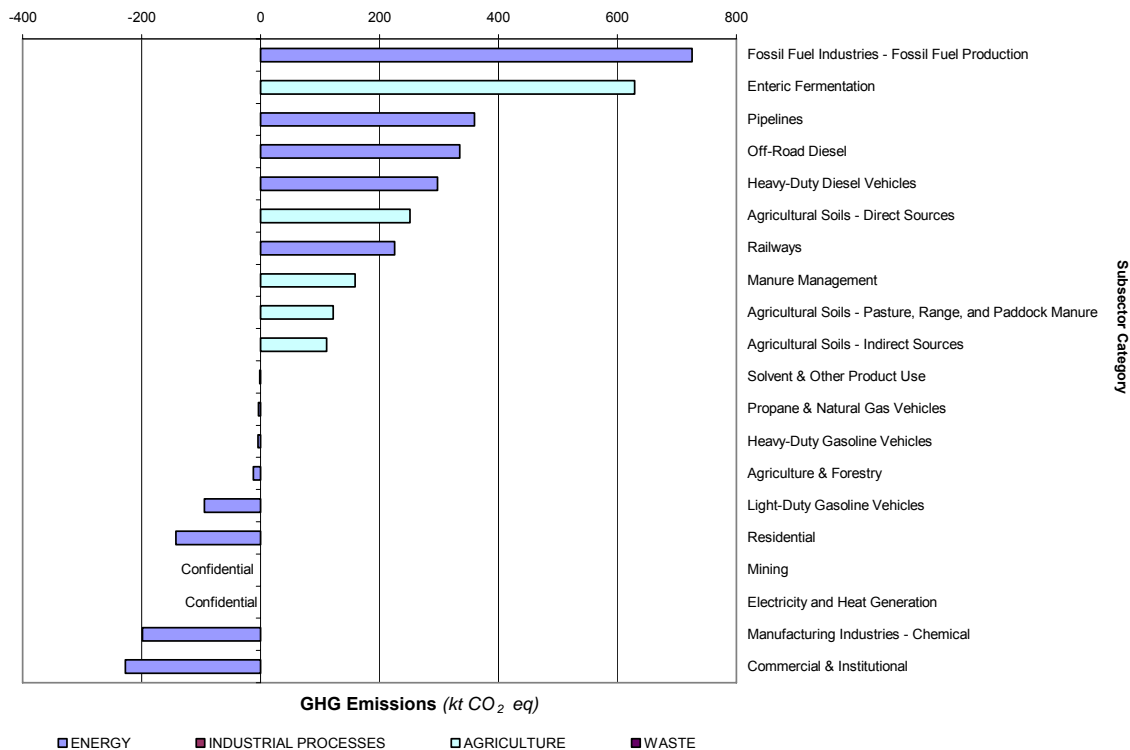


Figure A10-16: Saskatchewan Short-Term Emission Trends, 2003–2005

A10.9 Alberta

Table A10-9: Trends in GHG Emissions and GHG Intensity, Alberta

	1990	1995	2000	2003	2005
Total GHG Emissions (Mt)	170	198	224	232	233
Growth Since 1990	N/A	16.5%	31.8%	36.9%	37.4%
Annual Change	N/A	2.6%	4.0%	3.5%	0.8%
GDP Expense – Annual Change	N/A	2.5%	6.3%	2.6%	2.8%
GHG Intensity (Mt/\$B GDP)	2.20	2.15	1.93	1.86	1.75
Annual Change	N/A	0.1%	-2.1%	0.9%	-2.0%

N/A = Not Applicable

The province of Alberta generated 12.4% of Canada's GDP in 2005, with 10.1% of the total population. Between 1990 and 2005, GDP and GHG output increased 72.5% and 37.4% to \$132.9 billion and 233 Mt, respectively (Table A10-9). The short-term (2003-2005) trends show a 0.4% growth in total GHG emissions, while observing a 6.7% increase in economic output and an 8.5% decrease in HDDs.

Alberta, known for its abundant fossil fuel-based natural resources, provided 64% of Canada's primary energy production in 2005. Not surprisingly, the province's total GHG emissions are dominated by emissions related to the electricity generation, fossil fuel industries (including emissions from natural gas transmissions and fugitive emission sources), mining and the transport sector. With 86% of the provincial total from the Energy Sector, the remaining sources are a combination of the Agriculture (8%) and Industrial Processes (5%) sectors.

A10.9.1 Long-Term Trends (1990–2005)

Long-term emissions growth has contributed an additional 63.4 Mt to the provincial total, predominantly driven by increases from electricity and heat generation (13.2 Mt), fossil fuel production (12.6 Mt), mining (8.6 Mt), and fugitive sources from the oil and natural gas industry (8.0 Mt), all of which are constituents of the Energy Sector. As for the non-energy related subsectors, the other and undifferentiated production subsector (comprised primarily of petrochemical process emissions) showed an increase of 4.3 Mt while enteric fermentation emissions increased by 2.9 Mt from 1990. Decreases over the long term have been limited to combustion emissions from manufacturing industries (2.2 Mt) and light duty gasoline vehicles (0.9 Mt).

Agricultural emissions from enteric fermentation, manure management, and agricultural soils grew by 47%, 42% and 21% from enteric fermentation, manure management and agricultural soils, respectively between 1990 and 2005. The main factors contributing to the increased emissions were higher beef cattle and swine populations and greater use of synthetic nitrogen fertilizers.

Long-term emission trends in Alberta are illustrated in Figure A10-17.

A10.9.2 Short-Term Trends (2003–2005)

The short term increase in emissions of 0.4% was the result of increases in emissions from other and undifferentiated industrial production processes (1.6 Mt), HDDVs (1.0 Mt), and enteric fermentation (0.8 Mt) which were partially offset by decreases in electricity and heat generation (1.3 Mt) and fossil fuel production (1.2 Mt).

Agricultural short-term trends showed increases in N₂O by 2% and in CH₄ by 4%. These short-term changes in emissions were due mainly to increases in dairy and beef cattle population and crop production.

Short-term emission trends in Alberta are illustrated in Figure A10-18.

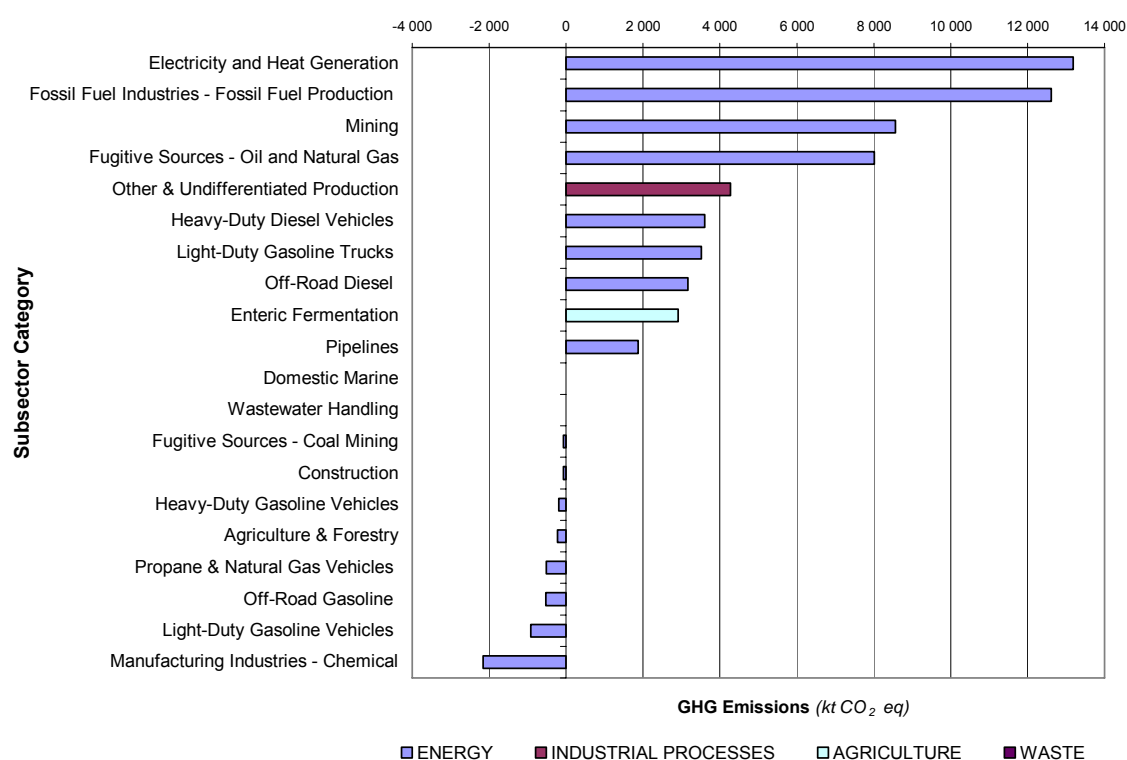


Figure A10-17: Alberta Long-Term Emission Trends, 1990–2005

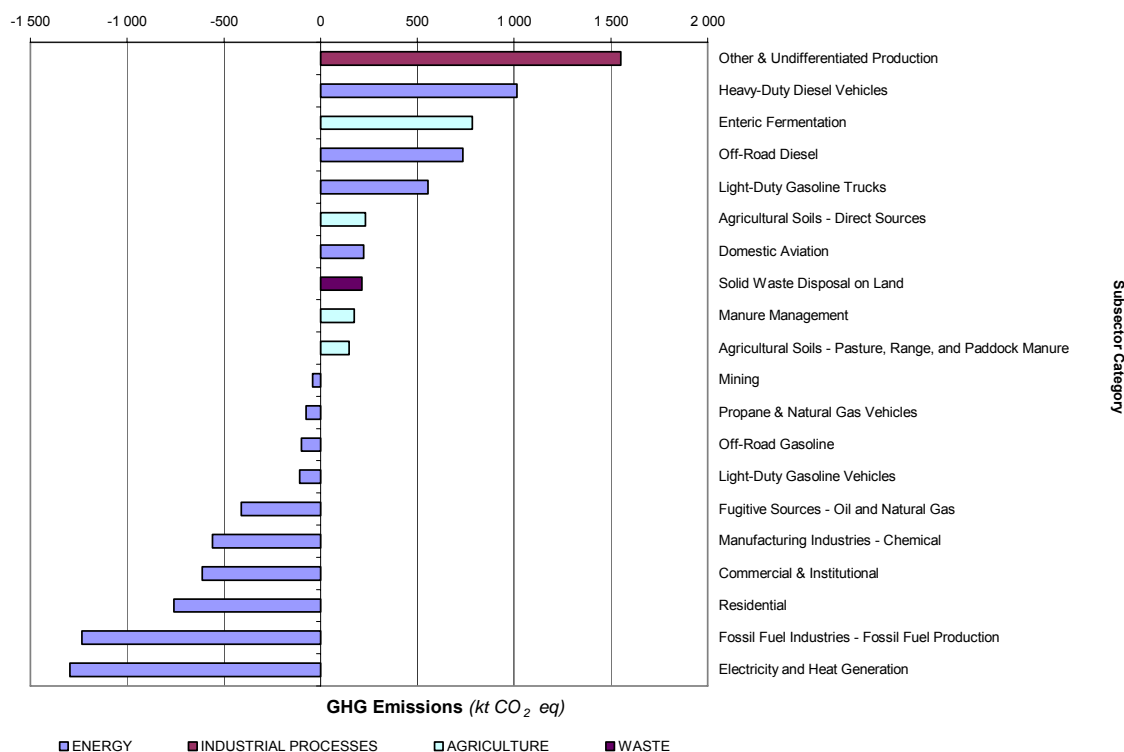


Figure A10-18: Alberta Short-Term Emission Trends, 2003–2005

A10.10 British Columbia

Table A10-10: Trends in GHG Emissions and GHG Intensity, British Columbia

	1990	1995	2000	2003	2005
Total GHG Emissions (Mt)	50.6	59.3	63.3	63.4	65.9
Growth Since 1990	N/A	17.1%	25.1%	25.3%	30.3%
Annual Change	N/A	8.6%	1.8%	3.4%	-2.4%
GDP Expense – Annual Change	N/A	2.8%	4.6%	3.1%	4.3%
GHG Intensity (Mt/\$B GDP)	0.60	0.60	0.55	0.52	0.51
Annual Change	N/A	5.6%	-2.7%	0.3%	-6.5%

Note:

N/A = Not applicable

In 2005, British Columbia's 4.3 million residents generated a total of 65.9 Mt of GHGs (Table A10-10) and contributed \$130.3 billion to the country's GDP. This represents 8.9% of Canada's total GHG emissions and 12.1% of the total GDP. Between 1990 and 2005, the province's total emissions increased 15.3 Mt or 30%, while GDP and population increased 54% and 29%, respectively. British Columbia's annual GHG generation rate, at 15.5 t GHGs per person in 2005, is slightly above what it was in 1990 (15.4 t GHGs per person), and its GHG per GDP equalled 506 kt per billion dollars in 2005. In the short term (2003–2005), total emission output increased 2.5 Mt, or 3.9%. The province's annual HDDs decreased by 7.5% between 1990 and 2005 and increased 1.3% from 2003.

A review of British Columbia's sector-specific emissions shows 84% of GHG emissions arising from the Energy Sector, while the Waste, Agriculture, and Industrial Processes sectors contribute 8%, 4%, and 5%, respectively. Within the Energy Sector, stationary sources represent 42%, transportation sources represent 47%, and fugitive emissions make up the remaining 11%, predominantly from oil and natural gas operations.

A10.10.1 Long-Term Trends (1990–2005)

Over the long term, British Columbia's Energy Sector and its subsectors contributed the most to changes in annual GHG emissions. Eight of the top 10 long-term emissions growth subsectors are in the Energy Sector, and five of those are transport related, a subsector that has registered almost 37% growth since 1990. Increases from LDGTs, HDDVs, off-road diesel vehicles and domestic aviation have been partially offset by reductions from railways, propane & natural gas vehicles and HDGVs. However, the greatest long term increases were from the fossil fuel industry. Fossil fuel production combustion emissions increased by 99% (3.7 Mt), while fugitive emissions from oil and natural gas increased 2.8 Mt, or 98%, between 1990 and 2005.

There were increases of 25% in CH₄ emissions from enteric fermentation and 9% in N₂O emissions from manure management and agricultural soils between 1990 and 2005, due mainly to the increase in beef cattle population.

Long-term emission trends in British Columbia are illustrated in Figure A10-19.

A10.10.2 Short-Term Trends (2003–2005)

In the short term, nine of the top 10 GHG growth subsectors belong to the Energy Sector. Fossil fuel production emissions increased by 29% (1.7 Mt), HDDVs increased by 14% (0.6 Mt), mining emissions increased by 317% (0.5 Mt) and electricity and heat generation emissions increased by 36% (0.5 Mt) from 2003. Manufacturing industry emissions decreased by 14% (0.9 Mt) between 2003 and 2005, with domestic marine emissions decreasing by 15% (0.5 Mt).

The short-term trend in Agriculture showed a decrease of 2% in CH₄ emissions between 2004 and 2005. This short-term increase was due mainly to the decrease in the beef cattle population.

Short-term emission trends in British Columbia are illustrated in Figure A10-20.

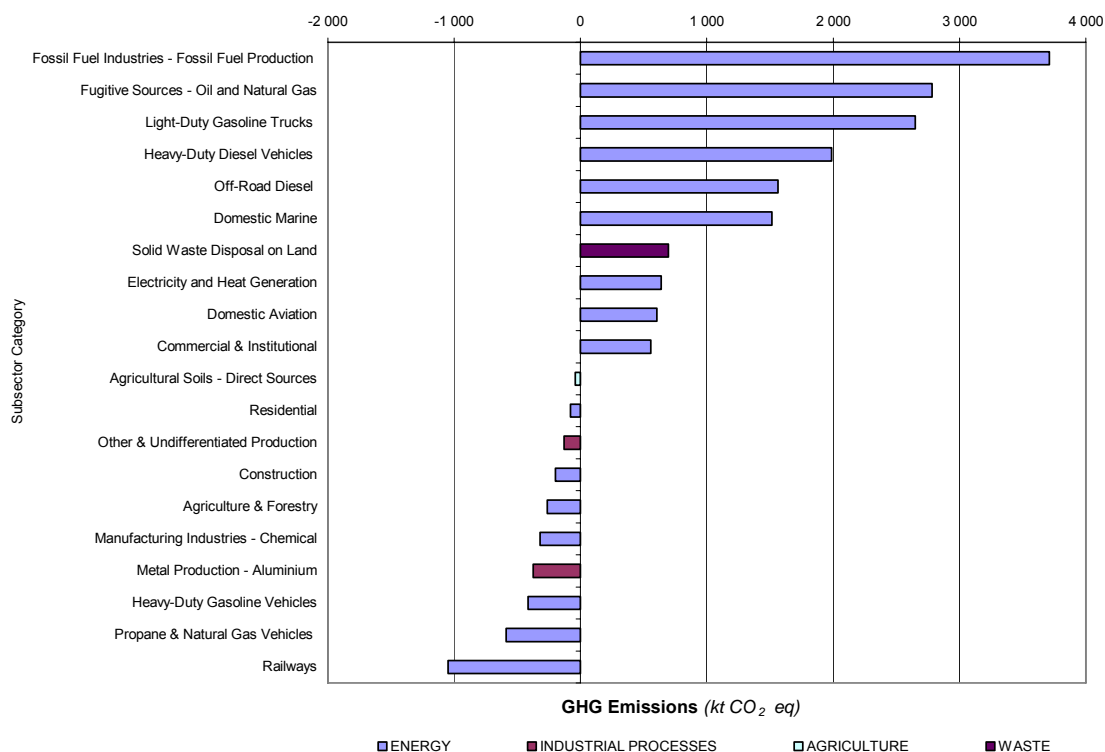


Figure A10-19: British Columbia Long-Term Emission Trends, 1990–2005

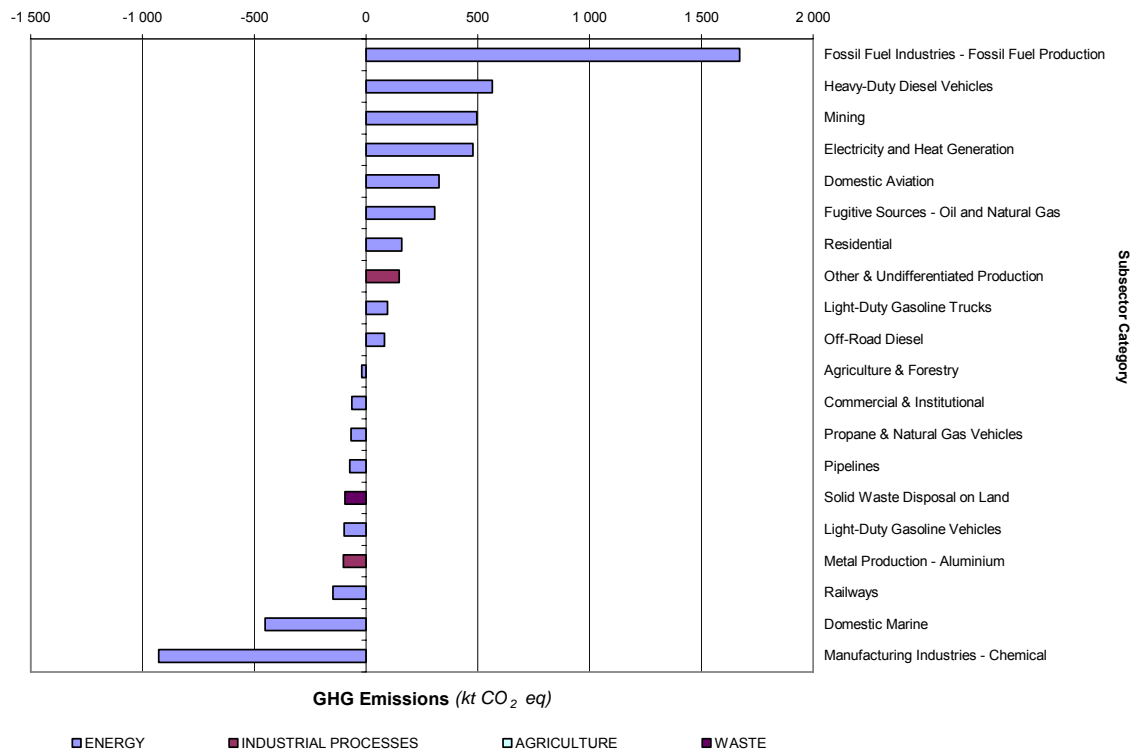


Figure A10-20: British Columbia Short-Term Emission Trends, 2003–2005

A10.11 Yukon, Northwest Territories, and Nunavut**Table A10-11: Trends in GHG Emissions and GHG Intensity, Total Territories**

	1990	1995	2000	2003	2005
Total GHG Emissions (Mt)	2.09	2.46	2.10	2.15	1.95
Growth Since 1990	N/A	17.8%	0.6%	3.0%	-6.6%
Annual Change	N/A	7.3%	11.2%	-5.0%	-5.5%
GDP Expense – Annual Change	N/A	5.7%	5.1%	12.5%	1.7%
GHG Intensity (Mt/\$B GDP)	0.64	0.73	0.52	0.41	0.34
Annual Change	N/A	1.5%	5.9%	-15.6%	-7.0%

Note:

N/A = Not applicable

Together, Canada's territories contributed 2.0 Mt (Table A10-11) or 0.3% to the national GHG total and \$5.7 billion to the national GDP in 2005. Over 95% of the territories' total emissions are from the Energy Sector.

Table A10-12: Trends in GHG Emissions, Yukon

	1990	1995	2000	2003	2005
Total GHG Emissions (Mt)	0.56	0.57	0.47	0.46	0.40
Growth Since 1990	N/A	1.2%	-17.1%	-17.7%	-28.6%
Annual Change	N/A	13.1%	-10.0%	-0.6%	-3.1%

Note:

N/A = Not applicable

Yukon, with a GHG emissions total for 2005 of 0.4 Mt (Table A10-12), has shown a 29% reduction since 1990, most of which is due to reductions in combustion emissions from the fossil fuel industry, commercial & institutional, agriculture & forestry and gasoline automobile subsectors. While total emissions went down, there was an increase in transportation related emissions, primarily HDDVs, off-road diesel and domestic aviation.

Since 1990, Yukon's population has increased almost 24%; and per capita, Yukon residents are each attributed 5.5 t GHGs annually.

Table A10-13: Trends in GHG Emissions, Northwest Territories and Nunavut

	1990	1995	2000	2003	2005
Total GHG Emissions (Mt)	1.53	1.89	1.64	1.69	1.55
Growth Since 1990	N/A	23.9%	7.1%	10.6%	1.5%
Annual Change	N/A	5.7%	19.3%	-6.1%	-6.1%

Note:

N/A = Not Applicable

The Northwest Territories and Nunavut generated approximately 1.5 Mt total GHGs in 2005 (Table A10-13). This is a 1.5% increase from 1990 that has been driven almost entirely by increases from the transportation and electricity and heat generation

subsectors. Since 1990, the combined population of these regions has increased 12% to over 31 000, while GHG emissions per capita registered 50 t in 2005, a 9.1% decrease over 1990.

As a whole, HDDs for the three territories for 2005 show an overall decrease of approximately 14% compared with 1990 and 6% less than in 2003.

Long-term emission trends in Yukon and in the Northwest Territories and Nunavut are illustrated in Figures A10-21 and A10-22, respectively. Short-term emission trends in Yukon and in the Northwest Territories and Nunavut are illustrated in Figures A10-23 and A10-24, respectively.

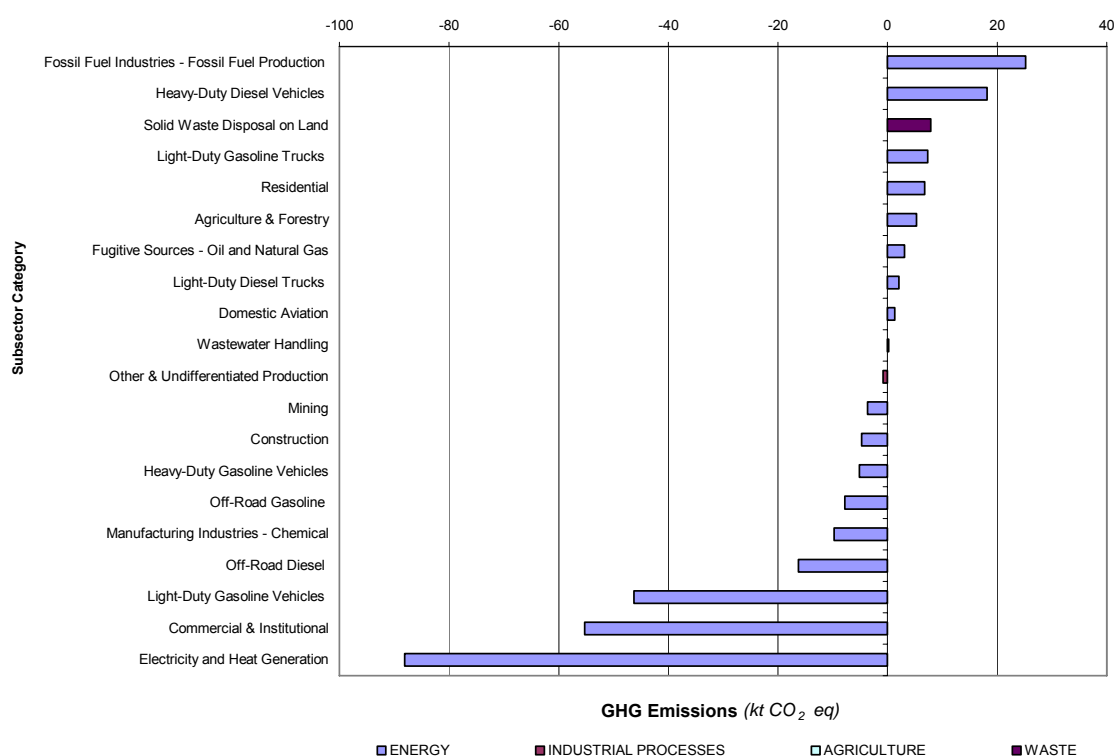


Figure A10-21: Yukon Long-Term Emission Trends, 1990–2005

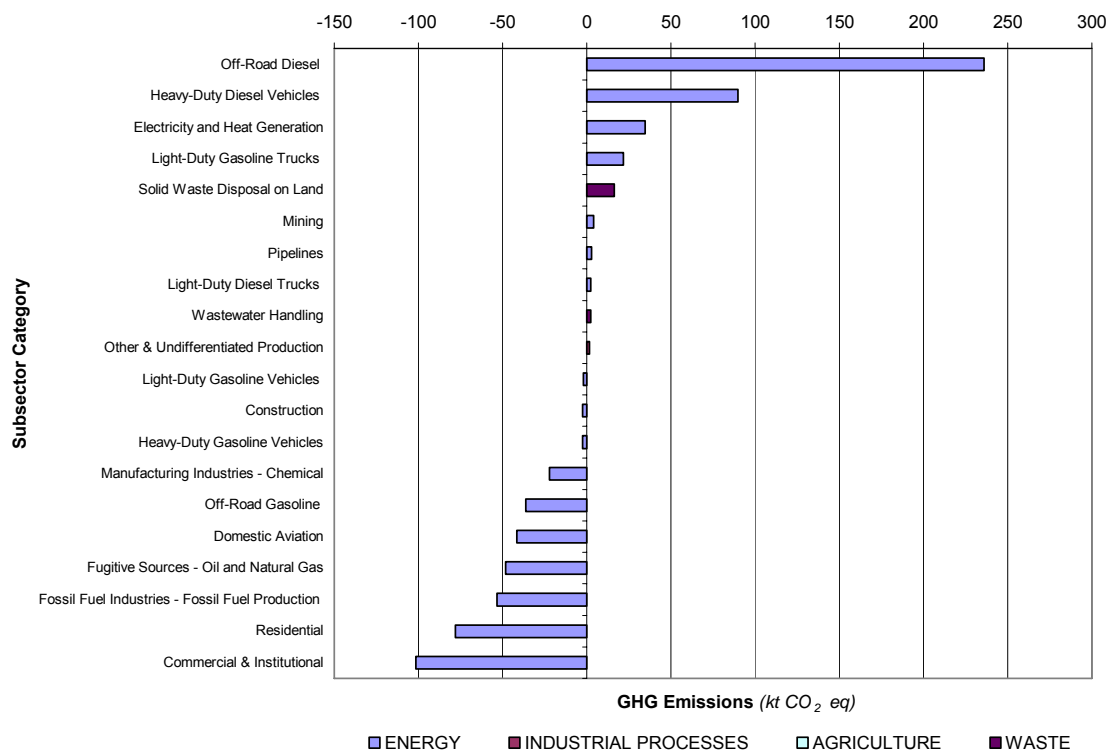


Figure A10-22: Northwest Territories and Nunavut Long-Term Emission Trends, 1990–2005

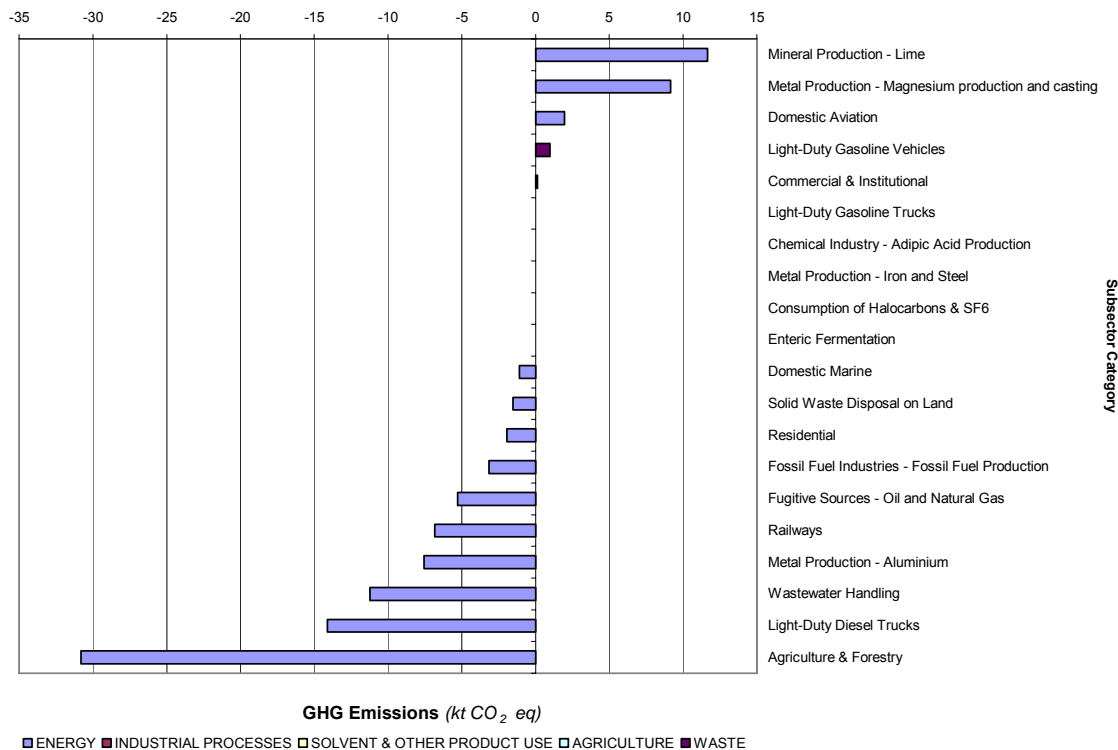


Figure A10-23: Yukon Short-Term Emission Trends, 2003–2005

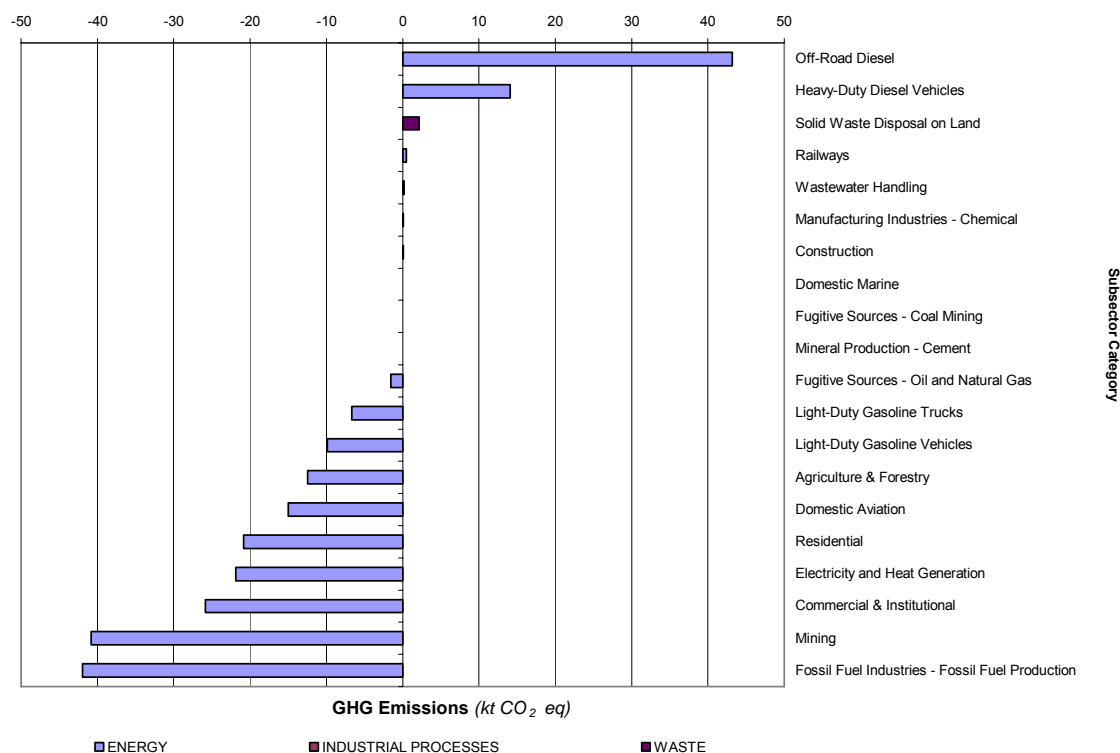


Figure A10-24: Northwest Territories and Nunavut Short-Term Emission Trends, 2003–2005

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Annex 11 Provincial/Territorial GHG Emissions Tables, 1990–2005

Summary tables illustrating GHG emissions by province/territory, sector, and year are included in Annex 11. Although the UNFCCC reporting guidelines require that only national-level detail be reported, provincial- and territorial-level detail is important due 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:

1. HFCs (e.g., fugitive releases from AC and refrigeration systems);
2. PFCs (used during the fabrication of semiconductors);
3. CO₂ from limestone and soda ash use; and
4. emissions associated with ammonia production.

Table A11-1: GHG Category Description**Greenhouse Gas 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 are included)
Mining	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 operation
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.
	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 houses)
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 consumption of fossil fuels (including non-CO ₂ emissions from ethanol) by vehicles licensed to operate on roads
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 domestically
Others - Off Road	Emissions resulting from the consumption of fossil fuels (including non-CO ₂ 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
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	
a. Mineral Products	Emissions resulting from the following process activities:
	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 aluminium, iron and steel, magnesium production and casting
d. Consumption of Halocarbons and SF₆	Use of HFCs and/or PFCs in air conditioning units, refrigeration units, fire extinguishers, aerosol cans, solvents, foam blowing, semi-conductor manufacturing and electronics industry; use of SF ₆ in electrical equipment and semi-conductors
e. Other & Undifferentiated Production	Non-energy use of fossil fuels
SOLVENT & OTHER PRODUCT USE	
	Emissions resulting from the use of N ₂ O as anaesthetic and propellant
AGRICULTURE	
a. Enteric Fermentation	Emissions resulting from:
	Livestock enteric fermentation
b. Manure Management	Livestock waste management
c. Agricultural Soils	
Direct sources	Direct N ₂ O emissions from synthetic fertilizer, manure on cropland, crop residue, tillage, summer-fallow, irrigation and cultivation of organic soils
Manure on Pasture, Range and Paddock	Direct N ₂ O emissions from manure deposited on pasture, range and paddock
Indirect Sources	Indirect N ₂ O emissions from volatilization and leaching of animal manure nitrogen, synthetic fertilizer nitrogen and crop residue nitrogen
WASTE	
a. Solid Waste Disposal on Land	Emissions resulting from:
	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

Table A11-2: 1990–2005 GHG Emissions Summary for Newfoundland and Labrador

Greenhouse Gas Categories	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
		<i>kt CO₂ eq</i>										
TOTAL	9 870	8 630	8 720	9 230	11 800	9 330	9 070	9 820	12 000	11 300	10 400	10 500
ENERGY	8 800	7 550	7 640	8 140	10 700	8 250	8 050	8 810	11 000	10 300	9 420	9 440
a. Stationary Combustion Sources	5 370	4 470	4 460	4 890	5 400	3 960	4 200	4 970	5 880	5 560	4 910	4 770
Electricity and Heat Generation	1 610	1 250	1 160	1 210	1 010	933	917	X	X	X	X	X
Fossil Fuel Industries	1 000	920	1 000	1 200	2 300	1 200	1 200	1 200	1 900	1 600	1 500	1 500
Mining & Oil and Gas Extraction	1 050	898	925	1 040	892	640	884	X	X	X	X	X
Manufacturing Industries	495	313	268	281	214	252	240	256	283	289	300	270
Construction	33.6	17.5	14.4	15.0	13.1	12.3	10.4	19.2	27.8	26.3	25.2	17.6
Commercial & Institutional	326	321	312	364	303	316	324	384	445	515	475	444
Residential	820	690	670	690	610	580	550	580	620	580	490	390
Agriculture & Forestry	25.1	57.3	58.9	75.8	76.2	69.5	47.8	X	X	X	X	X
b. Transportation¹	3 400	3 100	3 200	3 200	3 300	3 400	3 600	3 600	3 600	3 800	3 700	3 900
Domestic Aviation	460	350	360	350	320	300	370	360	320	410	440	460
Road Transportation	1 730	1 820	1 750	1 720	1 740	1 800	1 820	1 830	1 840	1 880	1 850	1 960
Light Duty Gasoline Vehicles	772	721	694	673	655	658	644	633	636	630	585	600
Light Duty Gasoline Trucks	453	595	590	599	625	665	673	677	701	733	719	778
Heavy Duty Gasoline Vehicles	131	85.7	68.8	60.5	56.8	49.8	47.3	60.3	54.4	55.3	53.9	55.3
Motorcycles	5.14	4.16	4.05	3.85	3.85	3.69	3.68	3.60	3.69	4.03	4.02	4.14
Light Duty Diesel Vehicles	1.82	1.51	1.37	1.26	1.20	1.19	1.05	1.13	1.16	1.20	1.21	1.24
Light Duty Diesel Trucks	5.83	9.95	10.0	10.9	11.9	13.3	14.7	16.7	17.6	18.6	18.6	21.6
Heavy Duty Diesel Vehicles	357	400	382	370	386	401	440	432	426	435	464	498
Propane & Natural Gas Vehicles	1.4	2.5	2.3	2.6	2.5	4.2	1.1	0.98	0.34	0.31	0.32	0.35
Railways	–	0.01	–	–	–	–	–	–	–	–	–	–
Domestic Marine	710	570	620	630	650	700	700	630	590	420	650	600
Others	500	300	500	600	500	600	700	800	900	1 000	800	900
Off Road Gasoline	100	50	80	60	50	60	80	70	70	60	30	40
Off Road Diesel	400	300	400	500	500	500	600	700	800	1 000	700	800
Pipelines	–	–	–	–	–	–	–	–	–	34.9	36.1	26.0
c. Fugitive Sources²	–	–	–	–	2 050	915	252	241	1 450	927	764	778
Coal Mining	–	–	–	–	–	–	–	–	X	X	X	X
Oil and Natural Gas	–	–	–	–	2 050	915	252	241	X	X	X	X
INDUSTRIAL PROCESSES³	75.3	84.6	77.2	90.9	87.7	89.1	22.8	22.6	25.4	29.3	23.4	93.6
a. Mineral Products	57	66	62	75	74	68	–	–	–	–	–	–
Cement Production	57	66	62	75	74	68	–	–	–	–	–	–
Lime Production	–	–	–	–	–	–	–	–	–	–	–	–
b. Chemical Industry	–	–	–	–	–	–	–	–	–	–	–	–
Nitric Acid Production	–	–	–	–	–	–	–	–	–	–	–	–
Adipic Acid Production	–	–	–	–	–	–	–	–	–	–	–	–
c. Metal Production	–	–	–	–	–	–	–	–	–	–	–	–
Iron and Steel Production	–	–	–	–	–	–	–	–	–	–	–	–
Aluminum Production	–	–	–	–	–	–	–	–	–	–	–	–
SF ₆ Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	–	–	–	–	–
d. Consumption of Halocarbons and SF₆	–	–	–	–	–	–	–	–	–	–	–	–
e. Other & Undifferentiated Production⁴	19	19	15	16	14	21	23	23	25	29	23	94
SOLVENT & OTHER PRODUCT USE	3.7	4.0	4.0	4.1	3.7	3.8	4.2	3.6	2.7	3.6	3.4	2.8
AGRICULTURE	49	49	49	47	44	44	44	44	46	45	44	46
a. Enteric Fermentation	18	18	18	18	18	18	19	20	21	20	20	21
b. Manure Management	14	13	13	12	11	10	9.7	9.0	8.9	8.8	8.8	9.1
c. Agriculture Soils	17	18	18	17	16	15	15	15	16	16	16	16
Direct Sources	10	11	11	10	9.6	9.2	9.0	8.8	9.7	9.8	9.6	10
Pasture, Range and Paddock Manure	2.0	2.0	2.0	2.0	1.9	2.0	2.1	2.2	2.2	2.1	2.1	2.1
Indirect Sources	5	5	5	5	5	4	4	4	4	4	4	4
WASTE	940	940	950	950	950	950	940	940	930	930	930	930
a. Solid Waste Disposal on Land	920	930	930	930	920	920	920	910	910	900	900	900
b. Wastewater Handling	13	14	21	21	23	29	27	29	29	29	29	29
c. Waste Incineration	–	–	–	–	–	–	–	–	–	–	–	–

Notes:

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

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 & SF₆ 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.

Totals may not add up due to rounding.

Table A11-3: 2005 GHG Emissions Summary for Newfoundland and Labrador

Greenhouse Gas Categories		Greenhouse Gases								
		CO ₂	CH ₄	CH ₄	N ₂ O	N ₂ O	HFCs	PFCs	SF ₆	TOTAL
		Global Warming Potential	21	310						
Unit		kt	kt	kt CO ₂ eq	kt	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq
TOTAL		9 020	56	1 200	0.99	310	—	—	—	10 500
ENERGY		8 930	11	240	0.9	300	—	—	—	9 440
a. Stationary Combustion Sources		4 530	9	200	0.2	50	—	—	—	4 770
Electricity and Heat Generation		X	X	X	X	X	—	—	—	X
Fossil Fuel Industries		1 430	3	70	0.05	10	—	—	—	1 500
Mining & Oil and Gas Extraction		X	X	X	X	X	—	—	—	X
Manufacturing Industries		268	0.01	0.2	0.01	2	—	—	—	270
Construction		17.6	0.00	0.00	0.00	0.06	—	—	—	17.6
Commercial & Institutional		441	0.01	0.1	0.01	3	—	—	—	444
Residential		260	5	100	0.06	20	—	—	—	390
Agriculture & Forestry		X	X	X	X	X	—	—	—	X
b. Transportation ¹		3 670	0.3	5	0.7	200	—	—	—	3 900
Domestic Aviation		448	0.02	0.4	0.04	10	—	—	—	460
Road Transportation		1 910	0.14	2.9	0.16	50	—	—	—	1 960
Light Duty Gasoline Vehicles		583	0.05	0.95	0.05	16	—	—	—	600
Light Duty Gasoline Trucks		749	0.06	1.3	0.09	27	—	—	—	778
Heavy Duty Gasoline Vehicles		54.2	0.00	0.07	0.00	1.0	—	—	—	55.3
Motorcycles		4.06	0.00	0.05	0.00	0.02	—	—	—	4.14
Light Duty Diesel Vehicles		1.21	0.00	0.00	0.00	0.03	—	—	—	1.24
Light Duty Diesel Trucks		21.1	0.00	0.01	0.00	0.5	—	—	—	21.6
Heavy Duty Diesel Vehicles		493	0.02	0.5	0.01	5	—	—	—	498
Propane & Natural Gas Vehicles		0.35	0.00	0.00	0.00	0.00	—	—	—	0.35
Railways		—	—	—	—	—	—	—	—	0
Domestic Marine		533	0.03	0.6	0.2	70	—	—	—	600
Others		780	0.08	2	0.3	90	—	—	—	900
Off Road Gasoline		30	0.04	0.8	0.00	0.2	—	—	—	40
Off Road Diesel		720	0.04	0.8	0.3	90	—	—	—	800
Pipelines		24.8	0.00	0.03	0.00	1	—	—	—	26.0
c. Fugitive Sources ²		730	2.2	47	—	—	—	—	—	778
INDUSTRIAL PROCESSES ³		94	—	—	—	—	—	—	—	93.6
a. Mineral Products		—	—	—	—	—	—	—	—	0
Cement Production		—	—	—	—	—	—	—	—	0
Lime Production		—	—	—	—	—	—	—	—	0
b. Chemical Industry		—	—	—	—	—	—	—	—	0
Nitric Acid Production		—	—	—	—	—	—	—	—	0
Adipic Acid Production		—	—	—	—	—	—	—	—	0
c. Metal Production		—	—	—	—	—	—	—	—	0
Iron and Steel Production		—	—	—	—	—	—	—	—	0
Aluminum Production		—	—	—	—	—	—	—	—	0
SF ₆ Used in Magnesium Smelters and Casters		—	—	—	—	—	—	—	—	0
d. Consumption of Halocarbons and SF ₆		—	—	—	—	—	—	—	—	0
e. Other & Undifferentiated Production ⁴		94	—	—	—	—	—	—	—	94
SOLVENT & OTHER PRODUCT USE		—	—	—	0.01	2.8	—	—	—	2.8
AGRICULTURE		—	1.2	25	0.07	21	—	—	—	46
a. Enteric Fermentation		—	0.98	21	—	—	—	—	—	21
b. Manure Management		—	0.20	4.2	0.02	4.9	—	—	—	9.1
c. Agriculture Soils		—	—	—	0.05	16	—	—	—	16
Direct Sources		—	—	—	0.03	10	—	—	—	10
Pasture, Range and Paddock Manure		—	—	—	0.01	2.1	—	—	—	2.1
Indirect Sources		—	—	—	0.01	4	—	—	—	4
WASTE		—	44	920	0.04	10	—	—	—	930
a. Solid Waste Disposal on Land		—	43	900	—	—	—	—	—	900
b. Wastewater Handling		—	0.87	18	0.04	10	—	—	—	29
c. Waste Incineration		—	—	—	—	—	—	—	—	0

Notes:

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

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 & SF₆ 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.

Totals may not add up due to rounding.

Table A11-4: 1990–2005 GHG Emissions Summary for Prince Edward Island

Greenhouse Gas Categories	1990		1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
						kt CO ₂ eq							
TOTAL	2 070		2 000	2 130	2 170	2 150	2 140	2 290	2 170	2 200	2 300	2 310	2 280
ENERGY	1 460		1 350	1 460	1 500	1 460	1 460	1 610	1 530	1 520	1 610	1 620	1 570
a. Stationary Combustion Sources	749		648	692	747	667	620	751	696	685	743	719	663
Electricity and Heat Generation	102		38.8	27.3	36.7	11.1	19.4	55.8	X	X	X	X	X
Fossil Fuel Industries	0.12		1.6	1.8	1.7	1.8	0.59	2.2	4.3	-	-	0.02	0.01
Mining & Oil and Gas Extraction	0.77		0.79	1.41	1.42	0.58	2.27	4.97	X	X	X	X	X
Manufacturing Industries	53.9		70.9	90.4	109	93.5	56.0	133	124	118	136	138	136
Construction	11.4		6.59	6.09	5.22	6.27	5.97	6.81	5.39	5.98	4.36	6.42	7.68
Commercial & Institutional	162		179	184	192	175	171	198	197	212	242	244	218
Residential	400		310	330	350	330	320	320	300	310	300	290	270
Agriculture & Forestry	19.0		40.5	47.4	51.0	49.0	44.2	32.1	X	X	X	X	X
b. Transportation¹	710		700	770	760	790	840	860	830	840	860	900	910
Domestic Aviation	13		6.0	8.2	9.0	8.8	8.2	7.5	7.4	7.3	9.5	10	12
Road Transportation	543		606	587	586	592	615	608	610	609	622	648	646
Light Duty Gasoline Vehicles	248		254	234	237	236	249	235	232	231	227	226	221
Light Duty Gasoline Trucks	118		168	170	174	184	201	204	207	216	225	236	245
Heavy Duty Gasoline Vehicles	69.2		34.0	34.5	28.8	25.5	20.5	18.1	26.3	24.3	24.2	25.4	25.1
Motorcycles	1.01		0.91	0.96	0.99	1.02	1.22	1.42	1.73	2.26	2.45	2.62	2.77
Light Duty Diesel Vehicles	1.81		1.82	1.59	1.55	1.54	1.55	1.45	1.57	1.48	1.52	1.64	1.61
Light Duty Diesel Trucks	3.34		5.61	5.31	5.50	6.48	7.13	7.58	7.91	8.31	8.69	9.38	10.2
Heavy Duty Diesel Vehicles	101		141	140	136	136	132	139	132	126	133	147	140
Propane & Natural Gas Vehicles	1.1		0.92	1.2	1.4	1.5	2.2	0.70	1.7	0.04	0.05	0.04	0.04
Railways	-		-	-	-	-	-	-	-	-	-	-	-
Domestic Marine	91		64	110	73	67	74	86	86	80	86	100	100
Others	60		30	60	90	100	100	200	100	100	100	100	100
Off Road Gasoline	30		20	50	60	70	70	70	60	80	80	80	80
Off Road Diesel	30		7	10	30	60	80	90	70	70	70	60	70
Pipelines	-		-	-	-	-	-	-	-	-	-	-	-
c. Fugitive Sources²	-		-	-	-	-	-	-	-	-	-	-	-
Coal Mining	-		-	-	-	-	-	-	-	X	X	X	X
Oil and Natural Gas	-		-	-	-	-	-	-	-	X	X	X	X
INDUSTRIAL PROCESSES³	3.33		3.13	3.21	3.21	3.07	3.18	2.85	2.58	2.47	2.47	2.52	1.88
a. Mineral Products	-		-	-	-	-	-	-	-	-	-	-	-
Cement Production	-		-	-	-	-	-	-	-	-	-	-	-
Lime Production	-		-	-	-	-	-	-	-	-	-	-	-
b. Chemical Industry	-		-	-	-	-	-	-	-	-	-	-	-
Nitric Acid Production	-		-	-	-	-	-	-	-	-	-	-	-
Adipic Acid Production	-		-	-	-	-	-	-	-	-	-	-	-
c. Metal Production	-		-	-	-	-	-	-	-	-	-	-	-
Iron and Steel Production	-		-	-	-	-	-	-	-	-	-	-	-
Aluminum Production	-		-	-	-	-	-	-	-	-	-	-	-
SF ₆ Used in Magnesium Smelters and Casters	-		-	-	-	-	-	-	-	-	-	-	-
d. Consumption of Halocarbons and SF₆	-		-	-	-	-	-	-	-	-	-	-	-
e. Other & Undifferentiated Production⁴	3.3		3.1	3.2	3.2	3.1	3.2	2.8	2.6	2.5	2.5	2.5	1.9
SOLVENT & OTHER PRODUCT USE	0.82		0.95	0.97	1.0	0.94	0.97	1.1	0.94	0.72	0.96	0.91	0.76
AGRICULTURE	460		480	500	500	510	500	500	460	490	510	510	530
a. Enteric Fermentation	150		150	150	150	150	150	140	140	140	140	140	140
b. Manure Management	60		58	58	58	59	58	56	56	56	56	56	56
c. Agriculture Soils	250		280	290	290	300	290	300	270	300	320	320	330
Direct Sources	170		190	200	200	210	200	210	190	210	220	220	240
Pasture, Range and Paddock Manure	24		24	24	24	25	24	23	22	22	22	22	22
Indirect Sources	60		60	70	70	70	70	70	60	70	70	70	70
WASTE	150		160	160	170	170	170	180	180	180	180	180	190
a. Solid Waste Disposal on Land	140		150	150	150	160	160	160	160	170	170	170	170
b. Wastewater Handling	3.7		4.0	4.3	4.1	4.1	4.2	4.1	4.2	4.2	4.2	4.2	4.2
c. Waste Incineration	9.1		9.1	9.1	9.1	9.1	9.2	9.4	9.2	9.3	9.4	9.5	9.5

Notes:

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

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 & SF₆ 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.

Totals may not add up due to rounding.

Table A11-5: 2005 GHG Emissions Summary for Prince Edward Island

Greenhouse Gas Categories		Greenhouse Gases								
		CO ₂	CH ₄	CH ₄	N ₂ O	N ₂ O	HFCs	PFCs	SF ₆	TOTAL
		Global Warming Potential	21	310						
Unit		kt	kt	kt CO ₂ eq	kt	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq
TOTAL		1 500	18	380	1.3	410	—	—	—	2 280
ENERGY		1 490	1.7	36	0.1	40	—	—	—	1 570
a. Stationary Combustion Sources		622	2	30	0.03	8	—	—	—	663
Electricity and Heat Generation		X	X	X	X	X	—	—	—	X
Fossil Fuel Industries		0.01	0.00	0.00	0.00	0.00	—	—	—	0.01
Mining & Oil and Gas Extraction		X	X	X	X	X	—	—	—	X
Manufacturing Industries		135	0.01	0.1	0.00	0.8	—	—	—	136
Construction		7.65	0.00	0.00	0.00	0.03	—	—	—	7.68
Commercial & Institutional		217	0.00	0.04	0.00	1	—	—	—	218
Residential		231	2	30	0.02	6	—	—	—	270
Agriculture & Forestry		X	X	X	X	X	—	—	—	X
b. Transportation ¹		866	0.1	3	0.1	40	—	—	—	910
Domestic Aviation		11.8	0.00	0.02	0.00	0.3	—	—	—	12
Road Transportation		628	0.05	1.1	0.06	17	—	—	—	646
Light Duty Gasoline Vehicles		214	0.02	0.40	0.02	6.4	—	—	—	221
Light Duty Gasoline Trucks		236	0.02	0.45	0.03	8.6	—	—	—	245
Heavy Duty Gasoline Vehicles		24.6	0.00	0.04	0.00	0.42	—	—	—	25.1
Motorcycles		2.72	0.00	0.04	0.00	0.02	—	—	—	2.77
Light Duty Diesel Vehicles		1.58	0.00	0.00	0.00	0.04	—	—	—	1.61
Light Duty Diesel Trucks		9.99	0.00	0.01	0.00	0.2	—	—	—	10.2
Heavy Duty Diesel Vehicles		138	0.01	0.1	0.00	1	—	—	—	140
Propane & Natural Gas Vehicles		0.04	0.00	0.00	0.00	0.00	—	—	—	0.04
Railways		—	—	—	—	—	—	—	—	0
Domestic Marine		90.2	0.01	0.1	0.04	10	—	—	—	100
Others		140	0.09	2	0.03	8	—	—	—	100
Off Road Gasoline		80	0.09	2	0.00	0.5	—	—	—	80
Off Road Diesel		60	0.00	0.07	0.02	8	—	—	—	70
Pipelines		—	—	—	—	—	—	—	—	0
c. Fugitive Sources ²		—	—	—	—	—	—	—	—	0
INDUSTRIAL PROCESSES ³		1.9	—	—	—	—	—	—	—	1.88
a. Mineral Products		—	—	—	—	—	—	—	—	0
Cement Production		—	—	—	—	—	—	—	—	0
Lime Production		—	—	—	—	—	—	—	—	0
b. Chemical Industry		—	—	—	—	—	—	—	—	0
Nitric Acid Production		—	—	—	—	—	—	—	—	0
Adipic Acid Production		—	—	—	—	—	—	—	—	0
c. Metal Production		—	—	—	—	—	—	—	—	0
Iron and Steel Production		—	—	—	—	—	—	—	—	0
Aluminum Production		—	—	—	—	—	—	—	—	0
SF ₆ Used in Magnesium Smelters and Casters		—	—	—	—	—	—	—	—	0
d. Consumption of Halocarbons and SF ₆		—	—	—	—	—	—	—	—	0
e. Other & Undifferentiated Production ⁴		1.9	—	—	—	—	—	—	—	1.9
SOLVENT & OTHER PRODUCT USE		—	—	—	0.00	0.76	—	—	—	0.76
AGRICULTURE		—	7.9	170	1.2	360	—	—	—	530
a. Enteric Fermentation		—	6.5	140	—	—	—	—	—	140
b. Manure Management		—	1.3	28	0.09	27	—	—	—	56
c. Agriculture Soils		—	—	—	1.1	330	—	—	—	330
Direct Sources		—	—	—	0.76	240	—	—	—	240
Pasture, Range and Paddock Manure		—	—	—	0.07	22	—	—	—	22
Indirect Sources		—	—	—	0.2	70	—	—	—	70
WASTE		8.0	8.3	170	0.01	4	—	—	—	190
a. Solid Waste Disposal on Land		—	8.2	170	—	—	—	—	—	170
b. Wastewater Handling		—	0.06	1.2	0.01	3	—	—	—	4.2
c. Waste Incineration		8.0	—	—	0.01	2	—	—	—	9.5

Notes:

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

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 & SF₆ 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.

Totals may not add up due to rounding.

Table A11-6: 1990–2005 GHG Emissions Summary for Nova Scotia

Greenhouse Gas Categories	1990		1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
						kt CO ₂ eq							
TOTAL	19 500		19 100	18 900	19 500	19 800	20 300	21 400	20 600	19 700	21 900	23 200	22 700
ENERGY	17 700		17 200	17 100	17 700	17 900	18 400	19 600	19 000	18 000	20 100	21 500	21 100
a. Stationary Combustion Sources	11 400		11 200	11 200	11 800	12 100	12 400	13 500	13 100	12 300	13 900	15 100	14 600
Electricity and Heat Generation	6 830		6 890	7 100	7 530	7 800	8 060	8 820	X	X	X	X	X
Fossil Fuel Industries	650		640	400	380	630	530	990	930	1 200	1 600	1 100	1 300
Mining & Oil and Gas Extraction	35.3		33.2	38.3	40.7	41.9	48.1	53.8	X	X	X	X	X
Manufacturing Industries	713		866	801	758	776	800	660	508	690	628	595	468
Construction	50.7		35.5	28.5	29.9	35.1	32.0	28.2	37.2	55.0	52.0	54.7	38.9
Commercial & Institutional	809		817	809	946	750	865	922	1 070	1 040	1 280	1 990	2 020
Residential	2 200		1 700	1 800	1 900	1 800	1 800	1 800	1 900	1 800	1 900	1 300	1 200
Agriculture & Forestry	106		203	227	250	222	209	237	X	X	X	X	X
b. Transportation ¹	5 100		5 200	5 100	5 200	5 300	5 800	5 700	5 500	5 600	6 100	6 300	6 400
Domestic Aviation	400		370	350	340	340	360	350	320	350	370	490	550
Road Transportation	3 260		3 600	3 550	3 500	3 330	3 680	3 590	3 630	3 650	3 760	3 850	3 860
Light Duty Gasoline Vehicles	1 610		1 540	1 470	1 440	1 320	1 440	1 320	1 360	1 360	1 350	1 330	1 290
Light Duty Gasoline Trucks	710		951	979	995	969	1 170	1 220	1 160	1 210	1 270	1 310	1 350
Heavy Duty Gasoline Vehicles	200		158	156	123	102	89.8	93.7	118	108	111	115	112
Motorcycles	9.88		8.09	7.97	7.90	8.78	8.32	7.59	7.68	8.27	9.05	9.54	9.37
Light Duty Diesel Vehicles	18.0		16.3	16.0	15.9	14.6	15.6	15.1	16.4	17.2	17.8	18.9	18.7
Light Duty Diesel Trucks	24.7		42.5	39.8	40.9	40.1	44.3	49.5	47.1	50.5	53.2	56.2	59.9
Heavy Duty Diesel Vehicles	679		881	867	869	870	897	887	913	893	944	1 010	1 020
Propane & Natural Gas Vehicles	7.5		5.2	6.4	8.9	8.4	14	4.2	5.0	4.0	4.0	4.2	4.9
Railways	70		50	30	40	40	60	80	70	80	200	100	100
Domestic Marine	620		570	570	600	660	720	670	540	500	680	770	860
Others	800		600	500	700	1 000	900	1 000	900	1 000	1 000	1 000	1 000
Off Road Gasoline	300		300	300	300	500	400	400	300	300	300	300	200
Off Road Diesel	500		300	300	400	400	600	700	600	700	800	800	800
Pipelines	-		-	-	-	-	-	-	-	-	12.0	30.0	34.3
c. Fugitive Sources ²	1 170		835	835	692	513	338	336	354	86.9	78.4	77.2	74.6
Coal Mining	1 000		800	800	700	500	300	300	300	X	X	X	X
Oil and Natural Gas	-		5.86	5.67	5.35	5.56	4.87	86.1	84.3	X	X	X	X
INDUSTRIAL PROCESSES³	272		313	275	226	357	313	285	195	285	323	288	280
a. Mineral Products	170		230	190	120	220	230	220	130	220	230	220	220
Cement Production	170		230	190	120	220	230	220	130	220	230	220	220
Lime Production	-		-	-	-	-	-	-	-	-	-	-	-
b. Chemical Industry	-		-	-	-	-	-	-	-	-	-	-	-
Nitric Acid Production	-		-	-	-	-	-	-	-	-	-	-	-
Adipic Acid Production	-		-	-	-	-	-	-	-	-	-	-	-
c. Metal Production	-		-	-	-	-	-	-	-	-	-	-	-
Iron and Steel Production	-		-	-	-	-	-	-	-	-	-	-	-
Aluminum Production	-		-	-	-	-	-	-	-	-	-	-	-
SF ₆ Used in Magnesium Smelters and Casters	-		-	-	-	-	-	-	-	-	-	-	-
d. Consumption of Halocarbons and SF ₆	-		-	-	-	-	-	-	-	-	-	-	-
e. Other & Undifferentiated Production ⁴	100		79	83	110	130	88	69	62	68	97	66	56
SOLVENT & OTHER PRODUCT USE	5.7		6.6	6.7	7.0	6.4	6.6	7.4	6.4	4.9	6.5	6.2	5.2
AGRICULTURE	510		520	530	520	510	500	500	480	490	500	500	500
a. Enteric Fermentation	210		210	210	210	200	200	200	190	190	190	190	190
b. Manure Management	96		95	96	96	95	94	92	90	89	88	87	87
c. Agriculture Soils	210		220	230	210	210	210	210	200	210	230	220	230
Direct Sources	120		130	140	130	130	120	130	120	130	140	140	140
Pasture, Range and Paddock Manure	32		32	32	32	30	29	28	28	28	27	28	28
Indirect Sources	50		60	60	60	60	50	50	50	50	60	60	60
WASTE	1 100		1 000	1 000	1 000	1 000	1 000	990	970	960	960	880	810
a. Solid Waste Disposal on Land	1 000		1 000	1 000	1 000	980	970	950	930	920	920	850	780
b. Wastewater Handling	26		24	28	25	25	30	26	27	26	26	26	26
c. Waste Incineration	21		16	15	14	13	13	12	12	12	11	11	11

Notes:

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

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 & SF₆ 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.

Totals may not add up due to rounding.

Table A11-7: 2005 GHG Emissions Summary for Nova Scotia

Greenhouse Gas Categories		Greenhouse Gases									
		CO ₂	CH ₄	CH ₄	N ₂ O	N ₂ O	HFCs	PFCs	SF ₆	TOTAL	
		Global Warming Potential		21		310					
		Unit	kt	kt	kt CO ₂ eq	kt	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq
TOTAL		20 800	61	1 300	2.1	660	—	—	—	22 700	
ENERGY		20 500	13	270	1	400	—	—	—	21 100	
a. Stationary Combustion Sources		14 300	9	200	0.3	100	—	—	—	14 600	
Electricity and Heat Generation		X	X	X	X	X	—	—	—	X	
Fossil Fuel Industries		1 320	1	20	0.01	4	—	—	—	1 300	
Mining & Oil and Gas Extraction		X	X	X	X	X	—	—	—	X	
Manufacturing Industries		455	0.08	2	0.04	10	—	—	—	468	
Construction		38.7	0.00	0.01	0.00	0.2	—	—	—	38.9	
Commercial & Institutional		2 010	0.03	0.5	0.04	10	—	—	—	2 020	
Residential		996	8	200	0.09	30	—	—	—	1 200	
Agriculture & Forestry		X	X	X	X	X	—	—	—	X	
b. Transportation ¹		6 140	0.7	10	0.8	300	—	—	—	6 400	
Domestic Aviation		534	0.02	0.4	0.05	10	—	—	—	550	
Road Transportation		3 760	0.27	5.6	0.30	94	—	—	—	3 860	
Light Duty Gasoline Vehicles		1 250	0.10	2.1	0.11	35	—	—	—	1 290	
Light Duty Gasoline Trucks		1 300	0.11	2.2	0.15	46	—	—	—	1 350	
Heavy Duty Gasoline Vehicles		109	0.01	0.12	0.01	2.3	—	—	—	112	
Motorcycles		9.19	0.01	0.12	0.00	0.06	—	—	—	9.37	
Light Duty Diesel Vehicles		18.3	0.00	0.01	0.00	0.4	—	—	—	18.7	
Light Duty Diesel Trucks		58.4	0.00	0.03	0.01	1	—	—	—	59.9	
Heavy Duty Diesel Vehicles		1 010	0.05	1	0.03	9	—	—	—	1 020	
Propane & Natural Gas Vehicles		4.80	0.00	0.04	0.00	0.03	—	—	—	4.9	
Railways		105	0.01	0.1	0.04	10	—	—	—	100	
Domestic Marine		809	0.06	1	0.1	50	—	—	—	860	
Others		940	0.3	7	0.3	90	—	—	—	1 000	
Off Road Gasoline		200	0.3	5	0.01	2	—	—	—	200	
Off Road Diesel		680	0.04	0.8	0.3	80	—	—	—	800	
Pipelines		33.3	0.03	0.70	0.00	0.3	—	—	—	34.3	
c. Fugitive Sources ²		7.3	3.2	67	—	—	—	—	—	74.6	
INDUSTRIAL PROCESSES ³		280	—	—	—	—	—	—	—	280	
a. Mineral Products		220	—	—	—	—	—	—	—	220	
Cement Production		220	—	—	—	—	—	—	—	220	
Lime Production		—	—	—	—	—	—	—	—	0	
b. Chemical Industry		—	—	—	—	—	—	—	—	0	
Nitric Acid Production		—	—	—	—	—	—	—	—	0	
Adipic Acid Production		—	—	—	—	—	—	—	—	0	
c. Metal Production		—	—	—	—	—	—	—	—	0	
Iron and Steel Production		—	—	—	—	—	—	—	—	0	
Aluminum Production		—	—	—	—	—	—	—	—	0	
SF ₆ Used in Magnesium Smelters and Casters		—	—	—	—	—	—	—	—	0	
d. Consumption of Halocarbons and SF ₆		—	—	—	—	—	—	—	—	0	
e. Other & Undifferentiated Production ⁴		56	—	—	—	—	—	—	—	56	
SOLVENT & OTHER PRODUCT USE		—	—	—	0.02	5.2	—	—	—	5.2	
AGRICULTURE		—	11	230	0.89	280	—	—	—	500	
a. Enteric Fermentation		—	9.1	190	—	—	—	—	—	190	
b. Manure Management		—	1.7	36	0.16	51	—	—	—	87	
c. Agriculture Soils		—	—	—	0.73	230	—	—	—	230	
Direct Sources		—	—	—	0.46	140	—	—	—	140	
Pasture, Range and Paddock Manure		—	—	—	0.09	28	—	—	—	28	
Indirect Sources		—	—	—	0.2	60	—	—	—	60	
WASTE		9.1	37	780	0.07	20	—	—	—	810	
a. Solid Waste Disposal on Land		—	37	780	—	—	—	—	—	780	
b. Wastewater Handling		—	0.28	5.9	0.06	20	—	—	—	26	
c. Waste Incineration		9.1	—	—	0.01	2	—	—	—	11	

Notes:

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

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 & SF₆ 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.

Totals may not add up due to rounding.

Table A11-8: 1990–2005 GHG Emissions Summary for New Brunswick

Greenhouse Gas Categories	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
		kt CO ₂ eq										
TOTAL	16 200	17 200	16 500	19 100	20 100	19 200	20 400	22 600	21 400	21 100	21 600	21 300
ENERGY	14 600	15 500	14 800	17 300	18 300	17 500	18 600	20 800	19 600	19 200	19 700	19 500
a. Stationary Combustion Sources	10 500	11 000	10 200	12 600	13 400	12 200	13 100	15 300	14 100	13 800	14 200	13 900
Electricity and Heat Generation	6 020	6 840	6 050	8 320	9 440	8 190	8 550	X	X	X	X	X
Fossil Fuel Industries	1 000	990	960	1 100	1 100	1 200	1 500	2 600	3 000	2 800	2 500	2 800
Mining & Oil and Gas Extraction	126	117	153	121	98.3	97.1	134	X	X	X	X	X
Manufacturing Industries	1 420	1 450	1 420	1 340	1 240	1 250	1 330	1 290	1 240	1 250	1 210	872
Construction	68.6	40.8	39.8	48.9	38.3	36.5	39.8	26.3	18.6	12.5	10.9	4.09
Commercial & Institutional	587	555	496	593	503	491	614	581	495	605	969	1 080
Residential	1 200	920	930	960	840	820	850	730	740	760	740	720
Agriculture & Forestry	54.3	131	110	119	105	101	65.9	X	X	X	X	X
b. Transportation ¹	4 100	4 400	4 600	4 800	5 000	5 300	5 500	5 500	5 500	5 400	5 600	5 600
Domestic Aviation	76	82	87	140	140	150	160	150	130	130	140	150
Road Transportation	3 110	3 620	3 500	3 590	3 650	3 850	3 770	3 720	3 750	3 810	3 900	3 970
Light Duty Gasoline Vehicles	1 350	1 270	1 210	1 260	1 260	1 290	1 170	1 160	1 160	1 140	1 120	1 080
Light Duty Gasoline Trucks	687	915	925	1 010	1 090	1 150	1 130	1 110	1 150	1 180	1 230	1 260
Heavy Duty Gasoline Vehicles	206	141	150	113	64.1	53.6	93.0	122	116	116	120	130
Motorcycles	7.04	6.05	6.13	6.61	6.98	7.38	6.84	8.40	9.25	9.96	10.5	10.6
Light Duty Diesel Vehicles	11.5	9.97	9.54	10.1	9.92	9.40	9.26	9.23	9.76	9.90	10.6	10.3
Light Duty Diesel Trucks	24.3	41.3	37.5	41.0	43.9	43.9	45.7	46.7	47.6	49.3	52.2	55.3
Heavy Duty Diesel Vehicles	820	1 230	1 160	1 140	1 160	1 290	1 300	1 250	1 250	1 300	1 360	1 420
Propane & Natural Gas Vehicles	5.1	8.1	8.3	10	9.2	16	6.8	8.0	1.6	1.4	1.3	0.68
Railways	100	100	100	100	200	200	200	300	300	300	300	300
Domestic Marine	270	300	310	310	330	360	410	430	400	370	440	430
Others	500	300	600	600	700	700	1 000	900	900	800	800	700
Off Road Gasoline	100	60	200	100	100	70	100	100	200	200	100	100
Off Road Diesel	400	300	400	500	600	600	900	800	800	600	700	600
Pipelines	-	-	-	-	-	-	-	-	-	-	-	-
c. Fugitive Sources ²	1.46	0.71	0.74	0.48	0.74	0.74	25.1	28.8	29.0	29.2	29.0	29.2
Coal Mining	1	0.7	0.7	0.5	0.7	0.7	0.6	0.4	X	X	X	X
Oil and Natural Gas	-	-	-	-	-	-	24.6	28.4	X	X	X	X
INDUSTRIAL PROCESSES³	149	274	248	246	240	236	226	260	296	285	296	243
a. Mineral Products	76	91	88	92	92	96	100	92	95	84	90	87
Cement Production	-	-	-	-	-	-	-	-	-	-	-	-
Lime Production	76	91	88	92	92	96	100	92	95	84	90	87
b. Chemical Industry	-	-	-	-	-	-	-	-	-	-	-	-
Nitric Acid Production	-	-	-	-	-	-	-	-	-	-	-	-
Adipic Acid Production	-	-	-	-	-	-	-	-	-	-	-	-
c. Metal Production	-	-	-	-	-	-	-	-	-	-	-	-
Iron and Steel Production	-	-	-	-	-	-	-	-	-	-	-	-
Aluminum Production	-	-	-	-	-	-	-	-	-	-	-	-
SF ₆ Used in Magnesium Smelters and Casters	-	-	-	-	-	-	-	-	-	-	-	-
d. Consumption of Halocarbons and SF ₆	-	-	-	-	-	-	-	-	-	-	-	-
e. Other & Undifferentiated Production ⁴	72	180	160	150	150	140	120	170	200	200	210	160
SOLVENT & OTHER PRODUCT USE	4.7	5.3	5.4	5.7	5.2	5.3	5.9	5.1	4.0	5.2	5.0	4.1
AGRICULTURE	460	440	450	450	460	460	470	460	480	490	490	490
a. Enteric Fermentation	170	160	160	160	170	170	160	160	160	160	160	160
b. Manure Management	72	70	71	73	75	75	76	77	76	75	75	74
c. Agriculture Soils	210	210	220	220	220	220	230	220	240	260	250	260
Direct Sources	140	130	140	140	140	140	150	140	160	170	170	170
Pasture, Range and Paddock Manure	26	25	25	25	25	25	24	24	23	23	23	23
Indirect Sources	50	50	50	50	50	50	60	60	60	60	60	60
WASTE	980	1 000	1 000	1 100	1 100	1 100	1 100	1 100	1 100	1 100	1 100	1 000
a. Solid Waste Disposal on Land	940	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000
b. Wastewater Handling	41	38	34	37	37	40	38	38	38	38	38	38
c. Waste Incineration	-	-	-	-	-	-	-	-	-	-	-	-

Notes:

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

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 & SF₆ 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.

Totals may not add up due to rounding.

Table A11-9: 2005 GHG Emissions Summary for New Brunswick

Greenhouse Gas Categories		Greenhouse Gases								TOTAL
Global Warming Potential	Unit	CO ₂	CH ₄	CH ₄	N ₂ O	N ₂ O	HFCs	PFCs	SF ₆	
				21		310				
		kt	kt	kt CO ₂ eq	kt	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	
TOTAL		19 200	69	1 400	2.2	670	—	—	—	21 300
ENERGY		18 900	11	220	1	300	—	—	—	19 500
a. Stationary Combustion Sources		13 600	9	200	0.4	100	—	—	—	13 900
Electricity and Heat Generation	X	X	X	X	X	X	—	—	—	X
Fossil Fuel Industries	2 770	0.05	1	0.02	6	—	—	—	—	2 800
Mining & Oil and Gas Extraction	X	X	X	X	X	X	—	—	—	X
Manufacturing Industries	849	0.1	3	0.06	20	—	—	—	—	872
Construction	4.07	0.00	0.00	0.00	0.02	—	—	—	—	4.09
Commercial & Institutional	1 080	0.02	0.4	0.02	7	—	—	—	—	1 080
Residential	520	8	200	0.09	30	—	—	—	—	720
Agriculture & Forestry	X	X	X	X	X	X	—	—	—	X
b. Transportation¹		5 300	0.5	10	0.8	200	—	—	—	5 600
Domestic Aviation	144	0.01	0.2	0.01	4	—	—	—	—	150
Road Transportation	3 870	0.28	5.8	0.29	91	—	—	—	—	3 970
Light Duty Gasoline Vehicles	1 050	0.09	1.9	0.10	30	—	—	—	—	1 080
Light Duty Gasoline Trucks	1 210	0.11	2.2	0.14	43	—	—	—	—	1 260
Heavy Duty Gasoline Vehicles	127	0.01	0.16	0.01	2.6	—	—	—	—	130
Motorcycles	10.4	0.01	0.14	0.00	0.06	—	—	—	—	10.6
Light Duty Diesel Vehicles	10.1	0.00	0.00	0.00	0.2	—	—	—	—	10.3
Light Duty Diesel Trucks	53.9	0.00	0.03	0.00	1	—	—	—	—	55.3
Heavy Duty Diesel Vehicles	1 410	0.06	1	0.04	10	—	—	—	—	1 420
Propane & Natural Gas Vehicles	0.67	0.00	0.01	0.00	0.00	—	—	—	—	0.68
Railways	246	0.01	0.3	0.1	30	—	—	—	—	300
Domestic Marine	384	0.02	0.5	0.1	40	—	—	—	—	430
Others	660	0.1	3	0.2	70	—	—	—	—	700
Off Road Gasoline	100	0.1	2	0.00	0.7	—	—	—	—	100
Off Road Diesel	560	0.03	0.6	0.2	70	—	—	—	—	600
Pipelines	—	—	—	—	—	—	—	—	—	0
c. Fugitive Sources²		0.01	1.4	29	—	—	—	—	—	29.2
INDUSTRIAL PROCESSES³		240	—	—	—	—	—	—	—	243
a. Mineral Products		87	—	—	—	—	—	—	—	87
Cement Production	—	—	—	—	—	—	—	—	—	0
Lime Production	87	—	—	—	—	—	—	—	—	87
b. Chemical Industry		—	—	—	—	—	—	—	—	0
Nitric Acid Production	—	—	—	—	—	—	—	—	—	0
Adipic Acid Production	—	—	—	—	—	—	—	—	—	0
c. Metal Production		—	—	—	—	—	—	—	—	0
Iron and Steel Production	—	—	—	—	—	—	—	—	—	0
Aluminum Production	—	—	—	—	—	—	—	—	—	0
SF ₆ Used in Magnesium Smelters and Casters	—	—	—	—	—	—	—	—	—	0
d. Consumption of Halocarbons and SF₆		—	—	—	—	—	—	—	—	0
e. Other & Undifferentiated Production⁴		160	—	—	—	—	—	—	—	160
SOLVENT & OTHER PRODUCT USE		—	—	—	0.01	4.1	—	—	—	4.1
AGRICULTURE		—	9.0	190	0.97	300	—	—	—	490
a. Enteric Fermentation		—	7.5	160	—	—	—	—	—	160
b. Manure Management		—	1.5	32	0.14	42	—	—	—	74
c. Agriculture Soils		—	—	—	0.84	260	—	—	—	260
Direct Sources	—	—	—	0.56	170	—	—	—	—	170
Pasture, Range and Paddock Manure	—	—	—	0.08	23	—	—	—	—	23
Indirect Sources	—	—	—	0.2	60	—	—	—	—	60
WASTE		—	49	1 000	0.05	20	—	—	—	1 000
a. Solid Waste Disposal on Land		—	48	1 000	—	—	—	—	—	1 000
b. Wastewater Handling		—	1.1	22	0.05	20	—	—	—	38
c. Waste Incineration		—	—	—	—	—	—	—	—	0

Notes:

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

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 & SF₆ 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.

Totals may not add up due to rounding.

Table A11-10: 1990–2005 GHG Emissions Summary for Quebec

Greenhouse Gas Categories	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
					kt CO ₂ eq							
TOTAL	85 300	82 700	83 300	83 200	85 100	84 800	85 700	83 700	86 400	91 200	91 400	89 400
ENERGY	58 200	57 400	58 300	58 200	60 100	60 000	60 900	58 700	60 900	65 900	65 900	64 100
a. Stationary Combustion Sources	29 400	27 100	28 000	27 000	27 500	26 900	28 000	26 300	27 200	30 800	30 000	28 000
Electricity and Heat Generation	1 510	396	425	459	1 550	1 160	579	641	580	1 860	1 640	1 720
Fossil Fuel Industries	3 100	3 200	3 200	2 400	3 200	3 100	3 300	3 300	3 300	3 500	3 600	3 500
Mining & Oil and Gas Extraction	734	823	825	869	778	758	920	834	933	933	445	423
Manufacturing Industries	12 000	10 800	11 400	11 500	11 200	10 900	11 000	9 980	9 970	10 200	10 900	9 830
Construction	459	189	191	225	188	191	191	191	254	297	322	291
Commercial & Institutional	4 270	5 070	5 000	5 000	4 680	4 710	5 720	5 760	6 520	7 900	6 920	6 830
Residential	7 000	6 300	6 700	6 300	5 600	5 900	6 000	5 300	5 400	5 800	5 800	5 100
Agriculture & Forestry	294	303	278	290	259	265	262	227	259	346	313	273
b. Transportation¹	29 000	30 000	30 000	31 000	32 000	33 000	32 000	32 000	33 000	35 000	35 000	36 000
Domestic Aviation	950	800	800	700	740	730	770	830	1 400	1 500	1 500	1 900
Road Transportation	21 600	24 000	23 700	24 300	25 200	25 600	25 700	26 600	27 100	27 400	28 200	28 500
Light Duty Gasoline Vehicles	12 300	11 800	11 500	11 300	11 100	11 200	11 400	11 200	11 200	11 100	11 100	10 800
Light Duty Gasoline Trucks	3 960	5 290	5 460	5 810	6 410	6 690	6 800	6 920	7 200	7 470	7 760	8 070
Heavy Duty Gasoline Vehicles	627	657	592	566	614	566	552	789	793	808	851	874
Motorcycles	32.2	30.8	31.9	33.2	42.4	40.6	47.6	57.4	67.1	73.2	78.5	82.4
Light Duty Diesel Vehicles	147	138	127	125	130	133	143	149	157	162	176	176
Light Duty Diesel Trucks	214	354	350	367	407	378	400	388	374	389	416	436
Heavy Duty Diesel Vehicles	4 190	5 690	5 570	5 980	6 410	6 540	6 320	7 060	7 220	7 370	7 810	8 010
Propane & Natural Gas Vehicles	110	47	35	45	43	35	36	56	35	30	39	34
Railways	600	600	400	500	700	900	800	800	800	800	800	700
Domestic Marine	1 400	910	930	1 100	1 600	1 300	1 400	1 600	1 400	1 000	1 400	1 300
Others	4 000	4 000	4 000	4 000	4 000	4 000	4 000	2 000	3 000	4 000	3 000	3 000
Off Road Gasoline	1 000	1 000	2 000	2 000	1 000	1 000	1 000	900	1 000	2 000	1 000	1 000
Off Road Diesel	3 000	2 000	2 000	3 000	2 000	3 000	3 000	1 000	1 000	2 000	2 000	2 000
Pipelines	26.1	24.5	18.2	26.1	16.6	25.2	108	203	331	357	251	338
c. Fugitive Sources²	281	396	404	406	439	441	444	450	490	492	496	496
Coal Mining	-	-	-	-	-	-	-	-	X	X	X	X
Oil and Natural Gas	281	396	404	406	439	441	444	450	X	X	X	X
INDUSTRIAL PROCESSES³	13 000	11 500	10 900	10 700	10 600	10 200	10 500	10 600	10 800	10 500	10 400	10 100
a. Mineral Products	1 600	1 700	1 500	1 600	1 600	1 600	1 600	1 500	1 600	1 600	1 700	1 700
Cement Production	1 300	1 500	1 300	1 200	1 200	1 200	1 200	1 200	1 200	1 200	1 200	1 200
Lime Production	270	250	240	380	380	400	430	380	400	450	490	470
b. Chemical Industry	80	110	100	78	61	67	-	-	-	-	-	-
Nitric Acid Production	79.7	105	101	78.4	61.4	66.9	-	-	-	-	-	-
Adipic Acid Production	-	-	-	-	-	-	-	-	-	-	-	-
c. Metal Production	10 200	8 820	8 530	8 370	8 440	7 590	7 640	7 730	7 950	7 640	6 910	6 860
Iron and Steel Production	-	6.63	7.99	5.81	8.14	6.57	11.7	12.1	8.31	8.29	29.5	7.21
Aluminum Production	7 800	7 500	7 700	7 600	7 600	6 800	6 400	6 400	6 400	6 400	5 900	6 800
SF ₆ Used in Magnesium Smelters and Casters ⁵	2 370	1 340	837	731	875	825	1 230	1 280	1 540	1 210	950	75.1
d. Consumption of Halocarbons and SF₆	-	-	-	-	-	-	-	-	-	-	-	-
e. Other & Undifferentiated Production⁴	1 100	870	690	670	520	950	1 200	1 300	1 300	1 300	1 900	1 600
SOLVENT & OTHER PRODUCT USE	44	51	52	55	50	52	58	51	39	52	50	42
AGRICULTURE	7 200	7 000	7 100	7 100	7 000	7 000	6 800	7 000	7 100	7 100	7 300	7 300
a. Enteric Fermentation	2 600	2 600	2 700	2 700	2 600	2 500	2 500	2 500	2 600	2 600	2 700	2 700
b. Manure Management	1 300	1 300	1 400	1 400	1 400	1 400	1 400	1 400	1 400	1 400	1 400	1 400
c. Agriculture Soils	3 200	3 000	3 000	3 000	3 100	3 100	3 000	3 100	3 100	3 100	3 200	3 200
Direct Sources	2 100	1 900	1 900	1 900	2 000	2 000	1 900	2 000	2 000	2 000	2 000	2 000
Pasture, Range and Paddock Manure	330	340	340	340	330	320	310	320	320	330	350	350
Indirect Sources	800	800	800	800	800	800	800	800	800	800	800	800
WASTE	6 800	6 900	7 000	7 100	7 300	7 500	7 400	7 400	7 500	7 600	7 800	7 900
a. Solid Waste Disposal on Land	6 500	6 500	6 600	6 800	6 900	7 100	7 100	7 000	7 100	7 300	7 400	7 600
b. Wastewater Handling	220	230	250	240	240	270	250	260	260	260	270	270
c. Waste Incineration	170	150	140	110	100	82	84	85	87	89	91	93

Notes:

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

2 Fugitive emissions from refineries are reported at the national level.

3 Emissions associated with the use of mineral products and consumption of halocarbons & SF₆ 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 SF₆ emissions from magnesium smelters are included. Information on SF₆ use in casters is confidential for this province.

X Indicates confidential data.

Totals may not add up due to rounding.

Table A11-11: 2005 GHG Emissions Summary for Quebec

Greenhouse Gas Categories		Greenhouse Gases								
		CO ₂	CH ₄	CH ₄	N ₂ O	N ₂ O	HFCs	PFCs	SF ₆	TOTAL
		Global Warming Potential	21	310						
	Unit	kt	kt	kt CO ₂ eq	kt	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq
TOTAL		69 100	590	12 000	17	5 300	—	2 400	93	89 400
ENERGY		61 400	61	1 300	4	1 000	—	—	—	64 100
a.	Stationary Combustion Sources	27 000	30	700	0.9	300	—	—	—	28 000
	Electricity and Heat Generation	1 710	0.08	1.6	0.04	10	—	—	—	1 720
	Fossil Fuel Industries	3 440	0.05	1	0.03	10	—	—	—	3 500
	Mining & Oil and Gas Extraction	420	0.02	0.3	0.01	3	—	—	—	423
	Manufacturing Industries	9 720	0.5	10	0.3	90	—	—	—	9 830
	Construction	289	0.01	0.1	0.01	2	—	—	—	291
	Commercial & Institutional	6 780	0.1	2	0.1	40	—	—	—	6 830
	Residential	4 320	30	700	0.4	100	—	—	—	5 100
	Agriculture & Forestry	268	0.00	0.09	0.02	5	—	—	—	273
b.	Transportation ¹	34 500	4	80	3	1 000	—	—	—	36 000
	Domestic Aviation	1 850	0.09	2	0.2	50	—	—	—	1 900
	Road Transportation	27 800	2.0	41	2.2	680	—	—	—	28 500
	Light Duty Gasoline Vehicles	10 500	0.84	18	0.95	290	—	—	—	10 800
	Light Duty Gasoline Trucks	7 780	0.62	13	0.90	280	—	—	—	8 070
	Heavy Duty Gasoline Vehicles	855	0.05	1.0	0.06	18	—	—	—	874
	Motorcycles	80.9	0.05	1.1	0.00	0.48	—	—	—	82.4
	Light Duty Diesel Vehicles	171	0.00	0.07	0.01	4	—	—	—	176
	Light Duty Diesel Trucks	425	0.01	0.2	0.03	10	—	—	—	436
	Heavy Duty Diesel Vehicles	7 930	0.4	8	0.2	70	—	—	—	8 010
	Propane & Natural Gas Vehicles	32.9	0.02	0.5	0.00	0.2	—	—	—	34
	Railways	630	0.03	0.7	0.3	80	—	—	—	700
	Domestic Marine	1 290	0.1	2	0.2	50	—	—	—	1 300
	Others	2 900	2	30	0.6	200	—	—	—	3 000
	Off Road Gasoline	1 000	1	30	0.02	7	—	—	—	1 000
	Off Road Diesel	1 500	0.08	2	0.6	200	—	—	—	2 000
	Pipelines	328	0.33	6.9	0.01	3	—	—	—	338
c.	Fugitive Sources ²	0.12	24	500	—	—	—	—	—	496
INDUSTRIAL PROCESSES ³		7 600	—	—	—	—	—	2 400	93	10 100
a.	Mineral Products	1 700	—	—	—	—	—	—	—	1 700
	Cement Production	1 200	—	—	—	—	—	—	—	1 200
	Lime Production	470	—	—	—	—	—	—	—	470
b.	Chemical Industry	—	—	—	—	—	—	—	—	0
	Nitric Acid Production	—	—	—	—	—	—	—	—	0
	Adipic Acid Production	—	—	—	—	—	—	—	—	0
c.	Metal Production	4 340	—	—	—	—	—	2 400	92.7	6 860
	Iron and Steel Production	7.21	—	—	—	—	—	—	—	7.21
	Aluminum Production	4 300	—	—	—	—	—	2 400	17.6	6 800
	SF ₆ Used in Magnesium Smelters and Casters ⁵	—	—	—	—	—	—	—	75.1	75.1
d.	Consumption of Halocarbons and SF ₆	—	—	—	—	—	—	—	—	0
e.	Other & Undifferentiated Production ⁴	1 600	—	—	—	—	—	—	—	1 600
SOLVENT & OTHER PRODUCT USE		—	—	—	0.13	42	—	—	—	42
AGRICULTURE		—	170	3 500	12	3 800	—	—	—	7 300
a.	Enteric Fermentation	—	130	2 700	—	—	—	—	—	2 700
b.	Manure Management	—	39	830	2.0	610	—	—	—	1 400
c.	Agriculture Soils	—	—	—	10	3 200	—	—	—	3 200
	Direct Sources	—	—	—	6.4	2 000	—	—	—	2 000
	Pasture, Range and Paddock Manure	—	—	—	1.1	350	—	—	—	350
	Indirect Sources	—	—	—	3	800	—	—	—	800
WASTE		67	370	7 700	0.6	200	—	—	—	7 900
a.	Solid Waste Disposal on Land	—	360	7 600	—	—	—	—	—	7 600
b.	Wastewater Handling	—	5.4	110	0.5	200	—	—	—	270
c.	Waste Incineration	67	0.06	1	0.08	20	—	—	—	93

Notes:

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

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 & SF₆ 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 SF₆ emissions from magnesium smelters are included. Information on SF₆ use in casters is confidential for this province.

Totals may not add up due to rounding.

Table A11-12: 1990–2005 GHG Emissions Summary for Ontario

Greenhouse Gas Categories	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
						kt CO ₂ eq						
TOTAL	175 000	175 000	182 000	186 000	187 000	191 000	201 000	193 000	199 000	203 000	199 000	201 000
ENERGY	133 000	131 000	138 000	144 000	148 000	156 000	166 000	160 000	164 000	169 000	161 000	165 000
a. Stationary Combustion Sources	83 700	77 400	82 900	86 300	89 600	94 200	104 000	99 400	102 000	106 000	96 200	97 700
Electricity and Heat Generation	26 600	19 100	20 900	26 000	33 600	35 800	42 800	40 700	40 600	41 300	32 200	35 500
Fossil Fuel Industries	6 000	5 800	6 000	4 600	6 300	5 800	6 000	6 000	7 500	7 400	7 100	6 800
Mining & Oil and Gas Extraction	492	666	669	648	517	459	470	405	414	411	448	583
Manufacturing Industries	22 700	21 100	21 500	21 900	20 900	21 200	20 800	19 500	20 500	20 600	21 600	19 600
Construction	574	374	445	493	452	477	439	392	523	550	548	545
Commercial & Institutional	9 180	9 860	10 900	11 400	10 300	11 500	13 200	13 600	12 900	14 100	14 100	14 000
Residential	17 000	19 000	21 000	20 000	17 000	18 000	19 000	18 000	19 000	21 000	19 000	20 000
Agriculture & Forestry	781	1 150	1 130	1 060	937	959	903	761	834	987	968	918
b. Transportation ¹	48 000	52 000	54 000	56 000	57 000	60 000	61 000	59 000	61 000	61 000	63 000	65 000
Domestic Aviation	1 600	1 300	1 400	1 600	1 700	1 700	1 600	1 300	1 200	1 500	1 800	1 700
Road Transportation	36 600	39 000	38 800	40 400	41 400	43 100	43 800	44 900	45 400	46 600	47 700	48 600
Light Duty Gasoline Vehicles	19 400	18 300	17 800	17 800	17 000	17 500	17 400	17 600	17 500	17 300	17 100	16 800
Light Duty Gasoline Trucks	7 970	10 400	10 700	11 800	12 800	13 700	14 200	14 900	15 400	16 000	16 500	17 300
Heavy Duty Gasoline Vehicles	1 620	1 080	999	1 020	1 100	1 110	1 100	1 130	1 140	1 190	1 320	1 300
Motorcycles	44.4	30.4	27.9	28.9	36.3	34.8	40.8	49.1	54.2	61.1	66.6	68.1
Light Duty Diesel Vehicles	114	102	98.1	98.6	103	112	120	126	132	136	146	147
Light Duty Diesel Trucks	152	281	301	329	372	381	384	400	412	428	452	494
Heavy Duty Diesel Vehicles	6 760	8 000	8 030	8 670	9 380	9 740	10 200	10 200	10 400	11 100	11 700	12 100
Propane & Natural Gas Vehicles	540	790	830	700	620	610	380	410	260	290	330	350
Railways	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	1 000	1 000	2 000
Domestic Marine	940	660	710	820	820	690	640	680	660	580	640	590
Others	7 000	10 000	10 000	10 000	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	3 000	3 000	3 000
Off Road Diesel	3 000	4 000	4 000	5 000	4 000	5 000	6 000	5 000	6 000	5 000	6 000	6 000
Pipelines	2 270	4 050	4 360	4 240	4 060	4 110	3 630	2 520	3 080	2 510	2 090	3 060
c. Fugitive Sources ²	1 340	1 480	1 510	1 540	1 570	1 640	1 700	1 810	1 800	1 800	1 830	1 830
Coal Mining	—	—	—	—	—	—	—	—	X	X	X	X
Oil and Natural Gas	1 340	1 480	1 510	1 540	1 570	1 640	1 700	1 810	X	X	X	X
INDUSTRIAL PROCESSES³	25 900	27 400	28 200	26 400	22 200	19 300	18 600	17 100	18 200	17 600	21 300	18 900
a. Mineral Products	3 400	3 900	3 800	3 900	4 000	4 100	4 200	4 000	4 000	4 100	4 400	4 400
Cement Production	2 300	2 800	2 800	3 000	3 000	3 100	3 300	3 300	3 200	3 300	3 600	3 600
Lime Production	1 100	1 100	1 100	980	960	1 000	900	750	780	760	820	800
b. Chemical Industry	11 000	11 000	12 000	10 000	5 200	1 800	990	890	1 300	1 200	3 200	2 700
Nitric Acid Production	99.4	92.0	99.5	98.5	88.6	86.1	88.8	85.3	95.6	90.1	101	84.8
Adipic Acid Production	11 000	11 000	11 000	9 900	5 100	1 700	900	800	1 300	1 100	3 100	2 600
c. Metal Production	7 780	8 600	8 480	8 430	8 930	9 250	9 400	8 330	8 480	8 280	9 340	8 180
Iron and Steel Production	7 060	7 860	7 730	7 540	7 670	7 880	7 880	7 270	7 110	7 040	8 130	7 000
Aluminum Production	—	—	—	—	—	—	—	—	—	—	—	—
SF ₆ Used in Magnesium Smelters and Casters	720	734	748	891	1 260	1 370	1 520	1 060	1 370	1 240	1 210	1 180
d. Consumption of Halocarbons and SF ₆	—	—	—	—	—	—	—	—	—	—	—	—
e. Other & Undifferentiated Production ⁴	4 000	4 100	4 300	4 100	4 100	4 100	4 000	3 800	4 400	4 100	4 400	3 600
SOLVENT & OTHER PRODUCT USE	65	78	79	85	78	82	92	81	64	86	82	69
AGRICULTURE	10 000	10 000	10 000	9 800	9 900	9 900	9 600	9 500	9 700	10 000	10 000	10 000
a. Enteric Fermentation	3 700	3 600	3 700	3 700	3 600	3 500	3 400	3 500	3 500	3 600	3 700	3 600
b. Manure Management	1 600	1 600	1 600	1 600	1 600	1 600	1 600	1 600	1 600	1 700	1 700	1 700
c. Agriculture Soils	5 000	4 800	4 700	4 600	4 700	4 800	4 500	4 400	4 600	4 800	4 800	4 600
Direct Sources	3 200	3 100	3 000	2 900	3 100	3 100	2 900	2 800	2 900	3 100	3 100	2 900
Pasture, Range and Paddock Manure	590	580	590	580	560	540	530	540	540	570	590	580
Indirect Sources	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000
WASTE	5 400	6 300	6 000	6 100	6 200	6 300	6 200	6 200	6 400	6 600	6 900	7 100
a. Solid Waste Disposal on Land	5 100	6 000	5 600	5 800	5 800	5 900	5 900	5 900	6 100	6 300	6 500	6 800
b. Wastewater Handling	230	250	250	260	260	260	270	290	290	290	300	300
c. Waste Incineration	130	99	99	67	69	69	73	76	45	48	52	55

Notes:

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

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 & SF₆ 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.

Totals may not add up due to rounding.

Table A11-13: 2005 GHG Emissions Summary for Ontario

Greenhouse Gas Categories				Greenhouse Gases						
	CO ₂	CH ₄	CH ₄	N ₂ O	N ₂ O	HFCs	PFCs	SF ₆	TOTAL	
Global Warming Potential			21		310					
Unit	kt	kt	kt CO ₂ eq	kt	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	
TOTAL	174 000	660	14 000	38	12 000	—	—	1 200	201 000	
ENERGY	159 000	120	2 600	10	3 000	—	—	—	165 000	
a. Stationary Combustion Sources	96 500	30	600	2	700	—	—	—	97 700	
Electricity and Heat Generation	35 300	1.8	39	0.6	200	—	—	—	35 500	
Fossil Fuel Industries	6 830	0.09	2	0.04	10	—	—	—	6 800	
Mining & Oil and Gas Extraction	576	0.01	0.2	0.02	7	—	—	—	583	
Manufacturing Industries	19 400	0.8	20	0.5	200	—	—	—	19 600	
Construction	541	0.01	0.2	0.01	4	—	—	—	545	
Commercial & Institutional	13 900	0.3	5	0.3	90	—	—	—	14 000	
Residential	19 000	20	500	0.6	200	—	—	—	20 000	
Agriculture & Forestry	910	0.02	0.3	0.02	8	—	—	—	918	
b. Transportation ¹	62 600	10	200	8	2 000	—	—	—	65 000	
Domestic Aviation	1 690	0.09	2	0.2	50	—	—	—	1 700	
Road Transportation	47 100	3.3	69	4.5	1 400	—	—	—	48 600	
Light Duty Gasoline Vehicles	16 200	1.2	24	1.8	550	—	—	—	16 800	
Light Duty Gasoline Trucks	16 600	1.0	22	2.2	680	—	—	—	17 300	
Heavy Duty Gasoline Vehicles	1 270	0.06	1.3	0.09	29	—	—	—	1 300	
Motorcycles	66.8	0.05	0.98	0.00	0.41	—	—	—	68.1	
Light Duty Diesel Vehicles	144	0.00	0.06	0.01	4	—	—	—	147	
Light Duty Diesel Trucks	482	0.01	0.3	0.04	10	—	—	—	494	
Heavy Duty Diesel Vehicles	12 000	0.5	10	0.4	100	—	—	—	12 100	
Propane & Natural Gas Vehicles	336	0.5	10	0.01	2	—	—	—	350	
Railways	1 400	0.08	2	0.6	200	—	—	—	2 000	
Domestic Marine	561	0.04	0.9	0.09	30	—	—	—	590	
Others	12 000	7	100	2	700	—	—	—	10 000	
Off Road Gasoline	3 000	4	80	0.07	20	—	—	—	3 000	
Off Road Diesel	5 600	0.3	6	2	700	—	—	—	6 000	
Pipelines	2 970	3.0	62	0.08	20	—	—	—	3 060	
c. Fugitive Sources ²	0.79	87	1 800	—	—	—	—	—	1 830	
INDUSTRIAL PROCESSES ³	15 000	—	—	8.82	2 730	—	—	1 200	18 900	
a. Mineral Products	4 400	—	—	—	—	—	—	—	4 400	
Cement Production	3 600	—	—	—	—	—	—	—	3 600	
Lime Production	800	—	—	—	—	—	—	—	800	
b. Chemical Industry	—	—	—	8.82	2 730	—	—	—	2 700	
Nitric Acid Production	—	—	—	0.27	84.8	—	—	—	84.8	
Adipic Acid Production	—	—	—	8.5	2 600	—	—	—	2 600	
c. Metal Production	7 000	—	—	—	—	—	—	1 180	8 180	
Iron and Steel Production	7 000	—	—	—	—	—	—	—	7 000	
Aluminum Production	—	—	—	—	—	—	—	—	0	
SF ₆ Used in Magnesium Smelters and Casters	—	—	—	—	—	—	—	1 180	1 180	
d. Consumption of Halocarbons and SF ₆	—	—	—	—	—	—	—	—	0	
e. Other & Undifferentiated Production ⁴	3 600	—	—	—	—	—	—	—	3 600	
SOLVENT & OTHER PRODUCT USE	—	—	—	0.22	69	—	—	—	69	
AGRICULTURE	—	210	4 400	18	5 500	—	—	—	10 000	
a. Enteric Fermentation	—	170	3 600	—	—	—	—	—	3 600	
b. Manure Management	—	37	790	2.9	910	—	—	—	1 700	
c. Agriculture Soils	—	—	—	15	4 600	—	—	—	4 600	
Direct Sources	—	—	—	9.4	2 900	—	—	—	2 900	
Pasture, Range and Paddock Manure	—	—	—	1.9	580	—	—	—	580	
Indirect Sources	—	—	—	4	1 000	—	—	—	1 000	
WASTE	46	320	6 800	0.9	300	—	—	—	7 100	
a. Solid Waste Disposal on Land	—	320	6 800	—	—	—	—	—	6 800	
b. Wastewater Handling	—	1.5	32	0.9	300	—	—	—	300	
c. Waste Incineration	46	—	—	0.03	9	—	—	—	55	

Notes:

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

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 & SF₆ are only reported at the national level.

4 Emissions coming from ammonia production are included in the category Other & Undifferentiated Production at provincial levels.

Totals may not add up due to rounding.

Table A11-14: 1990–2005 GHG Emissions Summary for Manitoba

Greenhouse Gas Categories	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
						kt CO ₂ eq						
TOTAL	18 000	19 000	19 800	19 400	19 700	19 600	20 200	19 000	19 500	20 100	20 400	20 300
ENERGY	12 400	12 700	13 100	12 500	12 600	12 500	13 100	11 900	12 300	12 500	12 500	12 800
a. Stationary Combustion Sources	4 840	4 210	4 620	4 300	4 840	4 600	5 350	4 570	4 890	4 960	4 690	4 700
Electricity and Heat Generation	570	218	341	244	962	546	993	X	X	X	X	X
Fossil Fuel Industries	0.14	0.04	0.02	0.01	0.02	0.03	0.03	0.03	0.33	0.01	0.01	0.01
Mining & Oil and Gas Extraction	73.6	12.6	10.9	12.5	39.3	27.4	29.5	X	X	X	X	X
Manufacturing Industries	1 050	822	838	807	910	1 080	1 140	1 060	1 210	1 080	1 210	1 360
Construction	63.6	33.8	32.3	44.9	84.6	76.1	62.3	61.4	68.6	78.9	82.7	85.7
Commercial & Institutional	1 410	1 590	1 670	1 650	1 490	1 470	1 680	1 590	1 710	1 590	1 590	1 460
Residential	1 600	1 500	1 600	1 400	1 300	1 300	1 400	1 200	1 300	1 300	1 300	1 100
Agriculture & Forestry	42.9	77.1	111	98.7	72.0	86.8	63.0	X	X	X	X	X
b. Transportation ¹	7 200	8 000	7 900	7 700	7 200	7 400	7 200	6 800	6 800	7 000	7 200	7 500
Domestic Aviation	330	370	380	390	330	360	360	350	360	400	340	350
Road Transportation	4 030	4 450	4 400	4 500	4 570	4 660	4 520	4 560	4 650	4 710	4 930	4 780
Light Duty Gasoline Vehicles	1 680	1 610	1 450	1 420	1 370	1 380	1 330	1 290	1 300	1 280	1 270	1 140
Light Duty Gasoline Trucks	884	1 180	1 210	1 320	1 420	1 510	1 510	1 510	1 580	1 630	1 720	1 650
Heavy Duty Gasoline Vehicles	452	234	291	250	240	213	224	256	246	247	260	240
Motorcycles	7.01	6.19	5.41	5.02	4.83	3.95	4.33	4.94	7.52	8.14	8.69	8.16
Light Duty Diesel Vehicles	11.0	9.40	9.08	8.73	8.40	8.37	8.01	7.97	8.28	8.43	9.09	8.28
Light Duty Diesel Trucks	41.1	72.9	71.7	76.6	82.1	84.0	90.9	92.6	97.3	101	108	109
Heavy Duty Diesel Vehicles	889	1 240	1 280	1 300	1 340	1 350	1 320	1 360	1 390	1 410	1 540	1 600
Propane & Natural Gas Vehicles	61	97	83	120	110	110	36	31	20	22	21	14
Railways	600	600	500	400	400	300	300	200	90	200	300	300
Domestic Marine	0.03	—	—	0.05	—	—	—	—	—	0.29	0.11	0.12
Others	2 000	3 000	3 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000
Off Road Gasoline	400	500	500	400	400	400	400	400	400	400	400	400
Off Road Diesel	1 000	800	800	700	600	600	700	700	700	800	900	1 000
Pipelines	847	1 300	1 300	1 200	959	1 060	828	543	658	450	432	600
c. Fugitive Sources ²	421	476	506	526	536	536	563	568	584	593	593	611
Coal Mining	—	—	—	—	—	—	—	—	X	X	X	X
Oil and Natural Gas	421	476	506	526	536	536	563	568	X	X	X	X
INDUSTRIAL PROCESSES³	437	302	305	316	311	455	486	465	364	390	391	459
a. Mineral Products	200	69	67	70	70	64	69	61	63	57	62	59
Cement Production	140	—	—	—	—	—	—	—	—	—	—	—
Lime Production	58	69	67	70	70	64	69	61	63	57	62	59
b. Chemical Industry	20	29	28	30	31	33	44	48	43	42	50	48
Nitric Acid Production	20.1	29.1	27.9	30.4	30.6	33.4	44.2	48.1	43.4	41.6	50.4	47.8
Adipic Acid Production	—	—	—	—	—	—	—	—	—	—	—	—
c. Metal Production	—	—	—	—	—	—	—	—	—	—	—	—
Iron and Steel Production	—	—	—	—	—	—	—	—	—	—	—	—
Aluminum Production	—	—	—	—	—	—	—	—	—	—	—	—
SF ₆ Used in Magnesium Smelters and Casters	—	—	—	—	—	—	—	—	—	—	—	—
d. Consumption of Halocarbons and SF ₆	—	—	—	—	—	—	—	—	—	—	—	—
e. Other & Undifferentiated Production ⁴	210	200	210	220	210	360	370	360	260	290	280	350
SOLVENT & OTHER PRODUCT USE	7.0	8.0	8.1	8.6	7.8	8.1	9.0	7.9	6.1	8.1	7.7	6.5
AGRICULTURE	4 400	5 200	5 600	5 700	5 800	5 700	5 700	5 600	5 800	6 200	6 400	6 000
a. Enteric Fermentation	1 500	1 800	2 000	2 100	2 000	2 000	2 000	2 000	2 100	2 200	2 400	2 500
b. Manure Management	560	680	720	750	760	750	770	810	860	880	940	950
c. Agriculture Soils	2 400	2 700	2 900	2 900	3 000	2 900	3 000	2 800	2 900	3 100	3 000	2 600
Direct Sources	1 400	1 500	1 700	1 600	1 700	1 700	1 700	1 600	1 600	1 700	1 600	1 300
Pasture, Range and Paddock Manure	270	340	360	380	370	360	360	370	380	400	450	460
Indirect Sources	700	800	900	900	900	900	900	900	900	1 000	900	800
WASTE	690	820	840	860	880	910	930	950	970	980	1 000	1 000
a. Solid Waste Disposal on Land	660	790	810	830	850	870	900	910	930	950	970	990
b. Wastewater Handling	33	33	32	33	33	34	34	35	34	34	35	35
c. Waste Incineration	—	—	—	—	—	—	—	—	—	—	—	—

Notes:

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

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 & SF₆ 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.

Totals may not add up due to rounding.

Table A11-15: 2005 GHG Emissions Summary for Manitoba

Greenhouse Gas Categories		Greenhouse Gases								TOTAL
Global Warming Potential		CO ₂	CH ₄	CH ₄	N ₂ O	N ₂ O	HFCs	PFCs	SF ₆	
Unit		kt	kt	21 kt CO ₂ eq	kt	310 kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	
TOTAL		12 200	220	4 600	11	3 600	—	—	—	20 300
ENERGY		11 800	32	670	1	300	—	—	—	12 800
a. Stationary Combustion Sources		4 600	3	60	0.1	40	—	—	—	4 700
Electricity and Heat Generation		X	X	X	X	X	—	—	—	X
Fossil Fuel Industries		—	—	—	0.00	0.01	—	—	—	0.01
Mining & Oil and Gas Extraction		X	X	X	X	X	—	—	—	X
Manufacturing Industries		1 350	0.05	1	0.03	10	—	—	—	1 360
Construction		85.2	0.00	0.03	0.00	0.5	—	—	—	85.7
Commercial & Institutional		1 450	0.03	0.6	0.03	9	—	—	—	1 460
Residential		1 050	3	50	0.05	20	—	—	—	1 100
Agriculture & Forestry		X	X	X	X	X	—	—	—	X
b. Transportation¹		7 170	1	30	0.9	300	—	—	—	7 500
Domestic Aviation		344	0.03	0.7	0.03	10	—	—	—	350
Road Transportation		4 660	0.36	7.5	0.35	110	—	—	—	4 780
Light Duty Gasoline Vehicles		1 110	0.10	2.2	0.10	32	—	—	—	1 140
Light Duty Gasoline Trucks		1 590	0.14	3.0	0.18	55	—	—	—	1 650
Heavy Duty Gasoline Vehicles		235	0.02	0.32	0.02	4.7	—	—	—	240
Motorcycles		8.01	0.01	0.10	0.00	0.05	—	—	—	8.16
Light Duty Diesel Vehicles		8.08	0.00	0.00	0.00	0.2	—	—	—	8.28
Light Duty Diesel Trucks		106	0.00	0.06	0.01	3	—	—	—	109
Heavy Duty Diesel Vehicles		1 590	0.07	2	0.05	10	—	—	—	1 600
Propane & Natural Gas Vehicles		13.3	0.01	0.3	0.00	0.08	—	—	—	14
Railways		236	0.01	0.3	0.1	30	—	—	—	300
Domestic Marine		0.12	0.00	0.00	0.00	0.00	—	—	—	0.12
Others		1 900	1	20	0.4	100	—	—	—	2 000
Off Road Gasoline		400	0.4	9	0.01	2	—	—	—	400
Off Road Diesel		980	0.05	1	0.4	100	—	—	—	1 000
Pipelines		583	0.59	12	0.02	5	—	—	—	600
c. Fugitive Sources²		32	28	580	—	—	—	—	—	611
INDUSTRIAL PROCESSES³		410	—	—	0.15	47.8	—	—	—	459
a. Mineral Products		59	—	—	—	—	—	—	—	59
Cement Production		—	—	—	—	—	—	—	—	0
Lime Production		59	—	—	—	—	—	—	—	59
b. Chemical Industry		—	—	—	0.15	47.8	—	—	—	48
Nitric Acid Production		—	—	—	0.15	47.8	—	—	—	47.8
Adipic Acid Production		—	—	—	—	—	—	—	—	0
c. Metal Production		—	—	—	—	—	—	—	—	0
Iron and Steel Production		—	—	—	—	—	—	—	—	0
Aluminum Production		—	—	—	—	—	—	—	—	0
SF ₆ Used in Magnesium Smelters and Casters		—	—	—	—	—	—	—	—	0
d. Consumption of Halocarbons and SF₆		—	—	—	—	—	—	—	—	0
e. Other & Undifferentiated Production⁴		350	—	—	—	—	—	—	—	350
SOLVENT & OTHER PRODUCT USE		—	—	—	0.02	6.5	—	—	—	6.5
AGRICULTURE		—	140	2 900	10	3 200	—	—	—	6 000
a. Enteric Fermentation		—	120	2 500	—	—	—	—	—	2 500
b. Manure Management		—	20	410	1.7	530	—	—	—	950
c. Agriculture Soils		—	—	—	8.4	2 600	—	—	—	2 600
Direct Sources		—	—	—	4.3	1 300	—	—	—	1 300
Pasture, Range and Paddock Manure		—	—	—	1.5	460	—	—	—	460
Indirect Sources		—	—	—	3	800	—	—	—	800
WASTE		—	47	1 000	0.08	20	—	—	—	1 000
a. Solid Waste Disposal on Land		—	47	990	—	—	—	—	—	990
b. Wastewater Handling		—	0.46	9.6	0.08	20	—	—	—	35
c. Waste Incineration		—	—	—	—	—	—	—	—	0

Notes:

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

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 & SF₆ 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.

Totals may not add up due to rounding.

Table A11-16: 1990–2005 GHG Emissions Summary for Saskatchewan

Greenhouse Gas Categories	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
					kt CO ₂ eq							
TOTAL	44 100	58 700	61 000	63 400	63 800	64 100	65 600	65 100	66 100	68 300	70 800	70 900
ENERGY	35 700	47 900	49 500	51 700	52 300	52 800	54 000	53 700	55 200	56 200	57 600	57 400
a. Stationary Combustion Sources	20 200	25 500	25 800	26 100	27 100	27 300	27 000	27 500	28 300	28 700	29 700	28 500
Electricity and Heat Generation	10 400	13 900	14 000	14 900	15 100	14 900	14 700	X	X	X	X	X
Fossil Fuel Industries	4 500	4 900	4 500	4 600	5 500	5 800	5 300	5 700	6 100	5 500	6 300	6 200
Mining & Oil and Gas Extraction	965	1 690	1 330	1 900	1 770	1 660	2 000	X	X	X	X	X
Manufacturing Industries	854	1 290	1 570	1 060	1 180	967	933	791	712	694	650	496
Construction	70.6	73.3	87.0	56.3	65.7	87.2	49.8	40.7	39.0	37.7	42.6	42.0
Commercial & Institutional	1 020	1 210	1 420	1 200	1 250	1 590	1 710	1 590	2 030	1 970	1 810	1 750
Residential	2 100	2 100	2 500	2 100	1 900	2 000	2 000	2 000	2 000	1 800	1 800	1 700
Agriculture & Forestry	302	328	387	349	292	339	281	X	X	X	X	X
b. Transportation¹	9 400	11 000	12 000	12 000	11 000	11 000	11 000	9 900	10 000	10 000	10 000	12 000
Domestic Aviation	210	170	170	150	170	140	110	120	130	120	110	140
Road Transportation	4 210	5 070	5 280	5 750	5 530	5 680	5 680	5 080	5 650	5 910	6 110	6 200
Light Duty Gasoline Vehicles	1 190	1 430	1 440	1 480	1 320	1 370	1 300	1 030	1 230	1 260	1 220	1 170
Light Duty Gasoline Trucks	853	1 390	1 580	1 700	1 670	1 800	1 760	1 410	1 750	1 890	1 950	1 960
Heavy Duty Gasoline Vehicles	745	486	438	445	400	357	355	309	370	385	398	381
Motorcycles	2.02	2.81	2.65	5.50	5.27	5.77	5.73	4.96	6.22	7.02	7.33	7.67
Light Duty Diesel Vehicles	6.90	6.84	8.30	8.16	7.41	7.88	7.68	6.44	8.28	8.76	9.23	9.00
Light Duty Diesel Trucks	52.7	138	141	167	172	178	197	166	215	233	243	262
Heavy Duty Diesel Vehicles	1 300	1 560	1 630	1 890	1 900	1 920	2 030	2 130	2 040	2 110	2 270	2 410
Propane & Natural Gas Vehicles	65	50	44	60	59	49	27	31	19	14	17	11
Railways	600	500	600	600	500	400	400	300	300	200	200	400
Domestic Marine	0.10	0.01	0.01	—	—	—	0.03	0.04	0.01	0.01	0.01	0.01
Others	4 000	6 000	6 000	5 000	5 000	5 000	5 000	4 000	4 000	4 000	4 000	5 000
Off Road Gasoline	1 000	900	800	500	700	600	700	1 000	800	800	700	800
Off Road Diesel	2 000	2 000	2 000	2 000	2 000	2 000	2 000	1 000	2 000	2 000	2 000	2 000
Pipelines	1 640	2 600	2 570	2 500	2 660	2 790	2 410	1 720	2 000	1 590	1 450	1 950
c. Fugitive Sources²	6 060	11 000	12 000	13 800	13 900	14 000	15 800	16 300	16 500	17 100	17 500	17 200
Coal Mining	10	10	10	10	10	10	10	10	X	X	X	X
Oil and Natural Gas	6 050	11 000	12 000	13 800	13 900	14 000	15 800	16 300	X	X	X	X
INDUSTRIAL PROCESSES³	285	720	778	985	1 030	940	1 050	1 080	923	1 040	1 160	1 110
a. Mineral Products	83	—	—	—	—	—	—	—	—	—	—	—
Cement Production	83	—	—	—	—	—	—	—	—	—	—	—
Lime Production	—	—	—	—	—	—	—	—	—	—	—	—
b. Chemical Industry	—	—	—	—	—	—	—	—	—	—	28	13
Nitric Acid Production	—	—	—	—	—	—	—	—	—	—	27.7	12.7
Adipic Acid Production	—	—	—	—	—	—	—	—	—	—	—	—
c. Metal Production	—	—	—	—	—	—	—	—	—	—	—	—
Iron and Steel Production	—	—	—	—	—	—	—	—	—	—	—	—
Aluminum Production	—	—	—	—	—	—	—	—	—	—	—	—
SF ₆ Used in Magnesium Smelters and Casters	—	—	—	—	—	—	—	—	—	—	—	—
d. Consumption of Halocarbons and SF₆	—	—	—	—	—	—	—	—	—	—	—	—
e. Other & Undifferentiated Production⁴	200	720	780	990	1 000	940	1 100	1 100	920	1 000	1 100	1 100
SOLVENT & OTHER PRODUCT USE	6.4	7.2	7.3	7.7	7.0	7.2	7.9	6.8	5.3	6.9	6.6	5.5
AGRICULTURE	7 300	9 100	9 800	9 800	9 500	9 400	9 500	9 300	9 000	10 000	11 000	11 000
a. Enteric Fermentation	2 900	3 800	3 900	3 900	3 800	3 700	3 700	3 900	4 000	4 300	4 700	4 900
b. Manure Management	810	1 000	1 000	1 000	1 000	990	1 000	1 100	1 100	1 200	1 300	1 300
c. Agriculture Soils	3 600	4 300	4 800	4 900	4 700	4 700	4 800	4 300	3 900	4 600	4 900	5 100
Direct Sources	2 000	2 400	2 800	2 800	2 700	2 700	2 700	2 300	2 000	2 400	2 600	2 700
Pasture, Range and Paddock Manure	560	720	750	740	720	700	710	740	760	820	910	940
Indirect Sources	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000
WASTE	800	910	930	950	970	980	1 000	1 000	1 000	1 000	1 100	1 100
a. Solid Waste Disposal on Land	760	870	890	910	930	940	960	970	990	1 000	1 000	1 000
b. Wastewater Handling	39	38	38	39	39	36	39	40	40	39	40	39
c. Waste Incineration	0.52	0.04	0.02	—	—	—	—	—	—	—	—	—

Notes:

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

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 & SF₆ 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.

Totals may not add up due to rounding.

Table A11-17: 2005 GHG Emissions Summary for Saskatchewan

Greenhouse Gas Categories		Greenhouse Gases								
		CO ₂	CH ₄	CH ₄	N ₂ O	N ₂ O	HFCs	PFCs	SF ₆	TOTAL
		Global Warming Potential	21	310						
Unit		kt	kt	kt CO ₂ eq	kt	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq
TOTAL		41 800	1 100	22 000	22	6 800	—	—	—	70 900
ENERGY		40 800	760	16 000	2	700	—	—	—	57 400
a. Stationary Combustion Sources		28 000	20	300	0.7	200	—	—	—	28 500
Electricity and Heat Generation		X	X	X	X	X	—	—	—	X
Fossil Fuel Industries		5 880	10	300	0.1	50	—	—	—	6 200
Mining & Oil and Gas Extraction		X	X	X	X	X	—	—	—	X
Manufacturing Industries		484	0.07	1	0.03	10	—	—	—	496
Construction		41.7	0.00	0.02	0.00	0.3	—	—	—	42.0
Commercial & Institutional		1 730	0.03	0.7	0.03	10	—	—	—	1 750
Residential		1 610	1	30	0.04	10	—	—	—	1 700
Agriculture & Forestry		X	X	X	X	X	—	—	—	X
b. Transportation ¹		11 200	3	70	1	400	—	—	—	12 000
Domestic Aviation		134	0.02	0.3	0.01	4	—	—	—	140
Road Transportation		6 060	0.48	10	0.42	130	—	—	—	6 200
Light Duty Gasoline Vehicles		1 130	0.12	2.6	0.10	32	—	—	—	1 170
Light Duty Gasoline Trucks		1 890	0.19	4.0	0.20	62	—	—	—	1 960
Heavy Duty Gasoline Vehicles		373	0.03	0.63	0.02	7.1	—	—	—	381
Motorcycles		7.53	0.00	0.10	0.00	0.05	—	—	—	7.67
Light Duty Diesel Vehicles		8.79	0.00	0.00	0.00	0.2	—	—	—	9.00
Light Duty Diesel Trucks		256	0.01	0.1	0.02	6	—	—	—	262
Heavy Duty Diesel Vehicles		2 380	0.1	2	0.07	20	—	—	—	2 410
Propane & Natural Gas Vehicles		10.3	0.01	0.3	0.00	0.07	—	—	—	11
Railways		373	0.02	0.4	0.2	50	—	—	—	400
Domestic Marine		0.01	0.00	0.00	0.00	0.00	—	—	—	0.01
Others		4 600	3	60	0.9	300	—	—	—	5 000
Off Road Gasoline		700	0.8	20	0.02	5	—	—	—	800
Off Road Diesel		2 000	0.1	2	0.8	200	—	—	—	2 000
Pipelines		1 900	1.9	40	0.05	20	—	—	—	1 950
c. Fugitive Sources ²		1 600	740	16 000	0.01	5	—	—	—	17 200
INDUSTRIAL PROCESSES ³		1 100	—	—	0.04	12.7	—	—	—	1 110
a. Mineral Products		—	—	—	—	—	—	—	—	0
Cement Production		—	—	—	—	—	—	—	—	0
Lime Production		—	—	—	—	—	—	—	—	0
b. Chemical Industry		—	—	—	0.04	12.7	—	—	—	13
Nitric Acid Production		—	—	—	0.04	12.7	—	—	—	12.7
Adipic Acid Production		—	—	—	—	—	—	—	—	0
c. Metal Production		—	—	—	—	—	—	—	—	0
Iron and Steel Production		—	—	—	—	—	—	—	—	0
Aluminum Production		—	—	—	—	—	—	—	—	0
SF ₆ Used in Magnesium Smelters and Casters		—	—	—	—	—	—	—	—	0
d. Consumption of Halocarbons and SF ₆		—	—	—	—	—	—	—	—	0
e. Other & Undifferentiated Production ⁴		1 100	—	—	—	—	—	—	—	1 100
SOLVENT & OTHER PRODUCT USE		—	—	—	0.02	5.5	—	—	—	5.5
AGRICULTURE		—	250	5 300	20	6 100	—	—	—	11 000
a. Enteric Fermentation		—	240	4 900	—	—	—	—	—	4 900
b. Manure Management		—	17	350	3.2	980	—	—	—	1 300
c. Agriculture Soils		—	—	—	16	5 100	—	—	—	5 100
Direct Sources		—	—	—	8.6	2 700	—	—	—	2 700
Pasture, Range and Paddock Manure		—	—	—	3.0	940	—	—	—	940
Indirect Sources		—	—	—	5	1 000	—	—	—	1 000
WASTE		—	50	1 100	0.07	20	—	—	—	1 100
a. Solid Waste Disposal on Land		—	49	1 000	—	—	—	—	—	1 000
b. Wastewater Handling		—	0.88	18	0.07	20	—	—	—	39
c. Waste Incineration		—	—	—	—	—	—	—	—	0

Notes:

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

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 & SF₆ 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.

Totals may not add up due to rounding.

Table A11-18: 1990–2005 GHG Emissions Summary for Alberta

Greenhouse Gas Categories	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
						kt CO ₂ eq						
TOTAL	170 000	198 000	203 000	206 000	208 000	215 000	224 000	225 000	224 000	232 000	231 000	233 000
ENERGY	148 000	172 000	176 000	178 000	180 000	186 000	195 000	196 000	196 000	203 000	199 000	200 000
a. Stationary Combustion Sources	95 900	110 000	110 000	110 000	111 000	118 000	126 000	125 000	128 000	134 000	129 000	129 000
Electricity and Heat Generation	40 200	49 200	48 400	51 200	51 400	50 100	52 100	53 500	53 000	54 600	53 300	53 300
Fossil Fuel Industries	32 000	34 000	33 000	31 000	34 000	43 000	44 000	45 000	46 000	45 000	43 000	44 000
Mining & Oil and Gas Extraction	2 400	3 340	4 280	3 930	3 430	3 460	5 500	5 900	7 530	11 000	10 400	11 000
Manufacturing Industries	9 410	9 940	9 940	10 500	9 580	9 670	9 610	7 900	7 760	7 820	7 860	7 260
Construction	236	189	216	211	136	167	172	168	171	159	158	166
Commercial & Institutional	4 950	5 520	4 970	5 020	4 800	4 590	5 290	4 760	5 720	6 070	6 100	5 460
Residential	6 600	7 600	8 700	7 700	7 600	7 500	8 300	7 200	8 000	8 200	8 100	7 400
Agriculture & Forestry	470	335	410	380	341	348	361	286	301	270	266	247
b. Transportation ¹	23 000	25 000	26 000	29 000	29 000	29 000	30 000	32 000	31 000	32 000	33 000	34 000
Domestic Aviation	1 100	1 000	1 100	1 200	1 200	1 200	1 300	1 400	1 300	1 300	1 400	1 500
Road Transportation	14 100	15 700	14 900	16 200	16 900	16 800	17 200	18 300	18 200	18 500	19 400	20 100
Light Duty Gasoline Vehicles	4 590	4 140	3 980	4 030	4 000	3 980	3 900	3 960	3 920	3 780	3 730	3 670
Light Duty Gasoline Trucks	3 360	4 270	4 310	4 900	5 290	5 640	5 760	5 950	6 210	6 320	6 610	6 870
Heavy Duty Gasoline Vehicles	1 880	1 490	1 290	1 330	1 380	1 190	1 240	1 740	1 640	1 610	1 680	1 690
Motorcycles	23.5	21.4	20.8	22.1	24.0	25.3	27.5	29.9	32.6	34.6	36.7	37.6
Light Duty Diesel Vehicles	23.5	18.2	17.7	18.6	18.4	18.8	17.9	20.0	21.8	21.8	23.4	23.4
Light Duty Diesel Trucks	169	346	310	356	397	399	469	522	574	587	621	689
Heavy Duty Diesel Vehicles	3 420	4 900	4 380	5 090	5 340	5 250	5 480	5 770	5 640	6 000	6 530	7 020
Propane & Natural Gas Vehicles	630	520	550	480	440	340	270	270	220	190	190	120
Railways	2 000	1 000	1 000	1 000	1 000	1 000	2 000	2 000	2 000	2 000	2 000	3 000
Domestic Marine	0.32	0.63	0.18	0.00	—	—	0.00	0.02	0.02	0.01	0.01	—
Others	6 000	7 000	9 000	10 000	10 000	10 000	10 000	10 000	9 000	9 000	10 000	10 000
Off Road Gasoline	1 000	1 000	2 000	1 000	1 000	1 000	1 000	1 000	1 000	900	900	800
Off Road Diesel	3 000	3 000	5 000	5 000	5 000	5 000	6 000	6 000	5 000	5 000	6 000	6 000
Pipelines	1 270	2 670	2 770	3 160	3 250	3 210	2 670	3 420	3 470	3 090	3 110	3 140
c. Fugitive Sources ²	29 100	37 300	39 400	39 300	39 600	38 400	39 100	38 800	36 900	37 500	37 500	37 100
Coal Mining	200	300	300	300	300	200	200	200	X	X	X	X
Oil and Natural Gas	28 900	37 000	39 200	39 000	39 300	38 200	38 900	38 600	X	X	X	X
INDUSTRIAL PROCESSES³	7 360	8 680	9 700	10 000	9 540	9 650	9 470	10 100	9 180	10 700	12 200	12 200
a. Mineral Products	850	930	850	1 100	1 100	1 100	1 100	1 100	1 200	1 100	1 100	1 100
Cement Production	740	800	730	950	940	1 000	960	940	1 000	1 000	980	990
Lime Production	100	130	120	130	130	140	150	150	130	120	130	120
b. Chemical Industry	810	780	880	850	850	980	1 100	1 200	1 100	1 100	1 000	1 100
Nitric Acid Production	813	778	878	851	855	981	1 100	1 150	1 120	1 130	1 050	1 120
Adipic Acid Production	—	—	—	—	—	—	—	—	—	—	—	—
c. Metal Production	—	—	—	—	—	—	—	—	—	—	—	—
Iron and Steel Production	—	—	—	—	—	—	—	—	—	—	—	—
Aluminum Production	—	—	—	—	—	—	—	—	—	—	—	—
SF ₆ Used in Magnesium Smelters and Casters	—	—	—	—	—	—	—	—	—	—	—	—
d. Consumption of Halocarbons and SF ₆	—	—	—	—	—	—	—	—	—	—	—	—
e. Other & Undifferentiated Production ⁴	5 700	7 000	8 000	8 100	7 600	7 500	7 300	7 800	6 900	8 400	10 000	10 000
SOLVENT & OTHER PRODUCT USE	16	19	20	21	20	21	24	21	16	22	21	18
AGRICULTURE	13 000	15 000	16 000	16 000	16 000	17 000	17 000	17 000	17 000	16 000	17 000	18 000
a. Enteric Fermentation	6 100	7 500	7 700	7 700	7 900	8 100	8 400	8 700	8 600	8 200	8 600	9 000
b. Manure Management	1 700	2 100	2 100	2 100	2 200	2 300	2 300	2 400	2 400	2 300	2 400	2 500
c. Agriculture Soils	5 200	5 700	6 000	5 900	6 100	6 400	6 500	6 100	5 700	5 900	6 300	6 400
Direct Sources	2 600	2 800	2 900	2 800	2 900	3 100	3 100	2 700	2 400	2 700	2 900	2 900
Pasture, Range and Paddock Manure	1 200	1 400	1 500	1 500	1 600	1 600	1 700	1 700	1 700	1 600	1 700	1 800
Indirect Sources	1 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000
WASTE	1 800	2 000	2 000	2 000	2 100	2 200	2 300	2 300	2 400	2 500	2 600	2 700
a. Solid Waste Disposal on Land	1 800	1 900	1 900	2 000	2 100	2 100	2 200	2 300	2 300	2 400	2 500	2 600
b. Wastewater Handling	73	69	86	71	68	90	71	71	68	67	68	69
c. Waste Incineration	—	—	—	—	—	—	—	—	—	—	—	—

Notes:

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

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 & SF₆ 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.

Totals may not add up due to rounding.

Table A11-19: 2005 GHG Emissions Summary for Alberta

Greenhouse Gas Categories			Greenhouse Gases								
			CO ₂	CH ₄	CH ₄	N ₂ O	N ₂ O	HFCs	PFCs	SF ₆	TOTAL
			Global Warming Potential	21	21	310	310				
	Unit	kt	kt	kt CO ₂ eq	kt	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	
TOTAL		179 000	2 000	42 000	38	12 000	—	—	—	233 000	
ENERGY		168 000	1 400	30 000	8	2 000	—	—	—	200 000	
a.	Stationary Combustion Sources	126 000	90	2 000	3	900	—	—	—	129 000	
	Electricity and Heat Generation	53 000	1.6	34	1	300	—	—	—	53 300	
	Fossil Fuel Industries	42 100	80	2 000	1	300	—	—	—	44 000	
	Mining & Oil and Gas Extraction	10 900	0.2	4	0.3	80	—	—	—	11 000	
	Manufacturing Industries	7 180	0.4	8	0.2	70	—	—	—	7 260	
	Construction	164	0.00	0.06	0.01	2	—	—	—	166	
	Commercial & Institutional	5 420	0.1	2	0.1	40	—	—	—	5 460	
	Residential	7 330	2	40	0.2	50	—	—	—	7 400	
	Agriculture & Forestry	245	0.01	0.1	0.01	2	—	—	—	247	
b.	Transportation ¹	32 600	6	100	5	1 000	—	—	—	34 000	
	Domestic Aviation	1 490	0.08	2	0.1	40	—	—	—	1 500	
	Road Transportation	19 600	1.4	29	1.4	450	—	—	—	20 100	
	Light Duty Gasoline Vehicles	3 560	0.33	7.0	0.33	100	—	—	—	3 670	
	Light Duty Gasoline Trucks	6 630	0.56	12	0.74	230	—	—	—	6 870	
	Heavy Duty Gasoline Vehicles	1 660	0.09	1.9	0.12	36	—	—	—	1 690	
	Motorcycles	36.9	0.02	0.48	0.00	0.22	—	—	—	37.6	
	Light Duty Diesel Vehicles	22.9	0.00	0.01	0.00	0.6	—	—	—	23.4	
	Light Duty Diesel Trucks	673	0.02	0.4	0.05	20	—	—	—	689	
	Heavy Duty Diesel Vehicles	6 950	0.3	7	0.2	60	—	—	—	7 020	
	Propane & Natural Gas Vehicles	115	0.07	1	0.00	0.7	—	—	—	120	
	Railways	2 250	0.1	3	0.9	300	—	—	—	3 000	
	Domestic Marine	—	—	—	—	—	—	—	—	0	
	Others	9 200	4	90	2	700	—	—	—	10 000	
	Off Road Gasoline	800	0.9	20	0.02	5	—	—	—	800	
	Off Road Diesel	5 400	0.3	6	2	700	—	—	—	6 000	
	Pipelines	3 050	3.1	64	0.08	30	—	—	—	3 140	
c.	Fugitive Sources ²	9 300	1 300	28 000	0.01	2	—	—	—	37 100	
INDUSTRIAL PROCESSES ³		11 000	—	—	3.61	1 120	—	—	—	12 200	
a.	Mineral Products	1 100	—	—	—	—	—	—	—	1 100	
	Cement Production	990	—	—	—	—	—	—	—	990	
	Lime Production	120	—	—	—	—	—	—	—	120	
b.	Chemical Industry	—	—	—	3.61	1 120	—	—	—	1 100	
	Nitric Acid Production	—	—	—	3.61	1 120	—	—	—	1 120	
	Adipic Acid Production	—	—	—	—	—	—	—	—	0	
c.	Metal Production	—	—	—	—	—	—	—	—	0	
	Iron and Steel Production	—	—	—	—	—	—	—	—	0	
	Aluminum Production	—	—	—	—	—	—	—	—	0	
	SF ₆ Used in Magnesium Smelters and Casters	—	—	—	—	—	—	—	—	0	
d.	Consumption of Halocarbons and SF ₆	—	—	—	—	—	—	—	—	0	
e.	Other & Undifferentiated Production ⁴	10 000	—	—	—	—	—	—	—	10 000	
SOLVENT & OTHER PRODUCT USE		—	—	—	0.06	18	—	—	—	18	
AGRICULTURE		—	460	9 600	27	8 300	—	—	—	18 000	
a.	Enteric Fermentation	—	430	9 000	—	—	—	—	—	9 000	
b.	Manure Management	—	28	600	6.0	1 900	—	—	—	2 500	
c.	Agriculture Soils	—	—	—	21	6 400	—	—	—	6 400	
	Direct Sources	—	—	—	9.4	2 900	—	—	—	2 900	
	Pasture, Range and Paddock Manure	—	—	—	5.7	1 800	—	—	—	1 800	
	Indirect Sources	—	—	—	6	2 000	—	—	—	2 000	
WASTE		—	120	2 600	0.2	70	—	—	—	2 700	
a.	Solid Waste Disposal on Land	—	120	2 600	—	—	—	—	—	2 600	
b.	Wastewater Handling	—	—	—	0.2	70	—	—	—	69	
c.	Waste Incineration	—	—	—	—	—	—	—	—	0	

Notes:

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

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 & SF₆ are only reported at the national level.

4 Emissions coming from ammonia production are included in the category Other & Undifferentiated Production at provincial levels.

Totals may not add up due to rounding.

Table A11-20: 1990–2005 GHG Emissions Summary for British Columbia

Greenhouse Gas Categories	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
						kt CO ₂ eq						
TOTAL	50 600	59 300	61 100	59 300	60 100	62 100	63 300	62 800	61 400	63 400	67 600	65 900
ENERGY	41 000	48 800	50 100	48 100	49 100	50 900	52 000	52 300	51 000	52 800	56 700	55 200
a. Stationary Combustion Sources	18 900	21 300	21 900	19 100	19 700	21 700	22 500	22 600	21 000	21 500	24 200	23 400
Electricity and Heat Generation	1 170	2 700	768	1 190	1 840	1 300	2 480	3 070	1 180	1 330	1 850	1 810
Fossil Fuel Industries	3 800	4 100	5 100	2 900	3 900	5 500	4 100	3 500	4 400	5 800	7 800	7 500
Mining & Oil and Gas Extraction	253	164	449	344	336	228	317	233	271	157	493	653
Manufacturing Industries	5 980	6 250	6 850	6 420	6 020	6 570	7 190	7 390	6 500	6 590	6 410	5 660
Construction	305	199	207	126	100	85.9	75.6	70.5	73.5	81.4	100	107
Commercial & Institutional	2 820	3 360	3 400	3 290	2 880	2 960	3 390	3 440	4 140	3 440	3 500	3 370
Residential	4 300	4 400	4 900	4 500	4 400	4 700	4 600	4 500	4 300	4 100	4 000	4 200
Agriculture & Forestry	324	155	191	270	252	263	315	358	126	80.9	68.3	61.4
b. Transportation¹	19 000	22 000	23 000	24 000	24 000	24 000	24 000	24 000	24 000	25 000	26 000	26 000
Domestic Aviation	1 100	1 200	1 200	1 300	1 300	1 500	1 400	1 100	1 400	1 300	1 500	1 700
Road Transportation	11 800	13 500	13 700	14 300	15 200	15 000	15 100	14 900	15 000	15 200	16 200	15 800
Light Duty Gasoline Vehicles	3 970	4 560	4 600	4 710	4 720	4 740	4 580	4 460	4 430	4 390	4 570	4 290
Light Duty Gasoline Trucks	2 270	3 490	3 710	4 060	4 460	4 610	4 600	4 670	4 750	4 820	5 150	4 920
Heavy Duty Gasoline Vehicles	2 100	1 880	1 820	1 870	1 970	1 760	1 720	1 610	1 550	1 670	1 770	1 690
Motorcycles	18.1	13.5	12.4	12.8	16.1	14.9	16.9	18.8	20.6	22.6	27.1	28.1
Light Duty Diesel Vehicles	27.0	29.9	31.2	32.9	37.1	38.2	38.4	38.4	40.2	39.9	45.0	46.8
Light Duty Diesel Trucks	36.2	64.8	67.2	67.9	75.9	74.0	66.4	55.6	48.3	55.4	58.5	57.5
Heavy Duty Diesel Vehicles	2 550	2 940	3 020	3 130	3 420	3 450	3 720	3 700	3 830	3 970	4 290	4 540
Propane & Natural Gas Vehicles	780	570	410	400	480	310	330	320	290	260	260	190
Railways	1 000	2 000	2 000	1 000	1 000	1 000	1 000	1 000	900	600	400	400
Domestic Marine	1 000	1 200	1 100	1 000	1 000	1 100	1 200	1 600	1 900	3 000	2 700	2 500
Others	3 000	5 000	5 000	6 000	5 000	5 000	5 000	5 000	5 000	5 000	6 000	5 000
Off Road Gasoline	400	400	400	500	400	400	500	400	400	500	500	500
Off Road Diesel	2 000	3 000	3 000	4 000	3 000	3 000	3 000	3 000	3 000	4 000	4 000	4 000
Pipelines	846	1 370	1 490	1 430	1 560	1 390	1 630	1 840	1 340	1 050	1 120	977
c. Fugitive Sources²	3 320	4 980	5 260	5 330	5 340	5 190	5 270	5 730	5 870	5 850	6 050	6 160
Coal Mining	500	600	600	700	600	500	500	500	X	X	X	X
Oil and Natural Gas	2 830	4 410	4 630	4 670	4 780	4 700	4 790	5 210	X	X	X	X
INDUSTRIAL PROCESSES³	3 100	3 350	3 450	3 640	3 750	3 930	3 970	2 960	2 880	3 020	3 180	3 150
a. Mineral Products	770	950	910	1 100	1 100	1 300	1 300	1 200	1 300	1 200	1 300	1 300
Cement Production	610	760	730	860	870	1 100	1 100	1 000	1 100	1 100	1 100	1 100
Lime Production	160	190	190	190	190	200	220	190	200	180	190	180
b. Chemical Industry	-	-	-	-	-	-	-	-	-	-	-	-
Nitric Acid Production	-	-	-	-	-	-	-	-	-	-	-	-
Adipic Acid Production	-	-	-	-	-	-	-	-	-	-	-	-
c. Metal Production	1 510	1 690	1 750	1 800	2 060	1 870	1 820	1 270	1 060	1 230	1 360	1 130
Iron and Steel Production	-	-	-	-	-	-	-	-	-	-	-	-
Aluminum Production	1 500	1 700	1 800	1 800	2 100	1 900	1 800	1 300	1 100	1 200	1 400	1 100
SF ₆ Used in Magnesium Smelters and Casters ⁵	-	-	-	-	-	-	-	-	-	-	-	-
d. Consumption of Halocarbons and SF₆	-	-	-	-	-	-	-	-	-	-	-	-
e. Other & Undifferentiated Production⁴	820	720	790	790	630	800	880	480	550	540	500	690
SOLVENT & OTHER PRODUCT USE	21	27	28	30	27	28	32	28	22	29	28	23
AGRICULTURE	2 100	2 300	2 400	2 400	2 100	2 300	2 200	2 300	2 300	2 400	2 600	2 500
a. Enteric Fermentation	1 100	1 200	1 200	1 200	1 200	1 200	1 200	1 200	1 200	1 300	1 400	1 300
b. Manure Management	370	410	420	420	420	430	430	440	450	460	480	470
c. Agriculture Soils	700	700	720	740	570	650	630	690	660	700	720	720
Direct Sources	330	300	310	330	210	260	240	280	260	280	280	290
Pasture, Range and Paddock Manure	180	210	210	210	200	210	210	210	220	220	240	230
Indirect Sources	200	200	200	200	200	200	200	200	200	200	200	200
WASTE	4 300	4 800	5 100	5 100	5 100	5 000	5 100	5 100	5 100	5 100	5 100	5 000
a. Solid Waste Disposal on Land	4 200	4 600	4 900	4 900	4 900	4 800	4 900	5 000	5 000	5 000	4 900	4 900
b. Wastewater Handling	90	100	99	100	110	100	110	110	110	110	110	110
c. Waste Incineration	66	73	72	73	72	70	70	67	69	69	69	68

Notes:

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

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 & SF₆ 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 SF₆ use in casters is confidential for this province.

X Indicates confidential data.

Totals may not add up due to rounding.

Table A11-21: 2005 GHG Emissions Summary for British Columbia

Greenhouse Gas Categories		Greenhouse Gases								
		CO ₂	CH ₄	CH ₄	N ₂ O	N ₂ O	HFCs	PFCs	SF ₆	TOTAL
		Global Warming Potential	21	310						
	Unit	kt	kt	kt CO ₂ eq	kt	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq
TOTAL		53 100	460	9 700	8.2	2 500	—	620	—	65 900
ENERGY		50 500	160	3 300	4	1 000	—	—	—	55 200
a.	Stationary Combustion Sources	22 600	30	500	0.8	200	—	—	—	23 400
	Electricity and Heat Generation	1 790	0.25	5.2	0.04	10	—	—	—	1 810
	Fossil Fuel Industries	7 050	20	400	0.2	60	—	—	—	7 500
	Mining & Oil and Gas Extraction	649	0.01	0.2	0.01	3	—	—	—	653
	Manufacturing Industries	5 540	0.7	20	0.3	100	—	—	—	5 660
	Construction	106	0.00	0.04	0.00	0.7	—	—	—	107
	Commercial & Institutional	3 350	0.06	1	0.06	20	—	—	—	3 370
	Residential	4 030	7	200	0.2	50	—	—	—	4 200
	Agriculture & Forestry	60.9	0.00	0.02	0.00	0.5	—	—	—	61.4
b.	Transportation ¹	24 500	3	60	4	1 000	—	—	—	26 000
	Domestic Aviation	1 630	0.08	2	0.1	50	—	—	—	1 700
	Road Transportation	15 300	1.1	24	1.5	460	—	—	—	15 800
	Light Duty Gasoline Vehicles	4 120	0.35	7.3	0.54	170	—	—	—	4 290
	Light Duty Gasoline Trucks	4 690	0.33	6.9	0.69	210	—	—	—	4 920
	Heavy Duty Gasoline Vehicles	1 660	0.12	2.4	0.10	31	—	—	—	1 690
	Motorcycles	27.5	0.02	0.40	0.00	0.17	—	—	—	28.1
	Light Duty Diesel Vehicles	45.7	0.00	0.02	0.00	1	—	—	—	46.8
	Light Duty Diesel Trucks	56.1	0.00	0.03	0.00	1	—	—	—	57.5
	Heavy Duty Diesel Vehicles	4 490	0.2	4	0.1	40	—	—	—	4 540
	Propane & Natural Gas Vehicles	190	0.1	2	0.00	1	—	—	—	190
	Railways	375	0.02	0.4	0.2	50	—	—	—	400
	Domestic Marine	2 410	0.2	4	0.4	100	—	—	—	2 500
	Others	4 800	2	30	1	400	—	—	—	5 000
	Off Road Gasoline	500	0.5	10	0.01	3	—	—	—	500
	Off Road Diesel	3 400	0.2	4	1	400	—	—	—	4 000
	Pipelines	949	0.95	20	0.03	8	—	—	—	977
c.	Fugitive Sources ²	3 400	130	2 700	—	—	—	—	—	6 160
INDUSTRIAL PROCESSES ³		2 500	—	—	—	—	—	620	—	3 150
a.	Mineral Products	1 300	—	—	—	—	—	—	—	1 300
	Cement Production	1 100	—	—	—	—	—	—	—	1 100
	Lime Production	180	—	—	—	—	—	—	—	180
b.	Chemical Industry	—	—	—	—	—	—	—	—	0
	Nitric Acid Production	—	—	—	—	—	—	—	—	0
	Adipic Acid Production	—	—	—	—	—	—	—	—	0
c.	Metal Production	510	—	—	—	—	—	620	—	1 130
	Iron and Steel Production	—	—	—	—	—	—	—	—	0
	Aluminum Production	510	—	—	—	—	—	620	—	1 100
	SF ₆ Used in Magnesium Smelters and Casters ⁵	—	—	—	—	—	—	—	—	0
d.	Consumption of Halocarbons and SF ₆	—	—	—	—	—	—	0	—	0
e.	Other & Undifferentiated Production ⁴	690	—	—	—	—	—	—	—	690
SOLVENT & OTHER PRODUCT USE		—	—	—	0.08	23	—	—	—	23
AGRICULTURE		—	70	1 500	3.4	1 000	—	—	—	2 500
a.	Enteric Fermentation	—	63	1 300	—	—	—	—	—	1 300
b.	Manure Management	—	6.7	140	1.1	330	—	—	—	470
c.	Agriculture Soils	—	—	—	2.3	720	—	—	—	720
	Direct Sources	—	—	—	0.92	290	—	—	—	290
	Pasture, Range and Paddock Manure	—	—	—	0.75	230	—	—	—	230
	Indirect Sources	—	—	—	0.6	200	—	—	—	200
WASTE		57	230	4 900	0.3	100	—	—	—	5 000
a.	Solid Waste Disposal on Land	—	230	4 900	—	—	—	—	—	4 900
b.	Wastewater Handling	—	1.0	21	0.3	90	—	—	—	110
c.	Waste Incineration	57	—	—	0.04	10	—	—	—	68

Notes:

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

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 & SF₆ 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 SF₆ use in casters is confidential for this province.

Totals may not add up due to rounding.

Table A11-22: 1990–2005 GHG Emissions Summary for Yukon

Greenhouse Gas Categories	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
						kt CO ₂ eq						
TOTAL	562	569	610	581	508	518	466	457	465	463	414	401
ENERGY	540	543	583	555	481	491	438	429	437	434	385	372
a. Stationary Combustion Sources	233	252	268	249	210	216	194	173	171	166	111	109
Electricity and Heat Generation	95.8	54.6	104	89.1	33.2	26.6	17.4	14.9	17.6	10.9	8.18	7.76
Fossil Fuel Industries	2.8	91	75	80	92	91	84	56	48	28	9.7	28
Mining & Oil and Gas Extraction	4.21	10.5	13.4	4.69	3.36	3.88	1.54	2.12	2.94	2.12	0.21	0.58
Manufacturing Industries	9.73	0.49	0.28	0.61	—	1.73	—	2.54	—	—	—	—
Construction	5.51	4.56	3.59	2.45	1.97	2.34	2.44	1.66	1.61	2.68	1.44	0.76
Commercial & Institutional	84.2	62.3	42.4	40.6	38.3	39.9	54.0	52.1	54.1	59.7	25.2	28.9
Residential	30	20	23	26	33	39	34	29	32	42	52	36
Agriculture & Forestry	1.26	7.84	6.24	6.07	7.76	10.6	0.98	14.4	15.2	20.7	13.7	6.55
b. Transportation¹	310	290	310	300	270	270	240	250	260	260	270	260
Domestic Aviation	21	21	24	16	22	21	23	16	15	21	22	22
Road Transportation	185	224	218	188	189	195	166	169	173	169	165	161
Light Duty Gasoline Vehicles	81.4	74.6	68.2	64.7	65.2	64.4	50.4	48.6	47.0	46.4	40.3	35.2
Light Duty Gasoline Trucks	31.3	42.9	41.7	44.1	49.2	49.0	40.8	42.6	43.8	45.5	41.5	38.7
Heavy Duty Gasoline Vehicles	10.5	9.99	10.3	8.14	8.10	8.15	6.07	6.47	6.27	6.50	6.01	5.42
Motorcycles	0.47	0.42	0.34	0.27	0.31	0.30	0.33	0.33	0.36	0.39	0.36	0.33
Light Duty Diesel Vehicles	0.57	0.52	0.51	0.47	0.47	0.47	0.36	0.35	0.34	0.35	0.33	0.29
Light Duty Diesel Trucks	0.62	0.98	1.69	2.71	2.98	3.03	2.57	2.61	2.64	2.77	2.60	2.71
Heavy Duty Diesel Vehicles	58.7	90.1	93.2	65.4	61.3	67.7	65.1	67.2	70.7	65.1	71.7	76.8
Propane & Natural Gas Vehicles	1.5	4.0	2.2	1.9	1.8	1.7	0.68	1.0	1.6	1.9	2.1	1.1
Railways	—	—	—	—	—	—	—	—	—	—	—	—
Domestic Marine	—	—	—	—	—	—	—	—	—	—	—	—
Others	100	40	70	100	60	60	50	70	70	70	80	80
Off Road Gasoline	10	8	7	6	20	20	10	10	10	10	3	3
Off Road Diesel	90	40	60	90	40	30	40	60	60	60	80	70
Pipelines	—	—	—	—	—	—	—	—	—	—	—	—
c. Fugitive Sources²	—	3.77	3.14	4.10	3.68	3.55	2.71	2.15	5.40	3.54	3.08	3.12
Coal Mining	—	—	—	—	—	—	—	—	X	X	X	X
Oil and Natural Gas	—	3.77	3.14	4.10	3.68	3.55	2.71	2.15	X	X	X	X
INDUSTRIAL PROCESSES³	1.38	2.09	1.88	1.19	0.72	0.81	0.71	0.61	0.99	0.75	0.49	0.57
a. Mineral Products	—	—	—	—	—	—	—	—	—	—	—	—
Cement Production	—	—	—	—	—	—	—	—	—	—	—	—
Lime Production	—	—	—	—	—	—	—	—	—	—	—	—
b. Chemical Industry	—	—	—	—	—	—	—	—	—	—	—	—
Nitric Acid Production	—	—	—	—	—	—	—	—	—	—	—	—
Adipic Acid Production	—	—	—	—	—	—	—	—	—	—	—	—
c. Metal Production	—	—	—	—	—	—	—	—	—	—	—	—
Iron and Steel Production	—	—	—	—	—	—	—	—	—	—	—	—
Aluminum Production	—	—	—	—	—	—	—	—	—	—	—	—
SF ₆ Used in Magnesium Smelters and Casters	—	—	—	—	—	—	—	—	—	—	—	—
d. Consumption of Halocarbons and SF₆	—	—	—	—	—	—	—	—	—	—	—	—
e. Other & Undifferentiated Production⁴	1.4	2.1	1.9	1.2	0.72	0.81	0.71	0.61	0.99	0.75	0.48	0.57
SOLVENT & OTHER PRODUCT USE	0.18	0.22	0.22	0.24	0.21	0.22	0.24	0.21	0.16	0.21	0.20	0.17
AGRICULTURE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
a. Enteric Fermentation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
b. Manure Management	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
c. Agriculture Soils	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Direct Sources	0.0	0.0	0.0	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	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	0.0	0.0	0.0
WASTE	21	24	24	25	26	26	26	27	27	28	28	29
a. Solid Waste Disposal on Land	18	21	21	22	22	23	23	24	24	25	25	26
b. Wastewater Handling	2.9	3.2	3.0	3.3	3.2	3.0	2.9	2.8	2.8	3.0	3.1	3.1
c. Waste Incineration	—	—	—	—	—	—	—	—	—	—	—	—

Notes:

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

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 & SF₆ 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.

Totals may not add up due to rounding.

Table A11-23: 2005 GHG Emissions Summary for Yukon

Greenhouse Gas Categories		Greenhouse Gases								TOTAL
Global Warming Potential	Unit	CO ₂	CH ₄	CH ₄	N ₂ O	N ₂ O	HFCs	PFCs	SF ₆	
		kt	kt	21 kt CO ₂ eq	kt	310 kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq
TOTAL		355	1.6	33	0.05	14	—	—	—	401
ENERGY		354	0.21	4.5	0.04	10	—	—	—	372
a. Stationary Combustion Sources		104	0.2	4	0.00	1	—	—	—	109
Electricity and Heat Generation		7.42	0.00	0.01	0.00	0.3	—	—	—	7.76
Fossil Fuel Industries		26.2	0.08	2	0.00	0.2	—	—	—	28
Mining & Oil and Gas Extraction		0.58	0.00	0.00	0.00	0.00	—	—	—	0.58
Manufacturing Industries		—	—	—	—	—	—	—	—	0
Construction		0.76	0.00	0.00	0.00	0.00	—	—	—	0.76
Commercial & Institutional		28.8	0.00	0.01	0.00	0.1	—	—	—	28.9
Residential		33.8	0.1	2	0.00	0.4	—	—	—	36
Agriculture & Forestry		6.53	0.00	0.00	0.00	0.02	—	—	—	6.55
b. Transportation¹		247	0.02	0.5	0.04	10	—	—	—	260
Domestic Aviation		21.8	0.00	0.06	0.00	0.6	—	—	—	22
Road Transportation		157	0.01	0.25	0.01	3.1	—	—	—	161
Light Duty Gasoline Vehicles		34.1	0.00	0.08	0.00	0.95	—	—	—	35.2
Light Duty Gasoline Trucks		37.4	0.00	0.08	0.00	1.2	—	—	—	38.7
Heavy Duty Gasoline Vehicles		5.30	0.00	0.01	0.00	0.11	—	—	—	5.42
Motorcycles		0.32	0.00	0.00	0.00	0.00	—	—	—	0.33
Light Duty Diesel Vehicles		0.28	0.00	0.00	0.00	0.01	—	—	—	0.29
Light Duty Diesel Trucks		2.64	0.00	0.00	0.00	0.06	—	—	—	2.71
Heavy Duty Diesel Vehicles		76.0	0.00	0.07	0.00	0.7	—	—	—	76.8
Propane & Natural Gas Vehicles		1.09	0.00	0.01	0.00	0.01	—	—	—	1.1
Railways		—	—	—	—	—	—	—	—	0
Domestic Marine		—	—	—	—	—	—	—	—	0
Others		68	0.01	0.1	0.03	8	—	—	—	80
Off Road Gasoline		3	0.00	0.07	0.00	0.02	—	—	—	3
Off Road Diesel		65	0.00	0.07	0.03	8	—	—	—	70
Pipelines		—	—	—	—	—	—	—	—	0
c. Fugitive Sources²		3.0	0.01	0.17	—	—	—	—	—	3.12
INDUSTRIAL PROCESSES³		0.57	—	—	—	—	—	—	—	0.57
a. Mineral Products		—	—	—	—	—	—	—	—	0
Cement Production		—	—	—	—	—	—	—	—	0
Lime Production		—	—	—	—	—	—	—	—	0
b. Chemical Industry		—	—	—	—	—	—	—	—	0
Nitric Acid Production		—	—	—	—	—	—	—	—	0
Adipic Acid Production		—	—	—	—	—	—	—	—	0
c. Metal Production		—	—	—	—	—	—	—	—	0
Iron and Steel Production		—	—	—	—	—	—	—	—	0
Aluminum Production		—	—	—	—	—	—	—	—	0
SF ₆ Used in Magnesium Smelters and Casters		—	—	—	—	—	—	—	—	0
d. Consumption of Halocarbons and SF₆		—	—	—	—	—	—	—	—	0
e. Other & Undifferentiated Production⁴		0.57	—	—	—	—	—	—	—	0.57
SOLVENT & OTHER PRODUCT USE		—	—	—	0.00	0.17	—	—	—	0.17
AGRICULTURE		—	—	—	—	—	—	—	—	—
a. Enteric Fermentation		—	—	—	—	—	—	—	—	—
b. Manure Management		—	—	—	—	—	—	—	—	—
c. Agriculture Soils		—	—	—	—	—	—	—	—	—
Direct Sources		—	—	—	—	—	—	—	—	—
Pasture, Range and Paddock Manure		—	—	—	—	—	—	—	—	—
Indirect Sources		—	—	—	—	—	—	—	—	—
WASTE		—	1.3	28	0.00	0.7	—	—	—	29
a. Solid Waste Disposal on Land		—	1.2	26	—	—	—	—	—	26
b. Wastewater Handling		—	0.12	2.5	0.00	0.7	—	—	—	3.1
c. Waste Incineration		—	—	—	—	—	—	—	—	0

Notes:

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

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 & SF₆ are only reported at the national level.

4 Emissions coming from ammonia production are included in the category Other & Undifferentiated Production at provincial levels.

Totals may not add up due to rounding.

Table A11-24: 1990–2005 GHG Emissions Summary for Northwest Territories and Nunavut

Greenhouse Gas Categories	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
		<i>kt CO₂ eq</i>										
TOTAL	1 530	1 890	2 020	1 730	1 570	1 370	1 640	2 180	1 800	1 690	1 650	1 550
ENERGY	1 480	1 760	1 900	1 670	1 510	1 320	1 580	2 120	1 740	1 630	1 590	1 480
a. Stationary Combustion Sources	871	1 090	992	919	691	642	829	1 020	915	815	761	651
Electricity and Heat Generation	215	372	350	348	374	302	293	302	258	271	264	250
Fossil Fuel Industries	180	23	14	3.8	2.8	3.3	170	320	280	170	190	130
Mining & Oil and Gas Extraction	49.8	101	44.0	49.2	43.3	70.7	79.5	106	107	94.9	66.7	54.0
Manufacturing Industries	22.3	20.5	18.2	9.52	0.00	0.00	0.00	0.00	0.00	0.08	0.18	0.18
Construction	3.83	20.6	0.70	0.72	0.59	0.85	0.53	0.69	1.44	1.29	1.62	1.35
Commercial & Institutional	237	444	375	334	176	172	163	153	127	161	147	135
Residential	160	110	190	170	94	94	120	120	120	99	87	79
Agriculture & Forestry	2.37	0.01	—	0.01	0.01	0.01	0.01	20.3	22.7	14.1	1.76	1.59
b. Transportation ¹	550	620	870	750	820	670	740	1 100	810	800	810	820
Domestic Aviation	170	180	250	210	170	110	110	210	140	140	150	120
Road Transportation	123	151	164	159	214	247	250	252	239	237	241	232
Light Duty Gasoline Vehicles	32.8	37.2	38.1	39.3	31.9	43.1	45.4	46.4	41.4	40.7	39.0	30.8
Light Duty Gasoline Trucks	14.1	23.1	25.3	29.1	23.9	36.9	41.5	43.5	40.0	42.4	43.2	35.7
Heavy Duty Gasoline Vehicles	5.84	3.80	3.77	3.54	2.91	3.58	4.01	4.57	3.99	3.94	4.05	3.27
Motorcycles	0.19	0.22	0.24	0.25	0.18	0.24	0.28	0.31	0.30	0.32	0.33	0.27
Light Duty Diesel Vehicles	0.23	0.26	0.28	0.29	0.23	0.31	0.37	0.39	0.34	0.35	0.36	0.29
Light Duty Diesel Trucks	0.23	0.50	0.90	1.61	1.36	1.92	2.44	2.66	2.50	2.70	2.80	2.63
Heavy Duty Diesel Vehicles	68.4	81.7	92.8	83.4	151	160	156	153	148	144	150	158
Propane & Natural Gas Vehicles	1.5	4.0	2.2	1.9	1.8	1.7	0.68	1.0	1.6	1.9	2.1	1.1
Railways	3	3	1	3	2	3	3	4	4	3	3	3
Domestic Marine	0.15	72	91	13	31	8.5	11	17	9.8	—	—	—
Others	300	200	400	400	400	300	400	600	400	400	400	500
Off Road Gasoline	50	50	60	60	30	20	30	30	10	20	20	20
Off Road Diesel	200	200	300	300	400	300	300	600	400	400	400	400
Pipelines	—	0.14	0.09	0.04	5.23	4.84	5.80	6.19	3.73	3.01	2.95	2.70
c. Fugitive Sources ²	63.0	41.3	38.6	6.20	4.92	4.91	9.36	11.4	14.1	16.5	19.7	14.9
Coal Mining	—	—	—	—	—	—	—	—	X	X	X	X
Oil and Natural Gas	63.0	41.3	38.6	6.20	4.92	4.91	9.36	11.4	X	X	X	X
INDUSTRIAL PROCESSES³	3.04	84.5	64.6	3.00	1.35	2.46	4.23	5.41	5.42	5.38	3.54	4.67
a. Mineral Products	—	—	—	—	—	—	—	—	—	—	—	—
Cement Production	—	—	—	—	—	—	—	—	—	—	—	—
Lime Production	—	—	—	—	—	—	—	—	—	—	—	—
b. Chemical Industry	—	—	—	—	—	—	—	—	—	—	—	—
Nitric Acid Production	—	—	—	—	—	—	—	—	—	—	—	—
Adipic Acid Production	—	—	—	—	—	—	—	—	—	—	—	—
c. Metal Production	—	—	—	—	—	—	—	—	—	—	—	—
Iron and Steel Production	—	—	—	—	—	—	—	—	—	—	—	—
Aluminum Production	—	—	—	—	—	—	—	—	—	—	—	—
SF ₆ Used in Magnesium Smelters and Casters	—	—	—	—	—	—	—	—	—	—	—	—
d. Consumption of Halocarbons and SF ₆	—	—	—	—	—	—	—	—	—	—	—	—
e. Other & Undifferentiated Production ⁴	3.0	85	65	3.0	1.4	2.5	4.2	5.4	5.4	5.4	3.5	4.7
SOLVENT & OTHER PRODUCT USE	0.37	0.47	0.48	0.51	0.46	0.48	0.54	0.47	0.37	0.50	0.48	0.40
AGRICULTURE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
a. Enteric Fermentation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
b. Manure Management	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
c. Agriculture Soils	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Direct Sources	0.0	0.0	0.0	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	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	0.0	0.0	0.0
WASTE	41	48	49	50	52	53	54	55	56	58	59	60
a. Solid Waste Disposal on Land	36	41	42	43	45	46	47	48	49	50	51	52
b. Wastewater Handling	5.3	7.0	6.9	7.0	6.9	7.0	7.0	7.2	7.4	7.5	7.6	7.7
c. Waste Incineration	—	—	—	—	—	—	—	—	—	—	—	—

Notes:

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

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 & SF₆ 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.

Totals may not add up due to rounding.

Table A11-25: 2005 GHG Emissions Summary for Northwest Territories and Nunavut

Greenhouse Gas Categories		Greenhouse Gases								
		CO ₂	CH ₄	CH ₄	N ₂ O	N ₂ O	HFCs	PFCs	SF ₆	TOTAL
		Global Warming Potential	21	310						
	Unit	kt	kt	kt CO ₂ eq	kt	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq	kt CO ₂ eq
TOTAL		1 410	3.5	74	0.23	70	—	—	—	1 550
ENERGY		1 400	0.73	15	0.2	70	—	—	—	1 480
a.	Stationary Combustion Sources	628	0.6	10	0.04	10	—	—	—	651
	Electricity and Heat Generation	241	0.01	0.21	0.03	9	—	—	—	250
	Fossil Fuel Industries	123	0.3	7	0.00	1	—	—	—	130
	Mining & Oil and Gas Extraction	53.8	0.00	0.02	0.00	0.3	—	—	—	54.0
	Manufacturing Industries	0.18	0.00	0.00	0.00	0.00	—	—	—	0.18
	Construction	1.35	0.00	0.00	0.00	0.01	—	—	—	1.35
	Commercial & Institutional	135	0.00	0.04	0.00	0.6	—	—	—	135
	Residential	72.7	0.2	5	0.00	0.9	—	—	—	79
	Agriculture & Forestry	1.58	0.00	0.00	0.00	0.01	—	—	—	1.59
b.	Transportation ¹	761	0.06	1	0.2	60	—	—	—	820
	Domestic Aviation	120	0.01	0.2	0.01	3	—	—	—	120
	Road Transportation	229	0.02	0.31	0.01	3.6	—	—	—	232
	Light Duty Gasoline Vehicles	29.9	0.00	0.07	0.00	0.84	—	—	—	30.8
	Light Duty Gasoline Trucks	34.5	0.00	0.07	0.00	1.1	—	—	—	35.7
	Heavy Duty Gasoline Vehicles	3.20	0.00	0.01	0.00	0.06	—	—	—	3.27
	Motorcycles	0.26	0.00	0.00	0.00	0.00	—	—	—	0.27
	Light Duty Diesel Vehicles	0.28	0.00	0.00	0.00	0.01	—	—	—	0.29
	Light Duty Diesel Trucks	2.57	0.00	0.00	0.00	0.06	—	—	—	2.63
	Heavy Duty Diesel Vehicles	157	0.01	0.2	0.01	1	—	—	—	158
	Propane & Natural Gas Vehicles	1.09	0.00	0.01	0.00	0.01	—	—	—	1.1
	Railways	2.96	0.00	0.00	0.00	0.4	—	—	—	3
	Domestic Marine	—	—	—	—	—	—	—	—	0
	Others	410	0.04	0.8	0.2	50	—	—	—	500
	Off Road Gasoline	20	0.02	0.4	0.00	0.1	—	—	—	20
	Off Road Diesel	390	0.02	0.4	0.2	50	—	—	—	400
	Pipelines	2.58	0.00	0.00	0.00	0.1	—	—	—	2.70
c.	Fugitive Sources ²	13	0.08	1.7	—	—	—	—	—	14.9
INDUSTRIAL PROCESSES ³		4.7	—	—	—	—	—	—	—	4.67
a.	Mineral Products	—	—	—	—	—	—	—	—	0
	Cement Production	—	—	—	—	—	—	—	—	0
	Lime Production	—	—	—	—	—	—	—	—	0
b.	Chemical Industry	—	—	—	—	—	—	—	—	0
	Nitric Acid Production	—	—	—	—	—	—	—	—	0
	Adipic Acid Production	—	—	—	—	—	—	—	—	0
c.	Metal Production	—	—	—	—	—	—	—	—	0
	Iron and Steel Production	—	—	—	—	—	—	—	—	0
	Aluminum Production	—	—	—	—	—	—	—	—	0
	SF ₆ Used in Magnesium Smelters and Casters	—	—	—	—	—	—	—	—	0
d.	Consumption of Halocarbons and SF ₆	—	—	—	—	—	—	—	—	0
e.	Other & Undifferentiated Production ⁴	4.7	—	—	—	—	—	—	—	4.7
SOLVENT & OTHER PRODUCT USE		—	—	—	0.00	0.40	—	—	—	0.40
AGRICULTURE		—	—	—	—	—	—	—	—	—
a.	Enteric Fermentation	—	—	—	—	—	—	—	—	—
b.	Manure Management	—	—	—	—	—	—	—	—	—
c.	Agriculture Soils	—	—	—	—	—	—	—	—	—
	Direct Sources	—	—	—	—	—	—	—	—	—
	Pasture, Range and Paddock Manure	—	—	—	—	—	—	—	—	—
	Indirect Sources	—	—	—	—	—	—	—	—	—
WASTE		—	2.8	58	0.01	2	—	—	—	60
a.	Solid Waste Disposal on Land	—	2.5	52	—	—	—	—	—	52
b.	Wastewater Handling	—	0.29	6.1	0.01	2	—	—	—	7.7
c.	Waste Incineration	—	—	—	—	—	—	—	—	—

Notes:

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

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 & SF₆ are only reported at the national level.

4 Emissions coming from ammonia production are included in the category Other & Undifferentiated Production at provincial levels.

Totals may not add up 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 NGLs

A12.1.1.1 CO₂

CO₂ emission factors for fossil fuel combustion are primarily dependent on the properties of the fuel and, to a lesser extent, 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 due to its raw nature, which includes ethane, propane and butane in addition to methane in the fuel mix.

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) due to the presence of impurities in the fuels.

A12.1.1.2 CH₄

Emissions of CH₄ 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, 2000). The emission factor for producer consumption of natural gas was developed based on a technology split for the upstream oil and gas industry (CAPP, 1999) and technology-specific emission factors from the U.S. EPA report AP-42 (EPA, 1996).

A12.1.1.3 N_2O

Emissions of N_2O 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, 2000).

Table A12-1: Emission Factors for Natural Gas and NGLs

Source	Emission Factors		
	CO_2	CH_4	N_2O
Natural Gas	<i>g/m³</i>	<i>g/m³</i>	<i>g/m³</i>
Electric Utilities	1 891 ¹	0.49 ²	0.049 ²
Industrial	1 891 ¹	0.037 ²	0.033 ²
Producer Consumption	2 389 ¹	6.5 ^{3,4}	0.06 ²
Pipelines	1 891 ¹	1.9 ²	0.05 ²
Cement	1 891 ¹	0.037 ²	0.034 ²
Manufacturing Industries	1 891 ¹	0.037 ²	0.033 ²
Residential, Construction, Commercial/Institutional, Agriculture	1 891 ¹	0.037 ²	0.035 ²
NGLs	<i>g/L</i>	<i>g/L</i>	<i>g/L</i>
Propane			
Residential	1 510 ¹	0.027 ²	0.108 ²
All Other Uses	1 510 ¹	0.024 ²	0.108 ²
Ethane	976 ¹	N/A	N/A
Butane	1 730 ¹	0.024 ²	0.108 ²

Notes:

1 Adapted from McCann (2000).

2 SGA (2000).

3 EPA (1996).

4 CAPP (1999).

N/A = Not available

A12.1.2 Refined Petroleum Products

A12.1.2.1 CO_2

CO_2 emission factors for fossil fuel combustion are primarily dependent on the properties of the fuel and, to a lesser extent, the combustion technology.

Emission factors have been developed for each major class of refined petroleum product based on standard fuel properties and an assumed fuel combustion efficiency of 98.5% (Jaques, 1992). Emission factors are presented in Table A12-2 for the majority of the refined petroleum products, and in Table A12-3 for petroleum coke and still gas.

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 the Canadian Industrial Energy End-use Data and Analysis Centre (CIEEDAC) in their Review of Energy Consumption reports on the refining and upgrading industry (CIEEDAC 2006; and 2003, respectively). 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. 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 2006; and 2003, respectively).

A12.1.2.2 CH₄

Emissions of CH₄ 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, 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 SGA (2000) study.

A12.1.2.3 N₂O

Emissions of N₂O from fuel combustion are technology dependent. Emission factors for refined petroleum products 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, 2000). Emission factors for petroleum coke (Table A12-4) 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		
	CO ₂	CH ₄	N ₂ O
Light Fuel Oil	g/L	g/L	g/L
Electric Utilities	2 830 ₁	0.18 ²	0.031 ²
Industrial	2 830 ₁	0.006 ²	0.031 ²
Producer Consumption	2 830 ₁	0.006 ²	0.031 ²
Residential	2 830 ₁	0.026 ²	0.006 ²
Forestry, Construction, Public Administration and Commercial/Institutional	2 830 ₁	0.026 ²	0.031 ²
Heavy Fuel Oil	g/L	g/L	g/L
Electric Utilities	3 080 ₁	0.034 ²	0.064 ²
Industrial	3 080 ₁	0.12 ²	0.064 ²
Producer Consumption	3 080 ₁	0.12 ²	0.064 ²
Residential, Forestry, Construction, Public Administration and Commercial/Institutional	3 080 ₁	0.057 ²	0.064 ²
Kerosene	g/L	g/L	g/L
Electric Utilities	2 550 ₁	0.006 ²	0.031 ²
Industrial	2 550 ₁	0.006 ²	0.031 ²
Producer Consumption	2 550 ₁	0.006 ²	0.031 ²
Residential	2 550 ₁	0.026 ²	0.006 ²
Forestry, Construction, Public Administration and Commercial/Institutional	2 550 ₁	0.026 ²	0.031 ²
Diesel	g/L	g/L	g/L
	2 730 ₁	0.133 ²	0.4 ²
Petroleum Coke	(see Table A12-3)	0.12 ² (see Table A12-3)	
Still Gas	(see Table A12-3)	N/A	0.00002 ²

Notes:

1 Jaques (1992).

2 SGA (2000).

N/A = not available

Table A12-3: CO₂ Emission Factors for Petroleum Coke and Still Gas

	CO ₂ Emission Factors								
	1990	1998	1999	2000	2001	2002	2003	2004	2005
	<i>g/l</i>								
Petroleum Coke									
Upgrading Facilities ¹	3 556	3 528	3 506	3 481	3 494	3 494	3 494	3 494	3 494 ³
Refineries & Others ²	3 766	3 760	3 777	3 711	3 763	3 806	3 828	3 806	3 826 ³
Still Gas									
Upgrading Facilities ¹	2 310	2 300	2 110	2 120	2 140	2 140	2 140	2 140	2 140
Refineries & Others ²	1 680	1 680	1 800	1 720	1 690	1 690	1 740	1 750	1 750

Notes:

1 CIEEDAC (2003)

2 CIEEDAC (2006)

3 Nyboer (2006) – Personal Communication between C.Ha (EC) and J.Nyboer (CIEEDAC)

Table A12-4: N₂O Emission Factors for Petroleum Coke

	N ₂ O Emission Factors ¹			
	1990 – 1995	1996	1997	1998-2005
	<i>g/l</i>			
Petroleum Coke				
Upgrading Facilities	0.0226	0.0231	0.0231	0.0231
Refineries & Others	0.0254	0.0254	0.0254	0.0265

Note :

1 IPCC (2006)

A12.1.3 Coal and Coal Products

A12.1.3.1 CO₂

CO₂ emission factors for coal combustion are dependent on the properties of the fuel and, to a lesser extent, 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 endpoints.

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: CO₂ Emission Factors for Coal and Coal Products

Province	Coals	CO ₂ Emission Factors								1998– 2005
		1990	1991	1992	1993	1994	1995	1996	1997	
g/kg										
Newfoundland and Labrador	Canadian Bituminous ¹	2300 ²	2294	2287	2281	2274	2268	2262	2255	2249 ³
	Anthracite	2390 ²	2390	2390	2390	2390	2390	2390	2390	2390 ³
Prince Edward Island	Canadian Bituminous ¹	2300 ²	2294	2287	2281	2274	2268	2262	2255	2249 ³
Nova Scotia	Canadian Bituminous	2300 ²	2294	2287	2281	2274	2268	2262	2255	2249 ³
	U.S. Bituminous	2330 ²	2325	2320	2314	2309	2304	2299	2293	2288 ³
	Sub-Bituminous ⁴	NO	NO	NO	NO	NO	NO	NO	NO	1733 ^{3,7}
New Brunswick	Canadian Bituminous	2230 ²	2201	2172	2142	2113	2084	2055	2026	1996 ³
	U.S. Bituminous	2500 ²	2476	2453	2429	2405	2382	2358	2334	2311 ³
Quebec	Canadian Bituminous ¹	2300 ²	2294	2287	2281	2274	2268	2262	2255	2249 ³
	U.S. Bituminous	2500 ²	2480	2461	2441	2421	2402	2382	2362	2343 ³
	Anthracite	2390 ²	2390	2390	2390	2390	2390	2390	2390	2390 ³
Ontario	Canadian Bituminous	2520 ²	2487	2454	2420	2387	2354	2321	2287	2254 ³
	U.S. Bituminous	2500 ²	2492	2483	2475	2466	2458	2449	2441	2432 ³
	Sub-Bituminous ⁴	2520 ²	2422	2323	2225	2126	2028	1930	1831	1733 ^{3,7}
	Lignite	1490 ²	1488	1486	1485	1483	1481	1479	1478	1476 ³
	Anthracite	2390 ²	2390	2390	2390	2390	2390	2390	2390	2390 ³
Manitoba	Canadian Bituminous	2520 ²	2486	2453	2419	2386	2352	2319	2285	2252 ³
	U.S. Bituminous ⁵	NO	NO	NO	NO	2387	2387	NO	NO	2432 ³
	Sub-Bituminous ⁴	2520 ²	2422	2323	2225	2126	2028	1930	1831	1733 ^{3,7}
	Lignite	1520 ²	1508	1496	1484	1472	1460	1448	1436	1424 ³
	Anthracite	2390 ²	2390	2390	2390	2390	2390	2390	2390	2390 ³
Saskatchewan	Canadian Bituminous ⁶	1700 ²	1719	1738	1757	1776	1795	1814	1833	1852 ³
	Sub-Bituminous ^{4,5}	NO	NO	NO	NO	1747	1747	NO	NO	NO
	Lignite	1340 ²	1351	1362	1373	1384	1394	1405	1416	1427 ³
Alberta	Canadian Bituminous	1700 ²	1719	1738	1757	1776	1795	1814	1833	1852 ³
	Sub-Bituminous ⁴	1740 ²	1743	1746	1749	1753	1756	1759	1762	1765 ³
	Anthracite	2390 ²	2390	2390	2390	2390	2390	2390	2390	2390 ³
British Columbia	Canadian Bituminous	1700 ²	1747	1793	1840	1886	1933	1979	2026	2072 ³
	U.S. Bituminous ⁵	NO	NO	NO	NO	NO	NO	NO	NO	2432 ³
	Sub-Bituminous ⁴	NO	NO	NO	NO	NO	NO	NO	NO	1765 ³
All Provinces										
	Coke	2480 ²	2480	2480	2480	2480	2480	2480	2480	2480 ³
g/m ³										
	Coke Oven Gas	1600 ²	1600	1600	1600	1600	1600	1600	1600	1600 ³

Notes:

1 Assumed same source of Canadian bituminous for Newfoundland and Labrador, Prince Edward Island, Nova Scotia, and Quebec.

2 Jaques (1992).

3 Adapted from McCann (2000).

4 Represents both domestic and imported sub-bituminous.

5 Used Canada weighted average for 1990.

6 Assumed same source of Canadian bituminous for Saskatchewan and Alberta.

7 Assumed same source of sub-bituminous for Nova Scotia, Ontario and Manitoba.

NO = Not occurring

A12.1.3.2 CH_4

Emissions of CH_4 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, 2000).

A12.1.3.3 N_2O

Emissions of N_2O 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, 2000).

Table A12-6: CH_4 and N_2O Emission Factors for Coals¹

Source	Emission Factors	
	CH_4 g/kg	N_2O g/kg
Coal		
Electric Utilities	0.022	0.032
Industry and Head & Steam Plants	0.03	0.02
Residential, Public Administration	4	0.02
Coke	0.03	0.02
	g/m ³	g/m ³
Coke Oven Gas	0.037	0.035

Note:

1 SGA (2000).

A12.1.4 Mobile Combustion

A12.1.4.1 CO_2

CO_2 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_4

Emissions of CH_4 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, 2000).

A12.1.4.3 N_2O

Emissions of N_2O 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, 2000).

Table A12-7: Emission Factors for Energy Mobile Combustion Sources

Mode	Emission Factors		
	CO_2 g/L fuel	CH_4 g/L fuel	N_2O g/L fuel
Road Transport			
Gasoline Vehicles			
Light-Duty Gasoline Vehicles (LDGVs)			
Tier 1	2360 ¹	0.12 ²	0.16 ⁴
Tier 0	2360 ¹	0.32 ²	0.66 ⁵
Oxidation Catalyst	2360 ¹	0.52 ⁴	0.20 ²
Non-Catalytic Controlled	2360 ¹	0.46 ⁴	0.028 ²
Light-Duty Gasoline Trucks (LDGTs)			
Tier 1	2360 ¹	0.13 ⁴	0.25 ⁴
Tier 0	2360 ¹	0.21 ⁴	0.66 ⁵
Oxidation Catalyst	2360 ¹	0.43 ⁴	0.20 ²
Non-Catalytic Controlled	2360 ¹	0.56 ²	0.028 ²
Heavy-Duty Gasoline Vehicles (HDGVs)			
Three-Way Catalyst	2360 ¹	0.068 ⁴	0.20 ⁴
Non-Catalytic Controlled	2360 ¹	0.29 ²	0.047 ²
Uncontrolled	2360 ¹	0.49 ²	0.084 ²
Motorcycles			
Non-Catalytic Controlled	2360 ¹	1.4 ²	0.045 ²
Uncontrolled	2360 ¹	2.3 ²	0.048 ²
Diesel Vehicles			
Light-Duty Diesel Vehicles (LDDVs)			
Advance Control	2730 ¹	0.051 ²	0.22 ²
Moderate Control	2730 ¹	0.068 ²	0.21 ²
Uncontrolled	2730 ¹	0.10 ²	0.16 ²
Light-Duty Diesel Trucks (LDDTs)			
Advance Control	2730 ¹	0.068 ²	0.22 ²
Moderate Control	2730 ¹	0.068 ²	0.21 ²
Uncontrolled	2730 ¹	0.085 ²	0.16 ²
Heavy-Duty Diesel Vehicles (HDDVs)			
Advance Control	2730 ¹	0.12 ²	0.082 ²
Moderate Control	2730 ¹	0.14 ²	0.082 ²
Uncontrolled	2730 ¹	0.15 ²	0.075 ²
Natural Gas Vehicles	1.89 ³	9×10^{-3} ²	6×10^{-5} ²
Propane Vehicles	1510 ³	0.64 ²	0.028 ²
Off-Road			
Off-Road Gasoline	2360 ¹	2.7 ²	0.050 ²
Off-Road Diesel	2730 ¹	0.15 ²	1.1 ²
Railways			
Diesel Train	2730 ¹	0.15 ²	1.1 ²
Marine			
Gasoline Boats	2360 ¹	1.3 ²	0.066 ²
Diesel Ships	2730 ¹	0.15 ²	1.1 ²
Light Fuel Oil Ships	2830 ¹	0.26 ²	0.073 ²

Mode	Emission Factors		
	CO ₂ g/L fuel	CH ₄ g/L fuel	N ₂ O g/L fuel
Heavy Fuel Oil Ships	3080 ¹	0.28 ²	0.079 ²
Aviation			
Aviation Gasoline	2330 ¹	2.2 ¹	0.23 ¹
Aviation Turbo Fuel	2550 ¹	0.080 ¹	0.23 ¹
Renewable Fuels			
Ethanol	1490 ⁶	**	**

Sources:

1 Jaques (1992).

2 SGA (2000).

3 McCann (2000).

4 ICF (2004).

5 Barton & Simpson (1994).

6 See Chapter 3

Notes:

* Tier 1 or Advanced Control emission factors are used for Tier 2 vehicle populations

** Gasoline CH₄ and N₂O emission factors (by mode and technology) are used for ethanol

A12.2 Fugitive Emission Factors: Coal Mining

Fugitive emissions from coal mining are predominantly CH₄. These emissions result from the release of entrained CH₄ 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 ₄ /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	CO ₂	Emission Factors		
			N ₂ O	CF ₄	C ₂ F ₆
Mineral Use			g/kg feed		
Limestone Use	In iron and steel, glass, non-ferrous metal production, pulp & 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			
Mineral Products			g/kg product		
Cement Production	Limestone calcination	507.1	—	—	—
Lime Production	Limestone calcination (high-calcium lime)	750			
	Limestone calcination (dolomitic lime)	860	—	—	—
Chemical Industry			kg/t product		
Ammonia Production	From natural gas reforming, which produces the hydrogen needed	1 560	—	—	—
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	—	—
Adipic Acid Production			kg/kg product		
	Plants without abatement	—	0.3	—	—
Metal Production			kg/t product		
Primary Aluminium	Electrolysis process — cell technology				
	Side-worked pre-baked	1 600	—	1.4	0.336
	Centre-worked pre-baked	1 600	—	0.2–0.4	0.034–0.068
	Horizontal stud Söderberg	1 700	—	0.6–0.7	0.054–0.063
	Vertical stud Söderberg	1 700	—	0.4–0.6	0.024–0.036
Iron and Steel Production			t/ t coke used		
	Iron ore reduction with coke	2.479	—	—	—
			kg/ t steel		
	Steel production in EAFs	5			

Sources:

CO₂ Emission Factors:

Limestone Use — ORTECH Corporation (1994).
Dolomite Use — AMEC (2006).
Soda Ash Use — AMEC (2006).
Magnesite Use — AMEC (2006).
Lime Production — IPCC (2000).
Cement Production — IPCC/OECD/IEA (1997).
Ammonia Production — Jaques (1992).
Primary Aluminium Production — AAC (2002).
Iron and Steel — Jaques (1992); IPCC (2000).

N₂O Emission Factors:

Nitric Acid — Collis (1992) and IPCC (2000).
Adipic Acid Production — IPCC (2000).

CF₄ and C₂F₆ Emission Factors:

Primary Aluminium Production — AAC (2002).

A12.3.2 Consumption of Halocarbons

The use of halocarbons in various applications, such as air conditioning, 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, air conditioning original equipment manufacturing (AC 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 <i>kg loss/kg consumed</i>	Assumptions
Aerosols	0.8	For aerosol products, the 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, meaning that emissions of 1994 production that occurred in 1995 would be equivalent to 25% of production in 1995. Therefore, the EF applied to the 1995 production was 75% or 80% (rounded).
Foams	1	For foam blowing, it was assumed that all HFCs used foam blowing in 1995 were for open-cell type. According to the Revised 1996 IPCC Guidelines, 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 Revised 1996 IPCC Guidelines. Therefore, a loss rate of 4% was assumed here.
AC Service	1	For AC Service, it was assumed that most service HFCs was used to replace operating losses. In other words, it was assumed that service HFC replaces identical amount of HFC which 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 Revised 1996 IPCC Guidelines, is 35%

Table A12-11 summarizes emission rates (in %) used to estimate 1996-2005 HFC emissions, and 1995-2005 PFC emissions.

Table A12-11: Emission Rates^a for Consumption of HFCs and PFCs.

HFC Applications	HFC Emission Rates (%)	PFC Applications	PFC Emission Rates (%)
Residential Refrigeration Equipment – assembly	2% (of charge)	Refrigeration Equipment – assembly	3.5% (of charge) ^b
Commercial Refrigeration Equipment – assembly	3.5% (of charge) ^b	Stationary AC Equipment – assembly	3.5% (of charge) ^b
Stationary AC Equipment – assembly	3.5% (of charge) ^b	Mobile AC Equipment – assembly	4.5% (of charge) ^c
Mobile AC Equipment – assembly	4.5% (of charge) ^c	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) ^d	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 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:

a Source: IPCC/OECD/IEA (1997).

b The Revised 1996 IPCC Guidelines provide two ranges of values: 2-3% and 4-5%. The midpoint of the two ranges was used.

c The Revised 1996 IPCC Guidelines provide a range of 4-5% as values. The average value was used.

d The Revised 1996 IPCC Guidelines 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 CO₂ emissions from non-energy use of natural gas, an emission factor of 1522 g CO₂/m³ was used (Cheminfo, 2005). Tables A12-12 to A12-15 show industry-average emission factors used to develop CO₂ emission estimates for non-energy applications of solid and liquid fuels.

Table A12-12: CO₂ Emission Factors for Coal and Coal Products

Table A12-12: CO ₂ Emission Factors for Coal and Coal Products										
Province	Coals	CO ₂ Emission Factors								
		1990	1991	1992	1993	1994	1995	1996	1997	1998–2005
						g/kg				
Newfoundland and Labrador										
	Canadian Bituminous ¹	2 300 ²	2 294	2 287	2 281	2 274	2 268	2 262	2 255	2 249 ³
	Anthracite	2 390 ²	2 390	2 390	2 390	2 390	2 390	2 390	2 390	2 390 ³
Prince Edward Island										
	Canadian Bituminous ¹	2 300 ²	2 294	2 287	2 281	2 274	2 268	2 262	2 255	2 249 ³
Nova Scotia										
	Canadian Bituminous	2 300 ²	2 294	2 287	2 281	2 274	2 268	2 262	2 255	2 249 ³
	U.S. Bituminous	2 330 ²	2 325	2 320	2 314	2 309	2 304	2 299	2 293	2 288 ³
New Brunswick										
	Canadian Bituminous	2 230 ²	2 201	2 172	2 142	2 113	2 084	2 055	2 026	1 996 ³
	U.S. Bituminous	2 500 ²	2 476	2 453	2 429	2 405	2 382	2 358	2 334	2 311 ³
Quebec										
	Canadian Bituminous ¹	2 300 ²	2 294	2 287	2 281	2 274	2 268	2 262	2 255	2 249 ³
	U.S. Bituminous	2 500 ²	2 480	2 461	2 441	2 421	2 402	2 382	2 362	2 343 ³
	Anthracite	2 390 ²	2 390	2 390	2 390	2 390	2 390	2 390	2 390	2 390 ³
Ontario										
	Canadian Bituminous	2 520 ²	2 487	2 454	2 420	2 387	2 354	2 321	2 287	2 254 ³
	U.S. Bituminous	2 500 ²	2 492	2 483	2 475	2 466	2 458	2 449	2 441	2 432 ³
	Sub-Bituminous ⁴	2 520 ²	2 422	2 323	2 225	2 126	2 028	1 930	1 831	1 733 ³
	Lignite	1 490 ²	1 488	1 486	1 485	1 483	1 481	1 479	1 478	1 476 ³
	Anthracite	2 390 ²	2 390	2 390	2 390	2 390	2 390	2 390	2 390	2 390 ³
Manitoba										
	Canadian Bituminous	2 520 ²	2 486	2 453	2 419	2 386	2 352	2 319	2 285	2 252 ³
	Sub-Bituminous	2 520 ²	2 422	2 323	2 225	2 126	2 028	1 930	1 831	1 733 ³
	Lignite	1 520 ²	1 508	1 496	1 484	1 472	1 460	1 448	1 436	1 424 ³
	Anthracite	2 390 ²	2 390	2 390	2 390	2 390	2 390	2 390	2 390	2 390 ³
Saskatchewan										
	Canadian Bituminous ⁵	1 700 ²	1 719	1 738	1 757	1 776	1 795	1 814	1 833	1 852 ³
	Lignite	1 340 ²	1 351	1 362	1 373	1 384	1 394	1 405	1 416	1 427 ³
Alberta										
	Canadian Bituminous	1 700 ²	1 719	1 738	1 757	1 776	1 795	1 814	1 833	1 852 ³
	Sub-Bituminous	1 740 ²	1 743	1 746	1 749	1 753	1 756	1 759	1 762	1 765 ³
	Anthracite	2 390 ²	2 390	2 390	2 390	2 390	2 390	2 390	2 390	2 390 ³
British Columbia										
	Canadian Bituminous	1 700 ²	1 747	1 793	1 840	1 886	1 933	1 979	2 026	2 072 ³
All Provinces										
	Metallurgical Coke	2 480 ²	2 480	2 480	2 480	2 480	2 480	2 480	2 480	2 480 ³

Notes:

- 1 Assumed same source of Canadian bituminous for Newfoundland and Labrador, Prince Edward Island, Nova Scotia, and Quebec.
- 2 Jaques (1992).
- 3 Adapted from McCann (2000).
- 4 Represents both domestic and imported sub-bituminous.
- 5 Assumed same source of Canadian bituminous for Saskatchewan and Alberta.

Table A12-13: CO₂ Emission Factors for Various Refined Petroleum Products

	Emission factors (g CO ₂ /L)	Sources
Still Gas	2 000	Jaques (1992)
Motor Gasoline	2 360	Jaques (1992)
Kerosene	2 550	Jaques (1992)
Diesel Fuel Oil	2 730	Jaques (1992)
Light Fuel Oil	2 830	Jaques (1992)
Heavy Fuel Oil	3 090	Jaques (1992)
Petroleum Coke Oil	4 200	Nyboer (1996)
Aviation Gasoline	2 330	Jaques (1992)
Aviation Turbo fuel	2 550	Jaques (1992)

Table A12-14: CO₂ Emission Factors for Natural Gas Liquids

	Fraction of carbon stored in products	Emission Factors (g CO ₂ /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 A12-15: CO₂ Emission Factors for Non-Energy Petroleum Products

Non-Energy Products	Carbon Factor (g C/L) (source: Jaques, 1992)	Molecular Weight Ratio between CO₂ and Carbon	Fraction of Carbon Stored (source: IPCC/OECD/IEA (1997))	Resulting CO₂ Emission Factor (g CO ₂ /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

A12.4 Solvent and Other Product Use

N₂O emissions can result from its use as anaesthetic and propellant. The development of the emission factors shown in Table 16 is described in the Solvent and Other Product Use chapter of the inventory report (Chapter 5).

Table A12-16: Emission Factors for Solvent and Other Product Use

Product	Application	N₂O Emission Rates (%)
N ₂ O Use	Anaesthetic Usage	97.5%
	Propellant Usage	100%

Source: Cheminfo, 2006

A12.5 Agriculture

Emissions from agriculture result from enteric fermentation, manure management, and agricultural soils (see Table A12-17 to Table A12-21). Methodologies for generating these emission estimates are detailed in Section A3.4 of Annex 3.

Table A12-17: CH₄ Emission Factors for Livestock and Manure

Animal Types	Emission Factors	
	Enteric Fermentation <i>kg CH₄/head per year</i>	Manure Management <i>kg CH₄/head per year</i>
Cattle		
Bulls	94 ¹	3.2 ²
Dairy Cows	See	See
	Table A12-188	Table A12-18
Beef Cows	90 ¹	3.5 ²
Dairy Heifers	73 ¹	15.4 ²
Beef Heifers	75 ¹	2.8 ²
Heifers for Slaughter	63 ¹	1.8 ²
Steers	56 ¹	2.0 ²
Calves	40 ¹	1.1 ²
Pigs		
Starters	1.5 ³	1.8 ²
Growers	1.5 ³	5.1 ²
Finishers	1.5 ³	7.9 ²
Sows	1.5 ³	6.3 ²
Boars	1.5 ³	6.4 ²
Other Livestock		
Sheep	8 ³	0.3 ²
Lambs	8 ³	0.2 ²
Goats	5 ³	0.3 ²
Horses	18 ³	2.3 ²
Bison	55 ³	2.0 ²
Poultry		
Chickens	Not Estimated	0.03 ²
Hens	Not Estimated	0.03 ²
Turkeys	Not Estimated	0.08 ²

Notes:

1 Sources of emission factors (Tier 2) are country-specific (Boadi *et al.*, 2004).

2 Sources of emission factors (Tier 2) are country-specific (Marinier *et al.*, 2004).

3 Source of emission factors is IPCC/OECD/IEA (1997).

Table A12-18: Enteric Fermentation and Manure Management Emission Factors for Dairy Cattle from 1990 to 2004

Year	Enteric Fermentation $EF_{(EF)T}^1$ <i>kg CH₄/head/year</i>	Manure Management $EF_{(EF)T}^2$ <i>kg CH₄/head/year</i>
1990	116.9	25.7
1991	117.7	25.9
1992	120.3	26.5
1993	122.3	26.9
1994	123.0	27.1
1995	123.8	27.3
1996	125.6	27.4
1997	126.1	27.7
1998	128.0	27.9
1999	130.1	28.2
2000	132.1	29.0
2001	132.9	29.3
2002	135.2	29.6
2003	135.3	29.7
2004	134.8	29.6
2005	134.9	29.7

Notes:

- 1 Emission factors are derived from Boadi *et al.* (2004) following Good Practice Guidance provided by IPCC (2000) with modifications to capture changes in milk productivity.
- 2 Emission factors are derived following Good Practice Guidance provided by IPCC (2006).

Table A12-19: Nitrogen Excretion Rate by Animal Type

Animal Type	Average Manure Nitrogen Excretion per 1000 kg Live Animal Mass per Day ¹	Nitrogen Excretion (N _{EX}) <i>kg N/head-year</i>
Non-Dairy Cattle	0.34	58.1
Dairy Cattle	0.45	108.2
Poultry	1.02	0.5
Sheep & Lambs	0.42	4.1
Swine	0.52	11.6
Goats	0.45	10.5
Horses	0.30	49.3
Bisons	0.34	58.1

Note:

- 1 ASAE Standards (ASAE, 2003).

Table A12-20: Percentage of Manure Nitrogen Handled by Animal Waste Management Systems

Animal Type	Liquid Systems	Solid Storage and Drylot	Pasture and Paddock	Other Systems
Non-Dairy Cattle	1	47	48	4
Dairy Cattle	42	40	18	0
Poultry	10	88	2	0
Sheep and Lambs	0	38	62	0
Swine	96	3	0	1
Horses and Bison	0	43	57	0
Goats	0	40	60	0

Source: Marinier *et al.* (2004).

Table A12-21: Percentage of Manure Nitrogen Lost as N₂O by Animal Type¹

Animal Type	Liquid Systems	Solid Storage and Drylot	Pasture and Paddock	Other Systems
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	1.0 ²	0.5
Sheep and Lambs	0.1	2.0	2.0	0.5
Swine	0.1	2.0	2.0	0.5
Other (Goat and Horse)	0.1	2.0	1.0 ²	0.5

Notes:

1 IPCC/OECD/IEA (1997), except where otherwise noted.

2 IPCC (2006).

A12.6 Biomass Combustion

A12.6.1 CO₂

Emissions of CO₂ 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 as required by the UNFCCC. Emissions from this source are primarily dependent on the characteristics of the fuel being combusted. The methodology for deriving the emission factors (Table A12-22) is described in the biomass combustion section of the inventory report (see Section 3.4.2).

CO₂ emissions occur during forest wildfires and from controlled burning during forest conversion activities. The carbon emitted as CO₂ (CO₂-C) during forest fires is considered in the forest carbon balance, while the CO₂-C emitted during controlled burns is reported under the new land-use categories. There is no unique CO₂ emission factor applicable to all fires, as the proportion of CO₂-C emitted for each pool can be specific to the pool, the types of forest and disturbance, and the ecological zone (see Section A3.5.2 in Annex 3).

A12.6.2 CH₄

Emissions of CH₄ from biomass fuel combustion are technology dependent. The emission factors (Table A12-22) were derived from a review of emission factors for combustion technologies (SGA, 2000). The factors are from the U.S. EPA AP-42 Supplement B (EPA, 1996).

Emissions of carbon as CH₄ (CH₄-C) from wildfires and controlled burning are always equal to 1/90th of CO₂-C emissions.

A12.6.3 N₂O

Emissions of N₂O from biomass fuel combustion are technology dependent. The emission factors (Table A12-22) were developed from a review of emission factors for combustion technologies and an analysis of combustion technologies typically used in Canada (SGA, 2000). The factors are from the U.S. EPA AP-42 Supplement B (EPA, 1996).

N₂O emissions from wildfires and controlled burning are equal to 0.017% vol/vol of CO₂ emissions. Since both gases have the same molecular weight, the same ratio can be applied on a mass basis (see Section A3.5.2 in Annex 3).

Table A12-22: Emission Factors for Biomass

Source	Description	Emission Factors		
		CO ₂ <i>g/kg fuel</i>	CH ₄ <i>g/kg fuel</i>	N ₂ O <i>g/kg fuel</i>
Wood Fuel/Wood Waste	Industrial Combustion	950	0.05	0.02
Forest Wildfires	Open Combustion	N/A	N/A ¹	N/A ²
Controlled Burning	Open Combustion	N/A	N/A ¹	N/A ²
Spent Pulping Liquor	Industrial Combustion	1 428	0.05	0.02
Stoves and Fireplaces	Residential Combustion			
Conventional Stoves		1 500	15	0.16
Conventional Fireplaces and Inserts		1 500	15	0.16
Stoves/Fireplaces with Advanced Technology or Catalytic Control		1 500	6.9	0.16
Other Wood-Burning Equipment		1 500	15	0.16

Notes:

1 Emission ratio for CH₄ is 1/90th CO₂. See Annex 3.5.

2 Emission ratio for N₂O is 0.017% CO₂. See Annex 3.5.

N/A = not applicable

CO₂ emissions from biomass combusted for energy purposes are not included in inventory totals, whereas CH₄ and N₂O emissions from these sources are inventoried under the Energy Sector. All GHG emissions including CO₂ from biomass burned in managed forests (wildfires and controlled burning) are reported under LULUCF and excluded from national inventory totals.

Sources:

CO₂ Emission Factors:

Wood Fuel/Wood Waste — EPA (1996).

Conventional Stoves — ORTECH (1994).

CH₄ Emission Factors:

Wood Fuel/Wood Waste — EPA (1985).

N₂O Emission Factors:

Wood Fuel/Wood Waste — Rosland and Steen (1990); Radke *et al.* (1991).

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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 source category. The number of significant figures to which each emission source and sink category has been rounded can be found in table A13-1.

Most of the uncertainty ranges that are used for various source categories were developed by Monte Carlo analysis, as performed by ICF Consulting (ICF, 2004, 2005), using the 2001 inventory estimates (submitted in NIR 2003). Default uncertainty values as published by IPCC (IPCC/OECD/IEA, 1997; IPCC, 2001), and those resulting from expert elicitation were also utilized for some ranges. It should be noted that the uncertainty values used for this analysis did not consider the uncertainty embodied in the GWP.

Uncertainty ranges have been calculated around the mean emission value, 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 the categories in 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: equal to and greater than 50%;
- two significant figures: between 10% and 50%; and
- three significant figures: 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 study, have been used to develop the estimates for the 2007 UNFCCC submission. For this Sector, the number of significant figures for each category was determined by expert opinion (elicitation).

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. Therefore, 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		Greenhouse Gases						TOTAL
		CO ₂	CH ₄	N ₂ O	HFCs	PFCs	SF ₆	
TOTAL		3	2	2	2	2	2	3
ENERGY		3	2	1				3
a.	Stationary Sources	3	1	1				3
	Electricity and Heat Generation	3	2	1				3
	Fossil Fuel Industries	3	1	1				2
	Petroleum Refining	2	1	1				2
	Fossil Fuel Production	3	1	1				3
	Mining	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.	Transportation	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 and 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.	Fugitives	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
INDUSTRIAL PROCESSES		2		3	2	2	2	3
a.	Mineral Production	2						2
	Cement	2						2
	Lime	2						2
	Mineral Product Use	3						3
b.	Chemical Industry	2		3				2
	Ammonia Production	2						2
	Nitric Acid Production			3				3
	Adipic Acid Production			2				2
c.	Metal Production	3				2	3	3
	Iron and Steel Production	3						3
	Aluminum Production	2				2	3	2
	SF ₆ Used in Magnesium Smelters and Casters						3	3
d.	Consumption of Halocarbons and SF₆				2	1	2	2
e.	Other & Undifferentiated Production	2						2
SOLVENT AND OTHER PRODUCT USE				2				2
AGRICULTURE			2	2				2
a.	Enteric Fermentation		2					2
b.	Manure Management		2	2				2
c.	Agriculture Soils			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
LAND USE, LAND-USE CHANGE AND FORESTRY		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

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Annex 14 Ozone and Aerosol Precursors

National summary tables for SO_x, NO_x, CO, and NMVOCs are included in this annex. These gases are reported to the UNECE by the CAC Division at Environment Canada under the Convention on Long Range Transboundary Air Pollution. As recommended by the Conference of Parties to the UNFCCC (FCCC/SBSTA/2004/8), Annex I Parties should provide information on indirect GHGs such as CO, NO_x, NMVOCs, and SO_x 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_x. 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 CO₂ 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
	kt CO															
National Total	15171	14265	14433	13974	13591	13658	12537	12253	11627	11667	11381	11060	10921	10728	10206	9372
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
1 A 1 b Petroleum Refining	13	13	13	19	19	18	18	19	19	19	17	17	59	16	16	16
1 A 1 c Manufacture of Solid Fuels and Other Energy Industries	193	186	196	216	245	262	272	305	318	328	339	355	379	430	466	397
1 A 2 Manufacturing Industries and Construction	633	605	667	998	891	921	929	928	876	913	709	715	657	716	727	392
1 A 3 a ii (i) Civil Aviation (Domestic, LTO)	40	36	34	33	33	33	33	35	36	37	37	37	35	36	36	30
1 A 3 a ii (ii) Civil Aviation (Domestic, Cruise)	27	24	23	22	23	23	22	22	24	23	23	23	21	22	22	21
1 A 3 b Road Transportation	9561	9260	9262	8836	8508	7882	7357	7061	6438	6415	6410	6009	5732	5391	4731	4389
1 A 3 c Railways	22	22	21	21	23	23	22	23	22	20	21	21	22	23	20	16
1 A 3 d ii National Navigation	11	10	10	10	10	10	9	9	9	9	9	9	9	9	9	10
1 A 3 e Other	2086	2130	2174	2218	2262	2307	2309	2301	2322	2343	2370	2413	2461	2510	2556	2608
1 A 4 a Commercial / Institutional	5	5	5	6	6	6	6	6	6	6	8	10	7	11	11	20
1 A 4 b Residential	1041	650	645	619	637	632	623	626	626	623	676	655	729	679	690	704
1 A 4 c Agriculture / Forestry / Fishing	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
1 A 5 b Other, Mobile (Including military)	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
1 B 2 Oil and Natural Gas	37	36	37	32	35	37	38	42	44	45	84	94	101	126	146	119
2 A Mineral Products ¹	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	18.7
2 B Chemical Industry	16	16	16	21	21	21	21	21	21	21	21	20	14	23	25	13
2 C Metal Production	360	320	313	339	311	326	312	330	328	316	254	275	403	333	340	471
2 D Other Production ¹	54	63	61	111	114	104	107	107	107	110	102	101	96	85	86	58
2 G Other	24	23	25	34	32	31	32	32	31	32	30	30	30	30	30	21
3 A Paint Application	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
3 C Chemical Products, Manufacture and Processing	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
4 B Manure Management ²	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
4 D 1 Direct Soil Emission	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
4 G Other ³	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
6 A Solid Waste Disposal on Land	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
6 C Waste Incineration ⁴	10	10	9	6	5	5	5	5	5	5	6	7	11	7	7	8
6 D Other Waste ⁵	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

Notes:

1 Including product handling.

2 Including NH₃ 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
	kt NO _x															
National Total	2390	2434	2420	2366	2451	2455	2371	2426	2440	2418	2463	2478	2473	2493	2491	2379
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
1 A 1 b Petroleum Refining	30	26	26	23	22	23	22	22	22	22	24	22	24	22	22	24
1 A 1 c Manufacture of Solid Fuels and Other Energy Industries	203	196	208	234	265	280	293	334	336	353	371	391	431	477	520	457
1 A 2 Manufacturing Industries and Construction	98	174	172	134	136	144	132	134	133	134	114	112	135	118	121	125
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
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
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
1 A 3 c Railways	114	115	112	111	118	118	114	122	114	107	109	118	120	111	112	117
1 A 3 d ii National Navigation	135	129	130	123	127	125	117	118	118	113	111	111	112	114	115	117
1 A 3 e Other	387	395	404	412	421	430	435	439	441	442	442	440	438	434	426	419
1 A 4 a Commercial / Institutional	24	24	24	29	30	29	29	29	29	29	30	32	34	38	36	34
1 A 4 b Residential	49	46	46	45	47	46	45	46	46	45	47	46	47	46	46	45
1 A 4 c Agriculture / Forestry / Fishing	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
1 A 5 b Other, Mobile (Including military)	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
1 B 2 Oil and Natural Gas	25	24	25	25	24	24	24	24	24	23	52	58	31	74	85	79
2 A Mineral Products ¹	34	27	27	32	32	34	31	31	34	31	33	32	38	34	34	40
2 B Chemical Industry	21	26	27	27	28	28	24	26	25	25	29	29	23	29	29	19
2 C Metal Production	-3	36	35	14	14	14	14	14	14	16	12	11	12	13	14	12
2 D Other Production ¹	30	30	30	24	25	26	24	24	24	24	23	23	25	23	24	20
2 G Other	19	20	20	20	20	20	19	19	19	19	15	15	21	16	16	22
3 A Paint Application	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
3 C Chemical Products, Manufacture and Processing	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
4 B Manure Management ²	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
4 D 1 Direct Soil Emission	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	NA
4 F Field Burning of Agricultural Wastes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4 G Other ³	0	0	0	1	1	0	1	1	1	1	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
6 A Solid Waste Disposal on Land	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
6 C Waste Incineration ⁴	2	3	2	3	3	3	3	3	3	3	6	6	7	6	6	4
6 D Other Waste ⁵	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

Notes:

1 Including product handling.

2 Including NH₃ 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_x) consists of nitric oxide (NO) and nitrogen dioxide (NO₂) and are reported as NO_x on a NO₂ 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
	kt NMVOC															
National Total	2808	2590	2586	2321	2333	2471	2273	2249	2236	2207	2443	2438	2420	2473	2472	2256
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
1 A 1 b Petroleum Refining	6	6	6	3	3	3	3	3	3	3	2	2	1	2	2	1
1 A 1 c Manufacture of Solid Fuels and Other Energy Ind	9	9	10	11	11	12	12	12	13	12	13	12	12	12	12	12
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
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
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
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
1 A 3 c Railways	6	6	6	6	6	6	6	6	6	5	6	6	6	5	5	3
1 A 3 d ii National Navigation	10	9	9	9	9	9	8	8	8	8	8	7	8	8	8	8
1 A 3 e Other	294	299	303	308	313	318	312	305	305	307	310	309	310	309	305	299
1 A 4 a Commercial / Institutional	0	0	0	0	0	0	0	0	0	0	0	1	0	2	2	0
1 A 4 b Residential	347	145	144	137	140	139	137	138	138	138	150	145	162	150	153	155
1 A 4 c Agriculture / Forestry / Fishing	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
1 A 5 b Other, Mobile (Including military)	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 B 2 Oil and Natural Gas	557	567	591	590	603	625	657	657	677	651	680	709	669	736	750	657
2 A Mineral Products ¹	5	5	4	4	4	3	4	4	4	4	2	2	2	1	1	0
2 B Chemical Industry	31	31	30	23	23	22	22	22	22	22	11	12	11	15	17	8
2 C Metal Production	20	18	18	18	18	17	18	18	18	18	15	16	3	15	15	4
2 D Other Production ¹	20	22	22	27	28	27	27	27	27	27	25	27	29	27	27	26
2 G Other	112	111	110	111	112	113	111	112	112	112	123	153	141	150	153	123
3 A Paint Application	148	153	147	121	119	127	111	119	116	113	102	95	94	107	109	66
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
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
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
4 B Manure Management ²	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	300.3
4 C Rice Cultivation	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
4 F Field Burning of Agricultural Wastes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4 G Other ³	174	165	150	14	13	174	15	13	13	13	215	198	272	205	209	0
5 B Forest and Grassland Conversion	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6 A Solid Waste Disposal on Land	7	5	5	5	5	7	5	5	5	5	9	7	8	7	7	13
6 B Wastewater Handling	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6 C Waste Incineration ⁴	2	2	2	2	2	2	2	2	2	2	2	2	3	2	2	2
6 D Other Waste ⁵	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7 Other	45	37	40	23	23	46	23	21	22	22	15	15	11	16	16	5

Notes:

1 Including product handling.

2 Including NH₃ 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 kt SO _x	1998	1999	2000	2001	2002	2003	2004	2005
National Total	3143	3497	3009	2347	2310	2446	2359	2389	2386	2365	2265	2312	2273	2228	2304	2066
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
1 A 1 b Petroleum Refining	102	109	110	137	126	120	120	124	122	124	101	100	84	95	96	78
1 A 1 c Manufacture of Solid Fuels and Other Energy Industries	163	157	165	182	204	215	222	249	244	250	265	274	278	324	348	197
1 A 2 Manufacturing Industries and Construction	266	278	280	203	209	203	226	219	207	212	129	133	137	135	136	155
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 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
1 A 3 b Road Transportation	35	33	34	38	40	31	27	30	22	21	21	21	18	14	9	8
1 A 3 c Railways	5	5	5	5	5	5	5	6	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
1 A 3 e Other	24	22	24	26	23	21	24	27	16	16	15	17	16	16	16	17
1 A 4 a Commercial / Institutional	20	19	20	13	13	14	13	13	13	13	20	22	21	39	39	37
1 A 4 b Residential	33	33	33	18	19	19	18	19	19	18	16	16	13	15	15	13
1 A 4 c Agriculture / Forestry / Fishing	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
1 A 5 b Other, Mobile (Including military)	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
1 B 2 Oil and Natural Gas	175	177	185	199	194	193	189	190	192	188	121	123	130	132	137	168
2 A Mineral Products ¹	34	39	37	28	29	31	27	28	29	28	30	31	38	31	31	36
2 B Chemical Industry	8	4	5	4	4	5	3	3	3	3	7	6	8	7	6	12
2 C Metal Production	1468	1799	1322	856	808	971	844	858	879	845	829	869	836	721	778	743
2 D Other Production ¹	33	36	36	18	19	18	18	18	18	18	17	18	18	18	18	15
2 G Other	19	17	16	12	12	12	12	12	12	12	6	9	9	9	9	20
3 A Paint Application	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
3 C Chemical Products, Manufacture and Processing	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
4 B Manure Management ²	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
4 D 1 Direct Soil Emission	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
4 G Other ³	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
6 A Solid Waste Disposal on Land	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
6 C Waste Incineration ⁴	2	2	2	1	1	1	1	1	1	1	1	2	2	2	2	3
6 D Other Waste ⁵	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7 Other	6	7	7	4	6	5	11	9	6	6	1	1	1	2	2	1

Notes:

1 Including product handling.

2 Including NH₃ 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.