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# National Inventory Report

1990–2012

GREENHOUSE GAS SOURCES  
AND SINKS IN CANADA

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

Part 1



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## **Readers' Comments**

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# Foreword

Canada ratified the United Nations Framework Convention on Climate Change (UNFCCC) on December 4, 1992. Under Decisions 3/CP.1, 9/CP.2 and 3/CP.5 of the UNFCCC, national inventories for UNFCCC Annex I Parties are to be submitted to the UNFCCC Secretariat each year, by April 15. As such, this report represents Canada's annual inventory submission under the Framework Convention.

Under the Copenhagen Accord, Canada committed to reducing its greenhouse gas emissions to 17 per cent below 2005 levels by the year 2020. On the international stage, Canada continues to play an active role in the UNFCCC, and is working constructively with other countries to negotiate a new international climate change agreement with legally binding commitments for all major emitters to be implemented by 2020.

The UNFCCC monitoring, reporting and review guidelines for national inventories incorporate the methodological Good Practice Guidance that has been developed by the Intergovernmental Panel on Climate Change. The reporting guidelines stipulate how emission estimates are to be prepared and what is to be included in the annual inventory report. They also commit Parties to improve the quality of national and regional emissions and removals estimates on an ongoing basis. Areas for improvement include both the quality of input data and the methodologies

utilized to develop emission and removal estimates. These improvements, and subsequent recalculations of inventory estimates, are described within the report.

Environment Canada, in consultation with a range of stakeholders, is responsible for preparing Canada's official national inventory. This National Inventory Report, prepared by the technical experts and scientists of the Pollutant Inventories and Reporting 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, and yearly from 1996 to 2013. In addition to the description and explanation of inventory data, the inventory report contains analysis of recent trends in emissions and removals, as well as information on Canada's National System.

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 variety of research activities, only a limited number have focused on measuring emissions or developing better emission estimates. Ongoing work, both in Canada and elsewhere, will continue to improve the estimates and reduce uncertainties associated with them.

April 2014

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# List of Acronyms, Abbreviations and Units

AAC	Aluminum Association of Canada
AAFC	Agriculture and Agri-Food Canada
AC	air conditioning
AER	Alberta Energy Regulator
AGEM	Aviation Greenhouse Gas Emission Model
AIA	Association de l'industrie d'aluminium du Québec
Al	aluminium
Al <sub>2</sub> O <sub>3</sub>	alumina
API	American Petroleum Institute
ASH	manure ash content
Asha	Ash content in baked anodes
Ashp	Ash content in pitch
ATV	all-terrain vehicle
AWMS	animal waste management system
BADA	Base of Aircraft Data
B <sub>0</sub>	maximum methane production potential
BC	average binder content in paste
BOF	basic oxygen furnace
BOD <sub>5</sub>	five-day biochemical oxygen demand
BSM	emissions of benzene-soluble matter
C	carbon
CAC	Criteria Air Contaminant
CaC <sub>2</sub>	calcium carbide
CaCO <sub>3</sub>	calcium carbonate; limestone
CaMg(CO <sub>3</sub> ) <sub>2</sub>	dolomite (also CaCO <sub>3</sub> •MgCO <sub>3</sub> )
CanFI	Canada's National Forest Inventory
CANSIM	Statistics Canada's key socioeconomic database
CanSIS	Canadian Soil Information System
CanWEA	Canadian Wind Energy Association
CaO	lime; quicklime; calcined limestone
CAPP	Canadian Association of Petroleum Producers
CBM	Carbon Budget Model
CBM-CFS3	Carbon Budget Model for the Canadian Forest Sector, version 3
CC	baked anode consumption per tonne of aluminium
CEA	Canadian Electricity Association
CEPA	1999 <i>Canadian Environmental Protection Act, 1999</i>
CESI	Canadian Environmental Sustainability Indicators
CF <sub>4</sub>	carbon tetrafluoride
C <sub>2</sub> F <sub>6</sub>	carbon hexafluoride
CFC	chlorofluorocarbon
CFS	Canadian Forest Service
CGA	Canadian Gas Association
CH <sub>3</sub> OH	methanol
CH <sub>4</sub>	methane
C <sub>2</sub> H <sub>6</sub>	ethane
C <sub>3</sub> H <sub>8</sub>	propane
C <sub>4</sub> H <sub>10</sub>	butane
C <sub>2</sub> H <sub>4</sub>	ethylene

C <sub>6</sub> H <sub>6</sub>	benzene
CHCl <sub>3</sub>	chloroform
CIEEDAC	Canadian Industrial Energy End-Use Data Analysis Centre
CKD	cement kiln dust
CLRTAP	Convention on Long-range Transboundary Air Pollution
CO	carbon monoxide
CO <sub>2</sub>	carbon dioxide
CO <sub>2</sub> eq	carbon dioxide equivalent
COD	chemical oxygen demand
CORINAIR	Core Inventory of Air Emissions in Europe
CPPI	Canadian Petroleum Products Institute
CRF	Common Reporting Format
CSPA	Canadian Steel Producers Association
CTS	crop and tillage system
CVS	Canadian Vehicle Survey
DE	digestible energy
DM	dry matter
DMI	dry matter intake
DOC	dissolved organic carbon (for LULUCF sector)
DOC	degradable organic carbon (for Waste sector)
DOCF	degradable organic carbon dissimilated
DOM	dead organic matter
EAF	electric arc furnace
EC	Environment Canada
EDC	ethylene dichloride
EF	emission factor
EF <sub>BASE</sub>	basic emission factor
EMEP	European Monitoring and Evaluation Programme
EPA	Environmental Protection Agency (United States)
EPGTD	Electric Power Generation, Transmission and Distribution
eq	equivalent
ERCB	Energy Resources Conservation Board
ERT	Expert Review Team
EU	European Union
FAA	Federal Aviation Administration (United States)
FAACS	Feasibility Assessment of Afforestation for Carbon Sequestration
FCR	fuel consumption ratio
FGD	flue gas desulphurization
FLCL	forest land converted to cropland
FLWL	forest land converted to wetland
FOI	Swedish Defence Research Agency
FTILL	tillage ratio factor
GCD	great-circle distance
GCV	gross calorific value
GDP	gross domestic product
GE	gross energy
GHG	greenhouse gas
GHGRP	Greenhouse Gas Reporting Program
GIS	geographic information system
Gt	gigatonne
GRI	Gas Research Institute

GTIS	Global Trade Information Services
GVWR	gross vehicle weight rating
GWP	global warming potential
H <sub>2</sub>	hydrogen
H <sub>2</sub> O	water
H <sub>2</sub> S	hydrogen sulphide
HCFC	hydrochlorofluorocarbon
HCl	hydrochloric acid
HDD	heating degree-day
HDDV	heavy-duty diesel vehicle
HDGV	heavy-duty gasoline vehicle
HE	harvest emissions
HF	hydrogen fluoride
HFC	hydrofluorocarbon
HHV	higher heating value
HNO <sub>3</sub>	nitric acid
HQ	Hydro-Québec
HRAI	Heating, Refrigeration and Air Conditioning Institute of Canada
HSS	horizontal stud Söderberg
HWP	harvested wood product
HWP-C	carbon stored in harvested wood products
IAI	International Aluminium Institute
ICAO	International Civil Aviation Organization
IE	included elsewhere
IEA	International Energy Agency
IESO	Independent Electricity System Operator
I/M	inspection and maintenance
Impa	fluorine and other impurities
IPCC	Intergovernmental Panel on Climate Change
IT	intensive tillage
KAR	kilometre accumulation rate
K <sub>2</sub> CO <sub>3</sub>	potassium carbonate
kg	kilogram
kha	kilohectare
kt	kilotonne
kWh	kilowatt-hour
L <sub>0</sub>	methane generation potential
LDDT	light-duty diesel truck
LDDV	light-duty diesel vehicle
LDGT	light-duty gasoline truck
LDGV	light-duty gasoline vehicle
LFG	landfill gas
LHV	lower heating value
LMC	land management change
LPG	liquefied petroleum gas
LTO	landing and takeoff
LULUCF	Land Use, Land-use Change and Forestry
m	metre
MARS	Monitoring, Accounting and Reporting System
MC	motorcycle
MCF	methane conversion factor (Agriculture)



MCF	methane correction factor (Waste)
Mg	magnesium; also megagram
MgCO <sub>3</sub>	magnesite; magnesium carbonate
MGEM	Mobile Greenhouse Gas Emission Model
MgO	magnesia; dolomitic lime
Mha	megahectare, equivalent to a million hectares
MMIC	Motorcycle & Moped Industry Council
MODTF	Modeling and Database Task Force
mol	mole
MP	total aluminum production
MS	manure system distribution factor
MSW	municipal solid waste
Mt	megatonne
MTOW	maximum takeoff weight
MW	megawatt
N	nitrogen
N <sub>2</sub>	nitrogen gas
Na <sub>2</sub> CO <sub>3</sub>	sodium carbonate; soda ash
Na <sub>3</sub> AlF <sub>6</sub>	cryolite
NA	not applicable
N/A	not available
NAICS	North American Industry Classification System
NCASI	National Council for Air and Stream Improvement
NCV	net calorific value
NE	not estimated
NEB	National Energy Board
NEU	non-energy use
NFR	nomenclature for reporting
NGL	natural gas liquid
NH <sub>3</sub>	ammonia
NH <sub>4</sub> <sup>+</sup>	ammonium
NH <sub>4</sub> NO <sub>3</sub>	ammonium nitrate
NIR	National Inventory Report
NMVOC	non-methane volatile organic compound
N <sub>2</sub> O	nitrous oxide
NO	nitric oxide; also used for not occurring
NO <sub>2</sub>	nitrogen dioxide
NO <sub>3</sub>	nitrate
NO <sub>x</sub>	nitrogen oxides
NOC	Nitrous Oxide of Canada
NPRI	National Pollutant Release Inventory
NRCan	Natural Resources Canada
NSCR	non-selective catalytic reduction
NT	no tillage
O <sub>2</sub>	oxygen
ODS	ozone-depleting substance
OECD	Organisation for Economic Co-operation and Development
OEM	original equipment manufacturer
OS/HOU	oil sands and heavy oil upgrading
PC	paste consumption
PFC	perfluorocarbon

PJ	petajoule
POP	persistent organic pollutant
P/PE	precipitation/potential evapotranspiration
PTRC	Petroleum Technology Research Centre
QA	quality assurance
QC	quality control
RA	reference approach
RES D	<i>Report on Energy Supply and Demand in Canada</i>
RPP	refined petroleum product
RT	reduced tillage
RTI	Research Triangle Institute
SA	sectoral approach
Sa	sulphur content in baked anodes
SAGE	System for assessing Aviation's Global Emissions
SBR	styrene-butadiene
Sc	sulphur content in calcinated coke
SCR	selective catalytic reduction
SF <sub>6</sub>	sulphur hexafluoride
SIC	Standard Industrial Classification
SiC	silicon carbide
SLC	Soil Landscapes of Canada
SMR	steam methane reforming
SO <sub>2</sub>	sulphur dioxide
SO <sub>x</sub>	sulphur oxides
SOC	soil organic carbon
Sp	sulphur content in pitch
SUV	sport utility vehicle
t	tonne
TWh	terrawatt-hour
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
UPCIS	Use Patterns and Controls Implementation Section
UOG	upstream oil and gas
VCM	vinyl chloride monomer
VKT	vehicle kilometres travelled
VSS	vertical stud Söderberg
VS	volatile solids
WMO	World Meteorological Organization

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# Executive Summary

## ES.1 Introduction

The United Nations Framework Convention on Climate Change (UNFCCC) is an international treaty established in 1992 to cooperatively tackle climate change issues. The ultimate objective of the UNFCCC is to stabilize atmospheric greenhouse gas (GHG) concentrations at a level that would prevent dangerous interference with the climate system. Canada ratified the UNFCCC in December 1992, and the Convention came into force in March 1994. At the 15th session of the Conference of the Parties (COP15) to the UNFCCC in 2009, Canada signed the Copenhagen Accord, under which Canada has committed to reducing its GHG emissions to 17% below the 2005 level by the year 2020.<sup>1</sup>

To achieve its objective and implement its provisions, the UNFCCC lays out several guiding principles and commitments. Specifically, Articles 4 and 12 commit all Parties to develop, periodically update, publish and make available to the COP the national inventories of anthropogenic emissions by sources and removals by sinks of all GHGs not controlled by the Montreal Protocol.<sup>2</sup>

Canada's National Inventory is prepared and submitted annually to the UNFCCC by April 15 of each year, in accordance with the December 2005 version of the *Guidelines for the preparation of national communications by Parties included in Annex I to the Convention, Part I: UNFCCC reporting guidelines for national inventories*. The annual inventory submission consists of the National Inventory Report (NIR) and the Common Reporting Format (CRF) Tables.

The inventory estimates include carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), sulphur hexafluoride (SF<sub>6</sub>), perfluorocarbons (PFCs) and hydrofluorocarbons (HFCs), in the following six Intergovernmental Panel on Climate Change (IPCC) sectors: Energy, Industrial Processes, Solvent and Other Product Use, Agriculture, Waste, and Land Use, Land-Use Change and Forestry (LULUCF). The GHG emission and removal estimates contained within Canada's GHG inventory are developed using methodologies consistent with the inventory guidelines

prepared by the IPCC. Given that the underlying data and methodology for estimating emissions are revised over time, emissions levels in all years are subject to change as both data and methods are improved.

Section ES.2 summarizes the latest information on Canada's net anthropogenic GHG emissions over the period 1990–2012, and links this information to relevant indicators of the Canadian economy. Section ES.3 outlines the major trends in emissions from each of the IPCC sectors.

There are several methods to categorize the sources of GHG emissions. For the purposes of analyzing trends and policies, it is useful to allocate emissions to the economic sector from which they originate. As such, this report also presents emissions by the following economic sectors: Oil and Gas, Electricity, Transportation, Emissions Intensive and Trade Exposed Industries, Buildings, Agriculture, Waste and Others. This is the approach taken for reporting against Canada's Copenhagen target<sup>3</sup> in the annual *Canada's Emissions Trends* report (Environment Canada 2013) as well as *Canada's Sixth National Communication and First Biennial Report* (Environment Canada 2014). Throughout this report, the word "Sector" generally refers to activity sectors as defined by the IPCC for national GHG inventories; exceptions occur when the expression "economic sectors" is used in reference to the Canadian context. Section ES.4 presents a synopsis of GHG emissions by economic sector, consistent with that submitted to the UNFCCC.

Canada is a geographically large federation composed of a federal government, 10 provincial governments, and three territories. Natural resources, including energy, fall mainly under provincial jurisdiction. Section ES.5 details GHG emissions for Canada's 13 sub-national jurisdictions.

Canada's annual inventory submission to the UNFCCC embodies over a decade of learning and improvements. Section ES.6 provides some detail on the components of this submission, and outlines key elements of its preparation.

## ES.2 Overview, National GHG Emissions

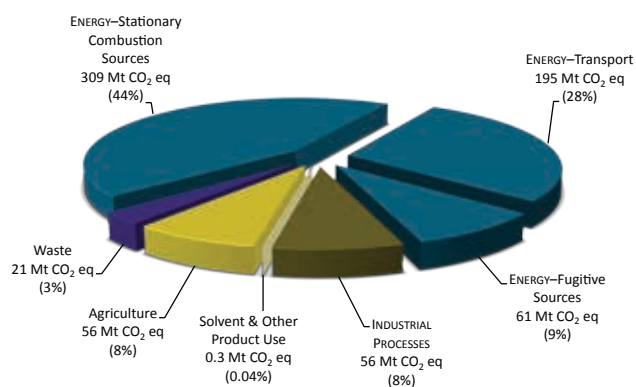
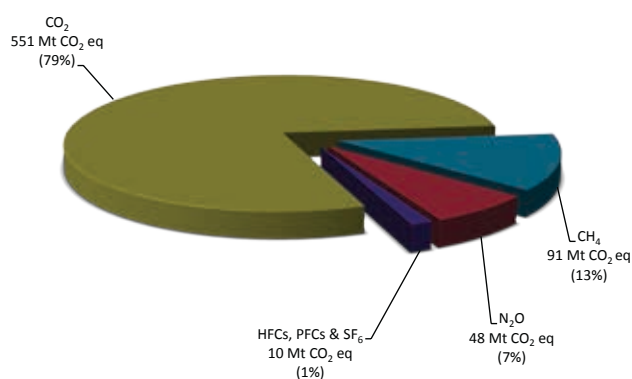
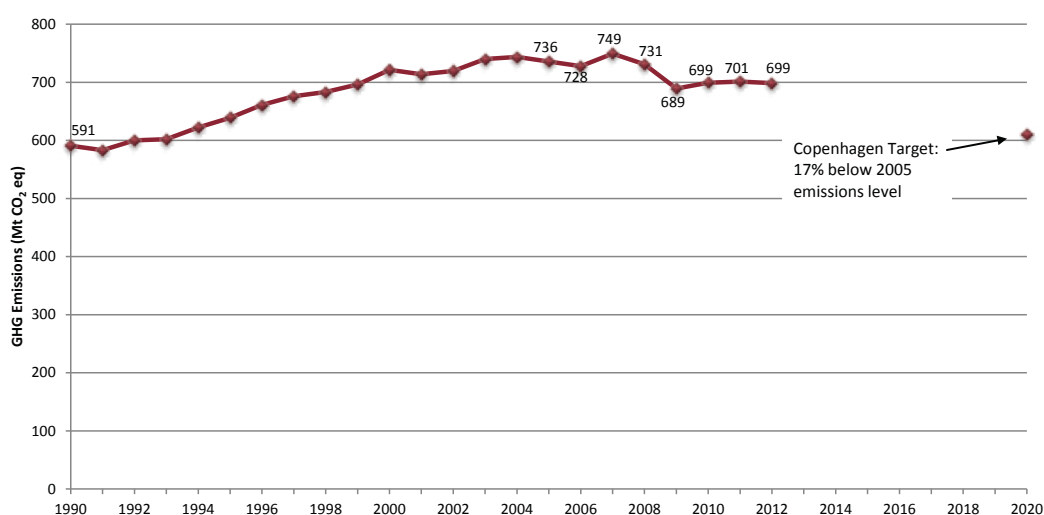
In 2012, the most recent annual dataset in this report, Canada's total GHG emissions were estimated to be 699 megatonnes of carbon dioxide equivalent (Mt CO<sub>2</sub> eq<sup>4</sup>), excluding LULUCF estimates. The Energy Sector (consisting of the Stationary Combustion Sources, Transport, and Fugitive Sources subsectors) accounted for the majority of Canada's GHG total emissions in 2012, at 81% or 566 Mt (Figure S–1). The remaining 19% of total emissions was largely generated by sources within the Agricul-

1 See <http://www.climatechange.gc.ca/default.asp?lang=En&n=AA3F6868-1>.

2 Under the United Nations Environment Programme (UNEP), the Montreal Protocol on Substances that Deplete the Ozone Layer is an international agreement designed to reduce the global consumption and production of ozone-depleting substances.

3 See <http://www.climatechange.gc.ca/default.asp?lang=En&n=AA3F6868-1>.

4 Unless explicitly stated otherwise, all emission estimates given in Mt represent emissions of GHGs in Mt CO<sub>2</sub> equivalent.

**Figure S–1 Canada's Emissions Breakdown by IPCC Sector (2012)**Total: 699 Mt CO<sub>2</sub> eq**Figure S–2 Canada's Emissions Breakdown by Greenhouse Gas (2012)****Figure S–3 Canadian GHG Emissions Trend (1990–2012) and Copenhagen Target**

ture Sector (8% of total emissions) and Industrial Processes Sector (8%), with minor contributions from the Waste Sector (3%). The LULUCF Sector was a net source of 41 Mt in 2012; in accordance with UNFCCC reporting guidelines, these emissions are excluded from national inventory totals.

In 2012, CO<sub>2</sub> contributed 79% of Canada's total emissions (Figure S–2). The majority of these emissions result from the combustion of fossil fuels. CH<sub>4</sub> accounted for 13% of Canada's total emissions, largely from fugitive emissions from oil and natural gas systems, as well as domestic livestock and landfills. N<sub>2</sub>O emissions, from activities such as agriculture soil management and transportation, accounted for 7% of emissions. Emissions of the synthetic gases (PFCs, SF<sub>6</sub> and HFCs) constituted the remainder (slightly more than 1%).

Canada's emissions in 2012 were 108 Mt (18%) above the 1990 total of 591 Mt (Figure S–3). Steady increases in annual emissions

characterized the first 15 years of this period, followed by fluctuating emission levels between 2005 and 2008, a steep drop in 2009, and more stable values thereafter. Between 2005 and 2012, emissions decreased by 37 Mt (5%), primarily due to decreases in the Electricity and Heat Generation subsector and Manufacturing Industries subsector (Table S–2).

Though GHG emissions have risen by 18% since 1990, Canada's economy grew much more rapidly, with the Gross Domestic Product (GDP) rising by 67%. As a result, the emission intensity for the entire economy (GHG per GDP) has improved considerably, dropping by 29% (Figure S–4 and Table S–1). Early in the period, emissions rose nearly in step with economic growth, with their paths beginning to diverge in 1995 (Figure S–4). In 1995, GHG emissions started to decouple from economic growth, a shift that can be attributed to increases in efficiency, the modernization of industrial processes, and structural changes in the economy. These long-term trends have led to continued

Figure S-4 Indexed Trend in GHG Emissions and GHG Emissions Intensity (1990–2012)

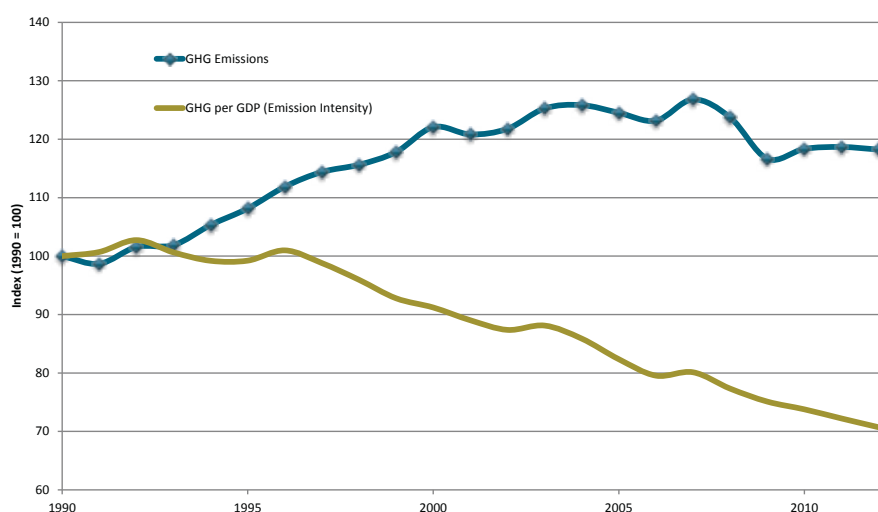
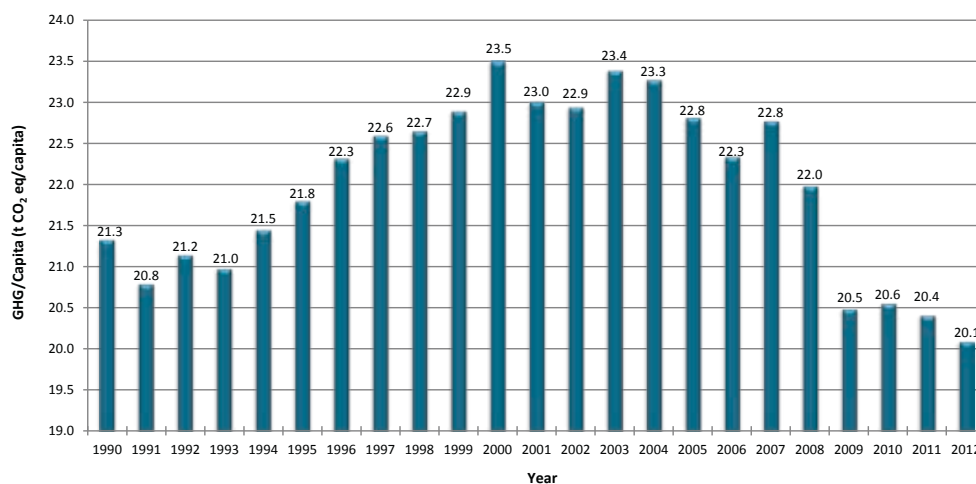


Table S-1 Trends in Emissions and Economic Indicators, Selected Years

Year	1990	2000	2005	2008	2009	2010	2011	2012
<b>Total GHG (Mt)</b>	591	721	736	731	689	699	701	699
Change Since 2005 (%)	NA	NA	NA	-0.6%	-6.3%	-5.0%	-4.7%	-5.1%
Change Since 1990 (%)	NA	22.1%	24.5%	23.7%	16.7%	18.3%	18.7%	18.2%
<b>GDP (Billions 2007\$)</b>	989	1 324	1 496	1 583	1 537	1 587	1 626	1 654
Change Since 2005 (%)	NA	NA	NA	5.8%	2.7%	6.1%	8.7%	10.6%
Change Since 1990 (%)	NA	33.8%	51.2%	60.0%	55.3%	60.4%	64.3%	67.2%
<b>GHG Intensity (Mt/\$B GDP)</b>	0.60	0.54	0.49	0.46	0.45	0.44	0.43	0.42
Change Since 2005 (%)	NA	NA	NA	-6.1%	-8.8%	-10.4%	-12.3%	-14.1%
Change Since 1990 (%)	NA	-8.8%	-17.6%	-22.7%	-24.9%	-26.2%	-27.8%	-29.3%

GDP Data Source: Statistics Canada. Table 380-0106 - Gross domestic product at 2007 prices, expenditure-based, annual (dollars), CANSIM (database).

Figure S-5 Canadian per Capita Greenhouse Gas Emissions (1990–2012)



Population data source: Statistics Canada (2013a)

improvement in emissions intensity since the late 1990s. Chapter 2 provides more information on trends in GHG emissions.

Canada represented less than 2% of total global GHG emissions in 2010 (CAIT 2013), although it is one of the highest per capita emitters, largely as a result of its size, climate (i.e. climate-driven energy demands) and resource-based economy. In 1990, Canadians released 21.3 tonnes (t) of GHGs per capita. In 2005 this had risen to 22.8 t; however, by 2012, it had dropped to an historic low of 20.1 t of GHGs per capita (Figure S–5).

## ES.3 Emissions and Trends by IPCC Sectors

### Overall Trends in Emissions

Over the period 1990–2012, total emissions grew by 108 Mt or 18%. This was driven mainly by a 97 Mt CO<sub>2</sub> eq (21%) increase in the Energy Sector. Increases were seen across all other sectors as well: 9 Mt CO<sub>2</sub> eq (19%) in the Agriculture Sector, 2 Mt CO<sub>2</sub> eq (8%) in the Waste Sector, 1 Mt CO<sub>2</sub> eq (1%) in the Industrial Processes Sector, and 0.1 Mt CO<sub>2</sub> eq (74%) in the Solvent and Other Product Use Sector (Figure S–6).

Table S–2 provides additional details about Canada's emissions and removals by IPCC sector for the years 1990, 2000, 2005 and 2008–2012. Further breakdowns by subsector and gas, and a complete time series, can be found in Annex 12.

In contrast to the increase of emissions over the longer term (1990–2012), total Canadian GHG emissions have decreased by 37 Mt (5%) since 2005. The Stationary Combustion Sources subsector within the Energy Sector has been the largest driver

of the overall downward trend, dropping by 29 Mt since 2005 (Figure S–7), with the largest contributor to this reduction being the Electricity and Heat Generation category within this subsector, where emissions fell 35 Mt (28%). Emissions from the Industrial Processes Sector, Agriculture Sector, Fugitive Sources subsector within the Energy Sector, and Waste Sector have also dropped (by 4 Mt, 3 Mt, 2 Mt and 1 Mt, respectively), while emissions from the Transport subsector (also within the Energy Sector) increased by 2 Mt.

The following describes the emissions and trends of each IPCC sector in further detail.

### Energy—2012 GHG Emissions (566 Mt)

#### Short-term Trends

In 2012, GHG emissions from the IPCC Energy Sector were 29 Mt (about 5%) below 2005 levels. Similar to the national trend, this decline was primarily driven by a decline in fossil fuel consumption for the Electricity and Heat Generation category and Manufacturing Industries category within the sector.

Decreasing generation by coal and oil sources, accompanied by an increase in hydro, nuclear and wind generation, was the largest driver of a 35 Mt (about 28%) decrease in emissions associated with Electricity and Heat Generation between 2005 and 2012. However, there were some fluctuations in emissions over that period, largely as a result of changes in the mix of electricity generation sources.<sup>5</sup> Chapter 2 provides more information on trends in GHG emissions.

5 The mix of electricity generation sources is characterized by the amount of fossil fuel vs. hydro, other renewable sources and nuclear sources. In general, only fossil fuel sources generate net GHG emissions.

Figure S–6 Trends in Canadian GHG Emissions by IPCC Sector (1990–2012)

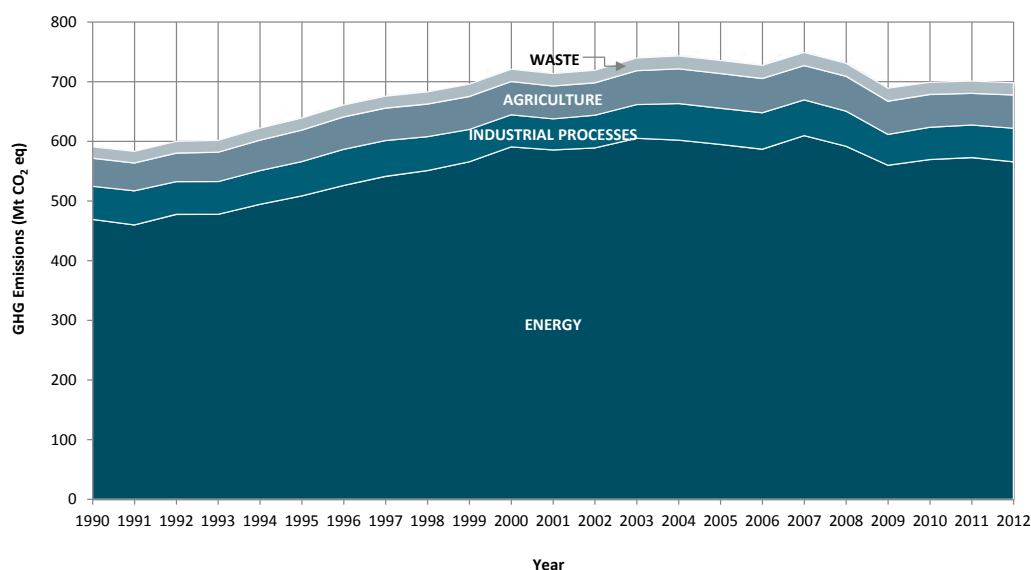


Table S-2 Canada's GHG Emissions by IPCC Sector (1990–2012)

Greenhouse Gas Categories		1990	2000	2005	2008	2009	2010	2011	2012
		Mt CO <sub>2</sub> equivalent							
TOTAL <sup>1,2</sup>		591	721	736	731	689	699	701	699
ENERGY		469	591	595	592	560	570	573	566
a.	Stationary Combustion Sources	280	347	338	334	313	313	316	309
	Electricity and Heat Generation	94	130	123	115	99	101	94	88
	Fossil Fuel Production and Refining	51	68	68	65	65	63	62	63
	Mining & Oil and Gas Extraction	7	12	19	30	32	35	36	41
	Manufacturing Industries	56	56	48	45	40	41	45	43
	Construction	2	1	1	1	1	1	1	1
	Commercial & Institutional	26	33	32	30	29	28	30	28
	Residential	43	45	44	46	44	41	44	41
	Agriculture & Forestry	2	3	2	3	3	3	3	4
b.	Transport	147	180	194	196	188	198	198	195
	Civil Aviation (Domestic Aviation)	7	8	8	7	6	6	6	6
	Road Transportation	97	118	130	132	132	134	132	132
	Railways	7	7	7	8	5	7	8	8
	Navigation (Domestic Marine)	5	5	7	7	7	7	6	6
	Other Transportation	31	43	42	42	38	44	46	43
c.	Fugitive Sources	42	63	63	62	59	58	60	61
	Coal Mining	2	1	1	1	1	1	1	1
	Oil and Natural Gas	40	62	62	61	58	57	59	60
INDUSTRIAL PROCESSES		56	54	60	59	52	54	55	56
a.	Mineral Products	8	10	10	9	7	8	8	8
b.	Chemical Industry	16	8	9	9	7	6	7	7
c.	Metal Production	23	23	20	19	15	16	17	16
d.	Production and Consumption of Halocarbons and SF <sub>6</sub>	1	3	5	6	7	7	8	8
e.	Other & Undifferentiated Production	7	10	16	16	16	17	15	17
SOLVENT & OTHER PRODUCT USE		0.2	0.4	0.4	0.3	0.3	0.2	0.2	0.3
AGRICULTURE		47	56	58	58	56	55	53	56
a.	Enteric Fermentation	16	20	22	20	19	18	17	18
b.	Manure Management	6	7	8	7	7	7	6	6
c.	Agriculture Soils <sup>3</sup>	25	29	29	31	30	30	29	32
WASTE		19	21	22	22	22	20	20	21
a.	Solid Waste Disposal on Land	17	19	20	20	20	19	19	19
b.	Wastewater Handling	1	1	1	1	1	1	1	1
c.	Waste Incineration	1	1	1	1	1	1	1	1
Land Use, Land-use Change and Forestry		-71	-52	53	-17	-27	76	77	41
a.	Forest Land	-98	-65	44	-26	-35	68	69	32
b.	Cropland	12	0	-4	-5	-5	-5	-5	-5
c.	Grassland	1	1	1	0	0	0	1	1
d.	Wetlands	5	3	3	3	3	3	3	3
e.	Settlements	9	9	10	10	9	10	10	10

## Notes:

1. National totals exclude all GHGs from the Land Use, Land-use Change and Forestry Sector.
2. These summary data are presented in more detail in Annex 12.
3. Includes emissions from Field Burning of Agricultural Residues.

■ Sectors shaded in grey represent those sectors with significant contributions to trends as described in Section ES.3

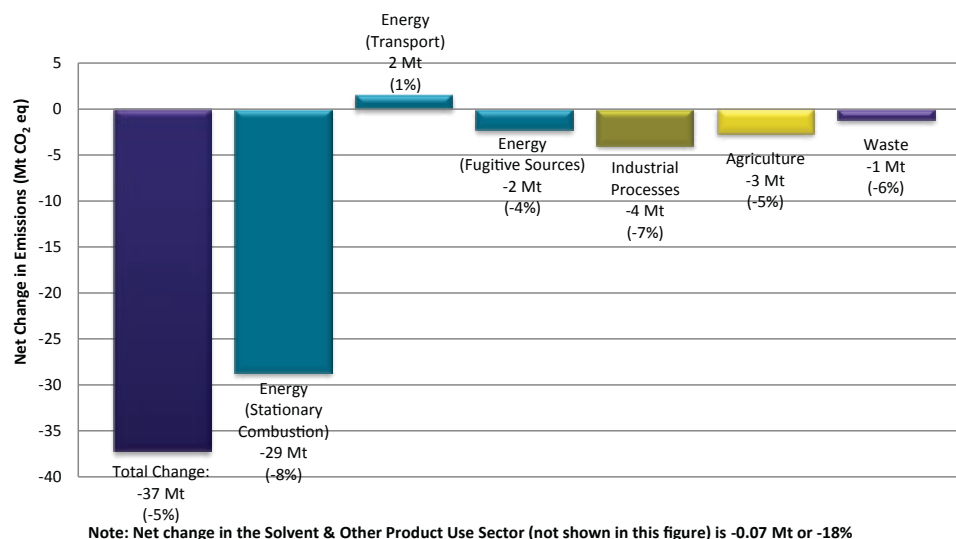
(GHG emissions from the Manufacturing Industries category dropped by 5.4 Mt (11%) between 2005 and 2012 while industries continue to recover from a decrease in production in 2009.

## Long-term Trends

The largest portion of Canada's total emissions growth is observed in the Energy Sector. The long-term sector emission trends (1990–2012) show a net growth of 97 Mt or 21%. As

described in Section ES.2, most of the growth in national emissions is observed in the Mining & Oil and Gas Extraction category and the Road Transportation category, which fall under the Energy Sector. The largest decreases in Energy Sector emissions were observed in the Manufacturing Industries category followed by the Electricity and Heat Generation category.

In 2012, emissions from the Mining & Oil and Gas Extraction category were about five times their 1990 values. Related to this

**Figure S-7 Short-term Emission Trends by IPCC Sector (2005–2012)**

has been a 72% increase in total production of crude oil and natural gas over the period. In addition, per-barrel GHG emissions from oil and gas production have been rising, due to an increase in the complexity of techniques used to produce conventional oil and to ongoing growth of oil production from the oil sands. However, the emissions intensity of oil sands operations declined steadily until about 2004, due to technological innovation and equipment turnover, increased reliability across operations, and the avoidance of upgrading emissions by exporting more crude bitumen. The most significant factor contributing to this overall trend has been declining rates of emissions associated with fuel combustion. Since 2004, the emissions intensity from oil sands operations has remained fairly static.

The majority of transportation emissions in Canada are related to the Road Transportation category, which dominated the GHG growth trend in this area. Emissions from Road Transportation rose by 35.8 Mt (37%) between 1990 and 2012. However, as vehicles are becoming more efficient, the rate of growth in emissions from Road Transportation has slowed, and emissions from this category have remained stable since 2008.

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 2013). In addition, the use of light trucks, a vehicle class that includes sport-utility vehicles and minivans, increased much more rapidly than cars. Given that light trucks have higher fuel consumption than cars, this shift also drove emission increases (NRCan 2013).

Emissions from heavy-duty diesel vehicles (large freight trucks) rose by 21.7 Mt (109%) between 1990 and 2012. Growth in emissions reflected a 137% increase in tonne-kilometres shipped by for-hire trucking between 1990 and 2003 (Statistics Canada

2013b). Between 2004 and 2011, tonne-kilometres shipped oscillated between +4% (2004–2005) and -7% (2008–2009), and ultimately resulted in zero growth across the seven-year period (Statistics Canada 2013c).

### Industrial Processes—2012 GHG Emissions (56.5 Mt)

The Industrial Processes Sector covers GHG emissions arising from non-energy sources such as limestone calcination (CO<sub>2</sub>) in cement production, or the use of HFCs and PFCs as replacement refrigerants for ozone-depleting substances (ODSs). Since 1990 the emissions in this sector have fluctuated, with peaks in 1996 and 2004; in 2012 emissions were 1.3% (0.75 Mt) above their 1990 level, and 3.3% (1.8 Mt) above the 2011 level. Of note in this sector is the rapid increase in emissions from the use of HFCs as refrigerants in place of ODSs, an increase of 2.5 Mt (47%) since 2005.

In the Metal Production category, CO<sub>2</sub> emissions from production of iron and steel have been fairly stable since the early 1990s, despite moderate increases in steel production, indicating the effect of increased use of recycled steel in Canadian steelmaking operations. The year 2009 saw a significant decline in production, followed by a gradual recovery from 2010 to 2012. The aluminium industry, while increasing its production by almost 100% since 1990, shows a reduction of its process emissions by 33% (3.1 Mt), largely due to emission control technology introduced by the sector to mitigate PFC emissions. The 57% reduction achieved overall in GHG emissions from industrial chemical processes between 1990 and 2012 is primarily a result of closure of an adipic acid plant in Ontario. Decreases were partly offset by increases in emissions within the Ammonia Production and Nitric Acid Production categories.



## Agriculture—2012 GHG Emissions (56 Mt)

Canadian agriculture can be differentiated into livestock and crop production components. The livestock industry is dominated by beef but also has large swine, dairy and poultry components. Crop production is mainly dedicated to the production of cereal and oil seeds. A wide variety of specialty crops and animals are produced, but represent a very small portion of the overall agricultural economy.

Emissions directly related to animal and crop production accounted for 56 Mt CO<sub>2</sub> eq or 8.0% of total 2012 GHG emissions for Canada, an increase of 9 Mt CO<sub>2</sub> eq or 19% since 1990. Agriculture accounts for 22% and 74% of the national CH<sub>4</sub> and N<sub>2</sub>O emissions, respectively.

The main drivers of the increase in emissions since 1990 in the Agriculture Sector are the expansion and intensification of the beef cattle and swine industries, and increases in the application of synthetic nitrogen fertilizers in the Prairies.

From 2005 to 2008, livestock populations decreased, while synthetic fertilizer consumption continued to increase and crop production was high; declines in emissions from livestock production were compensated for by increases in emissions from crop production. These trends have persisted in recent years, such that during the period 2005–2012 the relative proportion of emissions from livestock has steadily decreased from 67% to 57% of total agricultural emissions.

## Waste—2012 GHG Emissions (21 Mt)

The primary source category in the Waste Sector is CH<sub>4</sub> emissions from Solid Waste Disposal on Land, which accounted for about 92% of emissions for this sector. The CH<sub>4</sub> emissions from publicly and privately owned municipal solid waste landfills make up the bulk of emissions in the Solid Waste Disposal on Land category (approximately 87%). The remainder (approximately 13%) originates from pulp and paper and sawmill industries that landfill wood residues on-site; this practice is declining as markets for wood residues grow.

Since 1990, the overall emissions from this sector grew by 8%, mostly from increases in emissions from landfill operations. The emissions from this sector were significantly mitigated by the growing amounts of landfill gas (LFG) captured and combusted at the landfill sites. While the CH<sub>4</sub> emissions generated by all landfills increased by 34% to 1208 kilotonnes (kt), the amount of CH<sub>4</sub> captured increased by 120% to 425 kt in 2012. Of the overall CH<sub>4</sub> captured, 48% was combusted for energy recovery applications and the remainder was flared. The number of landfill sites with LFG capture systems is rapidly rising in Canada, with 81 such systems operating in 2012.

Wastewater treatment and waste incineration facilities in Canada are minor sources of CH<sub>4</sub> and N<sub>2</sub>O emissions, and have generally remained stable.

## Land Use, Land-use Change and Forestry—2012 (Net Source of 41 Mt)

The Land Use, Land-use Change and Forestry (LULUCF) Sector reports GHG fluxes between the atmosphere and Canada's managed lands, as well as those associated with land-use change. In contrast with other inventory estimates, GHG emissions and removals from Canada's managed lands can include very large fluxes from non-anthropogenic events such as wildfires and insect epidemics. All emissions and removals in the LULUCF Sector are excluded from the national totals.

In this sector, the net GHG flux is calculated as the sum of CO<sub>2</sub> emissions to, and removals from, the atmosphere, plus non-CO<sub>2</sub> emissions. In 2012, this net flux amounted to emissions of 41 Mt CO<sub>2</sub> eq, which would have increased the total Canadian GHG emissions by about 6% but would include non-anthropogenic sources. Trends in the LULUCF Sector are primarily driven by those in the sector's Forest Land and Cropland subsectors and Forest Conversion categories.

The net flux in forest land displays an important inter-annual variability due to the erratic pattern of forest wildfires, which masks underlying patterns of interest in the sector. Important subsectoral trends associated with human activities in managed forests include a 28% increase in the carbon removed in harvested wood between 1990 and the peak harvest year of 2004. Since then, significant reductions in forest management activities have occurred, with a 35% decline in harvest levels, which in 2009 reached their lowest point for the 23-year period covered by this report (30 Mt carbon). Nonetheless, the immediate and longterm effect of major natural disturbances in managed forests, notably the Mountain Pine Beetle infestation in western Canada, will undoubtedly continue to dominate the apparent trend.

Cropland shows a steady decline in emissions, notably in the period 1990–2006, from emissions of 12 Mt CO<sub>2</sub> eq in 1990 to net removals of 5 Mt CO<sub>2</sub> eq in 2006. This trend is a result of changes in agricultural land management practices in western Canada, such as the extensive adoption of conservation tillage practices (over 13 million hectares [Mha] of cropland since 1990) and the reduction in summer fallow by 76% in 2012. The net CO<sub>2</sub> removals due to the management of mineral soils increased from 2 Mt in 1990 to 11 Mt in 2012. A decline in the conversion of forest land to cropland has also contributed to this trend. Since 2006, net removals have tended to remain constant at around 5 Mt CO<sub>2</sub> eq as a result of the soil sink approaching equilibrium.

## ES.4 Economic Sectors

As previously noted, there are several methods to categorize the sources of GHG emissions that arise across Canada. For the purposes of analyzing trends and policies, it is useful to allocate emissions to the economic sector from which the emissions originate. These emissions are presented in Figure S–8 and Table S–3. In general, a comprehensive emission profile for a specific economic sector is developed by reallocating the relevant proportion of emissions from various IPCC subcategories. This reallocation simply re-categorizes emissions under different headings and does not change the overall magnitude of Canadian emissions estimates.

Similar to the trends under IPCC sectors, the increase in GHG emissions between 1990 and 2012 was driven by growth in the oil and gas and transportation sectors. Increased production of crude oil as well as the expansion of the oil sands resulted in an increase in emissions of 72 Mt in the oil and gas sector. In the

transportation sector, changes in subsectors such as light-duty and heavy-duty vehicles caused an increase in emissions of 37 Mt when compared to 1990 levels. These increases were offset by decreases in emissions in the Electricity and Emissions Intensive and Trade Exposed Industries, where emissions fell 6 Mt and 17 Mt, respectively.

Further information on the IPCC and economic sector definitions and trends, as well as a detailed cross-walk between IPCC and economic sector categories, can be found in Chapter 2, Table 2-14.

## ES.5 Provincial and Territorial GHG Emissions

Emissions vary significantly by province, due to factors such as population and socio-economic considerations, economic structure and weather. For example, provinces where the economy

Figure S–8 Canada's Emissions Breakdown by Economic Sector (2012)

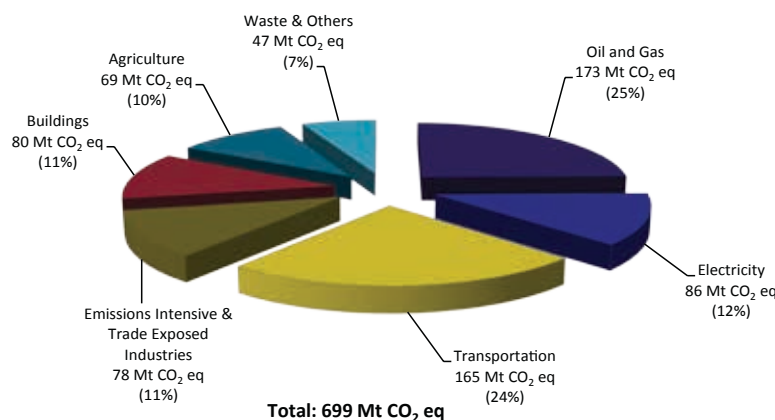


Table S–3 Canada's GHG Emissions by Economic Sector (1990–2012)

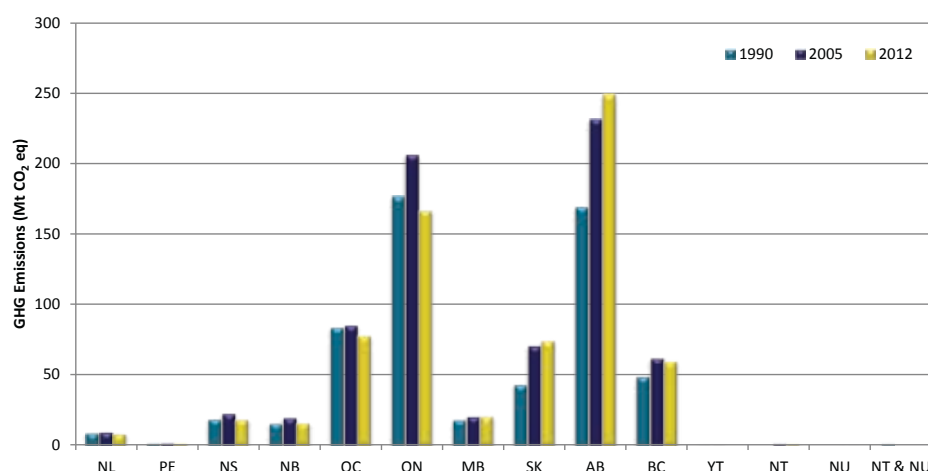
Greenhouse Gases	1990	2000	2005	2008	2009	2010	2011	2012
Mt CO <sub>2</sub> equivalent								
<b>NATIONAL GHG TOTAL</b>	<b>591</b>	<b>721</b>	<b>736</b>	<b>731</b>	<b>689</b>	<b>699</b>	<b>701</b>	<b>699</b>
Oil and Gas	101	151	159	162	161	163	164	173
Electricity	94	129	121	113	97	99	92	86
Transportation	128	155	168	166	163	167	166	165
Emissions Intensive & Trade Exposed Industries <sup>1</sup>	95	92	89	88	75	76	80	78
Buildings	70	82	84	84	82	79	85	80
Agriculture	54	66	68	71	66	68	67	69
Waste & Others <sup>2</sup>	48	46	47	48	45	46	47	47

Note: Totals may not add up due to rounding.

Estimates presented here are under continual improvement. Historical emissions may be changed in future publications as new data become available and methods and models are refined and improved. Recalculations resulting from methodological improvements are presented in Chapter 9, and recalculations resulting from changes to underlying activity data are presented in the chapter(s) associated with the sector where the changes occurred (Chapters 3-8).

1. The Emissions Intensive & Trade Exposed Industries represent emissions arising from non oil and gas mining activities, smelting and refining, and the production and processing of industrial goods such as paper or cement.
2. "Others" includes Coal Production, Light Manufacturing, Construction & Forest Resources.



**Figure S–9 Emissions by Province in 1990, 2005 and 2012**

is oriented more toward resource extraction will tend to have higher emission levels, while service-based economies tend to have lower emission levels. Electricity generation sources also vary, with provinces that rely on fossil fuels for their electricity generation having higher emissions than provinces relying more on hydroelectricity.

Although Ontario, with its large manufacturing base, started off as the largest-emitting province in 1990, as of 2005 it had been surpassed by Alberta (see Figure S–9), where emissions have increased 47% since 1990—mostly driven by the enhanced production of petroleum resources.

Since 2005, Ontario's electricity sector saw its emissions decrease by 58% (19.7 Mt)—largely due to the closures of coal-fired electricity generation plants.

Quebec and British Columbia, which rely on abundant hydroelectric resources for their electricity production, show more stable emission patterns across the time series and a decreasing pattern since 2005. Quebec experienced an 8.5% (7.3 Mt) decrease from its 2005 emissions level, while British Columbia had a decline of 3.5% (2.2 Mt). In contrast to these decreases, emissions in Saskatchewan increased by 5.1% (3.7 Mt) between 2005 and 2012, as a result of activities in the oil and gas industry as well as potash and uranium mining.

## ES.6 National System

Environment Canada is the single national entity with responsibility for the preparation and submission of the National Inventory Submission to the UNFCCC and for the establishment of a national inventory system. Canada's national system for the estimation of anthropogenic emissions from sources and removals by sinks of all GHGs not controlled by the Montreal Protocol encompasses the institutional, legal and procedural arrange-

ments necessary to ensure that Canada meets its reporting obligations.

The national system consists of institutional arrangements for the preparation of the inventory, including formal agreements supporting data collection and estimate development; a quality assurance / quality control plan; the ability to identify key categories and generate quantitative uncertainty analysis; a process for performing recalculations for improvement of the inventory; procedures for official approval; and a working archives system to facilitate third-party review.

Submission of information to the national system, including details on institutional arrangements for inventory preparation, is also an annual requirement under the UNFCCC reporting guidelines on annual inventories (see Chapter 1, Section 1.2).

### Structure of Submission

The UNFCCC requirements include both the annual compilation and submission of the National Inventory Report (NIR) and Common Reporting Format (CRF) tables. The CRF tables are a series of standardized data tables, containing mainly numerical information, which are submitted electronically. The NIR contains the information to support the CRF tables, including a comprehensive description of the methodologies used in compiling the inventory, the data sources, the institutional structures and quality assurance and quality control procedures.

Part 1 of the NIR includes Chapters 1 to 9. Chapter 1 (Introduction) provides an overview of Canada's legal, institutional and procedural arrangements for producing the inventory (i.e. the national inventory system) as well as a description of Canada's facility emission-reporting system. Chapter 2 provides an analysis of Canada's GHG emission trends in accordance with the UNFCCC reporting structure as well as a breakdown of emission trends by Canadian economic sectors. Chapters 3 to 8 provide descriptions

and additional analysis for each broad emission and removal category according to UNFCCC reporting requirements. Chapter 9 presents a summary of recalculations and planned improvements.

Part 2 of the NIR consists of Annexes 1 to 10, which provide a key category analysis, detailed explanations of estimation methodologies, a comparison of the sectoral and reference approaches in the Energy Sector, quality assurance and quality control procedures, completeness assessments, inventory uncertainty, emission factors, rounding procedures, and a summary of ozone and aerosol precursors.

Part 3 comprises Annexes 11 to 13, which present summary tables of GHG emissions for each provincial and territorial jurisdiction, sector and gas, as well as additional details on the GHG intensity of electricity generation.

# Chapter 1

## Introduction

### 1.1. Greenhouse Gas 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.

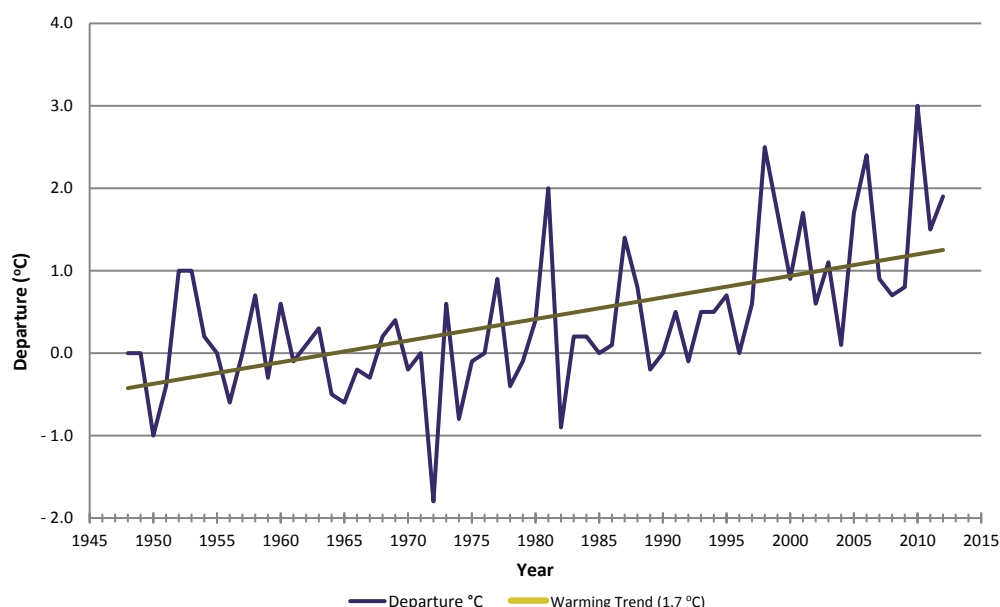
On the other hand, climate is the average pattern of weather (usually taken over a 30-year period) for a particular region. Climatic elements include precipitation, temperature, humidity, sunshine, wind velocity, phenomena such as fog, frost and hailstorms, and other measures of the weather. The term “climate change” refers to changes in long-term weather patterns caused by natural phenomena and human activities that alter the chemi-

cal composition of the atmosphere through the build-up of greenhouse gases (GHGs), which trap heat and reflect it back to the Earth’s surface.

It is now well known that atmospheric concentrations of GHGs have grown significantly since pre-industrial times. Since 1750, the concentration of atmospheric carbon dioxide (CO<sub>2</sub>) has increased by 141%; of methane (CH<sub>4</sub>) by 260%; and of nitrous oxide (N<sub>2</sub>O) by 120% (WMO 2013). Warming of the climate system is unequivocal, and, since the 1950s, many of the observed changes are unprecedented over decades to millennia (IPCC 2013). The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, the sea level has risen, and concentrations of GHGs have increased. Continued emissions of GHGs will cause further warming and will bring about changes in all components of the climate system. In 2011 the concentrations of CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O exceeded pre-industrial levels by about 40%, 150% and 20%, respectively; these increases are caused by anthropogenic emissions from the use of fossil fuels as a source of energy, and from land use and land use changes, in particular agriculture (IPCC 2013).

In Canada, the impact of climate change may be felt in extreme weather events, the reduction of fresh water resources, increased risk and severity of forest fires and pest infestations, a reduction in arctic ice and an acceleration of glacial melting. Canada’s national average temperature for 2012 was 1.9°C above normal (see Figure 1–1). Annual temperatures in Canada have been at or above normal since 1993, with a warming trend of 1.7°C over the last 65 years (Environment Canada 2013).

Figure 1–1 Annual Canadian Temperature Departures and Long-term Trend, 1948–2012



Data source: Environment Canada (2013)

### 1.1.1. Reporting of Canada's National Greenhouse Gas Inventory

Canada ratified the United Nations Framework Convention on Climate Change (UNFCCC) in December 1992, and the Convention came into force in March 1994. The ultimate objective of the UNFCCC is to stabilize atmospheric GHG concentrations 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. It requires governments to gather and share information on GHG emissions, national policies and best practices; to launch national strategies for addressing GHG emissions and adapting to expected impacts; and to cooperate in preparing for adaptation to the impacts of climate change. Specifically, Articles 4 and 12 and Decision 3/CP.5 of the Convention commit all Parties to develop, periodically update,<sup>1</sup> publish and make available to the Conference of the Parties (COP) national inventories of anthropogenic<sup>2</sup> emissions by sources and removals by sinks of all GHGs not controlled by the Montreal Protocol<sup>3</sup> that use comparable methodologies.

This National Inventory Report (NIR) provides Canada's annual GHG emissions estimates for the period 1990–2012. The NIR, along with the Common Reporting Format (CRF) tables, comprise Canada's submission to the UNFCCC. The NIR and CRF tables have been prepared in accordance with the updated *"Guidelines for the preparation of national communications by Parties included in Annex I to the Convention, Part I: UNFCCC reporting guidelines on annual inventories,"* which include the revisions to the Land Use, Land-use Change and Forestry Sector adopted by the COP at its eleventh session in 2005.

### 1.1.2. Greenhouse Gases and the Use of Global Warming Potentials (GWPs)

This report provides estimates of Canada's emissions and removals of the following GHGs: CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, sulphur hexafluoride (SF<sub>6</sub>), perfluorocarbons (PFCs) and hydrofluorocarbons (HFCs). In addition, and in keeping with the UNFCCC reporting guidelines for Annex I Parties, Annex 10 contains estimates of the following ozone and aerosol precursors: carbon monoxide (CO), nitrogen oxides (NO<sub>x</sub>), non-methane volatile organic compounds (NMVOC) and sulphur oxides (SO<sub>x</sub>).

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

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

3 Under the United Nations Environment Programme (UNEP), the Montreal Protocol on Substances that Deplete the Ozone Layer is an international agreement designed to reduce the global consumption and production of ozone-depleting substances.

#### 1.1.2.1. Carbon Dioxide (CO<sub>2</sub>)

CO<sub>2</sub> is a naturally occurring, colourless, odourless, incombustible gas formed during respiration, combustion, decomposition of organic substances, and the reaction of acids with carbonates. It is present in the Earth's atmosphere at low concentrations and acts as a GHG. The global carbon cycle is made up of large carbon flows and reservoirs. Through these, CO<sub>2</sub> is constantly being removed from the air by its direct absorption into water and by plants through photosynthesis and, in turn, is naturally released into the air by plant and animal respiration, decay of plant and soil organic matter, and outgassing from water surfaces. Small amounts of carbon dioxide are also injected directly into the atmosphere by volcanic emissions and through slow geological processes such as the weathering of rock (Hengeveld et al. 2005). Although human-caused releases of CO<sub>2</sub> are relatively small (1/20) compared to the amounts that enter and leave the atmosphere due to the natural active flow of carbon (Hengeveld et al. 2005), human influences now appear to be significantly affecting this natural balance. This is evident in the measurement of the steady increase of atmospheric CO<sub>2</sub> concentrations since pre industrial times across the globe (Hengeveld et al. 2005). Anthropogenic sources of CO<sub>2</sub> emissions include the combustion of fossil fuels and biomass to produce energy, building heating and cooling, transportation, land-use changes including deforestation, the manufacture of cement, and other industrial processes.

#### 1.1.2.2. Methane (CH<sub>4</sub>)

CH<sub>4</sub> is a colourless, odourless, flammable gas that is the simplest hydrocarbon. CH<sub>4</sub> is present in the Earth's atmosphere at low concentrations and acts as a GHG. CH<sub>4</sub> usually in the form of natural gas, is used as feedstock in the chemical industry (e.g. hydrogen and methanol production), and as fuel for various purposes (e.g. heating homes and operating vehicles). CH<sub>4</sub> is produced naturally during the decomposition of plant or organic matter in the absence of oxygen, as well as released from wetlands (including rice paddies), and through the digestive processes of certain insects and animals such as termites, sheep and cattle. CH<sub>4</sub> is also released from industrial processes, fossil fuel extraction, coal mines, incomplete fossil fuel combustion and garbage decomposition in landfills.

#### 1.1.2.3. Nitrous Oxide (N<sub>2</sub>O)

N<sub>2</sub>O is a colourless, non-flammable, sweet-smelling gas that is heavier than air. Used as an anaesthetic in dentistry and surgery, as well as a propellant in aerosol cans, N<sub>2</sub>O is most commonly produced via the heating of ammonium nitrate (NH<sub>4</sub>NO<sub>3</sub>). It is also released naturally from oceans, by bacteria in soils, and from animal wastes. Other sources of N<sub>2</sub>O emissions include the industrial production of nylon and nitric acid, combustion of fossil fuels and biomass, soil cultivation practices, and the use of commercial and organic fertilizers.

### 1.1.2.4. Perfluorocarbons (PFCs)

PFCs are a group of human-made chemicals composed of carbon and fluorine only. These powerful GHGs were introduced as alternatives to ozone-depleting substances (ODSs) such as chlorofluorocarbons (CFCs) in manufacturing semiconductors. PFCs are also used as solvents in the electronics industry, and as refrigerants in some specialized refrigeration systems. In addition to being released during consumption, they are emitted as a by-product during aluminium production.

### 1.1.2.5. Hydrofluorocarbons (HFCs)

HFCs are a class of human-made chemical compounds that contain only fluorine, carbon and hydrogen, and are powerful GHGs. As HFCs do not deplete the ozone layer, they are commonly used as replacements for ODSs such as chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs) and halons in various applications including refrigeration, fire-extinguishing, semiconductor manufacturing and foam blowing.

### 1.1.2.6. Sulphur hexafluoride (SF<sub>6</sub>)

SF<sub>6</sub> is a synthetic gas that is colourless, odourless, and non-toxic (except when exposed to extreme temperatures), and acts as a GHG due to its very high heat-trapping capacity. SF<sub>6</sub> is primarily used in the electricity industry as insulating gas for high-voltage equipment. It is also used as a cover gas in the magnesium industry to prevent oxidation (combustion) of molten magnesium. In lesser amounts, SF<sub>6</sub> is used in the electronics industry in the manufacturing of semiconductors, and also as a tracer gas for gas dispersion studies in industrial and laboratory settings.

### 1.1.2.7. Global Warming Potentials

GHGs are not all equal: each GHG has a unique atmospheric lifetime and heat trapping potential. The radiative forcing<sup>4</sup> effect of a gas within the atmosphere is a reflection of its ability to cause atmospheric warming. Direct effects occur when the gas itself is a GHG, whereas indirect radiative forcing occurs when chemical transformation of the original gas produces a gas or gases that are GHGs or when a gas influences the atmospheric lifetimes of other gases. The global warming potential (GWP) of a GHG takes into account both the instantaneous radiative forcing due to an incremental concentration increase and the lifetime of the gas and is a relative measure of the warming effect that the emission of a radiative gas (i.e. a GHG) might have on the surface atmosphere.

By definition, a GWP is the time-integrated change in radiative forcing due to the instantaneous release of 1 kg of the gas

expressed relative to the radiative forcing from the release of 1 kg of CO<sub>2</sub>. The concept of a GWP has been developed to allow scientists and policy-makers to compare the ability of each GHG to trap heat in the atmosphere relative to CO<sub>2</sub>. Often, GHG emissions are calculated in terms of how much CO<sub>2</sub> would be required to produce a similar warming effect over a given time period. This is called the carbon dioxide equivalent (CO<sub>2</sub> eq) value and is calculated by multiplying the amount of the gas by its associated GWP. For example, the 100-year GWP for methane (CH<sub>4</sub>) used in this inventory is 21. As such, an emission of one hundred kilotonnes (100 kt) of methane is equivalent to 21 x 100 kt = 2100 kt CO<sub>2</sub> eq.

Consistent with Decision 2/CP.3, the 100-year GWPs, provided by the IPCC in its *Second Assessment Report* (Table 1–1) and required for inventory reporting under the UNFCCC, are used in this report.

## 1.1.3. Canada's Contribution

While Canada represented less than 2% of total global GHG emissions in 2010 (CAIT 2013), it is one of the highest per capita emitters, largely as a result of its size, climate (i.e. energy demands due to climate), and resource-based economy. In 1990, Canadians released 21.3 tonnes (t) of GHGs per capita. In 2012, this had decreased to 20.1 t of GHGs per capita (Figure 1–2).

In terms of growth in total anthropogenic GHG emissions without Land Use, Land-use Change and Forestry (LULUCF), Canada ranks eighth among developed country Parties, with an increase in emissions of 18.7% over the 1990–2011 period (Figure 1–3), and ranks first among the G8 countries (UNFCCC 2013).

## 1.2. Institutional Arrangements for Inventory Preparation

The following section describes the national system and the 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.

The national entity responsible for Canada's national inventory system is the Pollutant Inventories and Reporting Division of Environment Canada. The National Inventory Focal Point is:

Director  
Pollutant Inventories and Reporting Division  
Science and Risk Assessment Directorate  
Science and Technology Branch  
Environment Canada  
10th Floor, 200 Sacré-Coeur Boulevard  
Gatineau QC K1A 0H3

<sup>4</sup> 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).

Table 1–1 1995 IPCC GWPs and Atmospheric Lifetimes

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

Sources:

GWP: IPCC, 1995. Available online at [http://unfccc.int/ghg\\_data/items/3825.php](http://unfccc.int/ghg_data/items/3825.php)

Atmospheric Lifetime: IPCC, 1995, Table 2.9.

Note:

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

A detailed description of the functions of the Pollutant Inventories and Reporting Division is provided in the Process for Inventory Preparation section (Section 1.3).

### 1.2.1. The National System

Canada's national system for the estimation of anthropogenic emissions from sources and removals by sinks of all GHGs not controlled by the Montreal Protocol encompasses the institutional, legal and procedural arrangements necessary to ensure that Canada meets its reporting obligations. Canada's inventory is supported by documentation and archiving to facilitate third party review.

Canada's national system was examined in November 2007 during the in-country review of Canada's initial report. The review team concluded that Canada's national system contained all the necessary elements: institutional arrangements for the preparation of the inventory, including procedures for official approval; a quality assurance/quality control (QA/QC) plan; a working

archives system; an adequate description of the process for collecting data and developing estimates; the ability to identify key categories and generate quantitative uncertainty analysis; and a process for performing recalculation for improvement of the inventory (UNFCCC 2008).

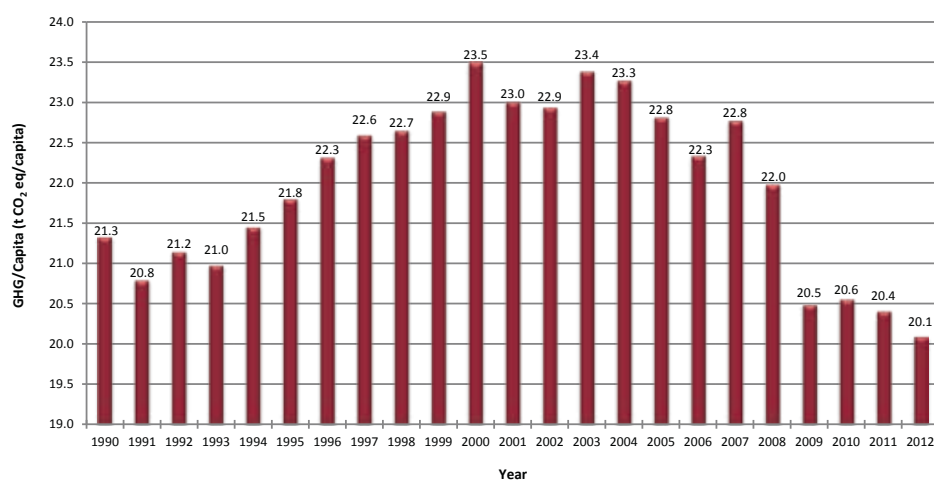
### 1.2.2. Institutional Arrangements

Environment Canada is responsible for preparing and submitting 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 international quality standards, Environment Canada has defined roles and responsibilities for the preparation of the inventory, both internally and externally.

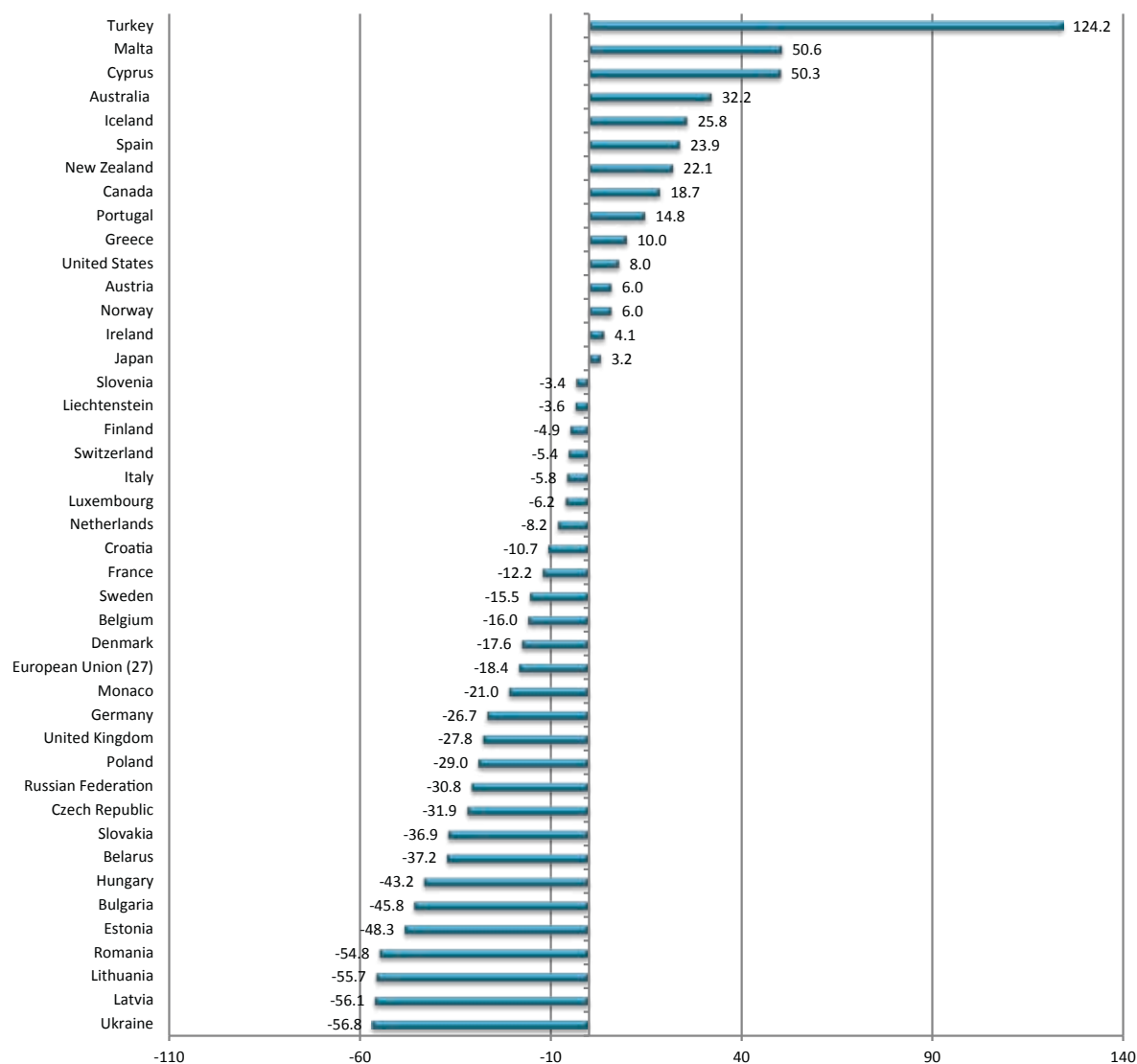
Sources and sinks of GHGs originate from a tremendous range of economic sectors and activities. As such, Environment Canada is involved in many partnerships with data providers and expert contributors in a variety of ways, ranging from informal to formal

Figure 1–2 Canadian Per Capita Greenhouse Gas Emissions (1990–2012)



Population data source: Statistics Canada (2013)

Figure 1–3 Percent Change in Aggregate GHG Emissions for Developed Country Parties without LULUCF, 1990–2011



Source: UNFCCC (2013)



arrangements. These partnerships include other government departments: Statistics Canada, Natural Resources Canada, Agriculture and Agri-Food Canada, and Transport Canada. These agreements are described in greater detail in the following sections. Environment Canada also has arrangements with industry associations, consultants and universities, as described in Section 1.2.2.3, and collaborates with provincial and territorial governments on a bilateral basis.

Figure 1–4 identifies the different partners of the inventory agency and their contribution to the development of Canada's national inventory.

### 1.2.2.1. Statistics Canada

Canada's national statistical agency, Statistics Canada, provides Environment Canada with a large portion of the underlying activity data to estimate GHG emissions for the Energy and the Industrial Processes Sectors. Statistics Canada is responsible for the collection, compilation and dissemination of Canada's energy balance in its annual *Report on Energy Supply–Demand in Canada* (RESO). The energy balance is transmitted annually to Environment Canada according to the terms of a Letter of Agreement established between the two departments. Statistics Canada also conducts an annual *Industrial Consumption of Energy* (ICE) survey, which is a comprehensive survey of industries that feeds into the development of the energy balance.

Statistics Canada's quality management system for the energy balance includes an internal and external review process. Owing to the complexity of energy data, the Working Group on Energy Statistics—consisting of members from Statistics Canada, Environment Canada and Natural Resources Canada (NRCAN)—was established to provide advice, direction and recommendations on improvements to the energy balance. In addition, a high-level Energy Steering Committee was formed in 2008 to review timing, quality and technical issues related to the RESO and ICE data. Refer to Annex 2 of this report for additional information on the use of the energy balance in the development of energy estimates.

Statistics Canada is also responsible for gathering other energy data such as mining and electricity information, and other non energy-related industrial information, including urea and ammonia production information. In addition, the statistics agency collects agricultural activity data (related to crops, crop production and management practices) through the *Census of Agriculture* and provides animal population data.

### 1.2.2.2. Natural Resources Canada and Agriculture and Agri-Food Canada: Canada's Monitoring and Accounting System for Land Use, Land-use Change and Forestry

Since 2005, Environment Canada has officially designated responsibilities to Agriculture and Agri-Food Canada (AAFC) and the Canadian Forest Service of Natural Resources Canada (NRCAN/CFS) for the development of key components of the Land Use, Land-use Change and Forestry (LULUCF) Sector and has established formal and explicit governance mechanisms to that effect through memoranda of understanding (MOUs).

Canada's Monitoring, Accounting and Reporting System (MARS) for LULUCF is overseen by an interdepartmental steering committee chaired by Environment Canada, with representatives from AAFC and NRCAN/CFS. Technical working groups address the subsectors of Forestry, Agriculture and Land-use Change, to ensure that the best available information and data from scientific research are integrated into the LULUCF Sector of the inventory. Under this framework, Environment Canada's MARS partners provide estimates, complete and transparent documentation, uncertainty analyses, and quality control and quality assurance of reports.

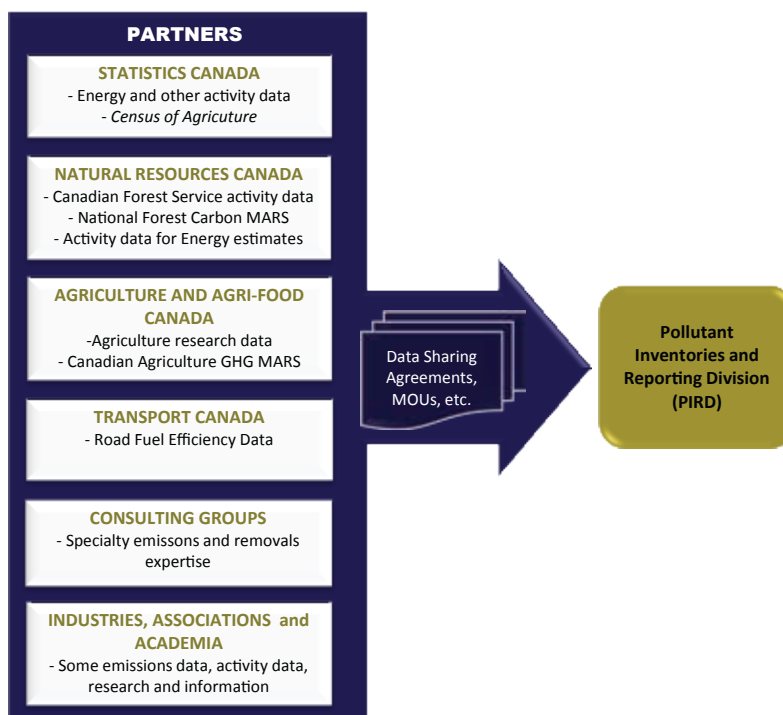
NRCAN/CFS has developed the National Forest Carbon MARS which has contributed major improvements to the emission and removal estimates in the LULUCF Sector. This program annually develops and delivers estimates for forest land, land conversion to forest land (afforestation) and forest land converted to other land (deforestation). The Deforestation Monitoring Group provides estimates of forest conversion activity.

AAFC has developed the Canadian Agricultural Greenhouse Gas MARS, which also significantly enhanced the quality of the emission and removal estimates in the LULUCF Sector. In concert with NRCAN/CFS, AAFC delivers cropland estimates for the LULUCF Sector that include the effect of management practices on agricultural soils and the residual impact of land conversion to cropland soils. In addition, AAFC provides scientific support to the Agriculture Sector of the inventory.

Environment Canada manages and coordinates the annual inventory development process, develops other LULUCF estimates, undertakes cross-cutting quality control and quality assurance, and generally ensures the consistency of land-based estimates through an integrated land representation system. In addition, the Earth Science Sector of NRCAN contributes earth observation expertise, while the Canadian Space Agency has supported the development of Earth observation products to improve land information within LULUCF MARS.



Figure 1–4 Partners of the National System



### 1.2.2.3. Other Partnerships

In addition to its support to Canada's MARS for LULUCF (see Section 1.2.2.2), Natural Resources Canada (NRCan) provides energy expertise and analysis, serves as expert reviewer for the Energy Sector data, and collects and provides activity data on mineral production, ethanol consumption and wood residues. Road vehicle fuel efficiency data are provided by both Transport Canada and NRCan.

When required, and resources permitting, contracts are established with consulting firms and universities to conduct in-depth studies—for example, on updating emission factors. A bilateral agreement with the Aluminum Association of Canada (AAC) has been signed, under which process-related emission estimates for CO<sub>2</sub>, PFCs and SF<sub>6</sub> are to be provided annually to Environment Canada. A similar agreement has been negotiated with the Canadian Electricity Association (CEA) for provision of SF<sub>6</sub> emissions and supplementary data relating to power transmission systems. Environment Canada has also been collaborating with magnesium casting companies and companies that import or distribute HFCs, with regard to their annual data on GHG emissions and/or supporting activity data.

## 1.3. Process for Inventory Preparation

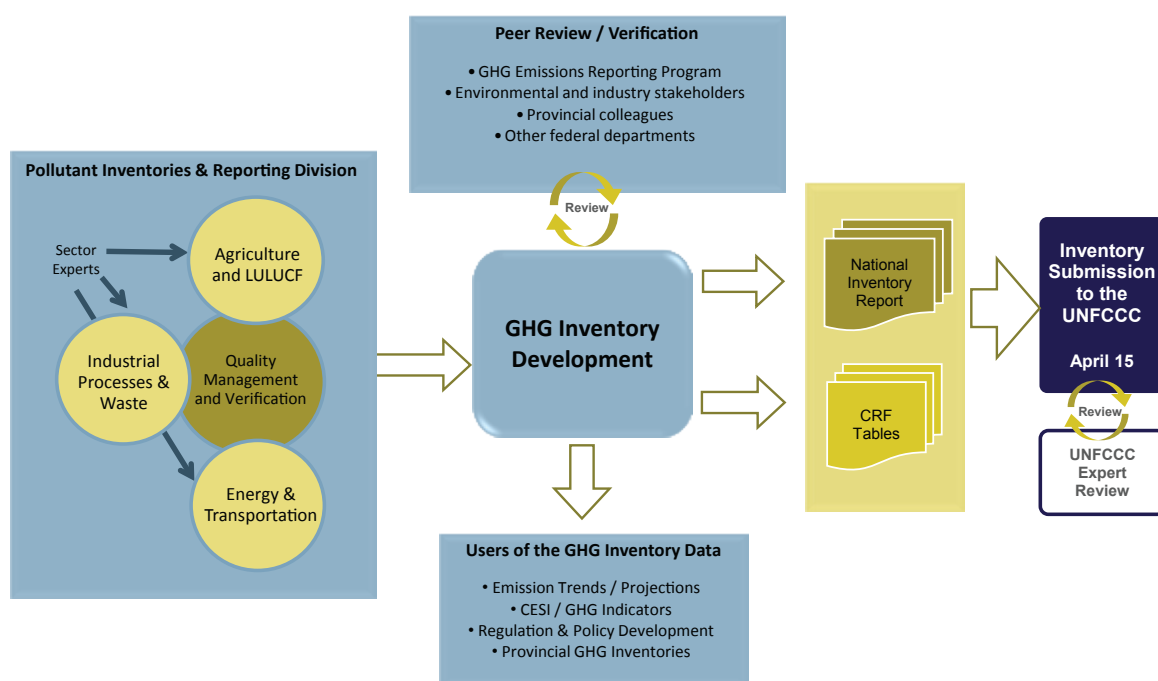
This section describes in general terms the annual inventory development cycle from the planning phase to the submission

to the UNFCCC. Continuous data collection and improvements are integral parts of the national inventory planning and quality management cycles (see Section 1.6). Canada's inventory is developed, compiled and reported annually by Environment Canada's Pollutant Inventories and Reporting Division, with input from numerous experts and scientists across Canada. Figure 1–5 identifies the various stages of the inventory preparation process.

The inventory is built around a continuous process of methodological improvements, refinements and review, according to the quality management and improvement plans. The Inventory Coordinator within the Quality Management and Verification section is responsible for preparing the inventory development schedule based on the results of the lessons-learned review of the previous inventory cycle, QA/QC follow-up, the UNFCCC review report, and collaboration with provincial and territorial governments. 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 for which a change in methodology or emission factor is proposed and for categories that are scheduled for a QA review of methodology or emission factor.

During the early stages of the inventory cycle (May to October), collection of the required data begins while the inventory publication schedule and roles and responsibilities are finalized. By the end of October, methodologies are finalized and the data collection process is almost complete. The data used to compile the national inventory are generally from published sources. Data

Figure 1–5 Inventory Preparation Process



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 and controlled for quality. Between November and January, draft estimates are calculated by designated inventory experts and subsequently internally reviewed. During February the NIR text and CRF tables are prepared according to UNFCCC guidelines. 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 calculation and documentation preparation.

Over the months of February and March, the compiled inventory is first reviewed internally and components of it are externally reviewed by experts, government agencies and provincial and territorial governments, after which the NIR is fully edited. Comments from the reviews 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 of the April submission are performed by the UNFCCC in May and June. Once finalized, the NIR is then translated and made available in French.

### 1.3.1. Procedures for the Official Consideration and Approval of the Inventory

In the process of considering the national inventory and the results, several briefings of senior officials take place prior to

the report being sent to the Minister. Once reviewed and/or approved, the National Inventory Focal Point prepares a letter of submission to accompany the NIR and CRF tables, which are then sent electronically.

## 1.4. Methodologies and Data Sources

The inventory is structured to match the reporting requirements of the UNFCCC and is divided into the following 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), the *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000), and the *Good Practice Guidance for Land Use, Land-Use Change and Forestry* (IPCC 2003) are followed to estimate emissions and removals of each of the following direct GHGs: CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, HFCs, PFCs and SF<sub>6</sub>. The *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006) contains updated methodologies; these guidelines will be implemented in the 2015 inventory submission.

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

indirect GHGs: SO<sub>x</sub>, NO<sub>x</sub>, CO and NMVOCs. For all categories except LULUCF, these gases (referred to as criteria air contaminants, or CACs) are inventoried and reported separately. CAC emissions in Canada are reported to the United Nations Economic Commission for the Environment.<sup>5</sup> As noted, a summary of these emissions is also included in the NIR (see Annex 10: 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 without attribution to individual emitters.

Emissions or removals are usually calculated or estimated using mass balance, stoichiometry or emission factor relationships under average conditions. In many cases, 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 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 requires a combination of repeated measurements and modelling. The need, unique to these systems, to separate anthropogenic impacts from large natural fluxes creates an additional challenge.

The methodologies (Annexes 2 and 3) and emission factors (Annex 8) 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 underlying data are lacking, 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.

Methodology and data improvement activities, which take into account results of QA/QC procedures, reviews and verification, are planned and implemented on a continuous basis by the staff of Environment Canada’s Pollutant Inventories and Reporting Division. It should be noted that planned improvements

are often implemented over the course of several years. These methodology and data improvement activities are carried out with a view to further refining and increasing the transparency, completeness, accuracy, consistency and comparability of the national inventory. As a result, changes in data or methods often lead to the recalculation of GHG estimates for the entire time series, from the 1990 base year to the most recent year available. Further discussion of recalculations and improvements can be found in Chapter 9.

### 1.4.1. Mandatory GHG Reporting

In March 2004, the Government of Canada established the Greenhouse Gas Emissions Reporting Program (GHGRP) under section 46(1) of CEPA 1999 to collect GHG emissions information annually from Canadian facilities on a mandatory basis.

The GHGRP applies to industrial and other facilities that are the largest emitters of GHGs and sets out basic reporting requirements. Key objectives of the program are to:

- provide Canadians with consistent information on GHG emissions;
- validate industrial emission estimates presented in the national GHG inventory; and
- support regulatory initiatives.

The GHG information is also shared with provincial and territorial jurisdictions. The data reported under the GHGRP are collected through Environment Canada’s Single Window (SW) reporting system.<sup>6</sup> Environment Canada launched this system to support integrated data collection to allow industry to submit information that is common to multiple programs and jurisdictions only once. This system was expanded to support an inclusive Canadian approach for GHG reporting in support of federal, provincial and territorial governments’ collaborative efforts to minimize duplication and reduce the reporting burden for industry and governments. Provincial partners currently using this SW system to collect GHG information to meet their GHG reporting regulations include Alberta, British Columbia and Ontario.

The types of large industrial facilities reporting GHG emissions to Canada’s GHGRP include:

- power generation plants that use fossil fuels to produce electricity, heat or steam;
- integrated steel mills;
- oil and gas extraction operations;
- facilities involved in the mining, smelting and refining of metals;
- pulp, paper and sawmills;

<sup>5</sup> Available online at <http://www.ceip.at/>

<sup>6</sup> Environment Canada’s Single Window reporting system is available online at <https://ec.ss.ec.gc.ca/>

- petroleum refineries; and
- chemical producers.

Information gathered from these large industrial facilities supports policy decisions and the potential development/implementation of future GHG regulations.

As per the legal notice published annually in the *Canada Gazette*, facilities that have emissions of 50 kt CO<sub>2</sub> eq or more annually are required to submit a GHG emission report by June 1 of the following year. Voluntary submissions from facilities with GHG emissions below the reporting threshold are accepted.

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 must use methods for estimating emissions that are consistent with the guidelines adopted by the UNFCCC and developed by the IPCC for the preparation of national GHG inventories.

#### 1.4.1.1. Facility-reported Emissions and the National GHG Inventory

Environment Canada's GHGRP website<sup>7</sup> provides public access to the reported GHG emission information (GHG totals by gas by facility). The total facility-reported GHG emissions for 2012 represent just over one third (37%) of Canada's total GHG emissions in 2012 (699 Mt) and over half (57%) of Canada's industrial GHG emissions.<sup>8</sup> The degree of coverage from the facility-reported data of industrial GHG emissions at the provincial level varies significantly from province to province, depending on the size and number of industrial facilities in each province that have emissions above the 50-kt reporting threshold.

It is important to note that the GHGRP applies to the largest GHG emitting facilities (mostly industrial) and does not cover other sources of GHG emissions (e.g. road transportation, agricultural sources), whereas the NIR is a complete accounting of all GHG sources and sinks in Canada.

Facility-level GHG emission data are used, where appropriate, to confirm emission estimates in the NIR developed from national and provincial statistics. 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.

#### 1.4.1.2. Reported 2012 Facility GHG Emissions

In the ninth year of reporting, the collected facility-level GHG data cover the period from 2004 to 2012. A total of 549 facilities reported GHG emissions for the 2012 calendar year, collectively emitting a total of 257 Mt of GHGs.<sup>9</sup> Of these, 313 facilities reported GHG emission levels greater than 100 kt CO<sub>2</sub> eq, accounting for 95% of the total reported emissions. Of the reporting facilities, 15 reported their GHG emissions for the first time and there were 68 voluntary reporters (i.e. emissions are below the reporting threshold). Reported emissions from voluntary reporters are included in the facility-level data presented in this section.

Facilities in Alberta accounted for the largest share of reported emissions, with approximately 49% of the total, followed by Ontario, Saskatchewan and Quebec, with 19%, 9% and 8% of reported emissions, respectively (Table 1–2). This regional breakdown of GHG emissions is reflective of the concentration of large industrial facilities in certain provinces relative to others and the use of fossil fuels for energy production.

When completing a report for the GHGRP, a reporter is required to identify the main activities occurring at its facility by selecting the North American Industry Classification System (NAICS)<sup>10</sup> code that corresponds to these activities. In 2012, three NAICS-defined industrial sectors accounted for the majority of GHG emissions:

- Utilities, primarily those generating electricity from fossil fuels, representing 35% (90 Mt CO<sub>2</sub> eq);
- Manufacturing, accounting for 31% (79 Mt CO<sub>2</sub> eq); and
- Mining, Quarrying, and Oil and Gas Extraction, accounting for 30% (77 Mt CO<sub>2</sub> eq) (Figure 1–6).

The "Other" category includes various types of facilities such as natural gas transportation pipelines, solid waste landfills, airports, universities, hospitals and public administration buildings. These facilities account for the remaining 4% (11 Mt CO<sub>2</sub> eq) of emissions, with the majority of these emissions stemming from natural gas transportation pipelines (6 Mt CO<sub>2</sub> eq) and solid waste landfills (4 Mt CO<sub>2</sub> eq).

Other key highlights from the 2012 GHGRP data collection cycle include the following:

- The main emission sources contributing to the reported 2012 GHG emission total are stationary fuel combustion and industrial processes, accounting for 75% and 15%, respectively, of

<sup>7</sup> The Greenhouse Gas Emissions Reporting Program website can be found at [www.ec.gc.ca/ges-ghg/default.asp?lang=En&n=040E378D-1](http://www.ec.gc.ca/ges-ghg/default.asp?lang=En&n=040E378D-1)

<sup>8</sup> Canada's "industrial GHG emissions" mentioned here include the following GHG categories from the *National Inventory Report 1990–2012: Greenhouse Gas Sources and Sinks in Canada*: Stationary Combustion Sources (except Residential), Other Transportation, Fugitive Sources, Industrial Processes and Waste.

<sup>9</sup> Data presented are current as of December 5, 2013.

<sup>10</sup> The NAICS is an industry classification system that was developed by the statistics agencies of Canada, the United States and Mexico to enable their national agencies to collect comparable statistical data. It is a comprehensive system that uses six-digit codes that encompass all economic activities. In Canada, the NAICS consists of 20 sectors, 102 subsectors, 323 industry groups, 711 industries and 922 national industries.

the combined total for carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O).

- Total facility-reported emissions in 2012 remained largely unchanged from the 2011 total of 254 Mt, reflecting a similar trend in recent years where year-to-year changes in the overall reported emissions have been relatively small (i.e. 4% or less).
- Total emissions from all reporting facilities have decreased overall by 7% since 2005. Ontario-based facilities within the Utilities and Manufacturing sectors experienced the largest declines (18 and 9 Mt, respectively) over this 8-year period, while reported emission increases occurred within the Mining, Quarrying and Oil and Gas Extraction sector, largely in Alberta.

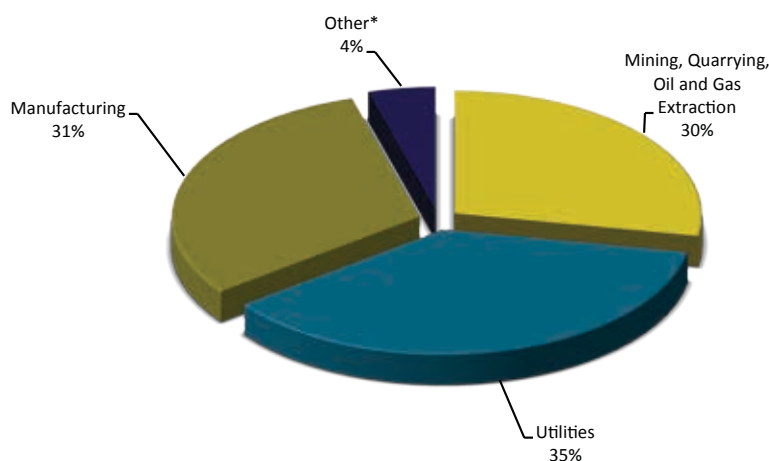
For more information on the facility data reported under Environment Canada's GHGRP, including short-term and long-term changes observed in facility emissions, please see the Environment Canada publication *Facility Greenhouse Gas Emissions Reporting Program – Overview of Reported 2012 Emissions*.<sup>11</sup>

## 1.5. Key Categories

The IPCC Good Practice Guidance (IPCC 2000, 2003) defines procedures (in the form of decision trees) for the choice of estimation methods recommended in the IPCC Guidelines. The decision trees formalize the choice of estimation method most suited

<sup>11</sup> The Overview Report is available online at [www.ec.gc.ca/ges-ghg/default.asp?lang=En&n=8044859A-1](http://www.ec.gc.ca/ges-ghg/default.asp?lang=En&n=8044859A-1)

**Figure 1–6 Facility-reported 2012 GHG Emissions by NAICS Industrial Sector (257 Mt CO<sub>2</sub> eq)**



\*"Other" includes various types of facilities such as natural gas transportation pipelines, solid waste landfills, airports, universities, hospitals and public administration buildings.

**Table 1–2 Facility-reported 2012 GHG Emissions by Province/Territory**

Province	Number of Facilities	Total Emissions (kt CO <sub>2</sub> eq)	% of Total Emissions
Newfoundland and Labrador	8	4,405	2%
Prince Edward Island	1	53	0.02%
Nova Scotia	11	8,822	3%
New Brunswick	13	6,421	2%
Quebec	79	20,569	8%
Ontario	143	49,909	19%
Manitoba	12	1,897	1%
Saskatchewan	40	23,459	9%
Alberta	162	126,371	49%
British Columbia	75	14,225	6%
Northwest Territories	4	549	0.2%
Nunavut	1	203	0.1%
Total	549	256,883	

Note: Totals may not add up due to rounding.



to national circumstances, considering at the same time the available knowledge and resources (both financial and human). Generally, the precision and accuracy of inventory estimates can be improved by using the most rigorous (highest-tier) methods; however, owing to practical limitations, the exhaustive development of all emissions categories is not possible. Therefore, it is good practice to identify and prioritize key categories in order to make the most efficient use of available resources.

In this context, a *key category* is one that is prioritized within the national inventory system because its estimate has a significant influence on a country's total inventory of direct GHG emissions in terms of the absolute level of emissions (level assessment), the trend in emissions from the base year to the current year (trend assessment), or both. As much as possible, two important inventory aspects of key categories should receive special consideration:

- preferential use of detailed, higher-tier methods; and
- additional attention with respect to QA/QC.

In the absence of quantitative data on uncertainties, a simplified Tier 1 method of identifying key categories provides a good approximation of those areas to which priority should be given to improve inventory estimates.

For the 1990–2012 GHG inventory, level and trend key category assessments were performed according to the Tier 1 approach, as presented in the IPCC Good Practice Guidance (IPCC 2000, 2003). The emission and removal categories used for the key category assessment generally follow those in the CRF and the LULUCF CRF; however, they have been aggregated in some cases and are specific to the Canadian inventory.

Major key categories based on the level and trend assessments (including LULUCF) are the fuel combustion categories (Stationary Combustion – Gaseous, Liquid and Solid Fuels, Road Transportation, and Off-road Transport), and the LULUCF category Forest Land Remaining Forest Land. Details and results of the key category assessments are presented in Annex 1.

## 1.6. Quality Assurance/ Quality Control

The national inventory and NIR must be prepared in accordance with international reporting guidelines and methods agreed to by the UNFCCC, including methodological procedures and guidelines prescribed by the IPCC. QA/QC and verification procedures are an integral part of the preparation of the inventory. The Pollutant Inventories and Reporting Division annually conducts QA/QC activities and is committed to improving data and methods in collaboration with industry, the provinces and territories, the scientific community, and the international community to ensure

that a credible and defensible inventory is developed. Improvement activities, which take into account results of QA/QC procedures, reviews and verification, are planned and implemented on a continuous basis to further refine and increase the transparency, completeness, accuracy, consistency and comparability of the national inventory. As a result, changes in data or methods often lead to the recalculation of GHG estimates for the entire time series, from the 1990 base year to the most recent year available.

The reader is referred to Annex 6 of this report for more information on the QA/QC plan, including verification and treatment of confidentiality issues where relevant.

## 1.7. Inventory Uncertainty

While national GHG inventories should be accurate, complete, comparable, transparent and consistent, estimates will always inherently carry some uncertainty. Uncertainties<sup>12</sup> in the inventory estimates may be caused by systematic and/or random uncertainties present within the input parameters or estimation models. Reducing uncertainty may require in depth reviews of the estimation models, improvements to the activity data regimes and evaluation of emission factors and other model parameters. In a limited number of cases, uncertainty may be reduced based on a validation exercise with an independent data set. IPCC guidelines specify that the primary purpose of quantitative uncertainty information is to assist in setting priorities to improve 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.

Annex 7 presents the uncertainty assessment for Canadian GHG emissions. While more complex (Tier 2) methods are in some cases applied to develop uncertainty estimates at the sectoral or category level, for the inventory as a whole these uncertainties were combined with the simple (Tier 1) error propagation method, using Table 6.1 in IPCC (2000). Separate analyses were conducted for the inventory as a whole with and without LULUCF. The calculation of trend uncertainties was only performed without the LULUCF Sector. For further details on uncertainty related to specific sectors, see the uncertainty sections throughout chapters 3 to 8.

Based on the Tier 1 error propagation method, the uncertainty for the national inventory, not including the LULUCF Sector, is  $\pm 4\%$ , consistent with the previously reported range of  $-3\%$  to  $+6\%$ . The Energy Sector had the lowest uncertainty, at  $\pm 3\%$ , while the Agriculture Sector had the highest uncertainty, at  $\pm 41\%$ . The Industrial Processes, Solvent & Other Product Use, and Waste Sec-

<sup>12</sup> 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).

tors had uncertainties of  $\pm 8$ ,  $\pm 19$  and  $\pm 34\%$ , respectively.

The categories that make the largest contribution to uncertainty at the national level are:

- Agriculture – Agricultural Soils – Indirect Emissions,  $\text{N}_2\text{O}$  ;
- Energy – Fuel Combustion – Public Electricity and Heat Combustion,  $\text{CO}_2$ ;
- Energy – Fuel Combustion – Other (Off-road) Transportation,  $\text{N}_2\text{O}$ ;
- Waste – Solid Waste Disposal on Land,  $\text{CH}_4$ ; and
- Energy – Fuel Combustion – Manufacturing Industries and Construction,  $\text{CO}_2$ .

The uncertainty when the LULUCF emissions and removals are included in the national total was found to be 6%.

The trend uncertainty, not including LULUCF, was found to be 1.1%. Therefore, the total increase in emissions since 1990 has a 95% probability of being in the range of 17.1–19.3%. Given the high interannual variability in the LULUCF estimates, and the fact that it is primarily driven by highly variable natural disturbance factors, this sector is not considered in the analysis of anthropogenic GHG emissions and removals trends uncertainties.

## 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 for certain minor subcategories typically relates to the following:

1. Categories that are not occurring in Canada;
2. Data unavailability; and
3. Methodological issues specific to national circumstances.

In some cases, the lack of appropriate and cost-effective methodologies has been the reason for exclusion of a minor source.

The Energy Sector has, since the 2007 UNFCCC in-country review, included biodiesel in transport as recommended by the expert review team. In the Agriculture Sector,  $\text{CH}_4$  and  $\text{N}_2\text{O}$  emissions from crop residue burning are estimated. In the LULUCF Sector,  $\text{CH}_4$  and  $\text{N}_2\text{O}$  emissions from burning of managed agricultural grasslands have been included, and significant improvements have been implemented starting in 2006, but completeness has not yet been fully met.

As part of the NIR improvement plans, efforts are continuously being made to identify and assess new knowledge, data improvements and overall improvements to the inventory system. Further details on the completeness of the inventory can be found in Annex 5 and in individual Sector chapters.

# Chapter 2

## Greenhouse Gas Emission Trends

### 2.1. Summary of Emission Trends

In 2012, Canada's greenhouse gas (GHG) emissions, excluding the Land Use, Land-use Change and Forestry (LULUCF) Sector, were 699 megatonnes (Mt), which is about an 18% increase over 1990 emissions. GHG emissions have remained relatively stable, with a 0.4% (2 Mt) change since 2011.

Since 1990, the net increase in total emissions has been 108 Mt, with the two largest contributors being Transport at 49 Mt and Fossil Fuel Industries<sup>1</sup> at 47 Mt. Significant increases in oil and gas production and in the number of motor vehicles are the main drivers of this rise in emissions. Agricultural activities and the consumption of halocarbons and sulfur hexafluoride (SF<sub>6</sub>) account for a non-negligible portion of this trend.

GHG emissions were approximately 37 Mt lower in 2012 than in 2005. During this period, GHG emissions attributed to electric power generation decreased by about 35 Mt, primarily the result of reduced generation by coal (which dropped to its lowest level since 1990), switching to renewable energy generation (hydro,

solar and wind) or low-emission sources (nuclear), and improved efficiencies in combustion generation.

Since 1990, Canada's gross domestic product (GDP) grew much more (about 67%) than the emissions, and therefore economic GHG intensity (or GHGs per \$GDP) decreased by about 29% (Table 2-1). Changes in emission trends since the early 2000s can be attributed to increases in efficiency, the modernization of industrial processes, and structural changes in the composition of the economy. Emissions in the Industrial Processes Sector decreased overall by about 4 Mt (6.6%) between 2005 and 2012. Together, efficiency increases and technological and structural changes (e.g. a shift from industrial-oriented to more service based industries) have resulted in a continuing weakening of the link between growth in GDP and emissions, so that the GHG intensity of the economy has consistently declined. This has resulted in the decoupling of economic growth and emissions.

### 2.2. Emission Trends by Gas

Carbon dioxide (CO<sub>2</sub>) is the largest contributor to Canada's GHG emissions (Figure 2-1), and its relative contribution has changed little between 1990 and 2012 (78% vs. 79%, respectively). The majority of these emissions result from the combustion of fossil fuels. Methane (CH<sub>4</sub>) accounted for 13% of Canada's total emissions, largely from fugitive emissions from oil and natural gas systems, as well as the Agriculture and Waste Sectors. Nitrous oxide (N<sub>2</sub>O) emissions from activities such as agriculture soil management and transport accounted for 7% of the emissions, while perfluorocarbons (PFCs), SF<sub>6</sub> and hydrofluorocarbons (HFCs) accounted for the remainder of the emissions (slightly more than 1%).

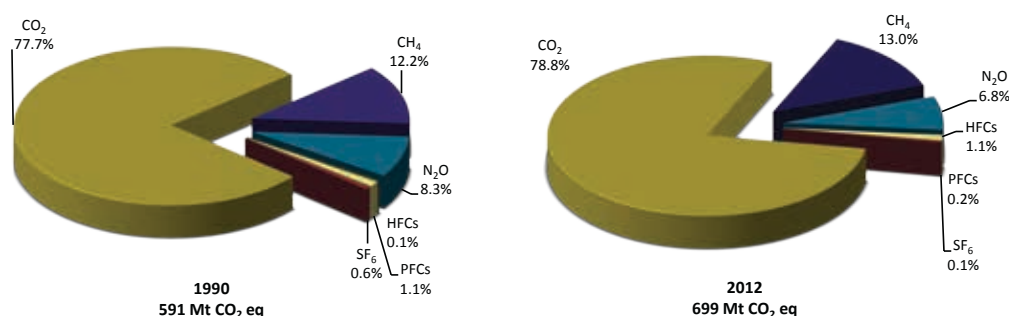
<sup>1</sup> Fossil Fuel Industries comprise the sum of the subsectors of Petroleum Refining, Fossil Fuel Production and Mining (also known as Mining and Oil and Gas Extraction).

**Table 2-1 Trends in Emissions and Economic Indicators, Selected Years**

Year	1990	2000	2005	2008	2009	2010	2011	2012
Total GHG (Mt)	591	721	736	731	689	699	701	699
Change Since 2005 (%)	NA	NA	NA	-0.6	-6.3	-5.0	-4.7	-5.1
Change Since 1990 (%)	NA	22.0	24.5	23.7	16.7	18.3	18.7	18.2
GDP - (Billions 2007\$)	989	1324	1496	1583	1537	1587	1626	1654
Change Since 2005 (%)	NA	NA	NA	5.8	2.7	6.1	8.7	10.6
Change Since 1990 (%)	NA	33.8	51.2	60.0	55.3	60.4	64.3	67.2
GHG Intensity (Mt/\$B GDP)	0.60	0.54	0.49	0.46	0.45	0.44	0.43	0.42
Change Since 2005 (%)	NA	NA	NA	-6.1	-8.9	-10.5	-12.4	-14.1
Change Since 1990 (%)	NA	-8.9	-17.6	-22.7	-24.9	-26.3	-27.8	-29.3

GDP Data Source: Statistics Canada. Table 380-0106 - Gross domestic product at 2007 prices, expenditure-based, annual (dollars), CANSIM (database).



**Figure 2–1 Relative Contribution of GHGs to Canada's Total Emissions, 1990 and 2012 (excluding LULUCF)****Table 2–2 GHG Emissions from Energy by IPCC category, Selected Years**

GHG Sources/Sinks	GHG Emissions (Mt CO <sub>2</sub> eq)							
	1990	2000	2005	2008	2009	2010	2011	2012
Energy	469	591	595	592	560	570	573	566
Fuel Combustion (Sectoral Approach) (1.A)	427	528	532	530	501	511	513	505
Energy Industries (1.A.1)	144	198	191	180	164	164	156	152
Manufacturing Industries and Construction (1.A.2) <sup>1</sup>	57.7	56.9	49.9	46.4	41.5	42.6	46.1	44.5
Mining (1.A.2.F.ii)	6.6	12.0	18.9	30.0	31.7	34.7	35.9	40.9
Transport (1.A.3)	147	180	194	196	188	198	198	195
Other Sectors (1.A.4) <sup>2</sup>	71.6	80.6	78.4	78.2	75.9	72.2	77.8	72.3
Fugitive Emissions (1.B)	42.4	63.0	63.4	62.0	58.8	58.5	59.6	61.1
Solid Fuels (Coal) (1.B.1)	2.0	1.0	1.0	0.9	0.9	1.0	1.0	1.0
Oil and Natural Gas (1.B.2)	40.2	62.1	62.4	61.1	58.0	57.4	58.6	60.1

Note:

Totals may not add up due to rounding.

1. Mining subsector removed from Manufacturing Industries and Construction and shown separately because the majority of emissions in this subsector are from oil and gas extraction.
2. The Other Sectors subsector comprises emissions from the Residential and Commercial categories, as well as contributions from stationary fuel combustion in Agriculture and Forestry.

## 2.3. Emission Trends by IPCC Category

Since 1990, there has been a 108 Mt net increase in Canada's total emissions, with the two largest contributors being Transport at 49 Mt and Fossil Fuel Industries<sup>2</sup> at 47 Mt. Major increases in oil and gas production and a large increase in the number of motor vehicles have resulted in this rise in emissions. Although increases in emissions from the Fossil Fuel Industries and Transport account for most of the emission trends since 1990, there have been increases in the categories of Agriculture (7 Mt), Consumption of Halocarbons and SF<sub>6</sub> (7 Mt), Commercial & Institutional (2 Mt) and Industrial Processes (0.8 Mt), while the Manufacturing Industries showed an emission decline of 12 Mt.

### 2.3.1. Energy Sector (2012 GHG emissions, 566 Mt)

Energy-related activities are by far the largest source of GHG emissions in Canada. The Energy Sector includes emissions of all GHGs from the production of fuels and their combustion for the primary purpose of delivering energy. The categorization of energy-related emission sources in Table 2–2 follows the *Revised 1996 Intergovernmental Panel on Climate Change's (IPCC) Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997); this breakdown corresponds to the United Nations Framework Convention on Climate Change (UNFCCC) Common Reporting Format (CRF) categories of Fuel Combustion (either stationary or in transport) and Fugitive Emissions. Specifically, fugitive emissions are defined as intentional or unintentional releases of GHGs from the production, processing, transmission, storage and delivery of fossil fuels.

Overall, fuel combustion and fugitive emissions accounted for 81% of total Canadian GHG emissions in 2012 (566 Mt). By this

2 Fossil Fuel Industries comprise the sum of the subsectors of Fossil Fuel Production and Refining, and Mining & Oil and Gas Extraction.

**Table 2–3 GHG Emissions from Public Electricity and Heat Generation, Selected Years**

GHG Source Category	GHG Emissions (Mt CO <sub>2</sub> eq)								Change (%)
	1990	2000	2005	2008	2009	2010	2011	2012	1990–2012
Electricity & Heat Generation <sup>1</sup>	93.6	130.1	122.9	114.5	99.1	101.1	93.7	88.3	-5.7%

Note: Totals may not add up due to rounding.

1. Heat generation represents a small portion of total Electricity & Heat Generation emissions (less than 1% in every year). For example, emission estimates for heat generation were 0.2 Mt CO<sub>2</sub> eq in 1990 and 0.6 Mt CO<sub>2</sub> eq in 2012.

breakdown, fuel combustion in the Energy Industries and Mining subsectors accounted for 152 and 40.9 Mt in 2012, respectively, while fugitive emissions represented 61 Mt. Between 1990 and 2012, fuel combustion-related emissions increased by 78 Mt (which includes 49 Mt in Transport), while emissions from fugitive releases rose by about 19 Mt (Table 2–2). In terms of relative growth, fuel combustion emissions in the Mining subsector have increased more rapidly than any other subsector in the Energy Sector. Between 1990 and 2012, these emissions rose by about 520%, due mainly to increased activity in Canada's oil sands.

### 2.3.1.1. Emissions from Fuel Combustion (2012 GHG emissions, 505 Mt)

GHG emissions from fuel combustion rose from 427 Mt in 1990 to 505 Mt in 2012, an 18% increase. Fuel combustion emissions are divided into the following IPCC subsectors: Energy Industries, Manufacturing Industries and Construction, Transport, and Other Sectors.

#### Energy Industries (2012 GHG emissions, 152 Mt)

The sum of the Energy Industries subsectors accounts for the second-largest portion of Canada's fuel combustion emissions (30%), behind Transport. Emissions included in this subsector are from stationary sources producing, processing and refining energy. This source includes Public Electricity and Heat Generation, Petroleum Refining, and Manufacture of Solid Fuels and Other Energy Industries. In 2012, combustion emissions from the Energy Industries subsectors totalled 152 Mt, an increase of 5% from the 1990 level of 144 Mt.

#### Public Electricity and Heat Generation<sup>3</sup> (2012 GHG emissions, 88.3 Mt)

This category accounts for 13% (88.3 Mt) of Canada's 2012 GHG emissions (Table 2–3) and for a 5.7% decrease in emissions between 1990 and 2012.

Emissions from electricity generation are unique in that electricity is generated to meet an instantaneous demand and, depending on the characteristics of that demand, the supply source can fluctuate between non-GHG-emitting and high GHG emitting sources. Electricity and heat generation increased substantially between 1990 and 2012, by 30% (Statistics Canada 1990–2004b, 2005–2012a, 2005–2012b), although emissions dropped by 5.4 Mt during this time. A less GHG-intensive mix of sources used to generate electricity in the latter part of the period counteracted this increase in demand (refer to “Combustion-Based Electricity Generation and GHG Emissions” sidebar). Between 2005 and 2012, however, generation rose by only 1%, while emissions fell significantly, by 34.7 Mt.

Major drivers influencing emissions in the electricity sector include demand, generation mix (combustion versus non combustion sources), fuel switching, energy efficiency, and emission factors. In the long term, the effect of increased demand (total generation) was largely offset by changes in fuel and generation mix (Figure 2–3). Demand was more stable in recent years, and ongoing changes in fuel and generation mix explain much of the emission reductions as illustrated in Figure 2–4.

**Demand** – Demand refers to the level of electricity generation activity in the utility sector, and consists of generation from combustion and non-combustion sources. In 2012, the amount of electricity generated was 30% higher than in 1990, due in part to a large (219%) increase in electricity exports to the United States (Statistics Canada 1990–2004b, 2005–2012a, 2005–2012b).

**Generation mix** – The generation mix refers to the relative share of combustion and non-combustion (zero-GHG) sources in generation activity. Combustion and non combustion sources respectively accounted for 4% and 96% of the increased generation between 1990 and 2012, improving the generation mix to one that became much less GHG-intensive. This increased level of zero-GHG sources in the generation mix in 2012 was the largest contributor to emission reductions since 1990 (–18.0 Mt), and 2005 (–25.9 Mt) (Statistics Canada 1990–2004b, 2005–2012a, 2005–2012b).

**Fuel mix (combustion generation)** – Between 1990 and 2012, the quantity of electricity generated by natural-gas-fired units increased by over 36 terawatt-hours (TWh), while the amount

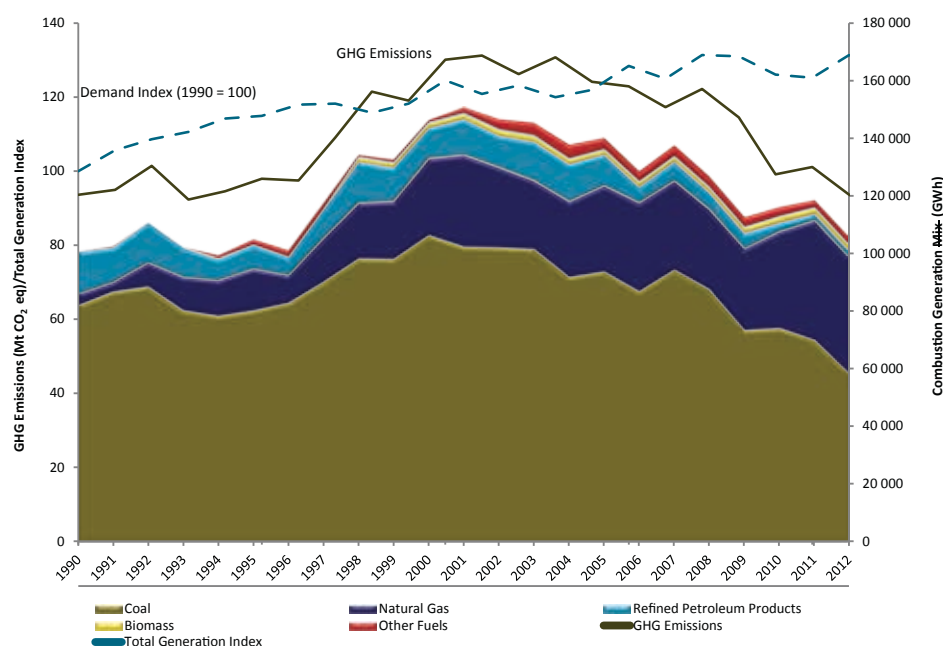
3 The Public Electricity and Heat Generation category follows the IPCC definition (see Section 3.2.1 for a detailed source description), which consists of emissions from utilities, some of which are sited in industrial facilities. It is important to note that some of these industrial facilities have been identified by Statistics Canada's surveys as utilities when surplus production is supplied to the grid. This is not identical to the method used for defining economic categories in Section 2.4. Also, some utilities are provincially owned, whereas others are privately owned.

## Combustion-Based Electricity Generation and GHG Emissions

Emissions of GHGs from electricity generation are driven by demand and by the amount and characteristics of combustion generation.

From 1994 to 2000, emissions rose 38%, although generation increased by only about 9%; however, coal, oil and natural gas use in generation increased rapidly during that time. Emissions peaked in 2001 and then decreased by 33% over the next 11 years, during which time the use of coal and oil in generation dropped rapidly while the use of natural gas rose. The shift towards a lower carbon-intensive fuel such as natural gas resulted in a decline in emissions. This illustrates the impact of fuel switching on GHG emissions. Between 1990 and 2012, the generation mix changed considerably in favour of non-combustion sources (such as hydro, nuclear and other renewables) and GHG emissions have consequently fallen.

**Figure 2-2 Utility-Generated Electricity by Source and GHG Emissions, 1990–2012**



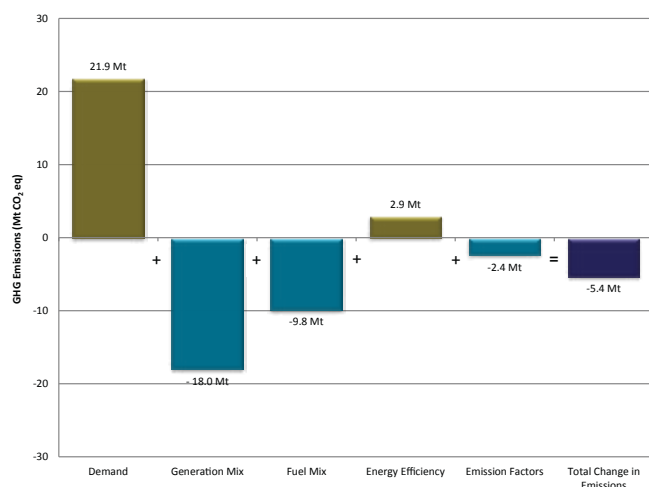
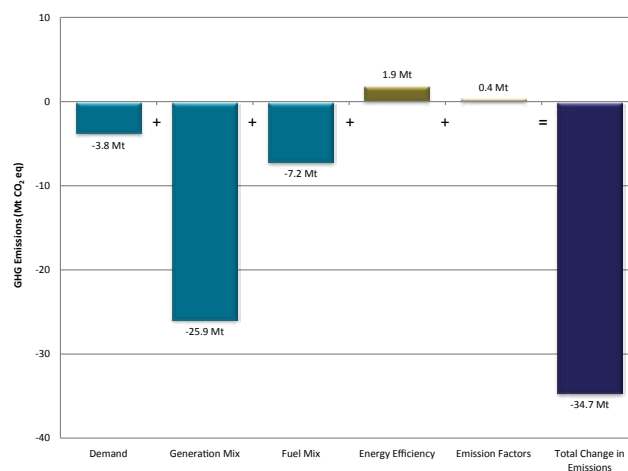
**Notes:**

1. Generation statistics refer to utility-based generation, which contributes approximately 92% of the total supply
2. Electricity Sector emissions do not include SF<sub>6</sub> emissions associated with transmission and distribution.
3. The total generation index tracks electricity generation at utilities (i.e. using both GHG- and non-GHG-emitting sources of energy)

generated by coal and refined petroleum products (RPPs) decreased by about 24 TWh and 12 TWh, respectively. Coal plant electricity generation peaked in 2000 and has decreased steadily; in 2012 it dropped by 17% (11.8 TWh) of its 2000 level (Statistics Canada 1990–2004b, 2005–2012a, 2005–2012b). Natural gas is about half as carbon-intensive as coal and approximately 25% lower than most RPPs, so the switch from other fuels to natural gas resulted in a decrease in the GHG intensity of combustion from electricity generation. The overall fuel switching impact was -7.2 Mt between 1990 and 2012 and -9.8 Mt between 2005 and 2012 (i.e. most of the emission reduction impacts have occurred since 2005).

**Energy efficiency and emission factors** – Energy efficiency refers to the efficiency of the equipment used in combustion related generation of electricity. Changes in fuel energy content over time are reflected in emission factors. The change between 1990 and 2012 largely relates to variations in natural gas emission factors by province, variations in emission factors and energy contents of types of coal, and variations in the petroleum coke emission factor.

For more information on electricity generation and trends, see Annex 13 – Electricity Intensity Tables.

**Figure 2–3 Influence of Contributing Factors on Change in Electricity Emissions, 1990–2012 (Mt CO<sub>2</sub> eq)****Figure 2–4 Influence of Contributing Factors on Change in Electricity Emissions, 2005–2012 (Mt CO<sub>2</sub> eq)**

Note: Emissions shown in the figures include those from electricity generation, but exclude SF<sub>6</sub> emissions from power transmission and distribution.

## Fossil Fuel Industries (2012 GHG emissions, 104 Mt)

Within the Fossil Fuel Industries,<sup>4</sup> the Petroleum Refining subsector mainly includes emissions from the combustion of fossil fuels during the production of refined petroleum products (RPPs), whereas the Fossil Fuel Production and Mining subsectors encompass fuel combustion emissions associated with the upstream oil and gas (UOG) industry. The Mining subsector includes emissions associated with oil (including crude bitumen from the oil sands), gas and coal extraction, as well as emissions associated with non-energy mining such as iron ore, gold, diamonds, potash and aggregates. As shown in Table 2–4, between 1990 and 2012 the emissions from the Petroleum Refining, Fossil Fuel Production and Mining subsectors increased by about

47 Mt, or 82%. This growth is due to increases in natural gas and oil production, particularly crude bitumen and heavy crude oil, largely for export.

### Production Growth

From 1990 to 2012, the production of total crude oil and natural gas increased by 103% and 44%, respectively (Figure 2–5). In contrast, bitumen and synthetic crude oil production from Canada's oil sands has increased by almost 450%, with most of the growth occurring from 1996 onward (AER 2013).

The 40% increase in production of crude oil between 2002 and 2012 was completely driven by oil sands operations, which showed a 140% growth in output, while conventional oil production decreased by about 10%. Coinciding with the production increases, emissions from overall crude oil production showed an increase of about 47% (29 Mt CO<sub>2</sub> eq), with oil sands increasing

4 For the purpose of this analysis, fossil fuel industries encompasses the Petroleum Refining, Fossil Fuel Production (also known as Manufacture of Solid Fuels and Other Energy Industries) and Mining (also known as Mining and Oil and Gas Extraction) categories.

**Table 2–4 GHG Emissions from Petroleum Refining, Fossil Fuel Production and Mining (Fossil Fuel Industries), Selected Years**

GHG Source Category	GHG Emissions (Mt CO <sub>2</sub> eq)							Change (%)
	1990	2000	2005	2009	2010	2011	2012	
Energy - Fuel Combustion - Energy Industries (CRF Sector: 1.A.1)								
Petroleum Refining	16.8	16.9	20.2	18.9	17.8	17.3	16.8	0%
Fossil Fuel Production	34.1	51.0	47.9	45.8	44.8	45.1	46.7	37%
Energy - Fuel Combustion - Manufacturing Industries and Construction								
Other - Mining (CRF Sector: 1.A.2.f.ii)	6.6	12.0	18.9	31.7	34.7	35.9	40.9	521%
<b>Total</b>	<b>57</b>	<b>80</b>	<b>87</b>	<b>96</b>	<b>97</b>	<b>98</b>	<b>104</b>	<b>82%</b>

Note: Stationary combustion only, excluding fugitive emissions. Totals may not add up due to rounding.

## Oil and Gas, Coal Production and Non-Energy Mining and Emissions

A more detailed breakdown of emissions from the Fossil Fuel Production and Mining subsector, including emissions from fugitive sources, Off-Road Transportation and cogeneration units, reveals the contribution of Natural Gas Production and Processing, Conventional Oil Production, Oil Sands, Coal Production and Non-energy Mining to GHG emissions in the upstream oil and gas industry (Table 2–5). The data show that the coal production and non-energy mining industries account for a comparatively small portion of the overall emissions from the categories Fossil Fuel Production and Mining.

**Table 2–5 GHG Emissions from All Sources (Stationary, Fugitive and Transport) for Oil and Gas, Coal Production and Non-energy Mining Sectors, Selected Years**

GHG Source Category	GHG Emissions (Mt CO <sub>2</sub> eq)							
	1990	2000	2005	2008	2009	2010	2011	2012
Upstream Oil and Gas	82	131	135	139	138	140	143	150
Natural Gas Production and Processing	33	55	54	54	50	49	48	48
Conventional Oil Production	22	34	32	30	28	29	29	30
Conventional Light and Frontier Oil Production	32	13	11	11	11	11	12	12
Conventional Heavy Oil Production	11	21	21	18	17	18	18	18
Oil Sands (Mining, Upgrading and In-Situ Extraction)	15	25	34	42	47	52	55	61
Mining and Extraction	4	5	9	11	13	14	14	15
In-situ	5	8	11	17	18	21	23	26
Upgrading	7	11	13	15	16	17	18	20
Oil and Gas Transmission	11	17	16	13	12	11	11	11
Downstream Oil and Gas	19	20	24	23	23	23	22	22
Petroleum Refining	18	19	22	21	21	21	20	20
Natural Gas Distribution	1	2	2	2	2	2	2	2
<b>Total Oil and Gas</b>	<b>101</b>	<b>151</b>	<b>159</b>	<b>162</b>	<b>161</b>	<b>163</b>	<b>164</b>	<b>173</b>
Coal Production	4	3	2	3	3	4	4	4
Non-energy Mining	6	6	6	8	7	7	7	8

Note: Totals may not add up due to rounding.

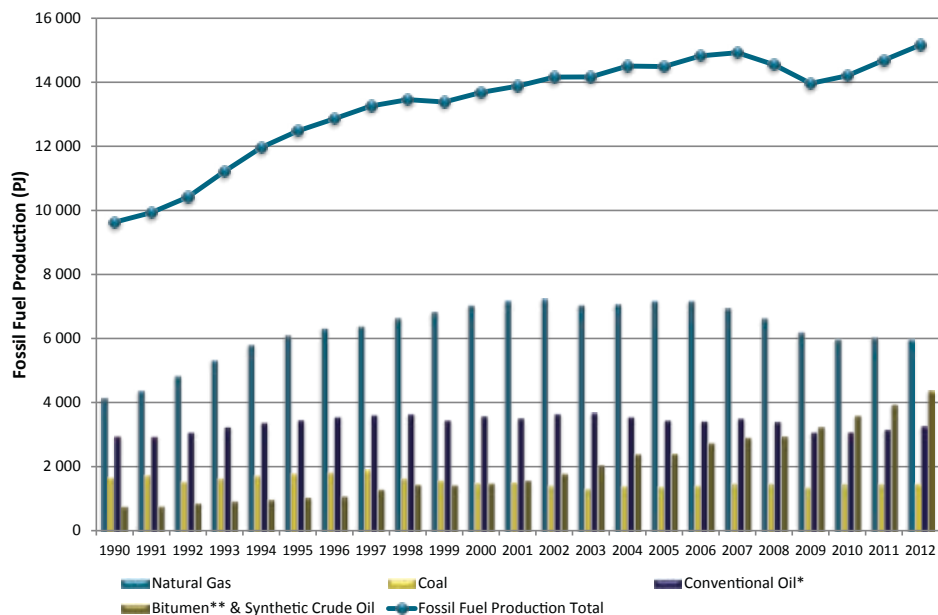
In 2012, approximately 87% of the total oil and gas sector emissions can be attributed to the upstream fossil fuel industry, while the downstream portion contributed the remaining 13% of total emissions (Table 2–5). The largest contributions to total oil and gas sector emissions were Oil Sands (Mining, Upgrading and In-situ Extraction) (35%), Natural Gas Production and Processing (28%), Conventional Oil Production (17%) and Petroleum Refining (11%), with Oil and Gas Transmission and Natural Gas Distribution making up the remaining 9%. The primary drivers of emissions within the oil and gas sector are production growth and production characteristics (emissions intensity).

by 32 Mt (114%), while conventional oil decreased by 3 Mt (10%). The rise in emission intensity for overall oil production results from efficiency gains in the oil sands being offset by the growth in the amount of bitumen and synthetic crude as a proportion of production, and the increased intensities of conventional oil production, particularly conventional heavy oil production where venting emissions contribute the most to its high intensity (Figure 2–5).

Natural gas production increased rapidly from 1990 to peak production levels in 2002 (Statistics Canada 2014c). From 2002 until 2010, overall production declined steadily<sup>5</sup> and, in the last few years, production has levelled off. However, unconventional natural gas production, including tight gas, coal bed methane and shale gas, accounts for the largest share of total production. In 2012, unconventional natural gas represented approximately

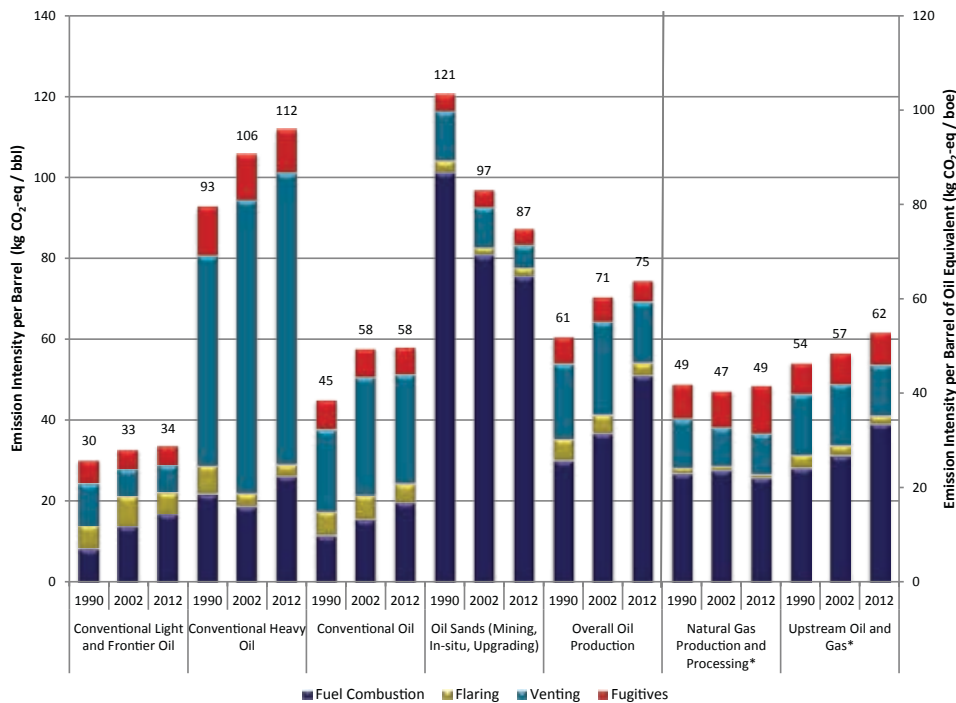
<sup>5</sup> Natural gas production decreased by 16% between 2002 and 2010 (Statistics Canada 2014a).

Figure 2–5 Canadian Production of Fossil Fuels, 1990–2012



Notes:  
\* Conventional oil includes light, medium and heavy oil production and pentanes plus or condensates.  
\*\* Bitumen from oil sands operations.

Figure 2–6 Emission Intensity by Source Type for Oil and Gas (1990, 2002 and 2012)



Notes:  
Intensities are based on total subsector emissions and relevant production amounts. They represent overall averages, not facility intensities.  
\*Natural Gas Production and Processing and Upstream Oil and Gas emission intensities calculated on a barrel of oil equivalent (boe) basis. Boe calculated by converting natural gas and crude oil production volumes to energy basis and then dividing by energy content of light crude oil (38.5 TJ / 10<sup>3</sup> m<sup>3</sup>).  
1 barrel (bbl) = 0.159 m<sup>3</sup>



50% of total gas production, compared to 20% in 2002 (NEB 2013).

Although gas production has declined somewhat since its peak in 2002, in 2012 natural gas production and processing contributed 32% to the oil and gas sector emissions total. Since 1990, emissions from natural gas production and processing have increased 44%. Generally, the overall emission intensity of natural gas production and processing in 2012 is the same as in 1990. Reduced amounts of facilities' own use of natural gas (i.e. raw natural gas consumed by the facility that produced it) has been partially offset by increased fugitive emissions, largely the result of multi-stage fracturing activities.

### *Production Characteristics (Emissions Intensity)*

Other contributors to the emission trend include a reduction in easily removable reserves of conventional crude oil, which are being replaced with more energy- and GHG-intensive sources, including synthetic crude oil (i.e. oil sands) production and heavier or more difficult-to-obtain conventional oils such as those from offshore sources or those extracted using enhanced oil recovery (EOR) operations. The increased use of horizontal wells and multi-stage fracturing techniques also increases emissions and the amount of energy required for drilling and well-completion activities.

The emission intensity of overall oil production (defined as the average amount of GHG emissions generated per barrel of oil equivalent) produced in Canada increased by about 23% between 1990 and 2012 (Figure 2-5). When natural gas is included, the emission intensity for the upstream oil and gas sector (not including transmission) increased by 14% in the same period.

The emission intensity of oils sands operations declined steadily from 1990 until about 2004, and since that time has remained fairly static. The initial decline in emission intensity was due to technological innovation and equipment turnover, increased reliability across operations, and an increase in exports of crude

bitumen. The most significant factor contributing to the overall reduction in emission intensity of oil sands operations has been declining rates of emissions associated with fuel combustion.

### **Manufacturing Industries and Construction<sup>6</sup> (2012 GHG emissions, 44.5 Mt)**

Combustion emissions from the Manufacturing Industries and Construction subsector include the combustion of fossil fuels by the iron and steel, non-ferrous metals, chemicals, cement, pulp, paper and print, construction and all other manufacturing industries. In 2012, GHG emissions were 44.5 Mt (Table 2-6). Overall, this subsector was responsible for 6.4% of Canada's total GHG emissions in 2012, down 13 Mt from 1990.

Between 1990 and 2012, there were both increases and decreases in emissions produced by the various categories within the Manufacturing Industries and Construction subsector (Table 2-6). The Chemicals, Iron and Steel, and Cement categories increased by 1.9, 0.5 and 0.4 Mt, respectively. The remaining categories have all shown long-term decreases, from 59% in the Pulp, Paper and Print category to less than 0.1% in the Non-ferrous Metals category. These decreases can be attributed to decreased output (much of which occurring in the 2008–2009 period), fuel switching and changes in manufacturing operations.

Between 2005 and 2012, notable decreases in GHG emissions occurred in the Pulp, Paper and Print (32%), Cement (26%) and Non-ferrous Metals (9%) categories (Table 2-6). These decreases reflect reduction in manufacturing output.

### **Transport (2012 GHG emissions, 195 Mt)**

Transport is a large and diverse subsector, which, with 195 Mt of GHG emissions, accounts for 28% of Canada's GHG emissions in 2012. This subsector includes emissions from fuel combustion for the transport of passengers and freight in five subcategories:

<sup>6</sup> The Mining subsector has been removed from Manufacturing Industries and Construction and included in the Fossil Fuel Industries for the purpose of this analysis, as the majority of emissions in this subsector are from oil and gas extraction.

**Table 2-6 GHG Emissions from Manufacturing and Construction, Selected Years**

GHG Source Category	GHG Emissions (Mt CO <sub>2</sub> eq)								Change (%)
	1990	2000	2005	2008	2009	2010	2011	2012	
Iron and Steel	4.95	6.21	5.55	5.76	4.28	4.44	5.27	5.48	11%
Non-ferrous Metals	3.26	3.53	3.57	3.75	2.81	2.95	3.27	3.25	0%
Chemicals	8.22	10.76	8.28	8.75	8.83	9.86	11.06	10.09	23%
Cement	3.92	4.58	5.38	4.91	4.48	4.03	4.28	3.96	1%
Construction	1.87	1.08	1.44	1.37	1.21	1.50	1.43	1.45	-22%
Pulp, Paper and Print	14.5	12.6	8.7	6.4	6.5	6.1	6.3	5.9	-59%
Other Manufacturing <sup>1</sup>	21.0	18.1	16.9	15.5	13.4	13.7	14.4	14.4	-32%
<b>Total</b>	<b>57.7</b>	<b>56.9</b>	<b>49.9</b>	<b>46.4</b>	<b>41.5</b>	<b>42.6</b>	<b>46.1</b>	<b>44.5</b>	<b>-23%</b>

Note: Totals may not add up due to rounding.

1. Mining emissions have been removed and are included in Fossil Fuel Industries.

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

From 1990 to 2012, GHG emissions from Transport—driven primarily by energy used for personal transportation and heavy-duty trucking—rose 33% (49 Mt), accounting for almost one half of Canada's emission growth from 1990 to 2012.

Emissions from light-duty gasoline trucks (LDGTs), the subcategory that includes sport utility vehicles (SUVs), pickups and minivans, increased 104% between 1990 and 2012 (from 20.3 Mt in 1990 to 41.4 Mt in 2012), while emissions from cars (light-duty gasoline vehicles or LDGVs) decreased 16% (from 45.5 Mt in 1990 to 38.3 Mt in 2012) (Table 2–7).

As shown in Table 2–8, the growth in road transport emissions is due not only to the 52% increase in the total vehicle fleet since 1990 (14% since 2005), but also to a shift in light-duty vehicle purchases from cars to trucks, which, on average, emit 45% more GHGs per kilometre.

Between 1990 and 2012, the increase of 21 Mt and 22 Mt for LDGTs and heavy-duty diesel vehicles (HDDVs), respectively, reflects the trend towards the increasing use of SUVs, minivans and pickups for personal transportation and heavy-duty trucks for freight transport (Table 2–8).

In 2012, emissions from heavy-duty diesel vehicles (HDDVs) contributed 42 Mt to Canada's total GHG emissions (an increase of about 108% from 1990 and 11% from 2005). Emissions from

**Table 2–7 GHG Emissions from Transport, Selected Years**

GHG Source Category	GHG Emissions (Mt CO <sub>2</sub> eq)							
	1990	2000	2005	2008	2009	2010	2011	2012
<b>Transport (Total)</b>	<b>147</b>	<b>180</b>	<b>194</b>	<b>196</b>	<b>188</b>	<b>198</b>	<b>198</b>	<b>195</b>
Civil Aviation (Domestic Aviation)	7.1	7.6	7.6	7.3	6.4	6.4	6.2	6.1
Light-duty Gasoline Vehicles	45.5	42.0	40.2	39.5	39.7	40.0	38.5	38.3
Light-duty Gasoline Trucks	20.3	36.4	42.7	42.3	42.5	42.9	41.2	41.4
Heavy-duty Gasoline Vehicles	7.44	5.47	6.54	6.80	6.91	7.02	6.71	6.91
Motorcycles	0.152	0.162	0.254	0.263	0.266	0.271	0.264	0.268
Light-duty Diesel Vehicles	0.469	0.466	0.574	0.652	0.699	0.750	0.788	0.824
Light-duty Diesel Trucks	0.702	1.660	1.920	2.020	2.030	2.090	2.050	2.130
Heavy-duty Diesel Vehicles	20.0	30.8	37.6	39.2	39.0	40.2	42.0	41.7
Propane & Natural Gas Vehicles	2.20	1.10	0.72	0.88	0.78	0.78	0.82	0.88
Railways	7	7	7	8	5	7	8	8
Navigation (Domestic Marine)	5.0	5.2	6.7	6.5	6.7	7.0	5.8	5.8
Off-road Gasoline	7.8	8.7	8.3	7.3	7.3	7.9	8.1	7.6
Off-road Diesel	16	23	24	28	25	30	32	30
Pipelines	6.85	11.20	10.10	7.46	6.31	5.67	5.60	5.70

Note: For full details on all years, please refer to Annex 12.

**Table 2–8 Trends in Vehicle Numbers for Canada, 1990–2012**

Year	Number of Vehicles (000s)							Total
	LDGVs	LDGTs	HDGVs	MCs	LDDVs	LDDTs	HDDVs	
1990	10 646	3 308	518	261	109	112	402	15 356
2000	10 863	6 065	376	288	123	224	649	18 587
2005	10 961	7 386	435	437	159	277	856	20 510
2008	11 663	7 879	465	465	170	298	918	21 858
2009	11 897	8 043	476	475	173	305	939	22 308
2010	12 130	8 208	486	484	177	312	960	22 757
2011	12 267	8 304	491	490	179	318	975	23 025
2012	12 405	8 401	497	495	182	323	990	23 293
Change Since 1990	17%	154%	-4%	89%	67%	190%	146%	52%

Notes:  
HDDVs = Heavy-duty Diesel Vehicles; HDGVs = Heavy-duty Gasoline Vehicles; LDDTs = Light-duty Diesel Trucks; LDDVs = Light-duty Diesel Vehicles; LDGTs = Light-duty Gasoline Trucks; LDGVs = Light-duty Gasoline Vehicles; MCs = Motorcycles.



heavy-duty gasoline vehicles (HDGVs) have remained relatively unchanged since 2004, at 7 Mt; this figure represents a decrease of 7% 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 (Statistics Canada 2013a).

Off-road fuel combustion emissions<sup>7</sup> (gasoline and diesel combined) increased by 58% between 1990 and 2012.

The pipeline emissions are combustion emissions arising primarily from natural gas transport. Since 2005, emissions have been steadily decreasing and have begun to level off in the most recent years, mainly due to a 36% reduction in natural gas throughput volumes (Statistics Canada 2014b).

### Residential and Commercial (69 Mt)

Emissions in these categories arise primarily from the combustion of fuel to heat residential and commercial buildings, excluding electricity. Fuel combustion in the Residential and Commercial categories<sup>8</sup> accounted for 5.9% (41 Mt) and 4.0% (28 Mt), respectively, of all GHG emissions in 2012.

7 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 industries; recreational vehicles such as snowmobiles and all-terrain vehicles (ATVs); and residential equipment such as lawnmowers and trimmers.

8 Commercial category emissions are based on fuel use as reported in the *Report on Energy Supply–Demand in Canada (RESDD)* (Statistics Canada #57-003) for the 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.

As shown in Figure 2–7, residential emissions fluctuate on an annual basis<sup>9</sup> and, overall, have decreased by 2.6 Mt between 1990 and 2012. Over the short term, residential emissions decreased by 3.4 Mt between 2011 and 2012. Commercial emissions increased 2.1 Mt between 1990 and 2012. Combined, emissions from the two categories have remained relatively stable, with a change of 0.4 Mt or 0.6% between 1990 and 2012.

Fluctuations in GHG emissions, particularly in the Residential category, largely reflect changes in heating degree-days (HDDs)<sup>10</sup> as shown in Figure 2–7. This close tracking indicates the important influence that weather can have on space heating requirements and the demand for fuels and, in turn, on GHG emissions.

There are several major factors that influenced the changes in energy-related GHG emissions in the Residential category (Figure 2–8). Both the population (Statistics Canada 2013b) and the floor space use per capita are the most significant drivers, having increased 26% and 30% respectively between 1990 and 2012, pushing emissions upwards by 9.5 Mt and 9.9 Mt, respectively<sup>11</sup> (the sum of these two drivers represents the total impact of floor space). These impacts have been offset to a large extent by energy efficiency improvements and changes in the fuel mix (-14.6 Mt and -2.2 Mt, respectively).

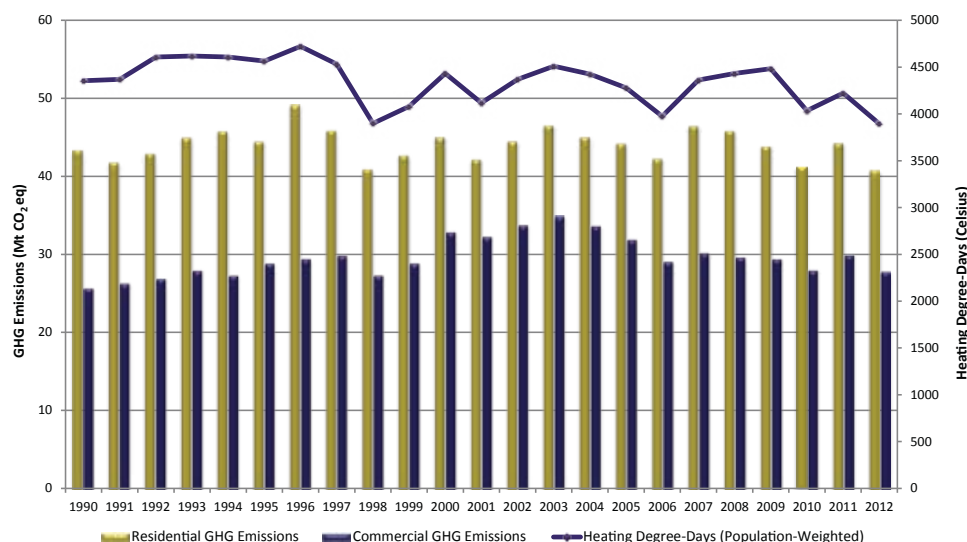
Energy efficiency improvements are due to better construction methods, increased insulation and higher-efficiency heating systems, while changes in the fuel mix are due to switching from

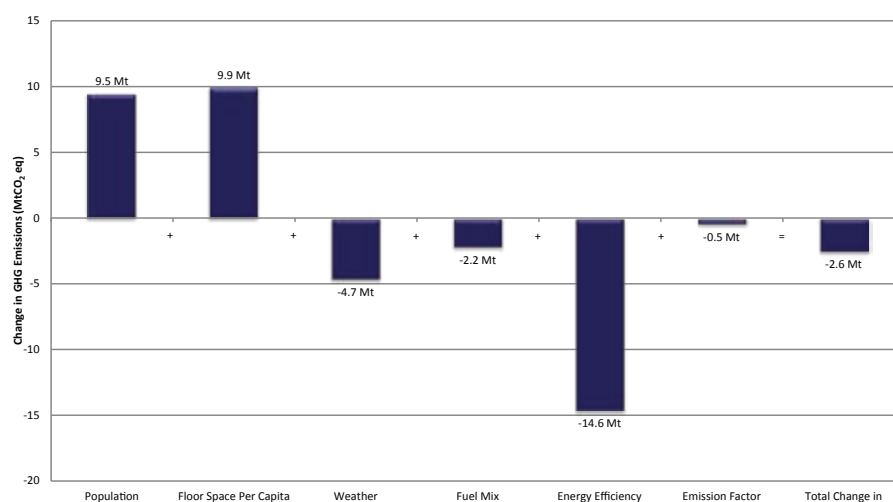
9 As such, weather does not affect the overall trend.

10 HDDs are calculated by determining the cross-Canada number of days below 18°C in a year, and multiplying this by the corresponding number of degrees below 18°C. The overall Canadian value is based on regional weightings by population.

11 See Figure 2-9 for the trend in floor space in Canada.

**Figure 2–7 GHG Emissions and Heating Degree-Days (HDDs) from Residential and Commercial Categories, 1990–2012**



**Figure 2–8 Major Influences on the Change in Stationary GHG Emissions from the Residential Category between 1990 and 2012**

RPPs and coal to natural gas. These improvements have been important because residential space heating requires the most energy of any end-use in Canadian homes, meaning that these changes led to significant reductions in GHG emissions.

Weather conditions can also have a major impact on emissions if there is a significant change in weather conditions between years. For instance, the difference in weather conditions between 1990 and 2012 had a -4.7 Mt impact on emissions in the Residential Sector. The “Reducing Heating Requirements in Commercial and Residential Buildings” sidebar provides information on the links between temperature, energy demand and improvements in energy use.

The Residential category is also a large consumer of electricity; therefore, efforts to increase efficiency in electricity use can have significant indirect impacts on reducing the requirements for electricity generation. The most significant of these changes have occurred with large appliances used in Canadian households. For example, although total appliance energy use increased 3% between 1990 and 2010, energy use by major appliances<sup>12</sup> improved by approximately 24%. This is offset by a 148% increase in energy use from other appliances<sup>13</sup> (NRCan 2013a).

### *Agriculture and Forestry*

Stationary fuel combustion–related emissions in Agriculture and Forestry amounted to 3.5 Mt in 2012, an increase of 48% from 1990. Emissions from these categories contributed approximately 0.5% of the total for 2012.

<sup>12</sup> Major appliances include refrigerators, freezers, dishwashers, clothes washers, clothes dryers and cooking ranges.

<sup>13</sup> Other appliances include microwaves, televisions, cable boxes, video playback and recording devices, sound systems and computers.

### **2.3.1.2. Fugitive Emissions from Fuels (2012 GHG emissions, 61 Mt)**

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 about 9% of Canada’s total GHG emissions for 2012 and, if considered separately from the Fossil Fuel Industries noted earlier in this section, contributed 17% to the growth in emissions between 1990 and 2012.

Table 2-9 summarizes the changes in fugitive emissions and fugitive emission intensity for the Coal Mining and Oil and Natural Gas categories. In total, fugitive emissions grew by about 44% between 1990 and 2012, from 42 to 61 Mt, with emissions from the Oil and Natural Gas category contributing 98.4% of the total fugitive emissions in 2012, far overshadowing the 1.6% contribution from Coal Mining. Although fugitive releases from the Solid Fuels category (i.e. coal mining) decreased by 1.2 Mt (54%) between 1990 and 2012 as a result of the closing of many mines in eastern Canada, emissions from oil and natural gas increased 50% during the same period. Although rising over the long term, in the period from 2005 to 2012 the total fugitive emissions fell by 2.2 Mt (3.6%).

The growth in emissions between 1990 and 2012 is a result of the increased production of natural gas and heavy oil (including crude bitumen) since 1990, largely due to increased worldwide demand for energy products. Since 1990, net energy exported from Canada has increased by 230% (refer to Section 3.5.4 in

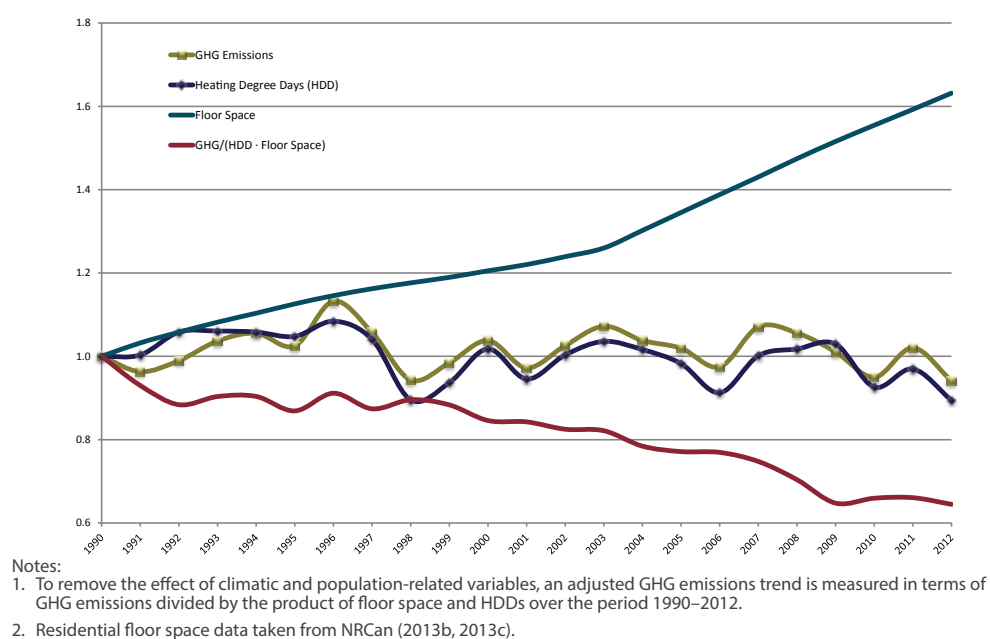
## Reducing Heating Requirements in Commercial and Residential Buildings

The amount of energy required to heat and cool a dwelling is closely related to the outside ambient air temperature. Two common indicators that are used to determine the impacts of weather on energy requirements and GHG emissions are annual heating degree-days (HDDs) and annual cooling degree-days (CDDs). Annual HDDs are the annual sum of the days when the average daily temperature is below 18°C multiplied by the number of degrees the temperature is below 18°C on each of those days. Annual CDDs are the annual sum of days when the average daily temperature is over 18°C multiplied by the number of degrees above 18°C on each of those days. Since Canada is a northern country, home heating consumes a much greater amount of energy for the average home on an annual basis compared with other countries, and cooling accounts for a much smaller portion of energy.

In general, there is a strong correlation between HDDs in Canada and the energy-related GHG emissions originating from the Residential category on an inter-annual basis (see Figure 2–9). This indicates the close relationship between outside air temperatures and how much energy is required to heat the home.

The longer-term trend (also shown in Figure 2–9) is evidenced by a decrease in GHG emissions per amount of floor space requiring heating (as indicated by the product of floor space and HDDs). In spite of increases in floor space, GHG emissions remained stable. This decoupling has been the result of increases in the efficiency of heating and the thermal envelope of buildings, as well as the result of some changes in the mix of heating fuels, such as natural gas substituting for light fuel oil.

**Figure 2–9 Relationship between HDDs and Residential GHG Emissions, 1990–2012**



Chapter 3 for a discussion of emissions associated with the export of oil and natural gas), accompanied by a 286% increase in GHG emissions associated with those net energy exports

Although overall fugitive emissions associated with oil and gas production have increased substantially since 1990, the overall fugitive emission intensity (emissions per unit of energy produced) of upstream oil and gas production has decreased by

14% (see Table 2–9). This reduction is due to a 40% decrease in oil sands fugitive emission intensity, which was somewhat offset by a 14% increase in conventional oil production intensity. The increase in conventional oil intensity is indicative of the fact that easily removable reserves of conventional crude oil are being replaced with more high energy- and GHG-intensive sources, including heavier and/or more difficult-to-obtain conventional oils such as those from offshore sources and enhanced oil

Table 2–9 Fugitive GHG Emission Intensity of Fossil Fuel Production by Category, Selected Years

	1990	2000	2005	2008	2009	2010	2011	2012
<b>COAL PRODUCTION</b>								
Fugitive Emissions (Mt CO <sub>2</sub> eq)	2	1	1	1	1	1	1	1
Production (PJ)	1 673	1 510	1 401	1 490	1 372	1 483	1 485	1 488
Fugitive Emissions Intensity (kt CO <sub>2</sub> eq / PJ)	1.31	0.64	0.72	0.63	0.63	0.68	0.67	0.68
<b>UPSTREAM OIL AND GAS PRODUCTION</b>								
Fugitive Emissions (Mt CO <sub>2</sub> eq)	38	59	59	57	54	54	55	56
Production (PJ)	7 958	12 171	13 091	13 059	12 593	12 721	13 203	13 674
Fugitive Emissions Intensity (kt CO <sub>2</sub> eq / PJ)	4.78	4.83	4.47	4.39	4.31	4.22	4.16	4.12
<b>Conventional Oil Production</b>								
Fugitive Emissions (Mt CO <sub>2</sub> eq)	16	25	23	21	19	18	19	20
Production (PJ)	2 973	3 590	3 459	3 418	3 090	3 098	3 173	3 287
Fugitive Emissions Intensity (kt CO <sub>2</sub> eq / PJ)	5.44	7.03	6.65	6.00	6.02	5.88	5.95	6.18
<b>Oil Sands Mining, Extraction and Upgrading</b>								
Fugitive Emissions (Mt CO <sub>2</sub> eq)	2.5	4.2	5.4	6.4	7.0	7.3	7.6	8.0
Production (PJ)	801	1 520	2 440	2 980	3 274	3 616	3 968	4 381
Fugitive Emissions Intensity (kt CO <sub>2</sub> eq / PJ)	3.06	2.79	2.19	2.15	2.14	2.02	1.91	1.83
<b>Natural Gas Production and Processing</b>								
Fugitive Emissions (Mt CO <sub>2</sub> eq)	15	24	25	25	23	22	23	22
Production (PJ)	4 184	7 062	7 192	6 661	6 229	6 007	6 062	6 006
Fugitive Emissions Intensity (kt CO <sub>2</sub> eq / PJ)	3.61	3.36	3.41	3.69	3.68	3.74	3.76	3.71
<b>Natural Gas Transmission</b>								
Fugitive Emissions (Mt CO <sub>2</sub> eq)	4.3	5.6	5.7	5.7	5.7	5.6	5.6	5.7
Pipeline Length (km)	64 222	81 390	83 245	84 077	84 013	81 495	81 709	82 170
Fugitive Emissions Intensity (kt CO <sub>2</sub> eq/km)	0.067	0.068	0.068	0.068	0.068	0.069	0.069	0.069
<b>DOWNSTREAM PRODUCTION</b>								
Fugitive Emissions (Mt CO <sub>2</sub> eq)	2.1	3.3	3.8	3.8	3.7	3.8	3.7	3.8
Production (PJ)	3 907	4 375	4 699	4 622	4 525	4 629	4 425	4 488
Fugitive Emissions Intensity (kt CO <sub>2</sub> eq / PJ)	0.54	0.75	0.80	0.82	0.82	0.82	0.83	0.84
<b>Petroleum Refining</b>								
Fugitive Emissions (Mt CO <sub>2</sub> eq)	0.9	1.7	2.0	1.9	1.8	1.8	1.7	1.7
Production (PJ)	3 907	4 375	4 699	4 622	4 525	4 629	4 425	4 488
Fugitive Emissions Intensity (kt CO <sub>2</sub> eq / PJ)	0.22	0.38	0.42	0.40	0.39	0.39	0.38	0.39
<b>Natural Gas Distribution</b>								
Fugitive Emissions (Mt CO <sub>2</sub> eq)	1.3	1.6	1.8	1.9	2.0	2.0	2.0	2.0
Pipeline Length (km)	168 813	212 991	241 344	254 512	259 844	261 308	264 058	266 854
Fugitive Emissions Intensity (kt CO <sub>2</sub> eq / km)	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008

recovery (EOR) operations. In addition, the increased use of multi-stage fracturing has increased fugitive emissions during the well-completion phase of production (Allen et al. 2013)

### 2.3.2. Industrial Processes Sector (2012 GHG emissions, 56.5 Mt)

The Industrial Processes Sector includes GHG emissions that result from manufacturing processes and use of products. Categories in this sector include Mineral Products, Chemical Industry, Metal Production, Production and Consumption of Halocarbons and SF<sub>6</sub>, and Other and Undifferentiated Production. GHG emissions from the Industrial Processes Sector contributed 56.5 Mt to the 2012 national GHG inventory, compared with 55.7 Mt in

1990. Total emissions in this sector result from activities in several diverse industries, and as a result do not display a consistent trend over time (Figure 2–10).

Overall, Industrial Process emissions in 2012 (56.5 Mt) are not significantly different from 1990 levels (55.7 Mt), but have increased since they reached their lowest point in 2009. Recent emission increases can primarily be explained by growth in Other and Undifferentiated Production (CO<sub>2</sub>)<sup>14</sup> and Consumption of Halocarbons, and to a lesser degree by increases in Ammonia Production (CO<sub>2</sub>) and Cement Production (CO<sub>2</sub>). These increases

14 Other and Undifferentiated Production is an aggregate emission category that includes emissions from petrochemical production and use of petroleum products as lubricants and solvents.

Figure 2–10 GHG Emissions from Industrial Processes by Subsector, 1990–2012

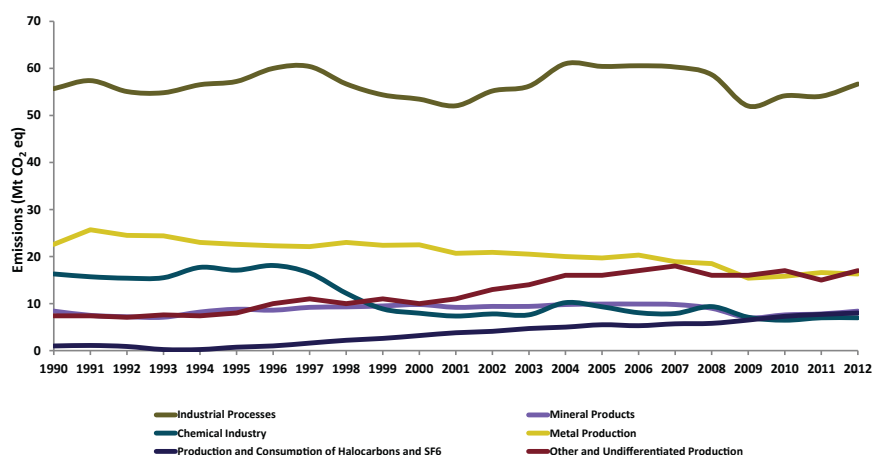


Table 2–10 GHG Emissions from Industrial Processes by Category, Selected Years

GHG Source Category	GHG Emissions (Mt CO <sub>2</sub> eq)							
	1990	2000	2005	2008	2009	2010	2011	2012
Total - Industrial Processes	55.7	53.8	60.4	59.0	51.8	54.1	54.7	56.5
Mineral Products	8.4	9.8	9.9	9.0	7.0	7.6	7.8	8.4
Cement Production	5.4	6.7	7.2	6.6	5.1	5.7	5.7	6.3
Lime Production	1.8	1.9	1.7	1.5	1.2	1.4	1.4	1.4
Limestone and Dolomite Use	0.80	0.77	0.64	0.67	0.54	0.36	0.36	0.43
Soda Ash Use	0.25	0.25	0.18	0.16	0.11	0.10	0.10	0.11
Magnesite Use	0.147	0.181	0.175	0.057	0.069	0.081	0.096	0.091
Chemical Industry	16.3	8.0	9.3	9.4	7.1	6.5	7.0	7.0
Ammonia Production	4.5	5.7	5.3	5.6	5.2	5.3	5.7	5.8
Nitric Acid Production	1.01	1.23	1.25	1.28	1.15	1.10	1.16	1.15
Adipic Acid Production	10.7	0.9	2.6	2.4	0.7	0.0	0.0	0.0
Petrochemical Production	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Metal Production	22.6	22.5	19.7	18.6	15.4	15.8	16.6	16.3
Iron and Steel Production	10.2	11.5	10.2	10.7	8.0	9.0	9.9	9.8
Aluminium Production	9.3	8.2	8.2	7.4	7.2	6.6	6.6	6.2
Magnesium Production	2.87	2.31	1.09	0.18	0.00	0.00	0.00	0.00
Magnesium Casting	0.236	0.471	0.201	0.280	0.193	0.190	0.200	0.257
Production and Consumption of Halocarbons	0.8	2.9	5.3	5.6	6.3	7.1	7.6	7.8
SF <sub>6</sub> Use in Electric Utilities and Semiconductors	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.2
Other & Undifferentiated Production	7.4	10.0	16.0	16.0	16.0	17.0	15.0	17.0

Note: Totals may not add up due to rounding.

were offset by emission reductions in Adipic Acid Production (N<sub>2</sub>O), Aluminium Production (PFCs), and Magnesium Production (SF<sub>6</sub>).

### 2.3.2.1. Mineral Products

Mineral product use (which comprises uses of limestone and dolomite, soda ash and magnesite) experienced a decrease in emissions of 0.6 Mt CO<sub>2</sub> eq (48%) from 1990 to 2012. Important industrial consumers of limestone and soda ash are the iron and steel industry, pulp and paper mills, and glass manufacturers. A significant decline in pulp and paper production, increased use of recycled glass (NRCan 2007), and a moderate decrease in steel

output resulted in the declining use of these mineral products and the associated emissions. Reductions in emissions from limestone and dolomite use resulted from reduced production in the iron and steel sector, particularly in 2001–2002 and 2006–2007.

Emissions from magnesite use occur when mined magnesite is calcined to produce magnesia (magnesium oxide) for use in various applications, or is chemically treated to form the intermediate product magnesium chloride to produce magnesium metal (AMEC 2006). The closure of all magnesium production facilities, the last one shutting down in 2008, contributed to significant

decreases in emissions since 1990.<sup>15</sup> In 2012, emissions resulting from magnesite use are purely from magnesia production for industrial, environmental and agriculture applications (Baymag 2011). As a result, emissions from magnesite use in 2012 have decreased by 38% compared to 1990 (0.06 Mt CO<sub>2</sub> eq).

Within the cement production subcategory, fluctuating emissions between 1990 and 2012 represent the net effect of decreasing clinker production to its lowest level (9.9 Mt) in 2009, followed by a rebound to 12.1 Mt in 2012 (Statistics Canada 1990 2004a, 2004–2010a, 2004–2010b). Clinker, the output of the cement kiln process, is a fused mixture of lime and silicates of metals such as iron and aluminium. The stage after clinker is the production of cement, which is a mixture of clinker and ground gypsum as hot clinker is cooled. CO<sub>2</sub> emissions are associated with the clinker stage in the decomposition of raw limestone in the kiln. The fluctuating production levels of clinker can be attributed to the changes in demand.

### 2.3.2.2. Chemical Industry

A decrease of 57% (9.4 Mt CO<sub>2</sub> eq) from 1990 to 2012 is observed for the chemical industry as a whole. The main driver of emission reduction in this industry from 1990 to 2012 was ceasing of operations in Canada's sole adipic acid plant. Emissions from adipic acid production were zero since 2010, as the Ontario plant became indefinitely idled in 2009; this represents a decrease of 10.7 Mt CO<sub>2</sub> eq from the 1990 level.<sup>16</sup> The same plant was responsible for significant emission reduction in the late 1990s due to the incorporation of more stringent controls on N<sub>2</sub>O emissions.

Emissions from the ammonia production industry have increased by 28% (1.3 Mt CO<sub>2</sub> eq) from 1990 to 2012. The increase is mainly due to general increase in demand for ammonia coming from agriculture activities (Cheminfo 2006).

### 2.3.2.3. Metal Production

Emissions reductions in the Magnesium, Aluminium and Iron and Steel categories contributed to the 28% (6.3 Mt CO<sub>2</sub> eq) overall reduction in emissions from Metal Production between 1990 and 2012. Magnesium production decreased 2.9 Mt CO<sub>2</sub> eq as compared to 1990 levels.

The aluminium industry has succeeded in bringing down its perfluorocarbon (PFC) emissions by 5.0 Mt CO<sub>2</sub> eq (77%), while increasing production by 77% between 1990 and 2012. Reductions in PFC emissions have been achieved through the incorporation of computerized sensors and automated alumina

feeders. In addition, the data show that the industry continued to increase its production from more modern plants (i.e. with prebaked technology), rather than from older plants (i.e. with Söderberg technology). However, the increase in aluminium production also gave rise to an increase in CO<sub>2</sub> emissions of 2.0 Mt CO<sub>2</sub> eq (or 73%). Overall emissions from aluminium production have decreased by 33% (3.1 Mt CO<sub>2</sub> eq) from 1990 to 2012.

From 1990 to 2012 the iron and steel industry experienced an emission decrease of 3.4% (0.35 Mt CO<sub>2</sub> eq). Emissions decreased considerably (25% or 2.6 Mt CO<sub>2</sub> eq) between 2008 and 2009, due to reduced production, but this was followed by a rebound, and by 2012 emissions had increased 23% (1.8 Mt CO<sub>2</sub> eq) compared to 2009.

### 2.3.2.4. Production and Consumption of Halocarbons and SF<sub>6</sub>

There has been an emission growth of 7.3 Mt CO<sub>2</sub> eq (990%) for consumption of hydrofluorocarbons (HFCs) since 1995. This can be explained by the displacement of ozone-depleting substances (ODSs) by HFCs within the refrigeration and air conditioning (AC) markets since the Montreal Protocol came into effect in 1996. The 1990 emissions from the Production and Consumption of Halocarbons in Table 2–10 represents only HFC-23 emissions from the production of HCFC-22, as emissions from the consumption of HFCs were negligible in 1990. Production of HCFC-22 ceased in 1993, and HFC emissions reported after this year are only from consumption.

### 2.3.2.5. Other and Undifferentiated Production

The Other and Undifferentiated Production category demonstrated an increase in emissions of 9.4 Mt CO<sub>2</sub> eq (128%) from 1990 to 2012. The increase can be attributed to the greater use of petroleum fuels as feedstock to meet increased demand for petrochemical products. The feedstock use of waxes, paraffin and unfinished petrochemical derivatives has increased by 1400% (6.7 Mt CO<sub>2</sub> eq) (Statistics Canada 57-003 – RESD), the use of ethane has increased by 220% (1.4 Mt CO<sub>2</sub> eq), and the use of petrochemical feedstock has increased by 34% (0.65 Mt CO<sub>2</sub> eq).

### 2.3.3. Solvent and Other Product Use Sector (2012 GHG emissions, 0.31 Mt)

The Solvent and Other Product Use Sector accounts for emissions related to the use of N<sub>2</sub>O as an anaesthetic in medical applications and as a propellant in aerosol products. It contributed 247 kt CO<sub>2</sub> eq to the 2011 national GHG inventory, compared to 179 kt CO<sub>2</sub> eq in 1990. The emission trends were primarily driven by the domestic demand for N<sub>2</sub>O for anaesthetic or propellant purposes.

<sup>15</sup> Timminco 2009, provided by Greg Donaldson from Timminco via email to Alice Au, Greenhouse Gas Division, dated November 27, 2009.

<sup>16</sup> Invista 2012, provided by Joe Hendriks from Invista via email to Pollutant Inventories and Reporting Division, dated November 22, 2013.



### 2.3.4. Agriculture Sector (2012 GHG emissions, 56 Mt)

The main sectors in Canadian agriculture are livestock and crop production. The livestock sector is dominated by beef, dairy, poultry and swine production, while crop production is mainly dedicated to the production of cereals and oil seeds. Canada also produces a wide variety of specialty crops and animals, but these represent a very small portion of the overall agricultural economy. Agricultural production is highly regionalized; approximately 75% of beef cattle and more than 90% of wheat, barley and canola are produced in the semi-arid to subhumid ecozones of the Prairies. On the other hand, approximately 75% of dairy cattle, 60% of swine and poultry, 95% of corn and 90% of soybeans are produced in the humid Mixedwood Plains ecozone in eastern Canada (Statistics Canada 2007). Traditionally Canada's Agriculture Sector has been composed of small family farms, but over the past 30 years, intensification has occurred in the Agriculture Sector and as a consequence, the number of farms has decreased and farm size and productivity have increased.

Non-energy emissions directly related to animal and crop production accounted for 56 Mt CO<sub>2</sub> eq or 8% of total 2012 GHG emissions for Canada, an increase of 9 Mt CO<sub>2</sub> eq or 19% since 1990. Agriculture accounted for 22% and 74% of the national CH<sub>4</sub> and N<sub>2</sub>O emissions, respectively. Nitrous oxide accounted for 63% of estimated sectoral emissions and CH<sub>4</sub> for 37% in 2012. All these emissions are from non-energy sources. Generally, agricultural emissions result from losses and inefficiencies in production processes, either losses of nutrition energy during animal digestion or losses of nutrient nitrogen. Emissions from energy used during the agricultural production process and the energy and fugitive emissions occurring during the production of nitrogen fertilizers and other agricultural chemicals are discussed

in Chapter 3 (Energy) and Chapter 4 (Industrial Processes) of this report.

The processes and activities that produce agricultural GHG emissions are attributed to either the livestock sector, which includes enteric fermentation emissions (CH<sub>4</sub>) and all emissions (CH<sub>4</sub> and N<sub>2</sub>O) from the storage and application of manure; or the crop production sector, which consists of N<sub>2</sub>O emissions from the application of synthetic nitrogen fertilizers, crop residue decomposition and the burning of agricultural residues (CH<sub>4</sub> and N<sub>2</sub>O) (Table 2–11).

In 2012, livestock emissions consisted of 18 Mt CO<sub>2</sub> eq from enteric fermentation and 14 Mt CO<sub>2</sub> eq from manure management, storage and application (56% and 44% of livestock emissions, respectively). Crop production produces N<sub>2</sub>O emissions during the application of synthetic nitrogen fertilizers (16 Mt CO<sub>2</sub> eq.) and from crop residue decomposition (7.7 Mt CO<sub>2</sub> eq), representing 66% and 34% of crop production emissions, respectively (Table 2–11).

A discussion of GHG trends in agricultural production must also take into account the complex interconnections between the two dominant branches of agriculture: livestock and crop production. These two sub-industries both compete for the same land base and contribute resources to and from that land base. For instance, high beef prices may stimulate more conversion of marginally arable annual cropland to perennial pasture and vice versa. Over the past decades, agriculture has undergone a gradual intensification of production per unit land area. In the crop production industry intensification has involved an increased reliance on off farm inputs such as fertilizers, herbicides and pesticides and has resulted in increased productivity per hectare and reduction of summerfallow. In the livestock industry this has also involved increased reliance on processed feeds and medicinal

Table 2–11 GHG Emissions from Agriculture by Production Systems for Selected Years<sup>1</sup>

Production System	GHG Emissions (Mt CO <sub>2</sub> eq)							
	1990	2000	2005	2008	2009	2010	2011	2012
Livestock	29	36	39	36	34	33	31	32
Dairy Cows	5.7	5.0	4.7	4.5	4.5	4.5	4.5	4.5
Beef Cattle	19	25	28	26	24	23	22	22
Swine	2.4	3.1	3.5	3.0	2.9	2.9	2.9	2.9
Other Livestock <sup>2</sup>	1.5	2.1	2.3	2.2	2.2	2.2	2.2	2.2
Crop	18	20	19	23	22	22	22	24
Synthetic Nitrogen Fertilizers	9.2	12	11	13	14	14	14	16
Crop Residue Decomposition	7.0	7.0	7.6	9.1	8.2	8.5	7.4	7.7
Other Management Practices <sup>3</sup>	1.8	1.0	0.4	0.2	0.1	0.0	-0.1	-0.3
<b>Agriculture (Total)</b>	<b>47</b>	<b>56</b>	<b>58</b>	<b>58</b>	<b>56</b>	<b>55</b>	<b>53</b>	<b>56</b>

1. Totals may not add up due to rounding.

2. Other livestock includes sheep, lamb, goat, horse, bison, poultry, llamas and alpacas.

3. Other management practices includes summerfallow, conservation tillage practices, irrigation, cultivation of organic soils and field burning of crop residues.



and non-medicinal supplements that have also increased output per animal. At the same time, over the past 30 years there has been an increased focus on soil conservation through conservation tillage and crop rotation. For these reasons, a comprehensive discussion of trends in emissions from agricultural production must at least touch on the dominant emissions from production practices, farm inputs, land management practices and land-use change (Statistics Canada 2007).

The main drivers of the emission trend in the Agriculture Sector are the expansion of the beef cattle and swine populations, and increases in the application of synthetic nitrogen fertilizers in the Prairies. Beef, swine and poultry populations in Canada are 13%, 25% and 39% higher, respectively, than in 1990. The increase in livestock populations largely accounts for the 10% increase, from 29 to 32 Mt CO<sub>2</sub> eq, in emissions associated with animal production over the 1990–2012 period (Table 2–11). In the case of beef cattle, emissions increased at greater rates than cattle populations as herd improvements resulted in an increase in live weight; consequently, an average animal now consumes more feed and also emits more GHGs.

Increases from beef production were, however, partially offset by a 30% reduction in the dairy population (Statistics Canada 2007). The dairy quota systems encouraged the dairy industry to invest in herd improvement in order to increase profitability. Emissions associated with dairy cows have fallen by approximately 22% since 1990, as the decline in the dairy herd has been partly offset by a 33% increase in average milk productivity, due to improved genetics and changes in feeding and/or management practices. Therefore, even though the decrease in dairy population is driving the emission decline in this category, as was the case with non-dairy cattle, an average cow produces more milk today than in 1990, and also emits more GHGs.

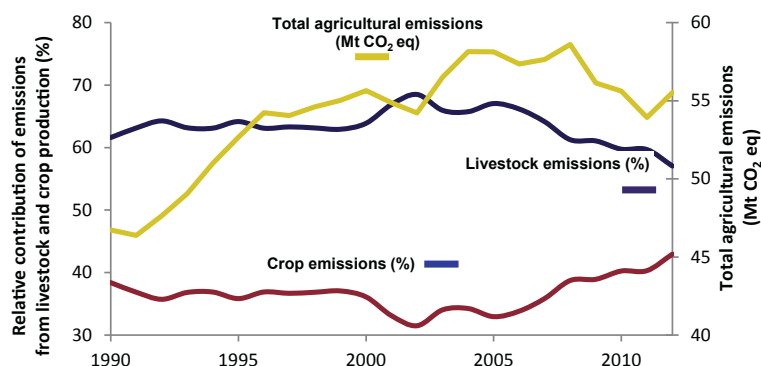
Overall, during the 1990–2005 period, the combination of increased livestock populations and increasing emissions per animal in some animal categories resulted in a change in the relative

proportion—from 61% to 68%—of GHGs originating from the livestock sector, increasing to the high of 68% during the drought years of 2001 and 2002 (Figure 2–11), but decreasing since the peak in 2002 to 57% in 2012.

Emissions attributed to crop production are due mainly to either the application of synthetic nitrogen fertilizers or to crop residue decomposition, which is directly proportional to crop yields. From 1990 to 2012, the use of synthetic nitrogen fertilizer increased from 1.2 Mt nitrogen to 2.3 Mt nitrogen. Even though the consumption of synthetic nitrogen fertilizers has increased steadily, two periods marked significant increases between 1991 and 1997 and between 2005 and 2012. The first period that marked a rapid increase in synthetic nitrogen consumption resulted mainly from the intensification of cropping systems or the reduction of summerfallow on the Canadian Prairies; the second period reflected a dramatic increase in grain price that encouraged farmers to use more nutrient inputs for better economic return. Major crops grown in Canada include corn, wheat, barley and canola, which require high rates of fertilization to achieve and sustain high levels of production. As a consequence, emissions from synthetic nitrogen fertilizer consumption have increased substantially, from 9.3 Mt CO<sub>2</sub> eq in 1990 to 16 Mt CO<sub>2</sub> eq in 2012.

Emissions from crop residue decomposition varied between 4.9 Mt CO<sub>2</sub> eq (in 2002) and 9.1 Mt CO<sub>2</sub> eq (in 2008). Severe drought for most regions of the Canadian Prairies in 2001 and 2002 resulted in very poor crop production and, in turn, lower emissions for these years. The impact of the drought is observed in both the emission trend and the relative proportion of emissions attributed to crop or animal growth (Figure 2–11). On the other hand, since 2005, favourable weather conditions along with good commodity prices resulted in record production for soybean, corn, pulse and canola and consequently greater emissions of nitrous oxide (N<sub>2</sub>O).

**Figure 2–11 Relative GHG Contribution from Livestock and Crop Production and Total Agricultural Emissions, 1990–2012**



### Recent Trends

Beef prices were strong from 1990 until 2003, when the occurrence of bovine spongiform encephalopathy (BSE, or mad cow disease) resulted in a worldwide ban on Canadian beef products. A sudden 9% increase in domestic animal populations occurred between January 2003 and January 2004. The BSE crisis was not completely resolved until 2005, and since the peak of the crisis in 2005, beef populations have decreased by 20%.

The prices of hogs were also strong from 1990 to 2003 (Statistics Canada 2009), and increases in population numbers occurred. However, prices have also decreased in recent years, and as a result, populations have decreased by 15% since their peak in 2005. These population decreases, combined with continued decreasing trends in dairy cattle populations, have decreased emissions from livestock by 19%, or roughly 7.3 Mt CO<sub>2</sub> eq since 2005. At the same time, since 2005, due to improved crop yields and strong grain commodity prices, emissions from crop production have increased by 24%, roughly 4.6 Mt CO<sub>2</sub> eq.

From 2005 to 2008, total overall emissions from agriculture were stable: animal populations decreased, but reduced livestock emissions were offset by emissions from increased fertilizer use as well as high crop production (resulting in high emissions from crop residue decomposition). Since 2008, livestock emissions have continued to decrease and fertilizer use continues to increase, but crop production has been lower than its peak in 2008 and, on average, annual agricultural emissions are 3.1 Mt CO<sub>2</sub> eq lower than average emissions from 2005 to 2008. Between 2011 and 2012, fertilizer use increased by 15%, animal populations remained stable and crop production increased slightly, resulting in an overall increase in emissions in 2012.

The decline in animal populations and continued increase in fertilizer use reversed the trend of an increasing proportion of

emissions originating from livestock production (Figure 2–11). The proportion of emissions from livestock in 2012 dropped to the lowest proportion of total agriculture emissions (57%) of the reporting period from 1990 (61%) and considerably lower than the proportion in 2005 (67% of total emissions).

### 2.3.5. Land Use, Land-use Change and Forestry Sector (2012 net GHG emissions, 41 Mt, not included in national totals)

The Land Use, Land-use Change and Forestry (LULUCF) Sector reports anthropogenic GHG fluxes between the atmosphere and Canada's managed lands, as well as those associated with land-use changes.

The net LULUCF flux, calculated as the sum of CO<sub>2</sub> emissions and removals and non-CO<sub>2</sub> emissions, displays high interannual variability over the reporting period. In 2012, this net flux amounted to emissions of 41 Mt (Figure 2–12).

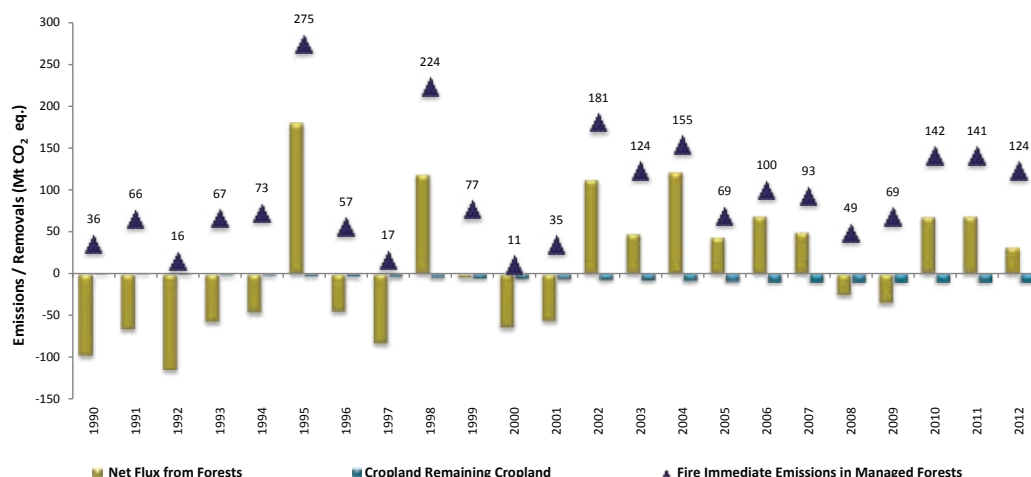
All emissions and removals in the LULUCF Sector are excluded from the national totals. In 2012, the estimated 41 Mt would, if included, increase the total Canadian GHG emissions by about 6%.

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

The Forest Land category includes GHG emissions from and removals by Canada's managed forests. Due to a methodological artefact, the net flux in forest land displays an important annual variability due to the erratic pattern of forest wildfires, which masks underlying patterns of interest in the Sector. Important subsectoral trends associated with human activities in managed

Figure 2–12 GHG Emissions from LULUCF Relative to Total Canadian Emissions, 1990–2012



**Figure 2–13 Selected GHG Emissions and Removals in LULUCF, 1990–2012**

forests include a 28% increase in the carbon removed in harvested wood biomass between 1990 and the peak harvest year, 2004. Significant reductions have occurred in forest management activities, with 2009 harvest levels reaching the lowest point (30 Mt C) in the 23-year period covered in this report. Even though the last three years show a modest increase, harvest levels in 2012 are still 35% below the peak year of 2004. This trend reflects a deep restructuring of the Canadian forest economic sector, aggravated by the consequences of the economic recession in the United States, Canada's main export market.

The high variability in the net flux from managed forests is associated with the immediate impact of wildfires, which are random, natural events; these wildfires alone represented annual emissions of between 11 and 275 Mt CO<sub>2</sub> eq over the period from 1990 to 2012 (Figure 2–13). Likewise, the immediate and long-term effect of the catastrophic Mountain Pine Beetle infestation in western Canada will undoubtedly continue to influence the GHG trends due to tree mortality and residual decay of dead organic matter.

Note that the current default approach to estimating emissions associated with harvesting ignores long-term carbon storage in wood products. Taking into account this storage, emission estimates from harvesting in the year 2012 alone could be reduced by 20 Mt.

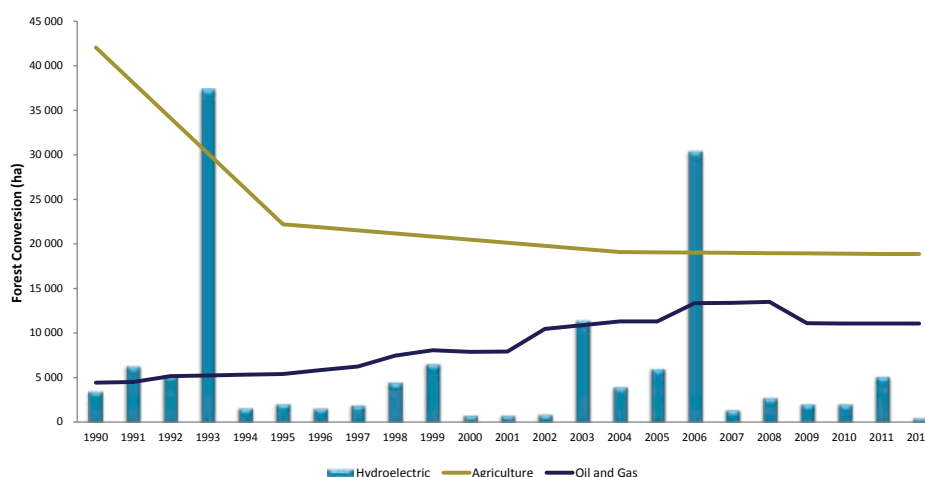
The Cropland subcategory includes the effect of agricultural practices on CO<sub>2</sub> emissions from, and removals by, arable soils and the immediate and long-term impacts of forest and grassland conversion to cropland. The trend shows a steady decline in emissions from cropland, notably in the period 1990–2006, going from a net source of 12 Mt CO<sub>2</sub> eq in 1990 to a net sink of 5 Mt CO<sub>2</sub> eq in 2006. This trend is a result of changes in agricultural land management practices in western Canada, such as

the extensive adoption of conservation tillage practices (over 13 million hectares of cropland since 1990) and a reduction in summerfallow by 76% in 2012 (Statistics Canada 2007). Since 2006, net removals have tended to remain constant around 5 Mt CO<sub>2</sub> eq, due to the soil sink approaching equilibrium. The net CO<sub>2</sub> removals due to the management of mineral soils increased from 2 Mt in 1990 to 11 Mt in 2012. A decline in forestland conversion to cropland has also contributed to this trend.

CO<sub>2</sub> emissions from peatlands managed for peat extraction and from land flooding are reported under the Wetlands category. Emissions from managed peatlands increased 76% from 1990 to 2000; since then, they show a slight decline amounting to 1.1 Mt in 2012. Emissions from land conversion to flooded lands (reservoirs) do not show a consistent trend. Higher values above 4 Mt/year were observed over the 1990–1993 period, explained by residual emissions from the creation of large reservoirs before 1990; emissions have since then declined, with moderate peaks in 1999 and 2005, decreasing to 1.4 Mt in 2012. Note that emissions from the surface of reservoirs flooded for more than 10 years are excluded from the accounting (IPCC 2003).

The conversion of forests to other land is a prevalent yet declining practice in Canada. It is driven by a great variety of circumstances across the country, including policy and regulatory frameworks, market forces and resource endowment. The economic drivers of forest conversion are diverse and result in heterogeneous spatial and temporal patterns of forest conversion (Kurz et al. 2013). Since 1990, more than one million hectares of forest have been lost in Canada. GHG emissions from forest conversion have dropped from 25 Mt CO<sub>2</sub> eq in 1990 to 18 Mt CO<sub>2</sub> eq in 2012. Geographically, the highest average rates of forest conversion occur in the Boreal Plain (24 kha yr<sup>-1</sup>) and the Boreal Shield East (8 kha yr<sup>-1</sup>), which account for 46% and 16% of the total forest area lost in Canada since 1990, respectively.

**Figure 2–14 Trends in Annual Rates of Forest Conversion due to Agricultural Expansion, Oil and Gas Extraction and Hydroelectric Developments**



Primary drivers of forest conversion include agricultural expansion, resource extraction and hydroelectric development. Forest conversion for agricultural expansion accounted for 44% of the cumulative area of forest conversion since 1990. Annual rates of deforestation to agriculture, however, have dropped from 42 kha in 1990 to 19 kha in 2012 (Figure 2–14). This decrease predominantly took place in the Boreal Plains, Subhumid Prairies and Montane Cordillera of western Canada, following a period of active agricultural expansion in the previous decades.

Forest clearing for resource extraction, which includes oil and gas extraction, forestry roads, mining, and peat extraction, is the second-largest driver of forest conversion. Resource extraction expanded at the expense of over 348 kha of forests and accounts for 29% of the cumulative area of forest conversion since 1990. Forest clearing for oil and gas extraction has more than doubled, from 4.4 kha per year in 1990 to 11.1 kha per year in 2012 (Figure 2–14) and has largely occurred in the Boreal Plains of the northern Prairies.

Forest conversion due to hydroelectric development is episodic, corresponding to the occasional impoundment of large reservoirs (e.g. LaForge-1 in 1993 and Eastmain 1 in 2006) (Figure 2–14). Cumulative areas of forests converted for the creation of hydro reservoirs and associated infrastructure equal 141 kha, which accounts for 12% of forest conversion over the time period. Hydroelectric development occurs mainly in the Taiga Shield East and the Boreal Shield East.

Other rates of forest conversion due to the development of built-up lands and transportation routes have remained relatively constant, at approximately 8 kha per year.

### 2.3.6. Waste Sector (2012 GHG emissions, 21 Mt)

From 1990 to 2012, GHG emissions from the Waste Sector increased by 8.2% (Table 2–12 and Figure 2–15), which is much less than the population growth of 25%, or the growth of total national GHG emissions of 18%. Per capita emissions from the Waste Sector decreased by 13% from 1990 to 2012, and the contribution of this sector to the total national GHG emissions is 2.9%. Of the 21 Mt total emissions from this sector in 2012, Solid Waste Disposal on Land, which includes municipal solid waste (MSW) landfills and wood waste landfills, accounted for 19 Mt (Table 2–12), while Wastewater Handling and Waste Incineration (excluding emissions from incineration of biomass material) contributed 1.0 Mt and 0.67 Mt, respectively. CH<sub>4</sub> emissions, produced by the decomposition of biomass in MSW landfills, represent 80% of the emissions from the Waste Sector. The tables in Annex 12 summarize this information nationally by CO<sub>2</sub> eq and by category (i.e. individual gas and source).

GHG emissions from landfills were estimated for two solid waste types: MSW disposal and wood waste landfills, both of which produce CH<sub>4</sub> anaerobically.<sup>17</sup> The CH<sub>4</sub> production rate at a landfill is a function of several factors, including the mass and composition of biomass being landfilled, the landfill temperature, and the moisture entering the site from rainfall.

The quantity of CH<sub>4</sub> captured at MSW landfills for flaring or combustion for energy recovery purposes in 2012 amounted to 35%

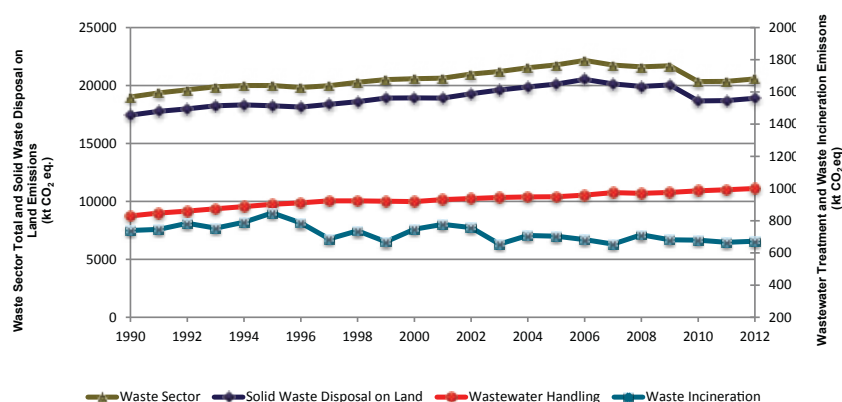
<sup>17</sup> When waste consists of biomass, the CO<sub>2</sub> produced from burning or aerobic decomposition is not accounted for in the Waste Sector. This is because, in the case of agricultural biomass, it is deemed to be a sustainable cycle (carbon in CO<sub>2</sub> will be sequestered when the biomass regenerates in crop reproduction). In the case of biomass from forest products, the emissions of CO<sub>2</sub> are accounted for as part of the LULUCF Sector (forest harvests). However, waste that decomposes anaerobically produces CH<sub>4</sub>, which is not used photosynthetically and therefore does not sequester carbon in biomass regeneration and is not accounted for in forest harvest estimates. The production and release of unburned CH<sub>4</sub> from waste are therefore accounted for in GHG inventories.

Table 2–12 GHG Emissions from Waste, Selected Years

GHG Source Category	GHG Emissions (Mt CO <sub>2</sub> eq)							
	1990	2000	2005	2008	2009	2010	2011	2012
Waste Sector	19	21	22	22	22	20	20	21
Solid Waste Disposal on Land	17	19	20	20	20	19	19	19
Wastewater Handling	0.83	0.92	0.95	0.97	0.98	0.99	0.99	1.00
Waste Incineration	0.74	0.75	0.70	0.71	0.68	0.68	0.67	0.67

Note: Totals may not add up due to rounding.

Figure 2–15 GHG Emissions from Waste, 1990–2011



of the total generated emissions from this source, as compared to 21% in 1990. Hence, of the 25 Mt CO<sub>2</sub> eq of CH<sub>4</sub> generated by MSW landfills in 2012, only 16 Mt were actually emitted to the atmosphere, with the difference (9 Mt) being collected. The number of landfill sites collecting gas since facility data collection was initiated in 1997 has increased considerably (Figure 2–16); landfill gas capture therefore contributed to containing the growth in CH<sub>4</sub> emissions from MSW landfills to 10% above their 1990 levels and to actual emission reductions in this category between 2006 and 2012.

Of the total amount of CH<sub>4</sub> collected in 2012, 48% (4.3 Mt CO<sub>2</sub> eq) was utilized for various energy purposes and the remainder was flared. Typically, a facility will start by installing the collection system and will flare the gas. Utilization systems are installed subsequently, once the capture system proves itself reliable and stable. The decline in relative gas utilization from 70% to 48% between 1997 and 2012 (Figure 2–17) is due to a growing number of recently installed facilities initiating gas collection where the gas is flared.

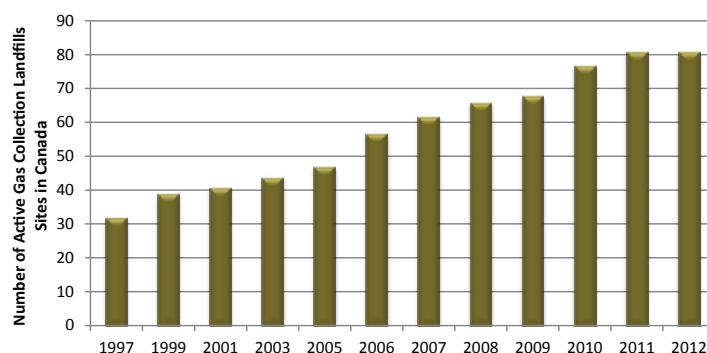
The quantity of waste placed in MSW landfills<sup>18</sup> increased by 29% from 1990 to 2012, although this quantity peaked in 2006 and

has steadily declined since then. The amount of waste diverted as a percentage of the waste generated has fluctuated from 22% to 25% over the period 1998–2010 (Statistics Canada 2000, 2003, 2004, 2007, 2008, 2010, 2013b). For this reason, and the presence of waste export activity since the mid-1990s, the landfilled quantity per capita has decreased by 13% from 1990 to 2012. The amount of residential and non-residential waste exported from Canada to the United States increased from 127 kt in 1990 to 2516 kt in 2012 (Environment Canada 2013a).

Emissions in the Wastewater Handling and Waste Incineration subsector showed a significant decrease in GHG emissions over the 1990–2012 time series (Figure 2–18). Total incineration emissions (MSW, sewage sludge and hazardous waste) per capita decreased by 27% over the time series, due mainly to declines in emissions from the closure of aging MSW incinerators between 1992 and 1997. A buffering factor to the significant drop in emissions from MSW incinerators was the increased use of dedicated hazardous waste incinerators (Environment Canada 2013c). Emissions from the latter source rose from 1990 to 1995 then roughly plateaued thereafter.

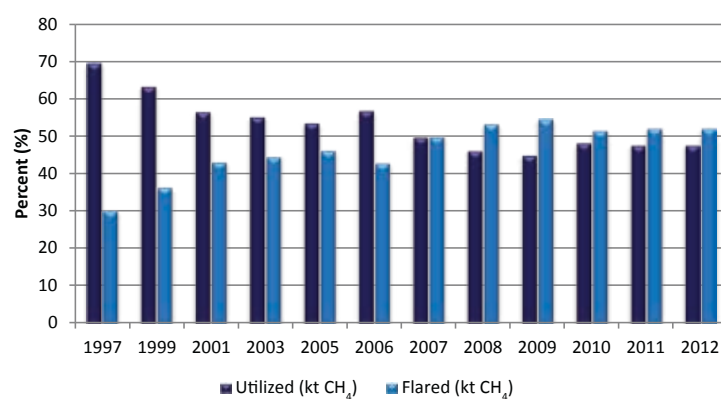
<sup>18</sup> The quantity of wastes placed in landfills is calculated as the waste disposed less the amounts incinerated and exported from Canada.

Figure 2-16 Number of Active MSW Gas Collection Landfill Sites in Canada



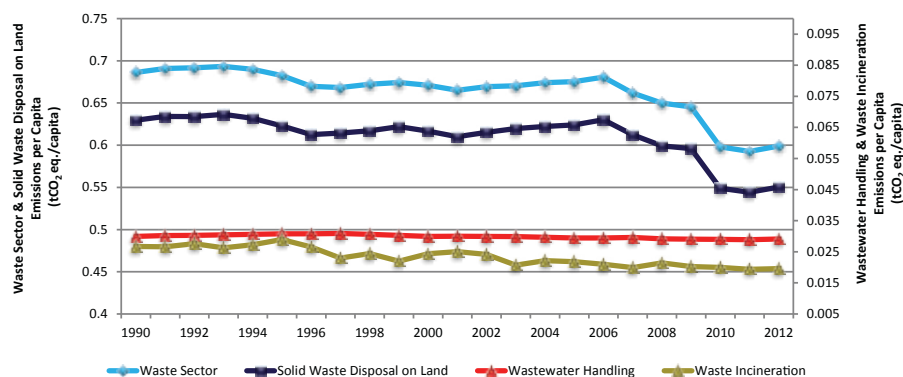
Note: 2012 data assumed constant from 2011 survey results (Environment Canada 2013b).

Figure 2-17 Proportion of Landfill Gas Utilized vs Flared



Note: 2012 data assumed constant from 2011 survey results (Environment Canada 2013b).

Figure 2-18 Per Capita GHG Emission Trend for Waste, 1990–2012





## 2.4. Economic Sector Emission Tables

In this report, emissions estimates are primarily grouped into the activity sectors defined by the IPCC (i.e. Energy; Industrial Processes; Solvent and Other Product Use; Agriculture; Land-Use, Land-use Change and Forestry; and Waste). While it is necessary to use this method of categorization for consistency with UNFCCC reporting guidelines, it is also useful to reallocate emissions into economic sector definitions since most people associate GHG emissions with a particular economic activity (e.g. producing electricity, farming, driving a car, etc.). This section reports emissions by the following economic sectors: oil and gas, electricity, transportation, emissions intensive trade exposed industries,<sup>19</sup> buildings, agriculture, and waste and other.

This reallocation takes the relevant proportion of emissions from various IPCC sub-categories to create a comprehensive emission profile for a specific economic sector. This is the approach taken for reporting against Canada's Copenhagen target in the annual Canada's Emissions Trends Report. Table 2–14 details the relationship between economic sectors and IPCC categories. Examining the historical path of Canadian GHG emissions by economic sectors facilitates the identification of pressure points and emerging issues with respect to emissions growth. Moreover, this allows for a better understanding of the connection between economic activities and GHG emissions for the purposes of analyzing trends and for policy and public analysis.

For example, the transportation economic sector represents emissions arising from the mobility requirements of people driving cars, trucks, trains, aircraft and ships, and also includes the mobility service emissions from heavy-duty trucks and other commercial vehicles. However, unlike the IPCC categorization, the transportation economic sector does not contain off road transportation emissions related to farming, mining, construction, forestry, pipelines or other industrial activities. Excluding off-road in the transportation economic sector ensures that emissions related to industrial activities do not appear as trends associated with on-road passenger and freight transportation requirements. For example, if there were any upward trend in farming or mining activity, emissions arising from the increased use in mobile farming machinery or mining trucks would be reflected in the economic sector estimates for agriculture or mining.

It is important to note that this re-allocation simply re-categorizes emissions under different headings but does not change the overall magnitude of Canadian emissions estimates. Table 2–13 shows the distribution of emissions allocated on the basis of the economic sector from which they originate. Each economic

sector includes emissions from energy-related and non energy related processes. Specifically, the oil and gas sector represents all emissions that are created in the exploitation, distribution, refining and upgrading of oil and gas products; the electricity sector represents all emissions from electric utility generation and transmission for residential, industrial and commercial users; the transportation sector represents all emissions arising from the tailpipes of domestic passenger and freight transport; the emissions intensive trade exposed industry sector represents emissions arising from mining activities, smelting and refining, and the production and processing of industrial goods such as paper or cement; the building sector represents emissions arising directly from residential homes and commercial buildings; the waste and other sector represents emissions that arise from solid and liquid waste, from waste incineration, and from coal production, light manufacturing, construction and forestry activities; and finally, the agriculture sector represents all emissions arising from farming activities including those related to energy combustion for farming equipment as well as those related to crop and animal production.

### 2.4.1. Emission Trends by Economic Sector

In 2012, the oil and gas economic sector produced the largest share of GHG emissions in Canada (25%). Between 1990 and 2012, emissions from this sector increased by 72 Mt. The majority of this increase (58 Mt) occurred between 1990 and 2005 as the sector expanded and adopted new extraction processes. However, growth in GHG emissions from the oil and gas sector slowed between 2005 and 2012, due to several factors including the economic downturn that resulted in a lower global demand for petroleum products, and the gradual exhaustion of traditional natural gas and oil resources in Canada.

Canada's transportation economic sector is the second-largest contributor to Canada's GHG emissions, representing 24% of total emissions in 2012. Although there was a small increase in GHG emissions arising from transportation between 2009 and 2012 (2.6 Mt), the rate of growth in emissions has not returned to its trend prior to the economic downturn. Emissions rose by 39 Mt between 1990 and 2005, an increase of around 30% over the period. These trends in GHG emissions in the overall transportation sector are driven by differing trends in subsectors such as heavy-duty vehicles and light-duty vehicles. For example, although the average fuel efficiency of light-duty vehicles has been increasing, the number of light trucks on the road continues to rise. Other factors affecting these emissions include changing demographics, changes in personal travel demand, higher gasoline prices, and government policies.

In 2012, the electricity sector contributed 12% to total Canadian emissions. Emissions from the electricity sector increased in

<sup>19</sup> The emissions intensive trade exposed industry sector represents emissions arising from mining activities other than oil and gas, i.e., smelting and refining, pulp and paper, iron and steel, cement, lime and gypsum, and chemicals and fertilizers.



Table 2-13 Details of Trends in GHG Emissions by Sector

	1990	2000	2005	2008	2009	2010	2011	2012
<i>Mt CO<sub>2</sub> equivalent</i>								
<b>NATIONAL GHG TOTAL</b>	<b>591</b>	<b>721</b>	<b>736</b>	<b>731</b>	<b>689</b>	<b>699</b>	<b>701</b>	<b>699</b>
<b>Oil and Gas</b>	<b>101</b>	<b>151</b>	<b>159</b>	<b>162</b>	<b>161</b>	<b>163</b>	<b>164</b>	<b>173</b>
Upstream Oil and Gas	82	131	135	139	138	140	143	150
Natural Gas Production and Processing	33	55	54	54	50	49	48	48
Conventional Oil Production	22	34	32	30	28	29	29	30
Conventional Light Oil Production	11	12	9	9	9	9	10	10
Conventional Heavy Oil Production	11	21	21	18	17	18	18	18
Frontier Oil Production	0*	1	2	2	2	2	2	2
Oil Sands (Mining, In-situ, Upgrading)	15	25	34	42	47	52	55	61
Mining and Extraction	4	5	9	11	13	14	14	15
In-situ	5	8	11	17	18	21	23	26
Upgrading	7	11	13	15	16	17	18	20
Oil and Natural Gas Transmission	11	17	16	13	12	11	11	11
Downstream Oil and Gas	19	20	24	23	23	23	22	22
Petroleum Refining	18	19	22	21	21	21	20	20
Natural Gas Distribution	1	2	2	2	2	2	2	2
<b>Electricity</b>	<b>94</b>	<b>129</b>	<b>121</b>	<b>113</b>	<b>97</b>	<b>99</b>	<b>92</b>	<b>86</b>
<b>Transportation</b>	<b>128</b>	<b>155</b>	<b>168</b>	<b>166</b>	<b>163</b>	<b>167</b>	<b>166</b>	<b>165</b>
Passenger Transport	78	91	96	96	96	97	93	94
Cars, Trucks and Motorcycles	69	83	87	87	87	88	85	85
Bus, Rail and Domestic Aviation	8	9	9	9	8	8	8	8
Freight Transport	39	48	57	59	57	60	61	61
Heavy-duty Trucks, Rail	32	41	49	52	49	52	54	54
Domestic Aviation and Marine	6	7	8	7	7	8	7	7
Other: Recreational, Commercial and Residential	12	16	14	10	10	11	12	11
<b>Emissions Intensive &amp; Trade Exposed Industries</b>	<b>95</b>	<b>92</b>	<b>89</b>	<b>88</b>	<b>75</b>	<b>76</b>	<b>80</b>	<b>78</b>
Mining	6	6	6	8	7	7	7	8
Smelting & Refining (Non-ferrous Metals)	17	15	14	13	11	11	11	10
Pulp & Paper	15	13	9	7	7	6	7	6
Iron & Steel	16	19	19	20	15	16	16	16
Cement	9	11	13	12	10	10	10	10
Lime & Gypsum	3	3	3	3	2	3	3	3
Chemicals & Fertilizers	29	25	25	26	23	24	26	25
<b>Buildings</b>	<b>70</b>	<b>82</b>	<b>84</b>	<b>84</b>	<b>82</b>	<b>79</b>	<b>85</b>	<b>80</b>
Service Industry	27	37	40	38	38	37	40	39
Residential	44	45	45	46	44	42	45	41
<b>Agriculture</b>	<b>54</b>	<b>66</b>	<b>68</b>	<b>71</b>	<b>66</b>	<b>68</b>	<b>67</b>	<b>69</b>
On-farm Fuel Use	8	10	10	13	10	13	14	14
Crop Production	18	20	19	23	22	22	22	24
Animal Production	29	36	39	36	34	33	31	32
<b>Waste &amp; Others</b>	<b>48</b>	<b>46</b>	<b>47</b>	<b>48</b>	<b>45</b>	<b>46</b>	<b>47</b>	<b>47</b>
Waste	19	21	22	22	22	20	20	21
Coal Production	4	3	2	3	3	4	4	4
Light Manufacturing, Construction & Forest Resources	26	23	23	23	20	22	23	22

Note:

Totals may not add up due to rounding.

Estimates presented here are under continual improvement. Historical emissions may be changed in future publications as new data become available and methods and models are refined and improved.

\* Less than 0.5 Mt CO<sub>2</sub> eq

parallel to rising demand for electricity both domestically and to satisfy export to the United States over the earlier years of the time period. Additionally, prior to 2005, fossil fuel power generation increased its share over non-emitting sources such as hydro

and nuclear power in the generating portfolio. Emissions from the electricity sector increased by 28 Mt (29%) over the 1990–2005 time period. More recently, electricity-related emissions have declined because of measures such as a return to service of

a number of nuclear units and fuel switching to natural gas, as well as the closure of a number of coal-fired electricity generation facilities. Further measures such as incremental fuel switching to natural gas and efficiency incentives coupled with the economic downturn have seen emissions decreased by a further 35 Mt (29%) between 2005 and 2012.

The emissions intensive trade exposed industry sector experienced some fluctuation in emissions over the time period. Emissions from this sector were responsible for 16% of total Canadian emissions in 1990, falling to 12% in 2005. In more recent years, emissions have fallen further as a result of the economic downturn and the continued evolution of Canadian production towards other sectors and services, representing a decrease of 11 Mt between 2005 and 2012. GHG emissions from the buildings sector had increased with population and commercial development but like all sectors of the economy have fallen marginally in the recessionary period. Emissions from the agriculture sector and the waste and other sector have generally continued a slow upward or relatively stable trend throughout the time period, respectively.

The relationship between economic sectors and IPCC categories is portrayed in Table 2-14.

## 2.5. Emission Trends for Ozone and Aerosol Precursors

While not mandatory, the UNFCCC reporting guidelines encourage Annex I Parties to provide information on the following indirect GHGs: sulphur oxides (SO<sub>x</sub>), nitrogen oxides (NO<sub>x</sub>), carbon monoxide (CO) and non-methane volatile organic compounds (NMVOCs). For all categories except LULUCF, these gases (referred to as criteria air contaminants or CACs) are inventoried and reported separately to the United Nations Economic Commission for Europe.<sup>20</sup> Emissions of ozone and aerosol precursors fell during the 1990–2012 period. SO<sub>x</sub> emissions decreased by 60%, NMVOC emissions declined by 28%, NO<sub>x</sub> emissions were down by 24% and CO emissions fell by 45% (see Annex 10 for 2012 data tables). National emission summaries for key air pollutants, along with historical national emission trends, are also available on Environment Canada's website.<sup>21</sup>

20 Available online at <http://www.ceip.at>.

21 Canada's 2012 Air Pollutant Emission Summaries and Historical Emissions Trends can be found at <http://www.ec.gc.ca/inrp-npri/default.asp?lang=En&n=F98AFAE7-1>.



Table 2–14 2012 GHG Emissions by National Inventory and Economic Categories

National Inventory Category <sup>a</sup>													
	Economic Category Total	Energy								Industrial Processes			
		Energy: Fuel Combustion				Energy: Fugitive				Mineral Products <sup>d</sup>	Chemical Industry <sup>e</sup>	Metal Production <sup>f</sup>	
		Stationary Combustion		Transport	Fugitive (Unintentional)	Flaring	Venting	Total					
		Stationary	Industrial Cogeneration										
		Electricity <sup>c</sup>	Steam for Sale										
Mt CO <sub>2</sub> equivalent													
National Inventory total <sup>a,b</sup>	699	297	11.0	1.1	195	26.8	4.7	29.5	566	8.3	7.0	16.3	
Oil and Gas	173	93.1	7.0	0.1	10.6	25.8	4.7	29.5	171.0				
Upstream Oil and Gas	150	76.8	6.6	-	10.6	23.7	4.5	28.1	150.3				
Natural Gas Production and Processing	48	22.6	3.0	-	0.3	11.7	0.7	9.9	48.3				
Conventional Oil Production	30	7.5	0.5	-	1.7	3.6	2.4	14.3	30.1				
Conventional Light Oil Production	10	3.1	0.1	-	1.3	1.8	1.6	2.5	10.3				
Conventional Heavy Oil Production	18	3.7	-	-	0.5	1.8	0.5	11.9	18.3				
Frontier Oil Production	2	0.7	0.4	-	0.0	0.0	0.4	0.0	1.6				
Oil Sands (Mining, In-situ, Upgrading) <sup>c</sup>	61	46.7	3.0	-	2.9	2.8	1.4	3.8	60.6				
Mining and Extraction	15	7.6	1.1	-	2.9	2.7	0.2	-	14.5				
In-situ	26	23.8	0.8	-	-	0.0	0.7	1.2	26.5				
Upgrading	20	15.2	1.2	-	-	0.0	0.5	2.6	19.6				
Oil and Natural Gas Transmission	11	-	-	-	5.6	5.7	0.0	0.0	11.3				
Downstream Oil and Gas	22	16.3	0.4	0.1	0.1	2.1	0.2	1.4	20.6				
Petroleum Refining	20	16.3	0.4	0.1	-	0.1	0.2	1.4	18.6				
Natural Gas Distribution	2	-	-	-	0.1	2.0	-	-	2.1				
Electricity	86	85.4		0.6					86.0				
Transportation <sup>b</sup>	165				162.6				162.6				
Passenger Transport	94				91.9				91.9				
Cars, Light Trucks and Motor-cycles	85				83.8				83.8				
Bus, Rail and Domestic Aviation	8				8.0				8.0				
Freight Transport	61				60.0				60.0				
Heavy-duty Trucks, Rail	54				53.6				53.6				
Domestic Aviation and Marine	7				6.5				6.5				
Other: Recreational, Commercial and Residential	11				10.7				10.7				
Emissions Intensive & Trade Exposed Industries	78	31.6	2.7	0.4	3.3				38	8.2	7.0	16.3	
Mining	8	4.0	0.7	-	3.0				7.7				
Smelting & Refining (Non-ferrous Metals)	10	3.2	0.0	0.0	0.1				3.3	0.0		6.5	
Pulp & Paper	6	4.8	1.1	0.1	0.1				6.1	0.0			
Iron & Steel	16	5.5	0.0	0.0	0.1				5.6	0.2		9.8	
Cement	10	4.0	-	-	0.0				4.0	6.3			
Lime & Gypsum	3	1.1	-	-	0.0				1.1	1.4			
Chemicals & Fertilizers	25	9.0	0.9	0.3	0.0				10.1	0.2	7.0		
Buildings	80	68.4	0.6						69.0				
Service Industry	39	27.5	0.6						28.1				
Residential	41	40.9							40.9				
Agriculture	69	3.4	0.0		10.2				13.6				
On-farm Fuel Use <sup>i</sup>	14	3.4	0.0		10.2				13.6				
Crop Production	24								-				
Animal Production	32								-				
Waste	21								-				
Solid Waste	19								-				
Waste Water	1								-				
Waste Incineration	1								-				
Coal Production	4	1.1	-	-	1.5	1.0	-	-	3.6				
Light Manufacturing, Construction & Forest Resources	22	14.4	0.6	0.0	6.9				22.0	0.2			
Light Manufacturing	15	12.9	0.6	0.0	0.7				14.1	0.2			
Construction	6	1.5	-	-	5.0				6.4				
Forest Resources	1	0.1	0.0	-	1.3				1.4				

Notes: Totals may not add up due to rounding. Economic category totals rounded to nearest megatonne (Mt).

Estimates presented here are under continual improvement. Historical emissions may be changed in future publications as new data become available and methods and models are refined and improved.

a. Categorization of emissions is consistent with the IPCC's sectors following the reporting requirement of the UNFCCC.

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

c. Industrial cogeneration includes emissions associated with the simultaneous production of heat and power. At some facilities, a portion of this power is generated by onsite utility-owned generators. As such, the cogeneration emissions for these specific facilities are included under the Public Electricity and Heat Generation category in the National Inventory (UNFCCC) format.

d. Mineral products includes cement production, lime production and mineral product use.

National Inventory Category <sup>a</sup>													
Industrial Processes				Agriculture				Waste					
Consumption of Halocarbon and SF <sub>6</sub>	Other & Undifferentiated Production	Solvent and Other Product Use <sup>g</sup>	Total	Manure Management	Enteric Fermentation	Agriculture Soils	Total	Solid Waste Disposal on Land	Waste Water Handling	Waste Incineration	Total	LULUCF <sup>b</sup>	
Mt CO <sub>2</sub> equivalent													
8.0	16.8	0.3	56.7	6.4	17.6	31.6	55.5	18.9	1.0	0.7	20.6	40.0	<b>National Inventory total<sup>a,b</sup></b>
	1.6		1.6										<b>Oil and Gas</b>
	0.1		0.1										Upstream Oil and Gas
													Natural Gas Production and Processing
													Conventional Oil Production
													Conventional Light Oil Production
													Conventional Heavy Oil Production
													Frontier Oil Production
	0.1		0.1										Oil Sands (Mining, In-situ, Upgrading) <sup>c</sup>
	0.1		0.1										Mining and Extraction
													In-situ
													Upgrading
													Oil and Natural Gas Transmission
	1.5		1.5										Downstream Oil and Gas
	1.5		1.5										Petroleum Refining
													Natural Gas Distribution
0.2			0.2										<b>Electricity</b>
2.5	0.1		2.6										<b>Transportation<sup>h</sup></b>
1.6	0.1		1.7										Passenger Transport
1.5	0.1		1.6										Cars, Light Trucks and Motorcycles
0.1	0.0		0.1										Bus, Rail and Domestic Aviation
0.9	0.0		1.0										Freight Transport
0.8	0.0		0.9										Heavy-duty Trucks, Rail
0.1	0.0		0.1										Domestic Aviation and Marine
													Other: Recreational, Commercial and Residential
0.5	8.4		40.4										<b>Emissions Intensive &amp; Trade Exposed Industries</b>
	0.1		0.1										Mining
	0.7		7.2										Smelting & Refining (Non-ferrous Metals)
	0.0		0.0										Pulp & Paper
	0.6		10.7										Iron & Steel
	0.0		6.3										Cement
	0.0		1.5										Lime & Gypsum
0.5	7.0		14.7										Chemicals & Fertilizers
4.7	6.4	0.3	11.4										<b>Buildings</b>
4.3	6.4	0.3	11.0										Service Industry
0.4		0.0	0.4										Residential
	0.0		0.0	6.4	17.6	31.6	55.5						<b>Agriculture</b>
	0.0		0.0										On-farm Fuel Use <sup>i</sup>
						23.9	23.9						Crop Production
				6.4	17.6	7.7	31.7						Animal Production
								18.9	1.0	0.7	20.6		<b>Waste</b>
								18.9			18.9		Solid Waste
									1.0		1.0		Waste Water
										0.7	0.7		Waste Incineration
													<b>Coal Production</b>
0.1	0.2		0.5										<b>Light Manufacturing, Construction &amp; Forest Resources</b>
0.1	0.2		0.5										Light Manufacturing
	0.0		0.0										Construction
	0.0		0.0										Forest Resources
												40.0	

ECONOMIC CATEGORY

e. Chemical industry includes ammonia production, nitric acid production, petrochemical production (CH<sub>4</sub> and N<sub>2</sub>O only), and adipic acid production.f. Metal production includes iron and steel production, aluminium production, and SF<sub>6</sub> used in magnesium smelters and casters.g. Solvent and Other Product Use includes N<sub>2</sub>O use in anaesthetics and aerosols.

h. Emissions from the consumption of propane and natural gas in Transportation are allocated to Cars, Light Trucks and Buses.

i. On-farm Fuel Use includes emissions associated with the use of lube oils and greases.

\* Less than 0.5 Mt CO<sub>2</sub> eq

# Chapter 3

## Energy (CRF Sector 1)

### 3.1. Overview

Overall, the Energy Sector contributed about 81% (or 566 Mt) of Canada's total greenhouse gas (GHG) emissions in 2012 (Table 3–1). The Energy Sector accounts for all GHG (CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O) emissions from stationary and transport fuel combustion activities as well as fugitive emissions from the fossil fuel industry.<sup>1</sup> Fugitive emissions associated with the fossil fuel industry are the intentional (e.g. venting) or unintentional (e.g. leaks, accidents) releases of GHGs that may result from production, processing, transmission and storage activities. Emissions from flaring activities by the oil and gas industry are reported in the Fugitive category, since their purpose is not to produce heat or to generate mechanical work (IPCC/OECD/IEA 1997).

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

<sup>1</sup> Emissions associated with the non-energy use of fossil fuels are allocated to the Industrial Processes Sector.

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

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

Fuel combustion sources include all emissions from the combustion of fossil fuels. Major subsectors include Energy Industries, Manufacturing Industries and Construction, Transport, and Other Sectors (which include the residential and commercial categories). Methods used to calculate emissions from fuel combustion are consistent throughout and are presented in Annex 2: Methodology and Data for Estimating Emissions from Fossil Fuel Combustion; the estimation methodologies are consistent with the revised 1996 Intergovernmental Panel on Climate Change (IPCC) Tier 2 approach, with country-specific emission factors and parameters.

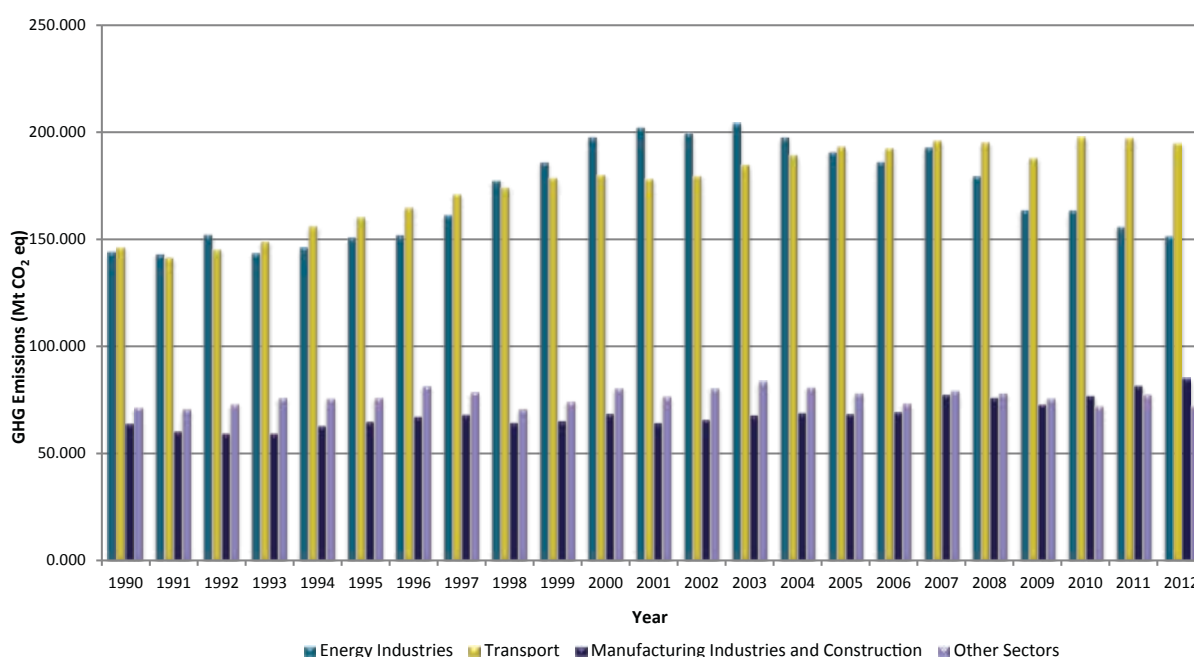
In 2012, about 505 Mt (or 72%) of Canada's GHG emissions were from the combustion of fossil fuels (Table 3–1). The overall GHG emissions from fuel combustion activities have increased by 18% since 1990 and have remained relatively steady since 2010. Between 1990 and 2012, emissions from the Stationary Combustion Sources category (i.e. the Energy Industries, (1.A.2) Manufacturing Industries and Construction and (1.A.4) Other sectors) and from the Transport category increased by about 10% and 33%, respectively (Figure 3–1).

**Table 3–1 GHG Emissions from Energy, Selected Years**

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)							
	1990	2000	2005	2008	2009	2010	2011	2012
Energy Sector	469 000	591 000	595 000	592 000	560 000	570 000	573 000	566 000
Fuel Combustion (1.A)	427 000	528 000	532 000	530 000	501 000	511 000	513 000	505 000
Energy Industries (1.A.1)	144 000	198 000	191 000	180 000	164 000	164 000	156 000	152 000
Manufacturing Industries and Construction (1.A.2)	64 300	68 900	68 800	76 400	73 200	77 300	82 000	85 400
Transport (1.A.3)	147 000	180 000	194 000	196 000	188 000	198 000	198 000	195 000
Other Sectors (1.A.4)	71 600	80 600	78 400	78 200	75 900	72 200	77 800	72 300
Fugitive Emissions from Fuels (1.B)	42 000	63 000	63 000	62 000	59 000	58 000	60 000	61 000

Note: Totals may not add up due to rounding.

Figure 3–1 GHG Emissions from Fuel Combustion, 1990–2011



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

#### 3.2.1.1. Source Category Description

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

In 2012, the Energy Industries subsector accounted for 152 Mt (or about 22%) of Canada's total GHG emissions, with an increase of about 6% in total emissions since 1990. The Public Electricity and Heat Production category accounted for 58% (or 88 Mt) of the Energy Industries' GHG emissions, while Petroleum Refining, and the Manufacture of Solid Fuels and Other Energy Industries contributed 11% (17 Mt) and 31% (47 Mt), respectively (Table 3–2). Additional discussions on trends in emissions from the Energy

Industries subsector are to be found in the Emission Trends chapter (Chapter 2).

The Energy Industries subsector includes all emissions from stationary fuel combustion sources related to utility electricity generation and many of the emissions from the production, processing and refining of fossil fuels. All of the emissions associated with the fossil fuel industry are estimated, although a portion of emissions from coal mining and from oil and gas extraction (including oil sands mining, extraction and upgrading) associated with the Manufacture of Solid Fuels and Other Energy Industries category are located in the Manufacturing Industries and Construction—Mining and the Transport—Other subsectors, because fuel consumption data at a lower level of disaggregation are not available. Combustion emissions associated with the pipeline transmission of oil and natural gas are included under Other Transportation according to the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997).

Table 3–2 Energy Industries GHG Contribution

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)							
	1990	2000	2005	2008	2009	2010	2011	2012
<b>Energy Industries TOTAL (1.A.1)</b>	<b>144 000</b>	<b>198 000</b>	<b>191 000</b>	<b>180 000</b>	<b>164 000</b>	<b>164 000</b>	<b>156 000</b>	<b>152 000</b>
Public Electricity and Heat Production	93 600	130 000	123 000	115 000	99 100	101 000	93 700	88 300
Petroleum Refining	16 800	16 900	20 200	19 500	18 900	17 800	17 300	16 800
Manufacture of Solid Fuels and Other Energy Industries	34 000	51 000	48 000	46 000	46 000	45 000	45 000	47 000

Note: Totals may not add up due to rounding.



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, Fuel Combustion (CRF Category 1.A)).

### 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 public utility thermal power plants.<sup>2</sup> The estimated GHG emissions from this sector do not include emissions from industrial generation; rather, these emissions have been allocated to the specific industrial sectors.

The electricity supply grid in Canada includes combustion-derived electricity as well as hydro, nuclear and other renewables (wind, solar and tidal power). Total power generated from wind, tidal and solar resources is relatively small compared with that from Canada's significant hydro and nuclear installations. Nuclear, hydro, wind, solar and tidal electricity generators are not direct emitters of GHGs; therefore, GHG estimates reflect emissions from combustion-derived electricity only. Steam generation and internal combustion engines are the primary systems used to generate electricity through thermal processes. Steam turbine boilers are fired with coal, petroleum coke, heavy fuel oil, natural gas or biomass. Reciprocating engines can use natural gas and/or a combination of refined petroleum products (RPPs). Gas turbines are also fired with natural gas or RPPs.

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

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

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

The Manufacture of Solid Fuels and Other Energy Industries category comprises fuel combustion emissions associated with the crude oil, natural gas, oil sands mining, bitumen extraction and upgrading, and coal mining industries. A portion of emissions associated with coal mining and oil and gas extraction (which includes oil sands mining, extraction and upgrading) are

reported in the Manufacturing Industries and Construction–Mining category, whereas emissions associated with pipeline transmission and with the use of transport fuels (such as gasoline and diesel) in off-road applications in the mining and the oil & gas mining and extraction industry are reported under Other Transportation, since the fuel data cannot be further disaggregated in the national energy balance as compiled by Statistics Canada.

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

The Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997) require the Public Electricity and Heat Production category to include only emissions generated by public utilities. Emissions associated with industrial generation are allocated to the industry that produces the energy under the appropriate industrial category within the Energy Sector, regardless of whether the energy is for sale or for internal use. The rationale for this is that the IPCC recognizes that it is difficult to disaggregate emissions in cogeneration facilities (i.e. to separate the electricity component from the heat component of fuel use). Statistics Canada fuel-use data in the RESO do distinguish industrial electricity generation data, but aggregate the data into one category titled industrial electricity generation. Industrial electricity generation emissions were reallocated to their respective industrial subsectors using the RESO input data. The methodology is described in greater detail in Annex 2.

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

Emissions for this category are calculated using all fuel use attributed to the petroleum refining industry and include all petroleum products (including still gas, petroleum coke and diesel) reported as producer consumed/own consumption as well as purchases of natural gas for fuel use by refineries. The fuel use data in the RESO include volumes of flared fuels; however, flaring emissions are

<sup>2</sup> Category as defined by Statistics Canada.

calculated and reported separately in the Fugitive category (refer to Section 3.3.2). The fuel use and emission data associated with flaring are subtracted to avoid double counting.

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

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

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

The estimated uncertainty range for the Energy Industries subsector is  $\pm 7\%$  for all gases and  $\pm 7\%$  for CO<sub>2</sub> alone.

The uncertainties for the Energy Industries subsector are largely dependent on the collection procedures used for the underlying activity data as well as on the representativeness of the emission factors for specific fuel properties. Commercial fuel volumes and properties are generally well known, whereas there is greater uncertainty surrounding both the reported quantities and properties of non-marketable fuels (e.g. *in-situ* use of natural gas from the producing wells and the use of still gas). For example, in the Petroleum Refining category, the CO<sub>2</sub> emission factors for non-marketable fuels as consumed, such as still gas, petroleum coke and catalytic coke, have a greater influence on the uncertainty estimate than the CO<sub>2</sub> factors for commercial fuels. Coal CO<sub>2</sub> emission factors were developed using statistical methods and 95% confidence intervals.

Approximately 78% of the 2012 emissions from the Manufacture of Solid Fuels and Other Energy Industries category are associated with the consumption of natural gas in the natural gas production and processing, conventional crude oil and *in-situ* bitumen extraction industries. The uncertainty for this fuel is influenced by the CO<sub>2</sub> emission factors ( $\pm 6\%$ ) and CH<sub>4</sub> emission factors (0% to +240%) for the consumption of unprocessed natural gas. Provincially weighted natural gas emission factors were used to estimate emissions for the natural gas industry due to a lack of plant-level information, such as the physical composition of unprocessed natural gas (which will vary from plant to plant). Thus, the overall uncertainty estimate is based on a rather broad assumption as well.

The estimated uncertainty for CH<sub>4</sub> ( $\pm 39\%$ ) and N<sub>2</sub>O ( $\pm 38\%$ ) emissions for the Energy Industries subsector is influenced by the uncertainty associated with the emission factors (ICF Consulting 2004). Additional expert elicitation is required to improve the CH<sub>4</sub>

and N<sub>2</sub>O uncertainty estimates for some of the emission factor uncertainty ranges and probability density functions developed by ICF Consulting, 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. A discussion on activity data based on RESD fuel use information is presented in Section 3.2.1.5, Recalculations.

#### 3.2.1.4. QA/QC and Verification

Quality control (QC) checks are done in a form consistent with the IPCC's *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (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.

#### 3.2.1.5. Recalculations

Several improvement activities have contributed to increased accuracy of the data, as well as to their comparability and consistency with that of the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997) and the United Nations Framework Convention on Climate Change (UNFCCC) reporting requirements. As discussed below in more detail, revised activity data contributed to recalculations along with the reallocation of emissions from the Manufacture of Solid Fuels and Other Energy Industries category to the Other Transport (Off-road diesel) category.

*Activity Data:* Revisions to the following activity data resulted in recalculations:

- The 2011 fuel-use data were revised by Statistics Canada, and estimates were recalculated accordingly.
- The 1995–2003 fuel-use data were revised using input from Statistics Canada, and estimates were recalculated accordingly to improve the consistency and comparability of the dataset up to 2012. The previous submission incorporated important methodological enhancements that were made to the RESD based on the following:
  - direct use of the annual Industrial Consumption of Energy (ICE) survey to better account for the manufacturing industries' fuel consumption values;
  - use of the North American Industrial Classification System (NAICS).

These activity data updates in this submission are a follow-up to last year's revisions, which affected 2004–2011 data. The latest revision ensures that the entire 1990–2012 time series is fully consistent, as per IPCC Good Practice Guidance.

*Reallocation of Activity Data:* In addition, diesel previously reported under Manufacture of Solid Fuels and Other Energy Industries has been reallocated to the Off-road Transportation category.

### 3.2.1.6. Planned Improvements

With the proliferation of publicly reported data, Tier 3 methods for the Public Electricity and Heat Production category are being investigated with the eventual goal of developing a bottom-up inventory. Increases in the usage of combined heat and power plants (and co-generation systems) require additional research and investigation to ensure that emissions are appropriately allocated.

## 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 2012, the Manufacturing Industries and Construction subsector accounted for 85 Mt (or 12%) of Canada's total GHG emissions, with a 33% (21.1 Mt) increase in overall emissions since 1990 (refer to Table 3–3 for more details). Within the Manufacturing Industries and Construction subsector, 60.7 Mt (or 71%) of the GHG emissions are from the Others category. The Others category is made up of cement, mining, construction and other manufacturing activities. This category is followed by (in order of decreasing contributions) the Chemical Industries; Pulp, Paper

and Print; Iron and Steel; and Non-ferrous Metals categories, at 10.1 Mt (or 11.8%), 5.9 Mt (or 6.9%), 5.5 Mt (or 6.4%), and 3.3 Mt (or 3.8%), 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.

Industrial emissions resulting from fuel combustion for the generation of electricity or steam for sale have been assigned to the appropriate industrial subsector. 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.

### 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, Transport (CRF Category 1.A.3)). Methodological issues specific to each manufacturing category are identified below.

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

In 2012, Canada had four integrated iron and steel facilities that manufacture all the coal-based metallurgical coke. All these facilities are structured in such a way that by-product gases from the integrated facilities (e.g. coke oven gas, blast furnace gas) are used in a variety of places throughout the facility (e.g. boilers,

Table 3–3 Manufacturing Industries and Construction GHG Contribution

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)							
	1990	2000	2005	2008	2009	2010	2011	2012
Manufacturing Industries and Construction TOTAL (1.A.2)	64 300	68 900	68 800	76 400	73 200	77 300	82 000	85 400
Iron and Steel	4 950	6 210	5 550	5 760	4 280	4 440	5 270	5 480
Non-ferrous Metals	3 260	3 530	3 570	3 750	2 810	2 950	3 270	3 250
Chemicals	8 220	10 800	8 280	8 750	8 830	9 860	11 100	10 100
Pulp, Paper and Print	14 500	12 600	8 740	6 400	6 510	6 070	6 330	5 890
Food Processing, Beverages and Tobacco <sup>1</sup>	IE	IE	IE	IE	IE	IE	IE	IE
Others	33 400	35 800	42 700	51 800	50 700	54 000	56 000	60 700
Cement	3 920	4 580	5 380	4 910	4 480	4 030	4 280	3 960
Mining	6 590	12 000	18 900	30 000	31 700	34 700	35 900	40 900
Construction	1 870	1 080	1 440	1 370	1 210	1 500	1 430	1 450
Other Manufacturing	21 000	18 100	16 900	15 500	13 400	13 700	14 400	14 400

Note:

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.

blast furnace, coke oven). As such, emissions from coke production are included in the Iron and Steel category. Since the plants are integrated, all the produced coke oven gas is used in the mills and reported in the RESD. Due to the way the fuel consumption is reported by the iron and steel industry, determining the amount of coke oven gas lost as fugitive emissions through flaring is difficult. However, Statistics Canada indicates that the amount of fuel flared is included in the energy statistics, indicating that fugitive emissions are being captured as well.

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 CH<sub>4</sub> and N<sub>2</sub>O from the combustion of biomass are included in the pulp and paper industrial category. CO<sub>2</sub> emissions from biomass combustion are not included in totals but are reported separately in the UNFCCC CRF tables as a memo item.

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

This category includes the remainder of industrial sector emissions, including the construction, cement, vehicle manufacturing, textiles, mining, food, beverage and tobacco sectors. Consumption of diesel associated with on-site off-road vehicles in mining (which also includes oil and gas mining and extraction use of diesel) have been allocated to the Other Transportation category.

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

The estimated uncertainty for the Manufacturing Industries and Construction subsector is  $\pm 2\%$  for all gases.

The underlying fuel quantities and CO<sub>2</sub> 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. Coal CO<sub>2</sub> emission factor uncertainties were recently updated with 95% confidence intervals (as discussed in Section 3.2.1.3).

As stated in the Energy Industries subsector uncertainty discussion, additional expert elicitation is required to improve the CH<sub>4</sub>

and N<sub>2</sub>O uncertainty estimates for some of the emission factor uncertainty ranges and probability density functions developed by the ICF Consulting study (ICF Consulting 2004), since these assumptions were not reviewed by industry experts owing to a lack of available time in the study's preparation.

The estimates for the Manufacturing Industries and Construction subsector have been prepared in a consistent manner over time using the same methodology. A discussion on updated RESD fuel use data is presented in Section 3.2.1.5, Recalculations.

### **3.2.2.4. QA/QC and Verification**

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

Tier 1 QC checks were completed on the entire stationary combustion GHG estimation model, which included checks of emission factors, activity data and CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O estimates for the entire time series. No mathematical or reference errors were found during the QC checks. 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**

Activity Data: The fuel-use data were revised based on Statistics Canada data and estimates were recalculated accordingly. Refer to Section 3.2.1.5, Recalculations for more details.

### **3.2.2.6. Planned Improvements**

As this is an activity that is continuously being improved, Environment Canada, Natural Resources Canada 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 28% of Canada's total GHG emissions (195 Mt—refer to Table 3–4 for more details). 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 104% (21.2 Mt) for LDGTs and 109% (21.7 Mt) for HDDVs. A long term decrease in some Transport categories has also been registered: specifically, reductions in emissions from light duty gasoline vehicles (LDGVs, i.e. cars), propane and natural gas vehicles, pipelines, domestic aviation,

Table 3–4 Transport GHG Contribution

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)							
	1990	2000	2005	2008	2009	2010	2011	2012
Transport TOTAL (1.A.3.)	147 000	180 000	194 000	196 000	188 000	198 000	198 000	195 000
Civil Aviation (Domestic Aviation)	7 100	7 600	7 600	7 300	6 400	6 400	6 200	6 100
Road Transport	96 700	118 000	130 000	132 000	132 000	134 000	132 000	132 000
Light-duty Gasoline Vehicles	45 500	42 000	40 200	39 500	39 700	40 000	38 500	38 300
Light-duty Gasoline Trucks	20 300	36 400	42 700	42 300	42 500	42 900	41 200	41 400
Heavy-duty Gasoline Vehicles	7 440	5 470	6 540	6 800	6 910	7 020	6 710	6 910
Motorcycles	152	162	254	263	266	271	264	268
Light-duty Diesel Vehicles	469	466	574	652	699	750	788	824
Light-duty Diesel Trucks	702	1 660	1 920	2 020	2 030	2 090	2 050	2 130
Heavy-duty Diesel Vehicles	20 000	30 800	37 600	39 200	39 000	40 200	42 000	41 700
Propane & Natural Gas Vehicles	2 200	1 100	720	880	780	780	820	880
Railways	7 000	6 600	6 600	7 900	5 100	6 600	7 500	7 600
Navigation (Domestic Marine)	5 000	5 200	6 700	6 500	6 700	7 000	5 800	5 800
Other Transport	31 000	43 000	42 000	42 000	38 000	44 000	46 000	43 000
Off-road Gasoline	7 800	8 700	8 300	7 300	7 300	7 900	8 100	7 600
Off-road Diesel	16 000	23 000	24 000	28 000	25 000	30 000	32 000	30 000
Pipelines	6 850	11 200	10 100	7 460	6 310	5 670	5 600	5 700

Note: Totals may not add up due to rounding.

heavy-duty gasoline vehicles (HDGVs) and off-road gasoline, for a combined decrease of 11.4 Mt since 1990. Generally, emissions from the Transport subsector have increased 33% and have contributed the equivalent of 45% of the total overall growth in emissions observed in Canada.

### 3.2.3.1. Source Category Description

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

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

### 3.2.3.2. Methodological Issues

Fuel combustion emissions associated with the Transport subsector are calculated using various adaptations of Equation A<sub>2</sub>-1 in Annex 2. However, because of the many different types of vehicles, activities and fuels, the emission factors are numerous and complex. In order to cope with the complexity, transport emissions are calculated using Canada's Mobile Greenhouse Gas Emission Model (MGEM) and the Aviation Greenhouse Gas Emission Model (AGEM). These models incorporate a version of the IPCC-recommended methodology for vehicle modelling (IPCC/

OECD/IEA 1997) and are used to calculate all transport emissions with the exception of those associated with pipelines (energy necessary to propel oil or natural gas).

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

This category includes all GHG emissions from domestic air transport (commercial, private, agricultural, etc.). In accordance with the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997), military air transportation emissions generated by consuming aviation turbo fuel are reported in the Other (Non-specified) subsector (CRF category 1.A.5). However, military emissions generated by consuming aviation gasoline are included in this category (1.A.3.a) since the current data source for this fuel type does not disaggregate military from civil fuel use. Emissions from transport fuels used at airports for ground transport and stationary combustion applications are reported under Other Transportation. Emissions arising from flights that have their origin in Canada and destination in another country are considered to be international in nature and are reported separately under memo items – International Bunkers (CRF category 1.C.1.a).

The methodologies for the Civil Aviation category are fuel-type dependent. They follow a modified IPCC Tier 1 approach for aviation gasoline and a modified IPCC Tier 3 approach for aviation turbo fuel. Emissions estimates employ a mix of country-specific, aircraft-specific and IPCC default emission factors. The estimates attributed to aviation gasoline consumption are performed



within MGEM, while those attributed to aviation turbo fuel are generated using AGEM. The estimates are calculated based on the reported quantities of aviation gasoline and turbo fuel consumed (IPCC/OECD/IEA 1997), as published in the RESD (Statistics Canada #57-003). Aircraft fuel sales are reported in the RESD; these figures represent aircraft fuels sold to Canadian airlines, foreign airlines, public administration and commercial/institutional sectors. All aviation gasoline use is designated domestic, other than that reported under foreign airlines (refer to Annex 2 for a description of the methodology).

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

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

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

The procedure used to estimate GHG emissions from railways adheres to an IPCC Tier 1 methodology (IPCC/OECD/IEA 1997). Emission estimates are performed within MGEM. Fuel sales data from the RESD (Statistics Canada #57-003), reported under railways, are multiplied by country-specific emission factors (refer to Annex 2 for a description of the methodology).

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

This category includes all GHG emissions from domestic marine transport. Emissions arising from fuel sold to foreign marine vessels are considered to be international bunkers and are reported separately under memo items (CRF Category 1.C.1.b). Comprehensive activity data that would enable the accurate disaggregation of domestic and international marine emissions are currently being investigated.

The methodology complies with IPCC Tier 1 techniques (IPCC/OECD/IEA 1997), and emission estimates are performed within MGEM. Fuel consumption data from the RESD, reported as domestic marine, are multiplied by country-specific emission factors (refer to Annex 2 for a description of the methodology).

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

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

## Off-road Transport

Non-road or off-road transport<sup>3</sup> (ground, non-rail vehicles and equipment) includes GHG emissions resulting from both gasoline and diesel combustion. Vehicles in this category include farm tractors, logging skidders, tracked construction vehicles and mobile mining vehicles as well as off-road recreational vehicles. Equipment in this category includes residential and commercial lawn and garden combustion machines, generators, pumps and portable heating devices.

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

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

## Pipeline Transport

Pipelines<sup>4</sup> represent the only non-vehicular transport in this sector. They use fossil-fuelled combustion engines to power motive compressors that propel their contents. The fuel used is primarily natural gas in the case of natural gas pipelines. Oil pipelines tend to use electric motors to operate pumping equipment, but some refined petroleum, such as diesel, is also consumed as a backup during power failures.

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

### 3.2.3.3. Uncertainties and Time-Series Consistency

The Transport subsector employs a Monte Carlo uncertainty analysis, established upon the recommendations and results reported in *Quantitative Assessment of Uncertainty in Canada's National GHG Inventory Estimates for 2001* (ICF Consulting 2004). Several modifications were introduced into the original model in order to more accurately reflect uncertainties in the latest Transport subsector emissions estimates.

<sup>3</sup> Referred to as non-road or off-road vehicles. The terms “non-road” and “off-road” are used interchangeably.

<sup>4</sup> Consisting of both oil and gas types.

Modifications to the original assessment include the addition of biofuel emission factor uncertainties, based on the assumption of similarities in emission control technologies between conventional transport fuels and biofuels. Biofuel activity data uncertainties were based on expert judgement. Aviation turbo fuel CH<sub>4</sub> and N<sub>2</sub>O emission factor uncertainties have been updated from those recommended in the ICF Consulting report to better reflect the improvements made by implementing AGEM. A number of on-road CH<sub>4</sub> and N<sub>2</sub>O emission factor uncertainties have also been modified from their values in the original Monte Carlo simulation based on recent laboratory data. Additionally, a thorough verification of the 2004 ICF Consulting report revealed a number of discrepancies in referenced uncertainty ranges. In these instances, the discrepancy was corrected to coincide with the original reference.

## Transport

The Transport category comprises 1) the mobile sources of transport, including on-road and off-road vehicles, railways, civil aviation and navigation; and 2) pipeline transport. The overall uncertainty of the 2012 estimates for the mobile subsector (not including pipelines) was estimated to be between -1.9% and +5.0%.

The uncertainty for Transport fuel combustion CO<sub>2</sub> emissions was  $\pm 0.4\%$ . In contrast, and similar to the stationary fuel combustion sources, CH<sub>4</sub> and N<sub>2</sub>O emission uncertainty ranges were two to three orders of magnitude greater than that of CO<sub>2</sub>. Hence, the overall uncertainty for the mobile Transport subsector reflects the predominance of CO<sub>2</sub> in total GHG emissions.

### Emissions from Civil Aviation (Domestic Aviation)

The uncertainty associated with overall emissions from domestic aviation was estimated to be within the range of -1% to +5%. This implied that the source category was more likely underestimated than overestimated. The high uncertainties associated with jet kerosene CH<sub>4</sub> (-50% to +50%) and N<sub>2</sub>O emission factors (-70% to +150%) resulted in a downward bias on the inventory. These effects were somewhat reduced by the large contribution of jet kerosene CO<sub>2</sub> emissions and its comparatively low emission factor uncertainty. The Civil Aviation category only contributed approximately 3% to total Transport GHG emissions and therefore did not greatly influence overall uncertainty levels.

### Emissions from Road Transportation

The uncertainty related to the overall emissions from on-road vehicles was estimated to be within the range of  $\pm 1\%$ , driven primarily by the relatively low uncertainties in gasoline and diesel activity data and their related CO<sub>2</sub> emissions. Conversely, the high uncertainties associated with CH<sub>4</sub> and N<sub>2</sub>O emissions, as well as biofuel activity data, did not greatly influence the analysis due to their comparatively minor contributions to the inventory.

Approximately 68% of the Transport subsector's GHG emissions were attributable to on-road transportation. Accordingly, the Transport subsector's relatively low inventory uncertainty is justified through the results of the Road Transportation category uncertainty analysis.

### Emissions from Railways

The uncertainty associated with emissions from rail transport was estimated to be between -11% and +31%, indicating that this category was potentially underestimated. The greatest influence was exerted by the high N<sub>2</sub>O emission factor uncertainty (-90% to +900%), whereas the relatively low uncertainties in diesel activity data and CO<sub>2</sub> emission factors contributed very little. It is important to note that railway emissions only accounted for approximately 4% of the Transport subsector GHG inventory and therefore did not greatly influence the overall uncertainty results.

### Emissions from Navigation (Domestic Marine)

The uncertainty associated with emissions from the domestic marine source category ranged from -7% to +14%, suggesting that GHGs were potentially underestimated. The high N<sub>2</sub>O emission factor uncertainty (-90% to +900) represented the largest contribution to uncertainty, while CO<sub>2</sub> emission factor uncertainties were insignificant. Since domestic marine emissions only made up 3% of the Transport subsector GHG inventory, they did not substantially alter the overall uncertainty results.

### Emissions from Other Transportation (Off-road)

The Off-road Transportation category includes both off-road gasoline and off-road diesel consumption. The uncertainty associated with the off-road transport sources ranged from -8% to +25%, indicating that the 2014 submission likely underestimates total emissions from this subcategory. Consistent with the inventory estimation methodology for this source category, off-road diesel consumption is calculated from the on-road diesel consumption residual, and likewise for off-road gasoline consumption. Consequently, activity data uncertainties from road transportation were employed in the off-road uncertainty analysis and did not greatly contribute to the results mentioned above since they were relatively low. Of greater influence was the N<sub>2</sub>O emission uncertainty for gasoline and diesel (-90% to +900%), which indicated a downward bias in the GHG estimate. Approximately 19% of the Transport subsector's GHG emissions were attributable to off-road transportation and therefore it had a significant effect on the overall uncertainty analysis.

## Summary

Generally, for the Transport subsector, the ICF Consulting study incorporated uncertainty values for CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O emission factors from two other reports: McCann (2000) and SGA Energy Ltd. (2000). The ICF Consulting study included values determined in these reports, along with limited expert elicitations addressing



the uncertainty of the activity data contributing to the Transport subsector estimates within its Monte Carlo analysis. A number of incremental improvements have been incorporated into the original analysis, as described in the opening paragraphs of Section 3.2.3.3.

Some of the weaker components of the uncertainty analysis 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, this is unlikely, and there are indications that compilation errors exist. Presently, inventory practitioners are conducting a study to re-establish the time series for the Canadian fleet. The current fleet uncertainty 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 categories in Transport, not just those designated as “key.” No significant mathematical errors were found. The QC activities are documented and archived in paper and electronic form.

In addition, certain verification steps were performed during the model preparation stage. Since MGEM uses national fuel data defined by type and region combined with country-specific emission factors, primary scrutiny is applied to the vehicle population profile, as this dictates the fuel demand per vehicle category and, hence, emission rates and quantities. Interdepartmental partnerships have been developed among Environment Canada, Transport Canada and Natural Resources Canada to facilitate the sharing of not only raw data but also derived information such as vehicle populations, fuel consumption ratios (FCRs), vehicle kilometres travelled (VKTs) and kilometre accumulation rates (KARs). This broader perspective fosters a better understanding of actual vehicle use and subsequently should promote better modelling and emission estimating. With support from Transport Canada and Natural Resources Canada, Statistics Canada historically published the Canadian Vehicle Survey (CVS), a quarterly report that provided both vehicle population and VKTs in aggregated regional classes. It provided alternative interpretation of provincial registration files and could therefore corroborate the commercially available data sets mentioned above. Unfortunately, the resolution necessary for emission modelling was unavailable from the CVS, and it therefore was not able to replace the annually purchased data sets. Although the CVS has been discontinued since 2009, interdepartmental collaboration continues on an improved and significantly expanded survey of on-road vehicle activity whose data are expected to be incorporated into MGEM in the coming years.

### 3.2.3.5. Recalculations

Transportation estimates were revised for the 1990–2011 period. As discussed below in more detail, revised activity data and emission factors contributed to recalculations along with the reallocation of emissions in the Off-road Transportation category.

*Activity Data:* The fuel-use data were revised based on Statistics Canada data, and estimates were recalculated accordingly. Refer also to Section 3.2.1.5.

*Propane Emission Factor:* The rounding of the propane CO<sub>2</sub> emission factor was corrected from 1510 kg/m<sup>3</sup> to 1507 kg/m<sup>3</sup>, which resulted in recalculations for the entire time-series. For further documentation on emission factors, refer to Annex 8.

*Emissions Reallocation:* Diesel previously reported under Manufacture of Solid Fuels and Other Energy Industries has been reallocated to the Off-road Transportation category.

These improvements have increased the transparency, accuracy and representativeness of fuel consumption at the sectoral and subsectoral levels.

### 3.2.3.6. Planned Improvements

The transportation model (MGEM) was upgraded in 2011–2012 and continuously evolves to accommodate an increasing number of higher-resolution data sets being made available through partnerships and reporting.

Future improvements will concentrate on the development of better on-road activity data. The decoding of vehicle identification numbers (VINs) progressed during the last year but there is still work to be done before it can be introduced into the inventory. This work will hopefully allow the use of provincial registration files to obtain a better representation of the Canadian fleet. Fuel consumption ratios (FCRs) are also being evaluated to ensure that estimates are representative of the Canadian situation.

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

### 3.2.4.1. Source Category Description

The Other Sectors subsector consists of three categories: Commercial/Institutional, Residential and Agriculture/Forestry/Fisheries. Emissions consist primarily of fuel combustion related to space and water heating. Emissions from the use of transportation fuels in these categories are allocated to Transport (Section 3.2.3).

Biomass<sup>5</sup> combustion is a significant source of emissions in the residential sector, and CH<sub>4</sub> and N<sub>2</sub>O emissions are included in the subsector estimates. However, CO<sub>2</sub> emissions from biomass combustion are reported separately in the CRF tables as memo items and are not included in Energy Sector totals. This method is consistent with the treatment of biomass in the Pulp, Paper and Print category.

In 2012, the Other Sectors subsector contributed 72.3 Mt (or 10%) of Canada's total GHG emissions, with an overall growth of about 1.0% (0.7 Mt) since 1990. Within the Other Sectors subsector, residential emissions contributed about 41 Mt (or 57%), followed by a 27.8 Mt (or 38%) contribution from the Commercial/Institutional category, which also includes emissions from the public administration sector (i.e. federal, provincial and municipal establishments). Since 1990, GHG emissions have grown by about 8% in the Commercial/Institutional category, while GHG emissions in the Residential category have declined by about 5%. Refer to Table 3–5 for additional details. Additional trend discussion for the Other Sectors subsector is presented in the Emission Trends chapter (Chapter 2).

### 3.2.4.2. Methodological Issues

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

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

Emissions are based on fuel-use data reported as commercial and public administration in the RESD, and, in the case of landfill gas (LFG), are based on volumes collected by the Waste Sector expert. CH<sub>4</sub> and N<sub>2</sub>O emissions from the combustion of LFG

are included, while CO<sub>2</sub> emissions are excluded from totals but reported separately in the UNFCCC CRF tables as a memo item.

#### 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 under CO<sub>2</sub> Emissions from Biomass (Section 3.4.2); although CO<sub>2</sub> emissions are not accounted for in the national residential GHG total (but reported as a memo item), the CH<sub>4</sub> and N<sub>2</sub>O emissions are reported here.

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

This source category includes emissions from stationary fuel combustion in the agricultural and forestry industries. However, emission estimates are included for the agriculture and forestry portion only. Fishery emissions are reported typically under either the Transportation subsector or the 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.

### 3.2.4.3. Uncertainties and Time-Series Consistency

The estimated uncertainty range for the Other Sectors subsector is  $\pm 5\%$  for all gases and  $\pm 5\%$  for CO<sub>2</sub>.

The underlying fuel quantities and CO<sub>2</sub> emission factors have low uncertainties, since they are predominantly commercial fuels, which have consistent properties and accurate tracking. Although the non-CO<sub>2</sub> emissions from biomass combustion contributed only 6% to the total Residential category, its CH<sub>4</sub> (-90% to +1500%) and N<sub>2</sub>O (-65% to +1000%) uncertainties are high due to the uncertainty associated with their emission factors (ICF

<sup>5</sup> Typically firewood.

Table 3–5 Other Sectors GHG Contribution

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)							
	1990	2000	2005	2008	2009	2010	2011	2012
Other Sectors TOTAL (1.A.4)	71 600	80 600	78 400	78 200	75 900	72 200	77 800	72 300
Commercial/Institutional	25 700	32 900	31 900	29 600	29 400	28 000	29 900	27 800
Commercial and Other Institutional	23 700	30 600	29 900	27 600	27 400	26 200	28 000	26 100
Public Administration	1 980	2 280	2 050	2 000	2 030	1 800	1 900	1 750
Residential	43 500	45 100	44 300	45 900	43 900	41 300	44 400	40 900
Agriculture/Forestry/Fisheries	2 390	2 550	2 100	2 610	2 530	2 880	3 430	3 540
Forestry	60	80	160	170	170	190	130	140
Agriculture	2 300	2 500	1 900	2 400	2 400	2 700	3 300	3 400

Note: Totals may not add up due to rounding.

Consulting 2004). As stated in the Energy Industries subsector, additional expert elicitation is required to improve the CH<sub>4</sub> and N<sub>2</sub>O uncertainty estimates for some of the emission factor uncertainty ranges and probability density functions developed by the ICF Consulting study, since insufficient time was available to have these assumptions reviewed by industry experts.

These estimates are consistent over the time series based on the same methodology. A discussion of Statistics Canada fuel use data is presented in Section 3.2.1.5, Recalculations.

### 3.2.4.4. QA/QC and Verification

The Other Sectors subsector 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 minor data errors were discovered 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

The fuel-use data were revised based on Statistics Canada input, and estimates were recalculated accordingly. A discussion on RESD fuel use data is presented in Section 3.2.1.5, Recalculations.

### 3.2.4.6. Planned Improvements

Future improvement plans for the Other Sectors subsector include a review of the activity data used by the residential biomass model.

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

The UNFCCC reporting guidelines assign military fuel combustion to this subsector. Turbo fuel emissions generated by military air transportation are estimated by AGEM and are included under this category. However, military emissions generated by consuming aviation gasoline are included under Civil Aviation (CRF Category 1.A.3.a), since the current data source for this type of fuel consolidates military and civil fuel use. As in previous submissions, 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 2012, the Fugitive Emissions category accounted for about 61 Mt (or 8.7%) of Canada's total GHG emissions, with about a 44%

Table 3–6 Fugitive GHG Contribution

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)							
	1990	2000	2005	2008	2009	2010	2011	2012
Fugitive Emissions from Fuels (1.B)	42 000	63 000	63 000	62 000	59 000	58 000	60 000	61 000
Solid Fuels—Coal Mining (1.B.1)	2 000	1 000	1 000	900	900	1 000	1 000	1 000
Oil and Natural Gas (1.B.2)	40 000	62 000	62 000	61 000	58 000	57 000	59 000	60 000
a. Oil <sup>1</sup>	4 200	5 400	5 700	5 500	5 500	5 700	5 900	6 500
b. Natural Gas <sup>1</sup>	11 000	18 000	19 000	20 000	19 000	19 000	19 000	19 000
c. Venting and Flaring <sup>2</sup>	24 400	38 400	37 500	36 100	33 400	32 300	33 700	34 700
Venting	20 000	33 000	32 000	31 000	29 000	28 000	29 000	30 000
Flaring	4 400	5 400	5 500	5 100	4 400	4 300	4 700	4 700

Notes:

1. All other fugitives except venting and flaring.

2. Both oil and gas activities.

Totals may not add up due to rounding.

growth in emissions since 1990. Between 1990 and 2012, fugitive emissions from oil and natural gas increased 50% to 60 Mt, and those from coal decreased by about 1 Mt from about 2 Mt in 1990. The oil and gas production, processing, transmission and distribution activities contributed 98% of the fugitive emissions. Refer to Table 3–6 for more details.

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

#### 3.3.1.1. Source Category Description

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

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

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

#### 3.3.1.2. Methodological Issues

In the early 1990s, King (1994) developed an inventory of fugitive emissions from coal mining operations, which is the basis for the coal mining fugitive emissions estimated. Emission factors were calculated by dividing the emission estimates from King (1994) by the appropriate coal production data.

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

### 3.3.1.3. Uncertainties and Time-Series Consistency

The CH<sub>4</sub> uncertainty estimate for fugitive emissions from coal mining is estimated to be in the range of -30% to +130% (ICF Consulting 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.

#### 3.3.1.4. QA/QC and Verification

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

#### 3.3.1.5. Recalculations

Estimates for fugitive emissions from coal mining were revised based on updated production data for 2011.

#### 3.3.1.6. Planned Improvements

There is an ongoing study of coal mining in Canada, with the primary objective of developing new fugitive emission factors. These will be used for improvements to this category, to be consistent with current and future IPCC Guidelines.

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

#### 3.3.2.1. Source Category Description

The Oil and Natural Gas category of fugitive emissions includes emissions from oil and gas production, processing, oil sands mining, bitumen extraction, *in-situ* bitumen production, heavy oil/bitumen upgrading, petroleum refining, 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, Manufacture of Solid Fuels and Other Energy Industries, and Mining categories (Section 3.2.1).

The Oil and Natural Gas source category has three main components: upstream oil and gas (UOG), oil sands / bitumen, and downstream oil and gas.

### Upstream Oil and Gas

UOG includes all fugitive emissions from the exploration, production, processing and transmission of oil and natural gas, excluding those from oil sands mining, bitumen extraction and upgrading activities. 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, and accidents, spills and deliberate vents.

The sources of emissions have been divided into major groups:

*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 subsector. Venting results from conventional service work, such as the release of solution gas from mud tanks and blow down treatment for natural gas wells. It is assumed that there is no significant potential for fugitive emissions from leaking equipment. Fugitive emissions from absolute open flow tests are assumed to be negligible.

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

*Light/Medium Oil Production:* This type of production is defined by wells producing light- or medium-density crude oils (i.e. density < 900 kg/m<sup>3</sup>). 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<sup>3</sup>. Production of this viscous liquid requires a

special infrastructure. There are generally two types of heavy oil production systems: primary and thermal. The emission sources from both types are wells, flow lines, batteries (single and satellite) and cleaning plants. The largest source is venting of casing and solution gas.

*In-situ 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, including primary production (or cold flow), cyclic steam stimulation (CSS), steam-assisted gravity drainage (SAGD); and experimental methods such as toe-to-heel air injection (THAI), vapour extraction process (VAPEX) and combustion overhead gravity drainage (COGD). The sources of emissions are wells, flow lines, satellite batteries and cleaning plants. The main source of emissions is the venting of casing gas.

*Natural Gas Processing:* Natural gas is processed before entering transmission pipelines to remove water vapour, contaminants and condensable hydrocarbons. There are four different types of natural gas 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 are considered in conjunction with gas processing. The largest source of emissions is equipment leaks.

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

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

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



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

### Oil Sands / Bitumen

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

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

### Downstream Oil and Gas

Downstream oil and gas includes all fugitive emissions from the production of refined petroleum products and the distribution of natural gas to end consumers. The emissions have been divided into two major groups:

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

*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 fugitive emissions from main and service pipelines and meter/regulator stations, which account for about 42% and 33% of emissions, respectively.

## 3.3.2.2. Methodological Issues

### Upstream Oil and Gas

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

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

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

The 1990–1999 and 2001–2012 fugitive emissions were estimated using annual industry activity data from conventional UOG production and the 2000 emission results. The 1990–1999 estimates and method are presented in Volume 1 of the UOG report. A consistent UOG estimation model (hereafter referred to as the UOG model) for 2001 and onwards was developed for use in estimating annual national- and provincial-level GHG estimates. The emissions for both time spans were estimated using emission data from the year 2000 together with the annual production and activity data for the relevant years. A detailed description of the methodology can be found in the UOG report (CAPP 2005a) and the UOG model report (CAPP 2005b). A summary of the estimation method of the UOG model is represented in Annex 3.

### Natural Gas Transmission

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



## Oil Sands / Bitumen

Fugitive GHG emissions from oil sands mining, bitumen extraction, heavy oil/bitumen upgraders and integrated cogeneration facilities are from the bitumen study, *An Inventory of GHGs, CACs, and H<sub>2</sub>S Emissions by the Canadian Bitumen Industry: 1990 to 2003* (CAPP 2006). The bitumen study is a compilation of GHG emissions from the following companies: Suncor Energy Inc., Syncrude Canada Ltd., Shell Canada Ltd. and Husky Energy Inc. Methods used to estimate fugitive emissions from in-situ bitumen extraction are from CAPP's UOG study (CAPP 2005a) (see Section 3.3.2.1).

In general, the IPCC Tier 3 approach was used by each operator to develop a bottom-up approach in estimating GHG emissions. Facilities' inventories were reviewed to ensure that each facility's estimates were complete, accurate and transparent; where gaps existed, estimates were developed and provided to each operator for review. QA/QC and an uncertainty analysis following the IPCC Good Practice Guidance (IPCC 2000) were also performed.

A bitumen estimation model (hereafter referred to as the bitumen model) was developed to allow annual updating of fugitive emissions from oil sands mining and bitumen/heavy oil upgrading activities from 2004 onwards. The bitumen model was developed based on relevant parameters and results from the original bitumen study along with annual activity data. The activity data required by the model are published in the following reports: *Alberta Mineable Oil Sands Plant Statistics* from the Alberta Energy Regulator (AER 2013) and the National Energy Board's (NEB 1998–2012) online statistics: *Estimated Production of Canadian Crude Oil and Equivalent*. These data are updated annually and used to estimate GHG emissions. Refer to both the bitumen study (CAPP 2006) and the bitumen model (Environment Canada 2007) for a detailed description of the methodology. A summary of the estimation method of the bitumen model is also presented in Annex 3.

Emissions for oil sands facilities not included in the original bitumen model, such as the CNRL Horizon Mine and Upgrader, Nexen Long Lake Upgrader, Fort Hills Mine, and Shell Jackpine Mine have been estimated using activity data from the AER (2013) and emission factors from similar facilities.

## 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* (CPPI 2004). Refer to the CPPI report for full details on the study. Historical fuel, energy and emission data were gathered from the Canadian Industrial Energy End-Use Data Analysis Centre (CIEEDAC) and directly from refineries for the

years 1990 and 1994–2002. Fugitive, venting and flaring emissions for the years 1991–1993 were interpolated, and emissions for 2003–2012 were extrapolated, using data in the CPPI report and the petroleum refinery energy consumption and production data from the RESD 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.

## Natural Gas Distribution

The emission estimates were derived from a study prepared for the Canadian Gas Association (CGA 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.

In the year 2000, the Gas Research Institute (GRI) reviewed and revised the 1997 CGA study, with more accurate and better substantiated data for station vents (GRI 2000).

General emission factors were developed for the distribution system based on the study data (CGA 1997; GRI 2000) and gas distribution pipeline distances by province provided by Statistics Canada. More details on the methodology used to estimate fugitive emissions from natural gas distribution systems are presented in Annex 3.

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

### 3.3.2.3. Uncertainties and Time-Series Consistency

#### Upstream Oil and Gas

The UOG fugitive emissions for 2000 are taken directly from CAPP's UOG study (CAPP 2005a). The emissions from 1990–1999 and from 2001–2012 have been estimated using the 2000 data, along with other factors discussed above. The uncertainty for the overall 2000 emissions is  $\pm 1.5\%$ . The uncertainties for the 2000 emissions for the oil and natural gas industries are listed in Table 3–7 and Table 3–8, respectively. The detailed uncertainties for each gas can be found in the UOG report (CAPP 2005a).

The uncertainties were determined using the Tier 1 uncertainty approach presented in the IPCC Good Practice Guidance (IPCC 2000). According to the IPCC (2000), there are three sources of

**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	—
<b>Total</b>	<b>-2.3 to +2.1</b>	<b>± 3.1</b>	<b>-16.7 to +16.8</b>

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

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

Source: CAPP (2005b).

uncertainties: definitions, natural variability of the process that produces the emissions, and the assessment of the process or quantity. Only the last two sources of uncertainty were considered in the analysis; it was assumed that the uncertainties from the definitions were negligible, as they were adequately controlled through QA/QC procedures. The uncertainty would be greater for those years that were estimated using the UOG model as compared with the uncertainty of the facility-based emission estimates for the 2000 data year.

### Downstream Oil and Gas

The emission data used in the inventory for fugitive emissions from refineries for 1990 and for 1994–2002 are taken directly from the CPPI (2004) study. There is greater uncertainty for the 1991–1993 and the 2003–2012 periods due to the available level of disaggregation of the activity data. Tier 1 and Tier 2 uncertainty analyses were performed, for comparison purposes, of the emission factors and activity data, for an overall CO<sub>2</sub> uncertainty in the 2002 data (CPPI 2004).

The results of these analyses are as follows: For the Tier 1 analysis, the overall uncertainty was ±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.

### Oil Sands / Bitumen

Only facility-level uncertainty estimates are currently available. An IPCC Good Practice Guidance Tier 1 uncertainty assessment was conducted for each facility, and full details of the assessment can be found in the bitumen study (CAPP 2006) and the bitumen model (Environment Canada 2007). Development of an overall

uncertainty range for this industry will be part of the uncertainty analysis improvement plan.

### 3.3.2.4. QA/QC and Verification

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

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

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

No significant mathematical errors were found during the QC checks. 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

*Petroleum Refining:* Fugitive emissions from refineries for the years 1995–2011 were recalculated based on updated activity data from Statistics Canada. These recalculations affected the above years for CRF category 1.B.2.A.4 Refining/Storage and 2003–2011 for CRF categories 1.B.2.c.i Venting – Oil and 1.B.2.c.i Flaring – Oil.

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

*Upstream Oil and Gas:* Updated activity data from various sources, including Statistics Canada and several provincial and industry reports, were utilized in the UOG extrapolation model; this resulted in changes in emissions for the 2011 data year.

### 3.3.2.6. Planned Improvements

*Upstream Oil and Gas:* A multi-year study is being commissioned to update the UOG study (CAPP 2005a) and is expected to be completed by spring 2014. This study will update emissions based on the most recent data available (i.e. 2011 data year) as well as incorporate new and emerging oil and gas sources. The results will be consistent with current and future IPCC Guidelines.

*Oil Sands / Bitumen:* In the long term, a comprehensive study to update the bitumen study (CAPP 2006) is planned with the goal of improving emission estimates from oil sands mining and extraction, in-situ production and upgrading in Canada. The new study will also develop a robust method for updating emission estimates in the rapidly expanding oil sands industry, as prioritized in recent expert review team (ERT) reviews.

*Natural Gas Transmission and Distribution:* Improvements to the natural gas transmission and distribution emissions model will be investigated with a focus on developing a method that will better reflect the improvements in efficiency made by the industry. The current models are not capable of capturing equipment changes or technology improvements, as emissions are estimated based on pipeline lengths and static emission factors.

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

### 3.4.1. International Bunker Fuels (CRF Category 1.C.1)

According to the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997), emissions resulting from fuels sold for international marine and aviation transportation should not be included in national inventory totals, but should be reported separately as emissions from 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, this assumption is no longer necessary due to the implementation of a true origin-destination aviation model.

For marine fuels, 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 reporting guidelines for bunkers, and modified statistical procedures may be required to track marine bunker fuels more accurately.

#### 3.4.1.1. Aviation (CRF Category 1.C.1.A)

Emissions (Table 3–10) have been calculated using the same methods listed in the Civil Aviation (Domestic Aviation) section (see Section 3.2.3.2). Fuel-use data are reported in the RESD (Statistics Canada #57-003) and are identified as being sold to foreign airlines; however, Statistics Canada is most confident in their published total fuel use value for aviation, with rapidly increasing uncertainty associated with further disaggregation into various categories such as foreign airlines. Therefore, the total fuel reported in the RESD is adhered to, with AGEM using flight-by-flight aircraft movements to determine whether or not a flight stage is domestic or international. This method greatly improves the allocation between domestic and international flights, as the highest resolution data available are being used to apply the mandated definitions.

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

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

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

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

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

### 3.4.2.1. Residential Firewood

Firewood is used as a primary or supplementary heating source for many Canadian homes. Combustion of firewood results in CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O emissions, which are considered technology-dependent. The main types of residential wood combustion devices considered are stoves, fireplaces, furnaces and other equipment (i.e. pellet stoves).

### 3.4.2.2. Industrial Wood Wastes

Biomass combusted in the industrial sector consists of industrial fuelwood and spent pulping liquor. This combustion of biomass is reported in the RESD and is attributed solely to the pulp, paper and print industry as it is the primary consumer. Data are not available at a high enough level of aggregation to determine usage by other industries.

### 3.4.2.3. Fuel Ethanol

Amounts of fuel ethanol used in transportation are presented in Table 3–12. Ethanol properties were developed according to chemistry and resulted in a higher heating value (HHV) (gross calorific value, or GCV) of 24.12 TJ/ML, 52.14% carbon content and 789.2 kg/m<sup>3</sup> density.

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

### 3.4.2.4. Fuel Biodiesel

The amounts of biodiesel fuel used in transportation are pre-

Table 3–10 GHG Emissions from Domestic and International Aviation

	GHG Emissions (kt CO <sub>2</sub> eq)							
	1990	2000	2005	2008	2009	2010	2011	2012
Aviation Bunkers (International)	6 100	9 200	10 000	9 300	8 800	9 300	9 400	9 100
Civil Aviation (Domestic)	7 100	7 600	7 600	7 300	6 400	6 400	6 200	6 100
<b>Total</b>	<b>13 200</b>	<b>16 900</b>	<b>17 600</b>	<b>16 600</b>	<b>15 200</b>	<b>15 700</b>	<b>15 600</b>	<b>15 100</b>

Note: Totals may not add up due to rounding.

Table 3–11 GHG Emissions from Domestic and International Navigation

	GHG Emissions (kt CO <sub>2</sub> eq)							
	1990	2000	2005	2008	2009	2010	2011	2012
Marine Bunkers (International)	3 100	3 200	3 100	2 900	2 300	2 400	1 700	1 700
Navigation (Domestic)	5 000	5 200	6 700	6 500	6 700	7 000	5 800	5 800
<b>Total</b>	<b>8 200</b>	<b>8 400</b>	<b>9 700</b>	<b>9 400</b>	<b>8 900</b>	<b>9 300</b>	<b>7 600</b>	<b>7 500</b>

Note: Totals may not add up due to rounding.

Table 3–12 E Ethanol Used for Transport in Canada

Year	1990	2000	2005	2008	2009	2010	2011	2012
Ethanol Consumed (ML)	7	227	267	1 364	1 529	1 874	2 718	2 723

Table 3–13 Biodiesel Used for Transport in Canada, 1990, 2000, 2005, 2008–2012

Year	1990	2000	2005	2008	2009	2010	2011	2012
Biodiesel Consumed (ML)	0	0	4	141	164	394	558	585

sented in Table 3–13. The properties used for biodiesel were extracted from a biodiesel study conducted between 2004 and 2005 (BioMer 2005). The higher heating value (HHV) (gross calorific value, or GCV) used is 35.18 TJ/ML, with a 76.5% carbon content and 882 kg/m<sup>3</sup> density.

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

## 3.5. Other Issues

### 3.5.1. Comparison of Sectoral and Reference Approaches

Refer to Annex 4: Comparison of Sectoral and Reference Approaches, which presents a full discussion of this topic.

### 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 fuels for generating heat or work. In addition to being combusted for energy production, fossil fuels are also consumed for non-energy purposes. Non-energy uses of fossil fuels include application as waxes, solvents, lubricants and feedstocks (including the manufacturing of fertilizers, rubber, plastics and synthetic fibres). Emissions from the non-energy use of fossil fuels have been included in the Industrial Processes Sector, whereas emissions from the use of fossil fuels associated with flaring activities by the oil and gas industry are included in the Fugitive subsector.

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

### 3.5.3. Carbon Capture and Storage – Enhanced Oil Recovery

In Canada, CO<sub>2</sub> from anthropogenic sources is used as a flooding agent in enhanced oil recovery (EOR) operations to increase crude oil production volume at two depleting oil reservoirs.

CO<sub>2</sub> flooding started in 2000 at the Weyburn site and in 2005 at the Apache Midale site in order to extend the life of these mature reservoirs by another 30 years. CO<sub>2</sub> is purchased from the Dakota Gasification Company located in North Dakota (U.S.) and is transported via pipeline to the field. This fresh supply is then combined with recycled CO<sub>2</sub> for re-injection back into the reservoir. Currently about 2.8 Mt per year of CO<sub>2</sub> is injected at the Weyburn-Midale operations.<sup>6</sup> The Weyburn site, from 2000 to 2011, injected over 20 Mt of fresh CO<sub>2</sub> as purchased from the Dakota gasification plant with an injection rate of 7000 t of CO<sub>2</sub> per day (PTRC 2011). Since 2005, the Midale site has injected more than 2 Mt of fresh CO<sub>2</sub>, with an injection rate of 1800 t of CO<sub>2</sub> per day (PTRC 2004).

CO<sub>2</sub> is used as flooding agent in EOR since it acts as a solvent and it helps increase the reservoir pressure, resulting in the release of trapped hydrocarbons to production wells. The flooding process of CO<sub>2</sub> at high pressure also results in CO<sub>2</sub> being trapped in the voids that were previously occupied by hydrocarbon molecules. This process is commonly known as geological storage of CO<sub>2</sub>.

In addition to being a CO<sub>2</sub> EOR operation, Weyburn is also the site of a full-scale geological CO<sub>2</sub> storage research program led by the International Energy Agency's Greenhouse Gas (IEA GHG) Research and Development Programme with the support of various industries, research organizations and governments. Modelling and simulation results from the first phase (from 2000 to 2004) of the IEA GHG's CO<sub>2</sub> monitoring and storage project, as managed by the Petroleum Technology Research Centre (PTRC), indicates that over 98% of CO<sub>2</sub> will remain trapped in the Weyburn reservoir after 5000 years and only 0.14% will be released to the atmosphere (Mourits 2008). Additional details on the findings of the first phase of the research project are available on the PTRC website ([www.ptrc.ca](http://www.ptrc.ca)—see PTRC 2004).

The final phase (from 2005 to 2011) of the IEA Weyburn-Midale research project as outlined on the PTRC website focused on technical and non-technical components such as site characterization, selection, well bore integrity, monitoring and verification, risk assessment, regulatory issues, public communication and outreach, and business environment policy in order to develop a best practice manual for future projects on the geological storage of CO<sub>2</sub>.

The net emission impacts of GHG emissions from all of these operations is included in Canada's inventory as part of the Energy Industries (1A.1) and Oil and Natural Gas (1B.2) categories.

<sup>6</sup> Mourits F. 2010. *CO<sub>2</sub> Injected for Weyburn and Midale Operation* information provided by F. Mourits IEA GHG Weyburn-Midale CO<sub>2</sub> Monitoring and Storage Project, Natural Resources Canada. January 2010.



### 3.5.4. Country-specific Issues: Emissions Associated with the Net Export of Fossil Fuels

Canada exports a large proportion of its produced fossil fuel resources, mostly to the United States. In 2012, Canada exported approximately 65% (energy equivalent) of its gross natural gas and crude oil production. The emissions associated with the export of crude oil and natural gas are estimated using the “Fossil Fuel Export” model (Smyth 2010). The model uses pre-existing models currently used in assembling the national emission estimates, as well as annually updated activity data from a variety of sources. The emissions/sectors included within the two main fuel stream estimates are as follows:

- *Natural Gas*: This category accounts for GHG emissions specific to the production, gathering, processing and transmission of natural gas. Only those sources that exist for the primary purpose of producing natural gas for sale are considered, including stationary, fugitive and transmission emissions. 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 stationary, fugitive and transport emissions related to the production, treatment, storage and movement of crude oils.

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.

The results demonstrate that, between 1990 and 2012, emissions associated with the exports of oil and gas have increased by almost 200%, coinciding with a similar increase in the total of oil and gas energy exported (Table 3–14). Over the same period,

oil exports have increased at a rate 2.5 times greater than the growth in domestic production, while the emissions associated with those exports have more than tripled (Table 3–15). This is due to increased exports of more GHG-intensive unconventional crude products (i.e. crude bitumen and synthetic crude oil) from Canada’s oil sands (Table 3–18). For natural gas, emissions associated with exports have increased by approximately 140%, coinciding with an increase of 121% in natural gas exports (almost three times the rate of growth of natural gas production) (Table 3–16).<sup>7</sup>

Conventional crude oil production is generally on the decline in Canada, with peak production occurring in 2003. However, in recent years production has increased with the increased use of horizontal drilling and hydraulic fracturing. Following this, the exports of conventional crude oil and the emissions associated with their export have also increased (Table 3–17). In contrast to the trend in conventional crude oil, production of unconventional crude oil<sup>8</sup> from Canada’s oil sands has been consistently increasing (Table 3–18). In 2012, production was over five times higher than in 1990, while exports were almost seven times higher than in 1990. Whereas exports have grown seven-fold, the emissions associated with these exports are only five times larger, reflecting improved efficiencies in extracting oil sands products.

<sup>7</sup> The source for all export and energy production data is Statistics Canada’s *Report on Energy Supply–Demand in Canada* (RES-D, #57-003). The 1990–2012 GHG emissions associated with net exports are from Smyth (2010).

<sup>8</sup> Unconventional crude oil includes crude bitumen from mining and *in-situ* sources as well as synthetic crude oil.

**Table 3–14 Combined Crude Oil and Natural Gas: Production, Export and GHG Emission Trends, Select Years**

Crude Oil & Natural Gas Trends	1990	2002	2005	2008	2009	2010	2011	2012
Domestic Production (PJ)	7 958	12 730	13 091	13 059	12 593	12 721	13 203	13 674
Energy Exported (PJ)	3 068	7 481	7 870	8 122	7 954	8 256	8 583	8 909
Emissions Associated with Gross Exports (Mt CO <sub>2</sub> eq.)	33.0	85.3	87.1	89.8	85.1	86.2	89.5	93.1

**Table 3–15 Crude Oil: Production, Export and GHG Emission Trends, Select Years**

Crude Oil Trends	1990	2002	2005	2008	2009	2010	2011	2012
Domestic Production (PJ)	3 774	5 480	5 899	6 398	6 363	6 714	7 141	7 668
Energy Exported (PJ)	1 531	3 377	3 804	4 181	4 294	4 582	5 020	5 516
Emissions Associated with Gross Exports (Mt CO <sub>2</sub> eq.)	21.4	50.4	53.7	54.5	59.3	58.1	62.5	65.8

**Table 3–16 Natural Gas: Production, Export and GHG Emission Trends, Select Years**

<b>Natural Gas Trends</b>	<b>1990</b>	<b>2002</b>	<b>2005</b>	<b>2008</b>	<b>2009</b>	<b>2010</b>	<b>2011</b>	<b>2012</b>
Domestic Production (PJ)	4 184	7 250	7 192	6 661	6 229	6 007	6 062	6 006
Energy Exported (PJ)	1 537	4 103	4 066	3 941	3 660	3 673	3 563	3 393
Emissions Associated with Gross Exports (Mt CO <sub>2</sub> eq.)	11.5	34.9	33.4	31.3	28.0	28.1	27.0	27.3

**Table 3–17 Conventional Crude Oil: Production, Export and GHG Emission Trends, Select Years**

<b>Crude Oil Trends</b>	<b>1990</b>	<b>2002</b>	<b>2005</b>	<b>2008</b>	<b>2009</b>	<b>2010</b>	<b>2011</b>	<b>2012</b>
Domestic Production (PJ)	2 973	3 657	3 459	3 418	3 090	3 098	3 173	3 287
Energy Exported (PJ)	1 112	2 319	2 293	2 153	2 310	2 315	2 608	2 623
Emissions Associated with Gross Exports (Mt CO <sub>2</sub> eq.)	12.7	32.1	31.7	28.8	25.5	21.1	24.7	23.6

**Table 3–18 Unconventional Crude Oil: Production, Export, and GHG Emission Trends, Select Years**

<b>Crude Oil Trends</b>	<b>1990</b>	<b>2002</b>	<b>2005</b>	<b>2008</b>	<b>2009</b>	<b>2010</b>	<b>2011</b>	<b>2012</b>
Domestic Production (PJ)	801	1 822	2 440	2 980	3 274	3 616	3 968	4 381
Energy Exported (PJ)	418	1 058	1 511	2 029	1 984	2 268	2 412	2 894
Emissions Associated with Gross Exports (Mt CO <sub>2</sub> eq.)	8.7	18.3	22.0	28.3	30.9	37.0	37.8	42.1



# Chapter 4

## Industrial Processes (CRF Sector 2)

### 4.1. Overview

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

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

The processes addressed in the Industrial Processes Sector include production and use of mineral products; metal production; chemical production (including CH<sub>4</sub> and N<sub>2</sub>O from petrochemicals); consumption of SF<sub>6</sub>; halocarbon production and use as alternatives to ozone-depleting substances; and other and undifferentiated production.

CO<sub>2</sub> emissions resulting from use of fossil fuels as feedstock in the production of chemicals, other than ammonia, are reported in the Other and Undifferentiated Production subsector (Section 4.22). This subsector also includes CO<sub>2</sub> emissions from other non-energy uses of fuels in the mining and processing of metals (exception is use of coke in iron and steel, which is a separate category).

Indirect GHGs (such as CO, non-methane volatile organic compounds [NMVOC] and SO<sub>2</sub>) from industrial process activities, including asphalt roofing, road paving with asphalt, pulp and paper production, and production of food and drink have not been estimated. However, these emissions and the indirect GHG emissions associated with energy activities are reported under Annex 10 of this National Inventory Report, as produced by Environment Canada's air pollutants inventory group.

As shown in Table 4-1, GHG emissions from the Industrial Processes Sector contributed 56.5 Mt to the 2012 national GHG inventory, compared with 55.7 Mt in 1990. The 2012 industrial process emissions represented 8.1% of the total Canadian GHG emissions in 2012. The contributing factors of the long-term and short-term trends in this Sector are discussed in detail in Chapter 2, and highlights of these are provided below.

The production of adipic acid ceased in 2009; this resulted in a decrease of 10.7 Mt CO<sub>2</sub> eq from 1990 to 2012 for the Adipic Acid Production source category, which contributed to an overall decrease of 57% (9.4 Mt CO<sub>2</sub> eq) for the Chemical Production subsector. Another notable source of decrease in emissions from 1990 to 2012 is the aluminium industry, which has decreased its PFC emissions by 77% (5.0 Mt CO<sub>2</sub> eq) through implementing emission control technologies, while increasing its production by 77% during the same time period. In addition, the industry has tried to gradually reduce its use of the old Söderberg production technology. The last magnesium production plant ceased operation in 2008; this resulted in the decrease of 2.9 Mt CO<sub>2</sub> eq for the Magnesium Production source category from 1990 to 2012.

Another notable industry that has experienced a decrease in emissions between 1990 and 2012 is the lime production industry (18%, 0.3 Mt CO<sub>2</sub> eq).

The emission decreases mentioned above were partly offset by significant increases in emissions from the Consumption of Halocarbons and from the Other and Undifferentiated Production subsectors between 1990 and 2012. Emissions from the consumption of halocarbons grew by 1440% (7.3 Mt CO<sub>2</sub> eq) since 1995 because of the progressive replacement of ODS, such as chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), by hydrofluorocarbons (HFCs), as per the requirements of the Montreal Protocol. On a similar magnitude, emissions from the Other and Undifferentiated Production subsector have increased by 128% (9.4 Mt CO<sub>2</sub> eq) since 1990, largely as a result of increases in the consumption of: natural gas liquids and refinery products used as feedstock in petrochemical manufacturing; and solvents in industrial and commercial applications.

A Tier 1 uncertainty assessment has been done for each of the categories under the Industrial Processes Sector. Results of the assessment are provided in the uncertainty section of each category.

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

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)							
	1990	2000	2005	2008	2009	2010	2011	2012
Industrial Processes TOTAL	55 700	57 400	60 300	58 700	52 000	54 200	54 700	56 500
a. Mineral Products	8 400	9 800	9 900	9 000	7 000	7 600	7 800	8 400
Cement Production	5 400	6 700	7 200	6 600	5 100	5 700	5 700	6 300
Lime Production	1 800	1 900	1 700	1 500	1 200	1 400	1 400	1 400
Limestone and Dolomite Use	800	770	640	670	540	360	430	430
Soda Ash Use	250	250	180	160	110	100	100	110
Magnesite Use	147	181	175	57	69	81	96	91
b. Chemical Industry	16 300	8 000	9 300	9 400	7 100	6 500	7 000	7 000
Ammonia Production	4 500	5 700	5 300	5 600	5 200	5 300	5 700	5 800
Nitric Acid Production	1 010	1 230	1 250	1 280	1 150	1 100	1 160	1 150
Adipic Acid Production	10 700	900	2 650	2 400	660	0	0	0
Petrochemical	110	100	80	70	60	60	60	60
c. Metal Production	22 600	22 500	19 700	18 500	15 400	15 800	16 600	16 300
Iron and Steel Production	10 200	11 500	10 200	10 700	8 030	9 030	9 860	9 840
Aluminium Production	9 300	8 200	8 200	7 400	7 200	6 600	6 600	6 200
Magnesium Production	2 870	2 310	1 090	175	0	0	0	0
Magnesium Casting	236	471	201	280	193	190	200	257
d. Production and Consumption of Halocarbons (HFCs & PFCs)	770	3 000	5 300	5 600	6 300	7 100	7 600	7 800
e. SF <sub>6</sub> Use in Electric Utilities and Semiconductors	230	220	180	220	190	190	150	190
f. Other and Undifferentiated Production	7 400	14 000	16 000	16 000	16 000	17 000	15 000	17 000

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

To ensure that the inventory was correctly prepared, the key and updated categories of this Sector have all undergone Tier 1 level quality control checks.

To keep up with the principle of continuous improvement, and to address comments made by the Inventory Expert Review Team (ERT) on our 2013 NIR submission, improvements to activity data, and rectification of transcription and calculation errors were made. Calculation and transcription errors that were identified in the 2013 submission as part of the QC measures were rectified. Detailed explanations for the changes in estimates as a result of the mentioned improvements are described in the recalculation sections of the respective source categories in this chapter. Again, following ERT recommendations on transparency, additional information has been provided in this NIR regarding these categories: Lime Production, Limestone and Dolomite Use, Iron and Steel Production, and Other and Undifferentiated Production.

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

### 4.2.1. Source Category Description

CO<sub>2</sub> is generated during the production of clinker, an intermediate product from which cement is made. Calcium carbonate

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



The lime is then combined with silica-containing materials in the higher-temperature section of the kiln (1350–1450°C) to produce clinker (greyish-black pellets about the size of 12 mm diameter marbles). The clinker is removed from the kiln, cooled and pulverized, and gypsum is added to produce Portland cement. According to Statistics Canada's publications (catalogue #44-001 and CANSIM tables 303-0060 and 303 0061), more than 90% of the cement produced in Canada is of the Portland cement type. Portland cement contains 95–97% clinker by weight. The lime content of clinker ranges between 60% and 67% (IPCC 2006). Other specialty cements are lower in lime, but are typically used in small quantities.

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

## 4.2.2. Methodological Issues

To estimate CO<sub>2</sub> emissions from cement production at national level, the equation recommended in the Intergovernmental Panel on Climate Change (IPCC) Good Practice Guidance (IPCC 2000), as shown below, was used:

### Equation 4–1:

$$CO_2 \text{ emissions} = EF_{\text{clinker}} \times \text{Clinker Production} \times \text{CKD Correction Factor}$$

where:

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

The IPCC default  $EF_{\text{clinker}}$  of 0.5071 kt CO<sub>2</sub>/kt clinker produced was applied. This factor was developed based on an average CaO content of 64.6% and the molecular weight ratio of CO<sub>2</sub> to CaO in the raw material, which is 0.785 (IPCC/OECD/IEA 1997). The IPCC Good Practice Guidance (IPCC 2000) suggests 1.02 (i.e. adding 2% to the CO<sub>2</sub> calculated for clinker) as the default CKD correction factor.

Clinker production data for 1990–1996 were obtained from *A Review of Energy Consumption and Related Data: Canadian Cement Manufacturing Industry, 1990 to 2008* (CIEEDAC 2010). Clinker production data for 1997–2004 were obtained from Statistics Canada (#44-001) and for 2005–2012 from CANSIM tables 303-0060 and 303-0061 (Statistics Canada 2005–2012). Applying Equation 4–1 above to the clinker production data is considered a Tier 2 type approach.

To estimate CO<sub>2</sub> provincial/territorial emissions, data on clinker capacity of cement plants across Canada were used. The source of 1990–2006 data was the *Canadian Minerals Yearbook* (NRCan 1990–2006, and the author of the cement section of the *Canadian Minerals Yearbook* provided the 2007–2012 data<sup>1</sup>). These data were used to derive the percentage of total national clinker capacity attributed to each province/territory. CO<sub>2</sub> emissions on a provincial/territorial level were estimated by multiplying the percentage attributed to each province/territory by the national emission estimate.

1 Panagapko D. 2008–2012. Personal communications (emails from Panagapko D. to A. Shen, Greenhouse Gas Division, on December 12, 2008; to A. Au, Greenhouse Gas Division, on November 13, 2009; to S. Chakrovorty, Greenhouse Gas Division, on June 22, 2010; to Mohamed Abdul, Pollutant Inventories Reporting Division, on September 20, 2011; and to Renata Zaremba, Greenhouse Gas Division, on September 19, 2013)

## 4.2.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty has been developed based on the IPCC (2006) default uncertainty values provided for various parameters in the equation for CO<sub>2</sub> emissions. Also considered was the error associated with the non-response rate of the Statistics Canada survey for clinker production data. The Tier 1 uncertainty associated with the CO<sub>2</sub> estimate for clinker production was  $\pm 14\%$ . The uncertainty value is applicable to all years of the time series. Equation 3.1 of the IPCC Good Practice Guidance (IPCC 2000) has been consistently applied over the time series. The activity data sources are described in Section 4.2.2.

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

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

## 4.2.5. Category-Specific Recalculations

No recalculation occurred for the Cement Production source category.

## 4.2.6. Category-Specific Planned Improvements

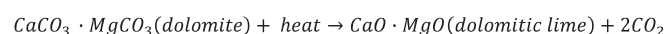
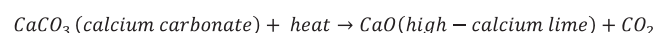
As a planned improvement for the category of Cement Production, a country-specific emission factor (EF) based on Canadian data is under development, which will replace the current IPCC default  $EF_{\text{clinker}}$  in the next submission.

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

### 4.3.1. Source Category Description

The production of lime involves a series of steps, including quarrying, crushing and sizing, and calcining (heat processing) of the raw materials, followed by transfer, storage and handling of the products (IPCC/OECD/IEA 1997). As mentioned in the source category description of cement production (Section 4.2.1), emissions of CO<sub>2</sub> occur at the calcination stage, in which lime is formed via the thermal decomposition of carbonates at

high temperatures in a rotary kiln. There are three main types of lime: high calcium lime, dolomitic lime and hydraulic lime. It is important to distinguish between these in the emission estimation because the first two types have different stoichiometric ratios and the third has a substantially lower CaO content (IPCC 2000). High-calcium quicklime (CaO) and dolomitic quicklime (CaO.MgO) are obtained by calcining quarried calcium carbonate (CaCO<sub>3</sub>) and dolomite (CaCO<sub>3</sub>.MgCO<sub>3</sub>), respectively, as shown in the reactions below:



Both high-calcium and dolomitic limes can be slaked (i.e. treated with water under controlled conditions) and converted to hydrated limes in the form of Ca(OH)<sub>2</sub> and Ca(OH)<sub>2</sub>.Mg(OH)<sub>2</sub>, respectively. Also, according to the IPCC Good Practice Guidance (IPCC 2000), when there is no information on hydraulic lime, as in the case of Canada, the proportion of hydraulic lime should be assumed to be zero.

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

### 4.3.2. Methodological Issues

The methodology used to estimate the CO<sub>2</sub> emissions from lime production is of the Tier 2 type, as country-specific emission factors were applied to national activity data. The country-specific emission factors for high-calcium lime and dolomitic lime were developed based on the information on Canadian lime compositions collected from the Canadian Lime Institute.<sup>2</sup> Data on total national lime production, hydrated lime production and lime plant calcining capacities were obtained from the *Canadian Minerals Yearbook* (NRCAN 1990–2006) or from the author of the lime section of the *Canadian Minerals Yearbook* (for 2007–2012). The national lime production is adjusted for water content of hydrated lime; the “dry” lime amount is then broken down into the two lime types: high calcium and dolomitic. Three types of lime plants are distinguished in Canada in terms of their final products: dolomitic lime only, high-calcium lime only, and both high-calcium and dolomitic lime. As per the IPCC Good Practice Guidance (2000), in the absence of disaggregated data on the breakdown of lime types, the 85/15 default value for high calcium/dolomitic lime was used for lime plants producing both

**Table 4–2 The Split between Dolomitic and High-Calcium Lime Production in Canada (1990–2012)**

Year	% Split	
	Dolomitic Lime	High-Calcium Lime
1990	14%	86%
1991	14%	86%
1992	14%	86%
1993	16%	84%
1994	16%	84%
1995	16%	84%
1996	16%	84%
1997	16%	84%
1998	16%	84%
1999	16%	84%
2000	8%	92%
2001	8%	92%
2002	8%	92%
2003	9%	91%
2004	9%	91%
2005	9%	91%
2006	9%	91%
2007	9%	91%
2008	9%	91%
2009	7%	93%
2010	7%	93%
2011	7%	93%
2012	7%	93%

high-calcium and dolomitic lime. Based on the type of products and calcining capacity of each plant (provided by Natural Resources Canada [NRCAN]) and the IPCC default ratio, total provincial and national splits have been calculated each year and used in the emission calculations. The following table shows the split, derived as explained, used each year to differentiate the dolomitic lime and high-calcium lime production.

The large decline in the share of dolomitic lime during the 1999–2000 time frame is caused by two major changes in Ontario plants in that period. First, Guelph DoLime Limited, which was producing only dolomitic lime up to 1999, stopped operating in 2000. Second, the Lafarge Canada quarry in Dundas switched from producing only dolomitic lime to both high-calcium and dolomitic lime in 1999–2000.<sup>3</sup> The slight decrease in the share of dolomitic lime in 2008–2009 is due to a decrease in calcining capacity at a plant in Ontario that produced only dolomitic lime. This is attributed to a lower market demand as a result of the economic downturn affecting the iron and steel industry (a major consumer of dolomite and dolomitic lime) in that time frame.<sup>4</sup>

<sup>3</sup> Confirmed by D. Panagapko (email to Maryam Edalatmanesh, Greenhouse Gas Division, on November 6, 2013).

<sup>4</sup> Confirmed by W. Kenefick (email to Maryam Edalatmanesh, Greenhouse Gas Division, on October 25, 2013).

<sup>2</sup> Kenefick W. Personal communication (email from Wayne Kenefick to Amy Shen, Greenhouse Gas Division, dated October 7, 2008). Canadian Lime Institute.

For any given year, the most recent lime production numbers provided are preliminary and are subject to revision in subsequent publications. As per the IPCC Good Practice Guidance (IPCC 2000), the total national lime production data were corrected by multiplying by a factor of  $1 - (x * y)$ , where  $x$  is the proportion of hydrated lime production to total lime production and  $y$  is the water content in the hydrated lime. Canadian hydrated lime has a  $y$  value (i.e. water content) of 28.25%.<sup>5</sup> Furthermore, the corrected lime production data were divided into high-calcium lime and dolomitic lime production based on the data on calcining capacities of lime production facilities across Canada. National CO<sub>2</sub> emissions were then calculated by applying the Canadian emission factors (provided in Annex 8) to the estimated yearly national lime production data, by lime type. To estimate CO<sub>2</sub> emissions at the provincial level, the national emissions were allocated by province, according to the calcining capacity of each province.

### 4.3.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has been performed for the Lime Production category. It took into account the uncertainties associated with the production data, emission factors, correction factor for hydrated lime and the percentage split between the two types of lime. The uncertainty associated with the category as a whole was evaluated at  $\pm 8.2\%$ , with lime production data and the percentage split being the largest contributors. The uncertainty value is applicable to all years of the time series.

The same emission factors were consistently applied over the time series. The activity data source is provided in Section 4.3.2.

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

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

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

### 4.3.5. Category-Specific Recalculations

Updates to the activity data for 2011 resulted in the recalculation of emissions for that year.

### 4.3.6. Category-Specific Planned Improvements

There are currently no improvements planned for this category.

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

### 4.4.1. Source Category Description

Limestone is a basic raw material used in a number of industries. In addition to its consumption in the production of cement and lime for resale, limestone is used as a raw material in glass factories. As well, significant amounts of limestone are used as flux stone in iron and steel furnaces and in non-ferrous smelters. Dolomite may also be used in 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. Moreover, limestone is used in other areas such as pulp and paper mills (used for makeup lime), flue gas desulphurization (FGD) in fossil fuel-burning power plants and other high-sulphur fuel industrial combustion, and wastewater treatment.

Since limestone at high temperatures is calcined to lime in these industries, CO<sub>2</sub> is produced by the same reaction described in Section 4.2.1 on cement production.

To avoid double counting, the category of Limestone and Dolomite Use does not include emissions from limestone used for cement and lime production. Emissions from limestone used to produce cement and lime are accounted for under the Cement Production and Lime Production categories, respectively.

### 4.4.2. Methodological Issues

CO<sub>2</sub> emissions from limestone and dolomite were calculated separately using two different emission factors. The emission estimation method used is considered to be of the Tier 2 type.

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

Dolomite consists of both limestone (CaCO<sub>3</sub>) and magnesite (MgCO<sub>3</sub>). A major Canadian producer of dolomite reported the composition of its dolomite to range from 56% to 58% CaCO<sub>3</sub> and

<sup>5</sup> Kenefick W. Personal communication (email from Wayne Kenefick to Amy Shen, Greenhouse Gas Division, dated October 22, 2008). Canadian Lime Institute.



from 38% to 41%  $\text{MgCO}_3$ . An overall emission factor of 468 g  $\text{CO}_2$ /kg of dolomite used was derived based on the emission factors for pure limestone (440 kg  $\text{CO}_2$ /tonne) and magnesite (522 kg  $\text{CO}_2$ /tonne), and the assumption that dolomite is composed of 58%  $\text{CaCO}_3$  and 41%  $\text{MgCO}_3$  (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 1990–2006) or from the author of the stone section of the Yearbook (for 2007–2012). Moreover, data for stone use as flux in iron and steel furnaces for all years were disaggregated into limestone and dolomite based on a 70/30 split (AMEC 2006). National  $\text{CO}_2$  emissions were estimated by multiplying the quantities of limestone and dolomite consumed by the corresponding emission factors.

It is not possible to present a comprehensive breakdown of “other chemical uses” due to the inability to retrieve relevant data from Natural Resources Canada. Therefore, even though it includes a variety of emissive and non-emissive uses of limestone/dolomite, this subcategory was assumed emissive and has been duly accounted for. In order to determine the shares of dolomite and limestone in this subcategory, the breakdown of the applications is needed. The FGD processes in power plants, sugar refineries and wastewater treatment plants consume the major emissive portion of limestone and dolomite in this category (AMEC 2006), as is the case in the United States. The *United States Mineral Yearbook* (Willet 2011) shows a 97% and 3% split between limestone and dolomite, respectively, in “sulfur oxide removal” (FGD) and their “other miscellaneous uses and specified uses not listed” altogether. Based on Canadian information,<sup>6</sup> only limestone is used for FGD processes in Canadian coal power plants. Continuing with reviewing other jurisdictions, the British Geological Survey (2006) states that the demand for dolomite is mainly in refractory materials manufacturing, and also as a flux in iron and steelmaking. The British Geological Survey also notes that the other markets of dolomite are glass making and agricultural use; neither of those is included in Canada’s “other chemical uses” subcategory. Also, as stated in other references, dolomite is usually less appropriate than limestone for most industrial applications, and most dolomite that is mined is merely crushed and sieved to be utilized as aggregate in concrete or asphalt (Bliss et al. 2008). Therefore, the “other chemical uses” subcategory in this NIR has been assumed to be 100% emissive and 100% composed of limestone. Table 4–3 exhibits the split between consumption of high calcium limestone and dolomite in the iron and steel sector (the major user of dolomite).

Provincial emission estimates were obtained by apportioning the national emissions according to the sum of the provincial gross output values for the major sectors in which limestone and

**Table 4–3 High Calcium and Dolomite Consumption Split in the Canadian Iron and Steel Sector**

Year	Total Limestone (kt)	High Calcium (kt)	Dolomite (kt)
1990	656	459	197
1991	491	344	147
1992	562	393	169
1993	198	139	59
1994	190	133	57
1995	307	215	92
1996	297	208	89
1997	332	232	100
1998	392	274	118
1999	392	274	118
2000	680	476	204
2001	477	334	143
2002	258	181	77
2003	282	197	85
2004	209	146	63
2005	216	151	65
2006	200	140	60
2007	99	69	30
2008	318	223	95
2009	260	182	78
2010	313	219	94
2011	501	350	150
2012	458	320	137

dolomite were used (i.e. pulp and paper, iron and steel, non-ferrous metal, glass and chemical sectors).

### 4.4.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has been performed for the category of Limestone and Dolomite Use. It took into account the uncertainties associated with the use of data by use type and emission factors. The uncertainty associated with the category as a whole for the time series ranged from  $\pm 11\%$  to  $\pm 34\%$ , with data on the use of limestone and dolomite in the chemical sector and as flux in iron and steel furnaces being the largest contributors.

The same emission factors were consistently applied over the time series. The activity data source is provided in Section 4.4.2.

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

This key category in the Industrial Processes Sector has undergone Tier 1 QC checks as elaborated in the QA/QC plan (see Annex 6). The checks performed are consistent with the Tier 1

<sup>6</sup> Steve Cook, personal communication (email from Steve Cook to Maryam Edalatmanesh, Greenhouse Gas Division, November 18, 2013).

General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC 2000). No anomalies were observed.

#### 4.4.5. Category-Specific Recalculations

Updates to activity data for 2011 resulted in the recalculation of emissions for that year.

#### 4.4.6. Category-Specific Planned Improvements

Currently there is no improvement planned for this category.

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

#### 4.5.1. Source Category Description

Soda ash (sodium carbonate,  $\text{Na}_2\text{CO}_3$ ) 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 desulphurization, and wastewater treatment (AMEC 2006). Based on the information on soda ash use by sector in AMEC (2006) and the Non-Metallic Mineral Products Industries (Statistics Canada #44-250) publication, it appears that soda ash in Canada is used mainly in the glass products manufacturing industry.  $\text{CO}_2$  is emitted as the soda ash decomposes at high temperatures in a glass manufacturing furnace.

$\text{CO}_2$  is also released during the Solvay process in which soda ash is produced. However, as the  $\text{CO}_2$  is a necessary component in the carbonation stage of the production process, it is usually recovered and recycled for use.

#### 4.5.2. Methodological Issues

Based on the carbon mass balance, there is one mole  $\text{CO}_2$  emitted for each mole of soda ash used. The emission factor (EF) for the mass of  $\text{CO}_2$  emitted is estimated based on the stoichiometry of the chemical process as follows:

Equation 4–2:

$$EF = \frac{1000g/kg \times 44.01g \text{ CO}_2/mol}{105.99g \text{ Na}_2\text{CO}_3/mol} = 415g \text{ CO}_2/kg \text{ Na}_2\text{CO}_3$$

National  $\text{CO}_2$  emissions were calculated by applying the emission factor of 415 g  $\text{CO}_2$ /kg to the national soda ash consumption

data, and by assuming that the soda ash used in Canada has a purity of 100%. Quantities of soda ash used were estimated based on soda ash production, import and export data. Canada stopped its soda ash production in 2001. Production before 2002 was assumed to be equal to the capacity of the only soda ash plant in Canada. Import and export data were obtained from Global Trade Information Services (GTIS 1995–2006, 2007–2009) and Statistics Canada's Canadian International Merchandise Trade Database (Statistics Canada 2010–2012). It should be noted that, since GTIS did not report trade data before 1995, it was assumed that the trade data for the years 1990–1994 were the average of the 1995–2000 trade data. The total quantities of soda ash used were distributed by application type, based on the U.S. pattern of soda ash consumption. According to the U.S. Geological Survey, soda ash can be used in the following sectors: glass, chemical, soaps and detergents, pulp and paper, flue gas desulphurization, and others.

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. Methodological issues for calculating  $\text{CO}_2$  emissions from soda ash use are not addressed specifically in the IPCC Good Practice Guidance (IPCC 2000).

Provincial emission estimates were obtained by apportioning the national emissions according to provincial gross output values of the sectors in which soda ash was used (i.e. glass, pulp and paper and inorganic chemical sectors).

There is currently no soda ash production in Canada. The only soda ash producing plant, which produced soda ash using the Solvay process, closed in 2001. Although most  $\text{CO}_2$  emitted from this facility was recovered for reuse (as mentioned in Section 4.5.1), some  $\text{CO}_2$  may have been released from vents on absorbers, scrubbers and distillation units. However, the amount of net  $\text{CO}_2$  emissions from soda ash production in Canada is assumed to be negligible (AMEC 2006).

#### 4.5.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has been performed for the category of Soda Ash Use. It took into account the uncertainties associated with the production data (for years before 2001), import and export data. The uncertainty associated with the category as a whole for the time series ranged from  $\pm 10.2\%$  to  $\pm 13.8\%$ .

The same emission factor was consistently applied over the time series. The activity data source is provided in Section 4.5.2.



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

The Tier 1 QC checklist was not completed for the category of Soda Ash Use, as it was not a key category. However, several checks that were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC 2000) were done. No anomalies were observed.

#### 4.5.5. Category-Specific Recalculations

Updates to Canadian soda ash imports and exports for 2008–2011 resulted in the recalculation of emissions for those years.

#### 4.5.6. Category-Specific Planned Improvements

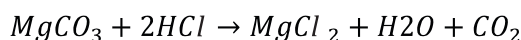
There are currently no improvements planned specifically for estimating CO<sub>2</sub> emissions from soda ash production and use.

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

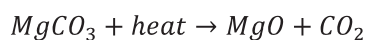
#### 4.6.1. Source Category Description

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

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



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



Three facilities in Canada have reported use of magnesite in their processes at different moments during the 1990–2008 period. One of them was closed in 1991 and another one in 2007.

#### 4.6.2. Methodological Issues

In the 5th *Strategic Diversification Newsletter* (SIDEX 2004), one of the facilities (users of magnesite) reported that the purity fraction of the magnesite it used was 97%, and this magnesite was mined

by the facility's parent company. Therefore, it was assumed that all three facilities used magnesite with a purity fraction of 97%. Taking the purity of magnesite into account, an overall emission factor of 506 g CO<sub>2</sub>/kg was derived and used in estimating CO<sub>2</sub> emissions from magnesite use.

For the plant that had operated between 1990 and 1991, as no magnesite use data were available, the amount used was backcalculated from the amount of magnesium produced. The amount produced was assumed to be half of the 1990 capacity reported in the Minerals and Metals Foundation Paper, 1999 (AMEC 2006).

For the other two plants, the 1990–2005 facility-specific magnesite use data came from British Columbia's Ministry of Energy, Mines and Petroleum Resources (2006) and Environment Canada, Quebec Region, Environmental Protection Branch.<sup>7</sup> For 2006 and 2007, activity data were not available; hence, to estimate the use of magnesite for these two plants, some assumptions were made.

For the plant that was closed in 2007, the ratio of magnesite use to magnesium production was first calculated for each year of the 1990–2005 period.<sup>8</sup> The average of the calculated (magnesite use / magnesium production) ratios was then taken. This average was multiplied by the plant's 2006 and 2007 magnesium production to yield the 2006 and 2007 magnesite use, respectively.

For the other plant (the only one still in operation in 2012), the 2006–2012 magnesite use data came from British Columbia's Ministry of Energy, Mines and Petroleum Resources.<sup>9 10</sup>

Finally, multiplying the consumption data (either actual or estimated, depending on the years) by the above-mentioned emission factor gave the national and provincial emission estimates for this subsector.

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

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

A Tier 1 uncertainty assessment has been performed for the category of Magnesite Use. It took into account the uncertainties associated with the activity data (for years before 2001) and emission factor. The uncertainty associated with the category as a

<sup>7</sup> Banville J. 2006. Personal communication (email from Banville J. to Renata Zarembo, Greenhouse Gas Division, dated March 3, 2006). Environment Canada, Environmental Protection Branch, Quebec Region.

<sup>8</sup> Banville J. 2007. Personal communication (email from Banville J. to Maryse Pagé, Greenhouse Gas Division, dated October 4, 2007). Environment Canada, Environmental Protection Branch, Quebec Region.

<sup>9</sup> Meredith-Jones S. 2012. Personal communication (email from Meredith-Jones S. to Maryam Edalatmanesh, Greenhouse Gas Division, dated October 30, 2013).

<sup>10</sup> B.C. Ministry of Energy, Mines and Petroleum Resources. (Also, see link: <http://www.empr.gov.bc.ca/mwg-internal/de5fs23hu73ds/progress?id=gOirEM321H>).

whole for the time series ranged from  $\pm 4\%$  to  $\pm 8\%$ , with data on the use of magnesite being the largest contributor.

The same emission factor was consistently applied over the time series. The activity data source is provided in Section 4.6.2.

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

The Tier 1 QC checklist was not completed for the category of Magnesite Use, as it was not a key category. However, several checks that were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC 2000) were done. No anomalies were observed.

#### 4.6.5. Category-Specific Recalculations

Updates to activity data for 2011 resulted in the recalculation of emissions for that year.

#### 4.6.6. Category-Specific Planned Improvements

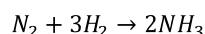
There are currently no improvements planned specifically for estimating CO<sub>2</sub> emissions from magnesite use.

### 4.7. Ammonia Production (CRF Category 2.B.1)

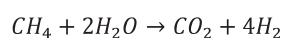
#### 4.7.1. Source Category Description

Ammonia (NH<sub>3</sub>) is gaseous at standard temperature and pressure. It is toxic and corrosive, and has a pungent odour. Commercially used ammonia is referred to as “anhydrous ammonia,” which must be stored under pressure or at low temperature to remain a liquid. It is used mainly in the production of fertilizers, explosives and polymers.

To produce anhydrous ammonia, nitrogen (N<sub>2</sub>) and hydrogen (H<sub>2</sub>) react together in the Haber-Bosch process. The reaction (as shown below) occurs at high temperature in the presence of a catalyst:

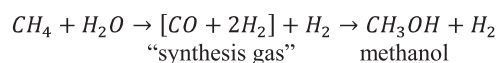


The nitrogen required is obtained from air. The typical source of hydrogen for ammonia plants is the catalytic steam reforming of CH<sub>4</sub> (and minor amounts of other hydrocarbons) contained in natural gas. CO<sub>2</sub> is also generated, as a by-product gas, during the steam methane reforming (SMR) process:



CO<sub>2</sub> is then removed from the process gas by absorption, usually with a solution of monoethanolamine or potassium carbonate (K<sub>2</sub>CO<sub>3</sub>). The primary release of CO<sub>2</sub> occurs during the regeneration (for reuse) of the CO<sub>2</sub>-rich absorption solution by steam stripping or boiling. The stripping gas, which contains CO<sub>2</sub> and other impurities, is then vented to the atmosphere. Alternatively, it can be directed to a neighbouring urea plant, where the CO<sub>2</sub> is recovered and utilized as a feedstock gas. Since the carbon will only be stored for a short period, no account should be taken for intermediate binding of CO<sub>2</sub> in downstream manufacturing processes and products (IPCC/OECD/IEA 1997).

For most Canadian ammonia production facilities, SMR plants are essential units for the operations, because they can generate hydrogen in sufficient quantities to support large-scale ammonia production. However, some plants may use by-product hydrogen to feed into the Haber-Bosch reaction, thereby eliminating release of CO<sub>2</sub> from the ammonia production process. In other words, the hydrogen needed for producing ammonia can also be obtained in ways that do not involve an on-site SMR operation. For instance, at methanol plants, a synthesis gas (or “syn gas”) consisting of one part CO and two parts hydrogen is prepared by using a variation of the SMR reaction. The reaction (as depicted below) produces an excess of hydrogen that is more than what is required for methanol production:



This excess of hydrogen is often purged from the methanol plant and used at neighbouring ammonia plants. Also, ethylene plants generate hydrogen as a co-product from cracking furnaces in making ethylene and other chemicals (e.g. propylene, butadiene). This hydrogen stream can be used at the nearby ammonia plants as well (Cheminfo Services 2006).

#### 4.7.2. Methodological Issues

The Ammonia Production source category only estimates CO<sub>2</sub> emissions resulting from the feedstock use of natural gas, from ammonia-producing facilities that employ the SMR process. The emissions resulting from the energy use of natural gas are accounted for in the Energy Sector. The feedstock use of natural gas is determined by multiplying the annual ammonia production and the ammonia-to-feed fuel conversion factor. The annual ammonia production data for 1990–2004 were gathered in a study conducted by Cheminfo Services (2006); those for 2005–2009 were collected by Environment Canada’s GHG Division through a voluntary data submission process with the fertilizer industry; and those for 2008–2012 were obtained from the data of Statistics Canada’s Industrial Chemical and Synthetic Resin Survey (Statistics Canada 2008–2012). The ammonia-to-feed fuel conversion factors were developed from the data collected

between 2005 and 2009 as part of Environment Canada's GHG Division voluntary data submission. The determined natural gas amount (used as feed) by each facility is then multiplied by the respective province's natural gas carbon content factor and the ratio of carbon to CO<sub>2</sub>, to determine the resulting CO<sub>2</sub> emission. The equations (shown below) are employed to estimate CO<sub>2</sub> emissions: first for each facility using ammonia production statistics, and then for the nation by summing up estimates across all facilities.

$$\begin{aligned} \text{CO}_2 \text{ from facility} &= \text{facility annual ammonia production} \\ &\times \text{facility ammonia-to-feed fuel factor} \\ &\times \text{Natural gas carbon content} \times 44/12 \\ \text{Process CO}_2 \text{ emission} &= \sum_{i=1}^n \text{CO}_2 \text{ from facility}_i \end{aligned}$$

The employed estimation technique is similar to the Tier 1 methodology found in the IPCC (2006) Guidelines, with the added improvement of using facility-level (vice national-level) ammonia production values.

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 natural gas amounts allocated by Statistics Canada for hydrogen production are systematically removed from the non-energy use of natural gas reported under the Other and Undifferentiated Production subsector. To ensure the confidentiality of facility-specific data, only national level CO<sub>2</sub> emissions from ammonia production are reported.

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

### 4.7.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has been performed for the category of Ammonia Production. It took into account the uncertainties associated with the national and facility-specific ammonia production data, ammonia-to-feed fuel factor, and the carbon content of natural gas. The uncertainty associated with the category as a whole was evaluated at  $\pm 4\%$  and is applicable to all years of the time series.

### 4.7.4. Category-Specific QA/QC and Verification

Ammonia production was a key category that has undergone Tier 1 QC checks as developed in the QA/QC plan (see Annex 6). The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC 2000). No issues of importance were detected from the Tier 1 QC process.

### 4.7.5. Category-Specific Recalculations

Updates to activity data for 2009 and 2010 resulted in the recalculation of emissions for these years.

### 4.7.6. Category-Specific Planned Improvements

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

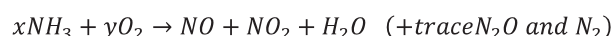
## 4.8. Nitric Acid Production (CRF Category 2.B.2)

### 4.8.1. Source Category Description

Nitric acid (HNO<sub>3</sub>) is a highly corrosive and toxic inorganic compound that is used mainly as a raw material in the manufacture of synthetic commercial fertilizer. It can also be used in the production of adipic acid and explosives, in metal etching, and in the processing of ferrous metals (IPCC/OECD/IEA 1997).

The production of nitric acid is a two-stage process involving catalytic oxidation of ammonia (NH<sub>3</sub>) to nitrogen dioxide (NO<sub>2</sub>) and then subsequent formation of nitric acid by addition of water (H<sub>2</sub>O) to NO<sub>2</sub>. As shown below, the first stage is the reaction of ammonia gas with oxygen (O<sub>2</sub>) (from air) at high temperatures:

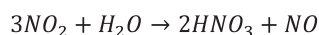
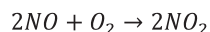
Stage 1 (Reaction):



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), NO<sub>2</sub>, and water vapour, with trace amounts of N<sub>2</sub>O and nitrogen (N<sub>2</sub>) (Cheminfo Services 2006). An excess of oxygen may drive the NO to be converted to NO<sub>2</sub>. Nitrogen oxidation steps under reducing conditions are sources of N<sub>2</sub>O. More specifically, NO, an intermediate in the production of nitric acid, can readily decompose to N<sub>2</sub>O and NO<sub>2</sub> at high pressures and at a temperature range of 30–50°C (IPCC/OECD/IEA 1997).

During the second stage of the production process, water is added at the top of an absorber tower to hydrate the NO<sub>2</sub> and to scrub the gases. As shown below, hydration of cooled NO<sub>2</sub> with water forms a 60–65% solution of nitric acid, leaving the bottom of the tower. To complete the conversion of NO to NO<sub>2</sub>, excess air (oxygen) is introduced at the bottom tray of the absorber tower. The NO<sub>2</sub> formed is also absorbed.

## Stage 2 (Absorption):



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 N<sub>2</sub>O, NO, NO<sub>2</sub>, and other nitrogen oxides (NO<sub>x</sub>). The concentration of N<sub>2</sub>O in the exhaust gases depends on the type of plant and its emission controls (Cheminfo Services 2006).

There exist two basic types of nitric acid production technology: high pressure and dual pressure. Both technologies can be found in Canadian nitric acid plants. The high-pressure design, commonly used in North America, applies a single pressure throughout the reaction and absorption stages. High-pressure process plants can function with a non-selective catalytic reduction (NSCR) or selective catalytic reduction (SCR) system. The emission abatement systems are classified as “non-selective” when natural gas is used as reductant to reduce all NO<sub>x</sub>. In contrast, a “selective” catalytic reduction (SCR) uses ammonia, which selectively reacts only with NO and NO<sub>2</sub> gases, and not with N<sub>2</sub>O (hence a higher N<sub>2</sub>O emission factor). Most Canadian plants operate with a high-pressure design and have NSCR abatement technology installed (Cheminfo Services 2006).

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 the absorption stage. To increase the efficiency of the absorption stage, dual-pressure plants can “extend” the absorption tower by adding more trays. This is referred to in Table 4–4 as “absorption Type 1.” Alternatively, plants can have in place a second tower to allow “double absorption.” This is referred to in Table 4–4 as “absorption Type 2” (Cheminfo Services 2006).

## 4.8.2. Methodological Issues

Data supporting the estimation of N<sub>2</sub>O emissions from nitric acid production for 1990–2004 were gathered through a study conducted for Environment Canada (Cheminfo Services 2006), those for 2005–2009 were obtained by the Department’s GHG Division from industry through a voluntary data submission process, and those for 2008–2012 were obtained from the micro data of Statistics Canada’s Industrial Chemical and Synthetic Resin Survey. The collected data were used in the country-specific hybrid emission estimation methodology, which could be described as three categories:

1. Plant-specific production data and plant-specific emission factors (i.e. Tier 3 type method) when these were available from companies (estimates made from 2008 onwards, for few of the larger HNO<sub>3</sub> producers, fall under this category); 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 (only one plant).

In all three scenarios, the equation applied was as follows:

### Equation 4–3:

$$N_2O \text{ Emission (t)} = \text{Production} - \text{Based Emission Factor (kg N}_2\text{O/t HNO}_3\text{)} \times \text{Production (kt HNO}_3\text{)}$$

To estimate emissions in scenarios 2 and 3, the types of production process and emission control technology of a plant were first determined. The reported or estimated production was then multiplied by the corresponding emission factor. The industry-typical emission factors used had been obtained from the Canadian Fertilizer Institute in the early 1990s. These were confirmed again, as being applicable, by industry representatives during the recent (Cheminfo Services 2006) study. In addition, another industry typical emission factor is provided in the IPCC Good Practice Guidance (IPCC 2000) and was confirmed through the

**Table 4–4 Nitric Acid Industry-Typical Emission Factors**

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

1. Collis G. 1992. Personal communication (letter from Collis G. to Director, Greenhouse Gas Division, dated March 23, 1992). Canadian Fertilizer Institute.

same study (Cheminfo Services 2006). Table 4–4 summarizes the industry-typical emission factors by process and control types.

For plants that did not have production data available, production was estimated based on the overall capacity utilization of other known plants. The estimated production was multiplied by what was believed to be the most appropriate industry-typical emission factor to estimate emissions coming from plants for which no or few data were available. For 1990–2004, the raw activity data and plant-specific emission factors (when available) used to develop emission estimates were collected through the 2006 Cheminfo study (Cheminfo Services 2006). For 2005–2011, the data used were reported by companies to Environment Canada's Greenhouse Gas Division on a voluntary basis in conjunction with the micro data from Statistics Canada's Industrial Chemical and Synthetic Resin Survey.

Finally, the estimates of N<sub>2</sub>O emissions (by plant) were summed either all together to yield the national emission estimate or by province to give the provincial emission estimate.

### 4.8.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has been performed for the category of Nitric Acid Production. It took into account the uncertainties associated with the national and facility-specific nitric acid production data and the emission factors. The uncertainty associated with the category as a whole was evaluated at ±10%, with the emission factors being the largest contributors. The uncertainty value is applicable to all years of the time series.

The same emission factors were consistently applied over the time series. The activity data source is provided in Section 4.8.2.

### 4.8.4. Category-Specific QA/QC and Verification

Nitric acid production was a category that has undergone Tier 1 QC checks as developed in the QA/QC plan (see Annex 6). The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC 2000). No issues of importance were detected from the Tier 1 QC process.

### 4.8.5. Category-Specific Recalculations

There have been no recalculations for the category Nitric Acid Production.

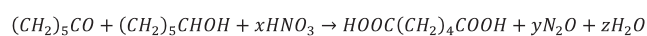
### 4.8.6. Category-Specific Planned Improvements

There are currently no improvements planned for this category.

## 4.9. Adipic Acid Production (CRF Category 2.B.3)

### 4.9.1. Source Category Description

Adipic acid (HOOC(CH<sub>2</sub>)<sub>4</sub>COOH) is a dicarboxylic acid used primarily in the production of Nylon 66, resins and plasticizers. It is produced via a two-stage oxidation process. The first step involves the oxidation of cyclohexane to form a cyclohexanone ((CH<sub>2</sub>)<sub>5</sub>CO) / cyclohexanol ((CH<sub>2</sub>)<sub>5</sub>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<sub>2</sub>O is generated as a by product in the second oxidation reaction, as shown below:



Emissions of N<sub>2</sub>O from this manufacturing process depend on both the amount generated and the amount that can potentially be destroyed in any subsequent abatement process. When emission abatement equipment is not installed at a facility, the N<sub>2</sub>O generated is generally vented to the atmosphere in a waste gas stream. Adipic acid production also results in emissions of non methane volatile organic compounds (NMVOC), CO, and NO<sub>x</sub> (IPCC/OECD/IEA 1997). Emissions of these indirect GHGs are not covered in this section. Annex 10 provides details on indirect GHG emissions.

Invista Canada, formerly Dupont Canada, located in Maitland, Ontario, had operated the only adipic acid production facility in Canada. It had significantly reduced its N<sub>2</sub>O emissions since 1997, when a catalytic N<sub>2</sub>O abatement system with an emission monitoring system was started up. The plant has, however, become indefinitely idled as of spring 2009, and hence both N<sub>2</sub>O and CO<sub>2</sub> are indicated as "NO" in the CRF.

### 4.9.2. Methodological Issues

Emission estimates for adipic acid production have always been provided by Invista. For the 1990–1996 period, 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<sub>2</sub>O/kg adipic acid.

As mentioned above, in 1997, Invista installed an N<sub>2</sub>O abatement system with a continuous emission monitor on the controlled



off-gas stream at the abatement system outlet. Since then, the emission estimation method applied by Invista has become the following:

#### Equation 4–4:

$$\begin{aligned} \text{Total Emissions (t)} \\ &= \text{N}_2\text{O Emissions (t) with abator} \\ &+ \text{N}_2\text{O Emissions (t) without abator} \end{aligned}$$

The first term accounts for emissions that occur when the abator is operating, and the second for emissions that occur when the abator is not operating because of maintenance or technical problems.

N<sub>2</sub>O Emissions with Abator:

#### Equation 4–5:

$$\begin{aligned} \text{N}_2\text{O Emissions (t) with Abator} \\ &= (\text{Production(t)}) \times \left( \frac{0.3t \text{ N}_2\text{O}}{t \text{ adipic acid}} \right) \\ &\times (1 - \text{Destruction Efficiency}) \times (\text{Abatement Utilization Ratio}) \end{aligned}$$

where:

Destruction Efficiency is determined based on the difference between the amount of N<sub>2</sub>O entering the abatement unit and that leaving the unit. It is a monthly average calculated using values recorded by analyzers, which are located at the inlet and outlet of the abator. The targeted instantaneous destruction efficiency is 97%.

Abatement Utilization Ratio is the number of hours during which N<sub>2</sub>O goes through the abator divided by the total operating time.

N<sub>2</sub>O Emissions without Abator:

#### Equation 4–6:

$$\begin{aligned} \text{N}_2\text{O Emissions (t) without Abator} \\ &= (\text{Production(t)}) \times \left( \frac{0.3t \text{ N}_2\text{O}}{t \text{ adipic acid}} \right) \\ &\times (1 - \text{Abatement Utilization Ratio}) \end{aligned}$$

It is important to note that the in-line continuous emission monitor has never been used to directly monitor net N<sub>2</sub>O emissions. This is because the analyzer is limited to accurately measuring relatively low concentrations of N<sub>2</sub>O only when the reactor is online and abating N<sub>2</sub>O gas. The analyzer is not capable of measuring the full range of N<sub>2</sub>O concentrations that could potentially exist in the stack. The N<sub>2</sub>O concentration can vary from a low nominal level of 0.3% when the stream leaves the abator to a high nominal level of 35–39% N<sub>2</sub>O in the unabated stream. When the abatement reactor is bypassed, there is no N<sub>2</sub>O abatement

occurring, and the analyzer will not record N<sub>2</sub>O stack emissions (Cheminfo Services 2006).

The calculation techniques used to estimate emissions for the periods 1990–1997 and 1998–2009 are basically the same as the default methods presented in the IPCC Good Practice Guidance (IPCC 2000) and the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997).

### 4.9.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has been performed for the category of Adipic Acid Production. It took into account the uncertainties associated with the adipic acid production data, the emission factor, the destruction efficiency and the abatement utilization factor. The uncertainty associated with the category as a whole was evaluated at ±11%, with the emission factor being the largest contributor. The uncertainty value is applicable to all years of the time series.

As explained in Section 4.9.2, two methods were applied in the time series: one for the period of time during which the plant operated *with* the emission abatement system and another for the period of time during which the plant operated *without* the emission abatement system.

### 4.9.4. Category-Specific QA/QC and Verification

Adipic Acid Production was a key category that has undergone Tier 1 QC checks as developed in the QA/QC plan (see Annex 6). The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC 2000). No issues of importance were detected from the Tier 1 QC process.

### 4.9.5. Category-Specific Recalculations

2010 and 2011 estimates are changed to zero, as confirmed with Invista.

### 4.9.6. Category-Specific Planned Improvements

There are currently no improvements planned specifically for this category.



## 4.10. Petrochemical Production – Carbide Production (CRF Category 2.B.4)

### 4.10.1. Source Category Description

Two kinds of carbide are considered in this section: silicon carbide (SiC) and calcium carbide (CaC<sub>2</sub>). SiC and CaC<sub>2</sub> are no longer produced in Canada, since the last of two SiC plants closed in 2002 and the only CaC<sub>2</sub> plant closed in 1992. Silicon carbide (SiC) is widely used as an abrasive and is also increasingly being used in electronics. It is produced by reducing silicon quartz (SiO<sub>2</sub>) using carbon as a reducing agent (reductant). Petroleum coke is usually used as a carbon source because of its high carbon content.

Calcium carbide (CaC<sub>2</sub>) is produced mainly as a precursor for the production of acetylene (C<sub>2</sub>H<sub>2</sub>). It is produced by reducing lime (CaO) using carbon as the reductant. Petroleum coke is commonly used as the carbon source. Approximately 67% of the carbon from the petroleum coke used is bound in the product.

The use of coke as a reductant has the potential to release small amounts of methane (CH<sub>4</sub>) gas in the high operating temperatures (1600–2500°C) of the electric resistance reduction furnaces used for carbide production. CH<sub>4</sub> can be released directly from the decomposition of coke (which still contains trace levels of methane absorbed in its structure) and can also be generated from the thermal decomposition (in the presence of hydrogen) of trace volatile compounds still contained in coke. Most CH<sub>4</sub> is likely to be released in the initial stages of carbide reduction when the coke is at high temperatures, particularly from the top layers of coke exposed directly to the atmosphere. When coke is manufactured from coal in coke ovens, most of the volatile matter in the coal is driven off as raw coke oven gas and recovered as liquids and fuel gas. Once the tars, liquid oils and ammonia are removed from raw coke oven gas, the remaining coke oven gas typically contains 60% hydrogen and 25% methane. This is an indication that: i) CH<sub>4</sub> is present in volatile organic matter contained in coal; and ii) significant hydrogen is present to contribute to methane formation from the thermal decomposition of heavier volatile compounds. The coking process removes the vast majority of volatile matter from coal, but the large solid masses of coke still contain trace amounts of volatile matter (Cheminfo Services 2010).

### 4.10.2. Methodological Issues

To estimate CH<sub>4</sub> emissions from carbide production at national and provincial/territorial levels, a Tier 1 method (i.e. with the application of Tier 1 IPCC default emission factors) was applied. Since no survey of active facilities was possible, research was

conducted by Cheminfo Services, on behalf of the GHG Division, to identify and establish the production capacities of the three carbide production facilities. A time series of process CH<sub>4</sub> emissions was estimated for the two silicon carbide facilities from 1990 to 2001, and one calcium carbide facility from 1990 to 1991, based on assumed capacity utilization and CH<sub>4</sub> emission factors. Only (SiC and CaC<sub>2</sub>) production capacity data during the time series were identified during the study. As such, the following equation was used to estimate total CH<sub>4</sub> emissions from carbide production:

#### Equation 4–7:

Total CH<sub>4</sub> emissions (t) =

$$\sum_y [(SiC\ capacity \times capacity\ utilization \times Emission\ Factor_{SiC}) + (CaC_2\ capacity \times capacity\ Emission\ Factor_{CaC_2})]$$

where:

y	=	companies
SiC or CaC <sub>2</sub> capacity	=	data collected from the industry, kt
Capacity utilization	=	based on Cheminfo Services' knowledge of the industry, %
Emission Factor <sub>SiC</sub>	=	11.6 kg CH <sub>4</sub> /t SiC (IPCC 2006)
Emission Factor <sub>CaC<sub>2</sub></sub>	=	4.8 kg CH <sub>4</sub> /t CaC <sub>2</sub> , derived from CH <sub>4</sub> emission factor for silicon carbide and the ratio of IPCC default Calcium Carbide CO <sub>2</sub> emission factor to IPCC default Silicon Carbide CO <sub>2</sub> emission factor (i.e. 11.6 (kg CH <sub>4</sub> /t SiC) * (1.09 tCO <sub>2</sub> /tCaC <sub>2</sub> / 2.62 tCO <sub>2</sub> /tSiC))

### 4.10.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has been performed for the category of Carbide Production (Cheminfo Services 2010), following the 2006 IPCC Guidelines - Propagation of error method for combining uncertainties. The Guidelines state that this method is applicable when the contributing variable uncertainties are below ±30%.

Since there is no longer carbide production in Canada, a set of default uncertainties (based on Cheminfo Services' knowledge of the industry) was used in the Cheminfo Services' Tier 1 uncertainty assessment. Regarding the carbide capacity data, an uncertainty of ±5% was applied when survey uncertainties were not provided. The uncertainty associated with the category as a whole for the time series ranged from ±0% to ±27% (Cheminfo Services 2010).

#### 4.10.4. Category-Specific QA/QC and Verification

The category of Carbide Production 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 Procedure 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

No recalculations were performed for this source category.

#### 4.10.6. Category-Specific Planned Improvements

There are currently no improvements planned specifically for this category, as Canadian carbide production stopped in 2002.

### 4.11. Petrochemical Production – Carbon Black Production (CRF Category 2.B.5.1)

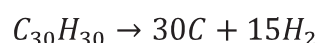
#### 4.11.1. Source Category Description

Carbon black is a solid product consisting of fine particles of carbon with small amounts of inorganic impurities. Carbon black is used in rubber compounding (e.g. tires), pigments, printing inks, and in many other additives. There are four facilities that have produced carbon black in Canada since 1990. Three facilities are currently operating.

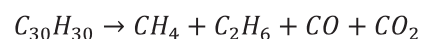
Carbon black is made from the pyrolysis or thermal cracking of various hydrocarbon feedstocks. Cracking reactions, which separate the hydrogen from the carbon, occur between 1200°C and 1600°C. There are two main carbon black processes used in Canada: 1) pyrolysis of liquid hydrocarbon feedstock; and 2) pyrolysis of natural gas feedstock, from which CH<sub>4</sub> can be emitted.

During pyrolysis of liquid hydrocarbon feedstock in the furnace black process, hydrogen atoms are separated from the carbon to yield the carbon black product particles (Cheminfo Services 2010).

Furnace Black Pyrolysis:



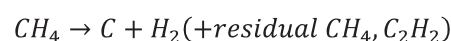
Side Reactions:



The vent gas from the furnace black process contains different products as hydrogen, methane, acetylene, carbon monoxide, carbon dioxide, sulphur compounds, carbon-sulphur compounds and water (IPCC 2006). A portion of the tail gas is burned for energy recovery for the process.

During pyrolysis of natural feedstock, purchased natural gas is injected into one of a pair of reactors that is preheated to a temperature of 1300°C, and decomposed to solid carbon particles, hydrogen and residual hydrocarbons.

Thermal Black Pyrolysis:



The mixture of solid carbon particles and hydrogen-rich by-product gas is cooled with water injection and the carbon is separated from the hydrogen by-product gas in a baghouse. The hydrogen by-product gas is used as fuel to preheat the second reactor of the unit up to the reaction temperature of 1300°C. As the process of producing the carbon black consumes energy, the first reactor cools to a point where the reaction becomes inefficient. This is when the production mode is switched, reactors trade roles and the second one, now hot, becomes the producing reactor while the first one is reheated (Cheminfo Services 2010).

#### 4.11.2. Methodological Issues

To estimate CH<sub>4</sub> emissions from carbon black production, a consulting study has been performed by Cheminfo Services (2010). A survey was sent to the three operating carbon black facilities requesting 1990–2009 data on carbon black capacity and production, and on process GHG emissions. All three facilities reported 1990–2009 data for carbon black capacity, but not all facilities reported process CH<sub>4</sub> emissions. From the received responses, two facility-specific Tier 3 emission factors were derived as weighted averages of the reported 2007–2009 data.

An EF of 1.3 kg/t for CH<sub>4</sub> and an EF of 0.032 kg/t for N<sub>2</sub>O were derived as weighted averages of the reported 2007–2009 data. One sector-wide process CH<sub>4</sub> emission factor was also calculated as a weighted average based on the same set of data reported by the two facilities (1.29 kg CH<sub>4</sub>/t product).

The sector-wide EF value is lower than the IPCC default value of 11 kg CH<sub>4</sub>/t product. It is suspected that the IPCC default EF, which is based on only one study, has included CH<sub>4</sub> from the combustion of fuel as well. The combination of process and combustion emissions, and assigning the combined EF as a process EF, is sometimes present in IPCC documents. The Canadian EF only includes the CH<sub>4</sub> that originates directly from the feed.

The above EF was applied when facility-specific emission factors could not be used. When process emissions were reported directly by a facility, the reported data were used in the inventory. When reported emission data were not available, estimates were calculated based on the unreported carbon black production (allocated to each non-reporting facility by its share of capacity) and the Tier 3 sector average emission factor (either facility-specific or sector-wide). The unreported carbon black production was calculated from total national carbon black production less the sum of all reported carbon black production. National carbon black production data were taken from Camford's CPI Product Profile for 1990–1995 and company-reported production for 2007–2009. Interpolations were made for years in between (i.e. 1996–2006) based on a sector average growth rate for 1990–1994. The total sector production for each year of 1996–2006 was calculated by multiplying the sector average growth rate by the total sector production of the preceding year (starting from 1995). Facility-specific production data for 2010 and 2011 were obtained from the micro data of Statistics Canada's Industrial Chemical and Synthetic Resin Survey.

### 4.11.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has been performed by Cheminfo Services for the category of Carbon Black Production following the 2006 IPCC Guidelines - Propagation of error method for combining uncertainties. The Guidelines state that this method is applicable when the contributing variable uncertainties are below  $\pm 30\%$ .

In the Cheminfo Services (2010) study, respondents were asked to provide their best estimate of the uncertainty of each variable reported. Very few survey respondents provided uncertainty estimates for their data. As such, a set of default uncertainties (based on Cheminfo Services' knowledge of the industry) was used in the analysis.

The following default uncertainties were applied when survey uncertainties were not provided:

- capacity data:  $\pm 5\%$ ;
- reported production data:  $\pm 2\%$ ;
- capacity share fractions used for allocation of national production data:  $\pm 10\%$ ;
- reported process CH<sub>4</sub> emissions:  $\pm 20\%$ ; and
- reported process N<sub>2</sub>O emissions:  $\pm 30\%$ .

The Tier 1 uncertainty associated with the CH<sub>4</sub> emission estimates ranged from  $\pm 9\%$  to  $\pm 11\%$ .

### 4.11.4. Category-Specific QA/QC and Verification

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

### 4.11.5. Category-Specific Recalculations

There was no recalculation of CH<sub>4</sub> emissions from Carbon Black Production.

### 4.11.6. Category-Specific Planned Improvements

There is no improvement planned specifically for this category.

## 4.12. Petrochemical Production – Ethylene Production (CRF Category 2.B.5.2)

### 4.12.1. Source Category Description

There have been five ethylene facilities operated by four companies in Canada since 1990, but one of these, Pétromont Varennes, was shut down in 2008. Ethylene is the key building block in the basic organic chemicals industry since it is a precursor to several high-volume industrial chemicals and resins. The most important ethylene derivatives include polyethylene, ethylene oxide/ethylene glycol, ethylene dichloride/vinyl chloride, styrene, linear alpha olefins, vinyl acetates and alcohols.

Ethylene is produced by thermally cracking natural gas liquids (NGLs) such as ethane (C<sub>2</sub>H<sub>6</sub>), propane (C<sub>3</sub>H<sub>8</sub>), or butanes (C<sub>4</sub>H<sub>10</sub>) or petroleum-based liquid feedstocks, such as naphthas or gas oils. The production of ethylene is a two-stage process in which the first stage is to thermally crack the bonds in the raw materials and the second stage is to separate the products of the thermal cracking reaction through distillation. The cracking reaction occurs in specially designed high-temperature, tubular furnaces. Each of the feedstocks requires different amounts of energy per unit of ethylene produced (or amount of feedstock used). Therefore, each feedstock has different GHG emission intensities.

Process CH<sub>4</sub> emissions from ethylene production come mainly from combustion of process off-gases, flaring of process materials containing methane, and fugitive emissions of volatile hydrocarbon streams that contain methane. Process N<sub>2</sub>O emissions

come mainly from the combustion of fuel gas derived from the feedstock (Cheminfo Services 2010).

#### 4.12.2. Methodological Issues

A consulting study has been performed by Cheminfo Services to estimate CH<sub>4</sub> and N<sub>2</sub>O emissions from ethylene production. Cheminfo Services, on behalf of the GHG Division, sent a questionnaire to the four companies that have had ethylene production operation in Canada, requesting 1990–2009 data on ethylene capacity and production, and on process CH<sub>4</sub> and N<sub>2</sub>O emissions. Responses were received from two companies for three of the four operating plants, representing 90% of Canadian ethylene capacity in 2009. Sector-wide CH<sub>4</sub> and N<sub>2</sub>O GHG emission factors were estimated as weighted averages based on the reported process emissions and production data from three facilities for 2007–2009. When possible, for 1990–2009, weighted average facility-specific process GHG emission factors were developed and applied to estimated facility ethylene production, because there was a significant difference between the calculated emission factors for each facility. Facility-specific ethylene production data for 2008–2011 were obtained from the micro data of Statistics Canada's Industrial Chemical and Synthetic Resin Survey.

When process GHGs were reported directly by a facility, the reported data were used in the inventory. When reported emission data were not available, emissions were estimated based on the unreported ethylene production (allocated to each non-reporting facility by share of capacity) and the corresponding emission factors. The unreported production was calculated by subtracting the sum of reported production by the total national production. National ethylene production data were taken from Camford's CPI Product Profile for 1990–1995 and company-reported production for 2007–2009. For 2008–2011, production data were obtained from the micro data of Statistics Canada's Industrial Chemical and Synthetic Resin Survey. It should be noted that the emission factors applied should be kept confidential, as they were derived from business-sensitive data.

##### Equation 4–8:

$$CH_4 \text{ or } N_2O \text{ emissions } (t) = \sum_y \left( \text{allocated unreported production} \times \text{Emission Factor } CH_4/N_2O \right) + \text{Reported emissions}$$

where:

y	=	companies
allocated unreported production (kt)	=	remaining unreported ethylene production x ethylene capacity of a specific company/total unreported ethylene capacity
remaining unreported ethylene production (kt)	=	total production – total reported sample

#### 4.12.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has been performed by Cheminfo Services (2010) for the category of Ethylene Production following the 2006 IPCC Guidelines - Propagation of error method for combining uncertainties. The Guidelines state that this method is applicable when the contributing variable uncertainties are below ±30%.

In the Cheminfo Services (2010) study, respondents were asked to provide their best estimate of the uncertainty of each variable reported. Very few survey respondents provided any uncertainty estimates for their data. As such, a set of default uncertainties (based on Cheminfo Services' knowledge of the industry) was used in the analysis. The following default uncertainties were applied when survey uncertainties were not provided:

- capacity data: ±5%;
- reported production data: ±2%;
- capacity share fractions used for allocation of national production data: ±10%;
- reported process CH<sub>4</sub> emissions: ±20%; and
- reported process N<sub>2</sub>O emissions: ±30%.

The uncertainties for the time series ranged from ±8% to ±12% for CH<sub>4</sub> emission estimates and from ±12% to ±21% for N<sub>2</sub>O emission estimates.

#### 4.12.4. Category-Specific QA/QC and Verification

This category 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 procedure outlined in the IPCC Good Practice Guidance (IPCC 2000).

#### 4.12.5. Category-Specific Recalculations

There were no recalculation of CH<sub>4</sub> and N<sub>2</sub>O emissions from the category of Ethylene Production.

#### 4.12.6. Category-Specific Planned Improvements

There is no improvement planned specifically for this category.

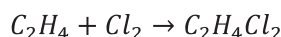
## 4.13. Petrochemical Production – Ethylene Dichloride (EDC) Production (CRF Category 2.B.5.3)

### 4.13.1. Source Category Description

Ethylene dichloride (EDC,  $C_2H_4Cl_2$ ) is the old name for 1,2-dichloroethane, a large-volume chlorinated hydrocarbon intermediate derived from ethylene that is used in the manufacture of vinyl chloride monomer (VCM,  $C_2H_3Cl$ ,  $CH_2=CHCl$ ), the precursor of polyvinyl chloride resins. Three EDC production facilities had operated in Canada during different periods of time between 1990 and 2009, but they are all closed now.

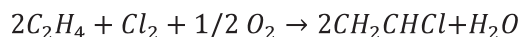
Two processes had been used for the production of EDC in Canada. One is the direct chlorination of ethylene in a vapour or liquid phase reaction using ethylene dibromide as catalyst.

Direct Chlorination:

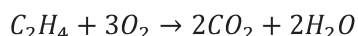


The second process is called oxychlorination. In this process the ethylene feed is chlorinated in the liquid phase. EDC vapours produced are condensed, degassed and a portion is withdrawn from the unit. The balance of the feed is passed onto the vinyl chloride section of a production plant where hydrochloric acid and oxygen in a fluidized catalyst bed reactor produce crude EDC. The crude EDC from both streams is combined and cracked in a reactor to form vinyl chloride with the by-product hydrochloric acid being recycled back into the oxychlorination unit.

Balanced EDC/VCM Reaction:



Feedstock Oxidation Reaction:



Regarding emissions, the process off-gas that contains the chlorinated hydrocarbons is combusted within the plant prior to release, so any carbon in this off-gas is converted to  $CO_2$ . The process  $CO_2$  emissions from EDC production come from the side reaction of feedstock oxidation. The process  $CH_4$  emissions would most likely come from light hydrocarbons from distillation operations that are not captured by a flare gas recovery system. These emissions are vented to the atmosphere (Cheminfo Services 2010).

### 4.13.2. Methodological Issues

Cheminfo Services Inc has been retained by the GHG Division to estimate 1990–2009  $CH_4$  emissions from EDC production. Since all EDC plants are currently closed and no survey response could be provided for historical data, a Tier 1 calculation approach (i.e. annual production \* Tier 1 IPCC default emission factor) was taken to develop 1990–2006 process  $CH_4$  emission estimates. The annual EDC production data come from the Canadian  $C_2+$  Petrochemical Report, which was obtained via the Cheminfo Services (2010) study. According to the study, the last plant closed in 2006. The default process  $CH_4$  emission factor for EDC as applied comes from Table 2-10 of the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997), under the name “dichloroethylene.” The Canadian  $C_2+$  Petrochemical Report was prepared and published by an independent consultant who supplies market intelligence to the Canadian chemical industry. It provides balances of ethylene and its derivatives using total production, dispositions and Canadian trade statistics. For the purpose of emission estimation at the provincial level, the annual EDC production was allocated by Cheminfo Services to each plant based on the capacity share (calculated from production capacity data reported by companies during the Cheminfo Services [2010] study).

### 4.13.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has been performed by Cheminfo Services (2010) for the category of EDC production following the 2006 IPCC Guidelines - Propagation of error method for combining uncertainties. The Guidelines state that this method is applicable when the contributing variable uncertainties are below  $\pm 30\%$ .

As no plant-specific uncertainty estimates could be collected by Cheminfo Services (2010), a set of default uncertainties (based on Cheminfo Services' knowledge of the industry) was used in the analysis. The uncertainty associated with the category as a whole for the time series is estimated at  $\pm 21\%$  (Cheminfo Services 2010).

### 4.13.4. Category-Specific QA/QC and Verification

This category 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 procedure outlined in the IPCC Good Practice Guidance (IPCC 2000). No issues of importance were detected from the Tier 1 QC process.



### 4.13.5. Category-Specific Recalculations

There was no recalculation of CH<sub>4</sub> emissions from EDC Production.

### 4.13.6. Category-Specific Planned Improvements

There are currently no improvements specifically planned for this category, as there is no more EDC production in Canada.

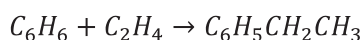
## 4.14. Petrochemical Production – Styrene Production (CRF Category 2.B.5.4)

### 4.14.1. Source Category Description

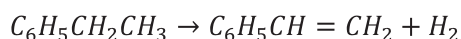
Styrene is a cyclic hydrocarbon liquid that is the precursor monomer for polystyrene and several copolymers, such as ABS resins, styrene-butadiene (SBR) rubber, styrene-butadiene latex and styreneacrylonitrile resin (SAN). These materials are used in rubber, plastic, insulation, fibreglass, pipes, automobile and boat parts, food containers, and carpet backing. There have been three styrene facilities that have produced styrene in Canada since 1990, but one facility closed in 1998.

Styrene is an organic chemical intermediate that is manufactured in a two-stage process in the same industrial facility. The first stage involves the alkylation of benzene (C<sub>6</sub>H<sub>6</sub>) with ethylene (C<sub>2</sub>H<sub>4</sub>) to produce ethylbenzene, a chemical intermediate. The second stage is the catalytic dehydrogenation of the ethylbenzene to produce styrene, as shown below:

Ethylbenzene Reaction:



Styrene Reaction:



The styrene is produced in multiple sequential dehydrogenation reactors operated under vacuum to increase conversion and selectivity towards styrene. Steam is used in the dehydrogenation reaction to provide the reaction energy, dilute the reactants and remove any coke build-up from the catalyst. The by-products from the reaction include process off-gas, benzene (recycled) and toluene, steam condensate, and tars, which must be separated from the product stream.

Process CO<sub>2</sub> emissions can come from the combustion of the process off-gas (fuel gas) as fuel or from flaring of over-pressured

process streams. Methane (CH<sub>4</sub>) could be present along with the process reactants ethylene and benzene and would be emitted if there was any venting of these process or recycle streams. Fugitive emissions from these streams would also contain methane (Cheminfo Services 2010).

### 4.14.2. Methodological Issues

Cheminfo Services Inc has been retained by the GHG Division to estimate 1990–2009 CH<sub>4</sub> emissions from styrene production. A survey was sent to the two operating facilities, but neither of them provided a response with respect to emission estimates. Since survey responses were not available, a Tier 1 calculation approach (i.e. annual production \* Tier 1 IPCC default emission factor) was taken to develop process CH<sub>4</sub> emissions estimates. Annual styrene production data come from the Canadian C<sub>2</sub>+ Petrochemical Report, which was obtained via the Cheminfo (2010) study. This report was prepared and published by an independent consultant to supply market intelligence to the Canadian Chemical Industry. It provides balances of ethylene and its derivatives using total production, dispositions and Canadian trade statistics. For the purpose of emission estimation at provincial level, the annual styrene production was allocated by Cheminfo Services to each plant based on capacity share (calculated from production capacity data reported by companies during the Cheminfo [2010] study). The default process CH<sub>4</sub> emission factor for styrene (4 kg/t) comes from Table 2-10 of the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997). As the 2006 IPCC Guidelines do not cover styrene production under its petrochemicals section, a more recent emission factor could not be found. No 2011 styrene production data could be found; as a result it was assumed that the 2010 production data (in turn assumed equal to 2009 data) would be applicable to 2011. The 2011 CH<sub>4</sub> estimates were calculated accordingly.

### 4.14.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has been performed by Cheminfo Services (2010) for the category of Styrene Production, following the 2006 IPCC Guidelines - Propagation of error method for combining uncertainties. The Guidelines state that this method is applicable when the contributing variable uncertainties are below ±30%.

As no plant-specific uncertainty estimates could be collected by Cheminfo Services, a set of default uncertainties (based on Cheminfo Services' knowledge of the industry) was used in the analysis. The Tier 1 uncertainty associated with the category as a whole for the time series was estimated at ±30% (Cheminfo Services 2010).



#### 4.14.4. Category-Specific QA/QC and Verification

The category of Styrene Production 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.

#### 4.14.5. Category-Specific Recalculations

There was no recalculation of CH<sub>4</sub> emissions from Styrene Production.

#### 4.14.6. Category-Specific Planned Improvements

Facility-specific data will be included in the micro data of Statistics Canada's Industrial Chemical and Synthetic Resin Survey and will be available starting 2012.

### 4.15. Petrochemical Production – Methanol Production (CRF Category 2.B.5.5)

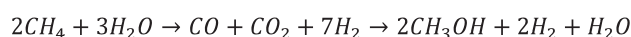
#### 4.15.1. Source Category Description

Methanol (CH<sub>3</sub>OH) is a flammable, highly volatile liquid alcohol at room temperature. It is primarily used as a chemical building block to manufacture formaldehyde, the key precursor of industrial thermoset resins and diverse products. There were three methanol production facilities operating in Canada during the 1990–2006 period. One was closed as of 2001, one as of 2005 and the other as of 2006. Methanol was last produced in Canada in 2006.

Methanol is produced by one of these two processes: 1) conventional reforming; and 2) combined (conventional and partial oxidation).

In conventional reforming, methanol is produced in a two-stage process by reacting a synthesis gas (syn gas) containing hydrogen (H<sub>2</sub>), carbon monoxide (CO), and carbon dioxide (CO<sub>2</sub>) over a copper/zinc oxide/alumina catalyst, then separating the product from water and other by-products.

Overall:

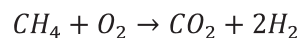


In combined reforming, a catalytic partial oxidation step is added to the conventional reforming process to achieve a better ratio of CO to H<sub>2</sub> in the synthesis gas. The catalytic partial oxidation reaction produces less hydrogen than the conventional reforming reactions step and eliminates by-product hydrogen.

Partial Oxidation Reaction:



Feedstock Oxidation Side Reaction:



Process GHG (CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O) emissions come mainly from process off-gas that is separated from methanol and combusted on-site for energy recovery. The process off-gas contains excess CO, CO<sub>2</sub> and light hydrocarbons. Additional CH<sub>4</sub> emissions can occur in venting of process gases containing CH<sub>4</sub> from the methanol distillation train and methanol storage tanks and fugitive emissions from equipment leaks (Cheminfo Services 2010).

#### 4.15.2. Methodological Issues

To estimate CH<sub>4</sub> emissions from methanol production, a consulting study has been performed by Cheminfo Services. A survey was sent to former employees of the methanol facilities who still have access to the facilities' records, requesting 1990–2009 data on methanol production capacity, production and process GHG emissions. A sector-wide process emission factor was developed as a weight-average using the reported data on CH<sub>4</sub> emissions. It was calculated by dividing the process CH<sub>4</sub> emission data set by the production data set obtained for the period 2004–2006. The sector-wide process emission factor was used, when necessary, to estimate CH<sub>4</sub> emissions for the 1990–2006 period (there has been no methanol production after 2006).

When CH<sub>4</sub> emission data directly reported by former employees for methanol production facilities were available, they were used in this submission. In the case where there were no reported data, emissions were estimated by multiplying the "unreported" methanol production by the sector-average emission factor. The "unreported" methanol production of a facility was calculated by multiplying its production capacity share (%) by the difference between total national methanol production and the sum of all reported methanol production. National methanol production values were taken from Camford's CPI Product Profile for 1990–1999 and estimated based on assumed capacity utilization for 2000–2006 (Cheminfo Services 2010).

### 4.15.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has been performed by Cheminfo Services (2010) for the category of Methanol Production, following the 2006 IPCC Guidelines - Propagation of error method for combining uncertainties. The Guidelines state that this method is applicable when the contributing variable uncertainties are below  $\pm 30\%$ .

As no plant-specific uncertainty estimates could be collected by Cheminfo Services (Cheminfo Services 2010), a set of default uncertainties (based on Cheminfo Services' knowledge of the industry) was used in the analysis:

- national methanol production: 5%;
- reported methanol production: 2%;
- facility methanol capacities: 5%;
- facility fraction of total sector unreported production: 10%;
- reported process CH<sub>4</sub> emissions: 20%;
- reported process N<sub>2</sub>O emissions: 30%.

The uncertainty associated with the category as a whole for the time series ranged from 0% (for the years with no production) to  $\pm 20\%$  for CH<sub>4</sub> emissions and ranged from 0% (for the years with no production) to  $\pm 30\%$  for N<sub>2</sub>O emissions.

### 4.15.4. Category-Specific QA/QC and Verification

This category 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.

### 4.15.5. Category-Specific Recalculations

There was no recalculation of CH<sub>4</sub> emissions from Methanol Production.

### 4.15.6. Category-Specific Planned Improvements

There are currently no improvements planned for this category, as there is no more methanol production in Canada.

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

### 4.16.1. 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 other carbonaceous material as the reducing agent. In most iron furnaces, the process is aided by the use of limestone fluxes (IPCC 2000). The majority of world's steel is produced in electric arc furnaces (EAFs) or in basic oxygen furnaces (BOFs). Low-carbon steel is produced in BOFs, where a mixture of pig iron and iron scrap is remelted in the presence of pure oxygen, which oxidizes the dissolved carbon to CO or CO<sub>2</sub>. Carbon and alloy steels are produced in EAFs, refractory-lined pots that utilize electric heating through graphite electrodes, which are consumed in the process (IPCC/OECD/IEA 1997). Steel plants that produce pig iron from iron ore using the blast furnace process, and from steel using the BOF process, are referred to as integrated plants. There are four integrated iron and steel mills in Canada, all located in Ontario. However, one Canadian integrated plant also uses the EAF process to produce a portion of its steel. Annex 3.2 provides additional details on the technologies employed in Canada to produce iron and steel, and on their emission profiles.

Total production of crude steel in Canada from 1980 to 2008 ranged from 11 871 000 to 16 595 000 tonnes. As a result of economic downturn, crude steel production in Canada decreased to 9 286 000 tonnes in 2009. The industry rebounded to 13 009 000 tonnes of production in 2010, and has maintained comparable levels of production in 2011 and 2012. In the production of pig iron, carbon plays the dual role of fuel and reductant. Emissions from the combustion of fuels such as coke oven gas are not reported in this category, but rather under the appropriate industrial category in the Energy Sector. CO<sub>2</sub> emissions from carbon oxidation, which occurs when iron ore is reduced to pig iron, are included in this category. Also accounted for in this category are emissions during steel production, which occur to a much lesser extent. These come from the oxidation of carbon in crude iron and electrode consumption. Additional CO<sub>2</sub> given off by limestone flux in the blast furnace is covered under the Limestone and Dolomite Use category (Section 4.4.1).

### 4.16.2. Methodological Issues

A new set of emission parameters—reflecting Canada-specific circumstances, e.g., emission factor for coke, carbon content of pig iron, and carbon content of pig iron entering the steelmaking process—has been used to develop the 1990–2012 estimates. The methodology used for the Iron and Steel Production category follows the IPCC Tier 2, as described in the IPCC Good Practice

Guidance (IPCC 2000), with the addition of a term to account for emissions arising from the ladle metallurgy stage—further processing, in electric arc furnaces, of steel output from basic oxygen furnaces. The fate of carbon is tracked throughout the production process, with emissions from iron production and steel production being calculated separately. The following equation was used to estimate emissions from pig iron production:

#### Equation 4–9:

$$\begin{aligned} \text{Emissions}_{\text{pig iron}} &= (\text{Emission Factor}_{\text{reductant}} \times \text{mass of reductant}) \\ &+ (\text{mass of carbon in the ore} - \text{mass of carbon in pig iron}) \times \left(\frac{44}{12}\right) \end{aligned}$$

where:

Emissions <sub>pig iron</sub>	=	emissions from pig iron production, kt
Emission factor <sub>reductant</sub>	=	year-specific emission factors (t CO <sub>2</sub> / t coke used) obtained from Cheminfo Services (2010) study
mass of reductant	=	mass of metallurgical coke used in the process, kt
mass of carbon in the ore	=	zero; according to IPCC (2000), 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 <sub>2</sub> to the molecular weight of carbon

According to a Cheminfo report (Cheminfo Services 2010), “The vast majority of process CO<sub>2</sub> emissions originate from carbon contributed by the metallurgical coke used to reduce iron ore to pig iron (also known as ‘hot metal’; 95% iron, 5% carbon) in the blast furnaces of ironmaking operations at integrated iron and steel mills. A small portion of the process CO<sub>2</sub> emissions originate from secondary carbon reductants added to the blast furnace, which include natural gas, fuel oil, or pulverized coal. Carbon can also be added to the steelmaking operation in the form of natural gas injection, but this is a negligible source of carbon compared to that added to the blast furnace.” For the purposes of this category’s emission estimates, it was assumed that the reductant used in Canadian industry is 100% metallurgical coke. The carbon content in ore is almost zero (IPCC 2000). The GHG emissions associated with the use of reductants other than metallurgical coke are estimated under the appropriate industrial category in the Energy Sector. This is due to the fact that data on use of these reductants, provided by Statistics Canada, are shown under the energy consumption lines of the RESD.

The data source for the use of metallurgical coke was the *Report on Energy Supply-Demand in Canada* (RESD – Statistics Canada #57-003). Data on total pig iron production in Canada came from Statistics Canada (for 1990–2003: #41-001; for 2004–2012:

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#41-019). The emission factors for coke use are year specific; they come from the Cheminfo Services (2010) study. During the study, Cheminfo Services surveyed four integrated steel mills in Canada for their coke consumption and their emission estimates for the years 1990–2009. The emission factors were calculated as ratios of CO<sub>2</sub> emissions to coke consumption. No Canada-specific coke carbon content is available for 2012; as a result, the 2009 coke carbon content is used for 2012. (Being a calcined product, coke is not expected to vary greatly with regard to its carbon content.) The coke carbon contents were then applied to the set of coke use data provided by Statistics Canada. With respect to the carbon content in pig iron, the Canadian Steel Producers Association (CSPA)<sup>11</sup> provided an industry-average content value, which has to be kept confidential.

Emissions from steel production were estimated using the following equation:

#### Equation 4–10:

$$\begin{aligned} &(\text{Carbon \% in iron charged to steel furnaces} \times \text{charge}) \\ &+ (\text{Carbon \% in scrap steel charge to steel furnace} \times \text{scrap steel}) \\ &- (\text{Carbon \% in steel prodBOF} \times \text{steel production in BOF}) \\ &- (\text{Carbon \% in steel prodEAF} \times \text{steel production in EAF}) \times \frac{44}{12} \\ &+ (\text{Emission Factor for EAF} \times \text{steel produced from EAF}) \\ &+ (\text{Emission Factor for BOF Ladle Metallurgy} \\ &\quad \times \text{Steel produced from BOF}) \end{aligned}$$

According to Equation 4–10, part of the amount of CO<sub>2</sub> emitted from the steel production process is estimated based on the difference between the amount of carbon in the iron and in scrap steel used to make steel and the amount of carbon in the steel produced in BOFs and EAFs. It should be noted that the amount of pig iron fed to steel furnaces (used in Equation 4–10) is not equal to the amount of total pig iron production (used in Equation 4–9). As part of the steel production process, there are also emissions coming from consumption of electrodes in EAFs and in the secondary ladle metallurgy. These are accounted for in the last two terms of the equation.

Data on the total pig iron charged to steel furnaces, on total steel production, and on the amount of steel produced in EAFs were obtained from Statistics Canada (for 1990–2003: #41-001, for 2004–2011: #41-019). The values of the carbon contents and emission factors mentioned in Equation 4–10 were all provided by the CSPA.<sup>12</sup>

The total emission from the category of Iron and Steel Production is the sum of Equation 4–9 and Equation 4–10 above.

Data on metallurgical coke use at provincial/territorial levels from

11 Chan K. 2009. Personal communication (email from Chan K. to Maryse Pagé, Greenhouse Gas Division, dated July 21, 2009). Canadian Steel Producers Association.

12 Chan K. 2009. Personal communication (email from Chan K. to Maryse Pagé, Greenhouse Gas Division dated July 21, 2009). Canadian Steel Producers Association.

the RESD (Statistics Canada #57-003) were used to derive the percentage of total reductant consumption attributed to each province and territory. CO<sub>2</sub> emissions at provincial/territorial levels were then estimated by multiplying the percentage derived by the national emission estimate.

It should be noted that RESD data (Statistics Canada #57-003) published for any given year are preliminary and subject to revision in subsequent publications.

The method described above does not account for additional CO<sub>2</sub> given off by the use of limestone as flux in blast furnaces, since the limestone consumption-related emissions are included in the subsector of Limestone and Dolomite Use.

The use of petroleum coke in EAF electrodes is reported by Statistics Canada with all other non energy uses of petroleum coke. To avoid double counting, the CO<sub>2</sub> emissions from the consumption of electrodes in the steel production process in EAFs are therefore subtracted from the total non-energy emissions. It is assumed that there are no imported electrodes used for steel production in EAFs in Canada. If electrodes are imported, the portion of CO<sub>2</sub> generated by the imported electrodes will need to be subtracted from the emissions from electrode consumption before being subtracted from the total non-energy emissions.

#### 4.16.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has been performed for the category of Iron and Steel Production. It took into account the uncertainties associated with all the parameters used in the equations stated above, such as data on metallurgical coke use, emission factor of coke, data on pig iron and steel production and carbon contents of pig iron and steel. The assessment also considered the error associated with the non-response rate of the Statistics Canada surveys. The uncertainty associated with the category as a whole for the time series is around  $\pm 5.4\%$ .

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

#### 4.16.4. 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.

#### 4.16.5. Category-Specific Recalculations

There was no recalculation of CO<sub>2</sub> emissions from Iron and Steel Production.

#### 4.16.6. Category-Specific Planned Improvements

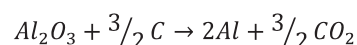
As noted earlier, a smaller part of the process CO<sub>2</sub> emissions associated with iron and steel production originates from the use of reductants other than metallurgical coke. A fraction of coal, shown in the RESD's non-energy line, is used in iron and steel making and is currently reported under the Other and Undifferentiated Production subsector. It is planned to allocate the aforementioned emission to Iron and Steel Production. The allocation of CO<sub>2</sub> emissions associated with the use of other reductants (i.e. other than coke and coal) to the Energy Sector will not change. This is due to the format of the RESD data, which portray fuel use in an aggregated manner.

### 4.17. Aluminium Production (CRF Category 2.C.3)

#### 4.17.1. Source Category Description

Primary aluminium is produced in two steps. In the first stage, bauxite ore is ground, purified and calcined to produce alumina (Al<sub>2</sub>O<sub>3</sub>). The latter is then, in the second stage, electrically reduced to aluminium 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 cryolite (Na<sub>3</sub>AlF<sub>6</sub>) bath. Passing a current through the resistance of the cell causes the heating effect, which maintains the contents in a liquid state. The aluminium forms at the cathode and gathers on the bottom of the pot.

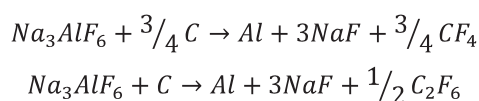
As the anode is consumed, CO<sub>2</sub> is formed in the following reaction, provided that enough alumina is present at the anode surface:



Although most of the CO<sub>2</sub> forms from the electrolysis reaction of the carbon anode with alumina as shown above, other sources, namely the baking of prebaked anodes, can contribute to some (usually less than 10%) of the total non-energy-related CO<sub>2</sub> emissions. Emissions from the combustion of fossil fuels used in the production of baked anodes are covered in the Energy Sector, but emissions arising specifically from the combustion of volatile matter released during the baking operation and from the

combustion of baking furnace packing material are accounted for under the Industrial Processes Sector (IPCC 2006).

In addition to CO<sub>2</sub> emissions, primary aluminium smelting is a major source of carbon tetrafluoride (CF<sub>4</sub>) and carbon hexafluoride (C<sub>2</sub>F<sub>6</sub>). When alumina levels are too low, these PFCs are formed during an occurrence known as the “anode effect” or “anode event.” In theory, when an anode event occurs, the cell resistance increases very suddenly (within a 50th of a second). As a result, the voltage rises and the temperature goes up, forcing the molten fluorine salts in the cell to chemically combine with the carbon anode (Laval University 1994). During the anode event, the competing reactions shown below occur to produce CF<sub>4</sub> and C<sub>2</sub>F<sub>6</sub>.



PFC emissions can be controlled by computerized alumina feeders. Sensors measure the alumina concentration and automatically feed more to the pot when levels become low. In this way, anode events can be controlled. The computers can be programmed to detect the onset of anode events as well, providing additional warning for the system to take counteractive measures. “Point” feeders, as opposed to “centre break” types, also tend to reduce emissions (Øye and Huglen 1990).

Besides CO<sub>2</sub>, CF<sub>4</sub> and C<sub>2</sub>F<sub>6</sub>, a small amount of SF<sub>6</sub> is also emitted from its use as cover gas at some aluminium plants that produce high magnesium-aluminium alloys.<sup>13</sup>

Aluminium plants are characterized by the type of anode technology employed. In general, older plants with Söderberg technology have higher emissions than newer plants, which usually use pre-baked anodes. The trend in the Canadian aluminium industry has been towards modernizing facilities, since production efficiency has improved. In some cases, this has meant taking old lines out of production as new ones are installed to meet increasing demand.

Finally, even though aluminium production consumes extremely large quantities of electrical energy, currently estimated to be 13.5 kWh/kg of aluminium (AIA 1993), GHG emissions associated with its electricity consumption are not necessarily high in a Canadian context. All of Canada’s primary aluminium smelters are located in Quebec and British Columbia, where almost all (95%) of the electricity generated is produced by hydraulic generators; these are believed to emit a negligible amount of GHGs compared with conventional fossil fuel-based electricity generators.

## 4.17.2. Methodological Issues

As of data year 2011, the Canadian aluminium companies, operating in Quebec and British Columbia, have developed and reported their GHG emissions under the methodological protocols and reporting rules of the Western Climate Initiative.<sup>14</sup> These rules have been translated into those provinces’ reporting regulations on GHGs. Under a memorandum of understanding signed in 2012 between Environment Canada and the Aluminum Association of Canada (AAC), Environment Canada receives the same data sets as those provided by AAC member companies in the provinces. The process-related estimates of CO<sub>2</sub>, PFCs and SF<sub>6</sub> are Tier 3 plant-level estimates using plant-specific parameters.<sup>15</sup>

Up to the NIR 2012 (1990–2010 data years), the process-related emission estimates for aluminium production were directly obtained from companies via the AAC. In addition to the smelter-specific emission estimates, information on the methodologies used by the aluminium producers to calculate CO<sub>2</sub>, PFC and SF<sub>6</sub> emissions and plant-specific production data for the time series were obtained from companies via 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. For example, Alcan, the largest Canadian producer of aluminium (now Rio Tinto Aluminium), reported that its 2008 emissions were developed using plant-specific parameters (Alcan 2010). For earlier years, and where plant-specific data were not available, companies have used Quebec’s Framework Agreement (see below) or International Aluminium Institute (IAI) EFs as the default (Alcan 2010). The methodology used for both PFC and CO<sub>2</sub> emissions is based on the Framework Agreement on voluntary greenhouse gas reductions in Quebec entered into between the Government of Quebec and the AAC (AAC 2002a).

Calculating CO<sub>2</sub> emissions:

Typically, the equations used by smelters to estimate CO<sub>2</sub> emissions from the reaction of the carbon anode with alumina (AAC 2002b) are as follows:

<sup>13</sup> Chaput P. 2007. Personal communication (email from Chaput P. to A. Au, Greenhouse Gas Division, dated Oct 12, 2007). Aluminum Association of Canada

<sup>14</sup> <http://www.westernclimateinitiative.org/>

<sup>15</sup> <http://www.env.gov.bc.ca/cas/mitigation/ggrcta/reporting-regulation/amendedquantificationmethods.html>



**Equation 4–11: for pre-baked anode consumption**

$$CO_2 Emissions (t) = \left[ \frac{CC \times MP \times (100 - \%S_a - \%Ash_a - \%Imp_a)}{100} \right] \times \left[ \frac{44}{12} \right]$$

where:

CC	=	baked anode consumption per tonne of aluminium (t C/t Al)
MP	=	total aluminium production (t)
S <sub>a</sub>	=	sulphur content in baked anodes (wt%)
Ash <sub>a</sub>	=	ash content in baked anodes (wt%)
Imp <sub>a</sub>	=	fluorine and other impurities (wt%)*
44/12	=	ratio of the molecular weight of CO <sub>2</sub> to the molecular weight of carbon

\*The weight percentage of fluorine and other impurities may not be a parameter considered by all the smelters.

**Equation 4–12: for Søderberg anode consumption**

$$CO_2 Emissions (t) = \left[ (PC \times MP) - \left( \frac{BSM \times MP}{1000} \right) - \left( \frac{\%BC}{100} \times PC \times MP \times \frac{\%S_p + \%Ash_p + \%H_2}{100} \right) - \left( \frac{(100 - \%BC)}{100} \times PC \times MP \times \frac{(\%S_c + \%Ash_c)}{100} \right) \right] \times \left[ \frac{44}{12} \right]$$

where:

PC	=	paste consumption (t paste/t Al)
MP	=	total aluminium production (t)
BSM	=	emissions of benzene-soluble matter (kg/t Al)
BC	=	average binder content in paste (wt%)
S <sub>p</sub>	=	sulphur content in pitch (wt%)
Ash <sub>p</sub>	=	ash content in pitch (wt%)
H <sub>2</sub>	=	hydrogen content in pitch (wt%)
S <sub>c</sub>	=	sulphur content in calcinated coke (wt%)
Ash <sub>c</sub>	=	ash content in calcinated coke (wt%)
44/12	=	ratio of the molecular weight of CO <sub>2</sub> to the molecular weight of carbon

The use of the above equations with actual plant-specific data is considered a Tier 3 type methodology. A Tier 2 type technique involves applying some measured data in combination with industry-typical values to these equations. Shown in Table 4–5 are Tier 2 industry-typical values that can be applied by facilities.

When no process data other than aluminium production are available, emission factors (EFs) for a Tier 1 method (as shown below) can be used. These factors depart slightly from the IPCC default factors, because the IPCC Tier 1 default factors reflect 1990 emissions and would produce considerable errors if applied

**Table 4–5 Default Tier 2 Parameter Values for the Estimation of CO<sub>2</sub> Emissions from Anode Consumption**

Parameter	Industry-Typical Value	Source
<b>For Pre-baked Anode Consumption:</b>		
sulphur content in baked anodes (wt %) - S <sub>a</sub>	2%	IAI 2006
ash content in baked anodes (wt %) - Ash <sub>a</sub>	0.4%	IAI 2006
fluorine and other impurities (wt %) - Imp <sub>a</sub>	0.4%	AAC 2002b
<b>For Søderberg Anode Consumption:</b>		
emissions of benzene-soluble matter (kg/t Al) - BSM	For HSS: 4.0 kg/ t Al For VSS: 0.5 kg/ t Al *	IAI 2006
average binder content in paste (wt %) - BC	Dry Paste: 24% Wet Paste: 27%	IAI 2006
sulphur content in pitch (wt %) - S <sub>p</sub>	0.6 %	IAI 2006
ash content in pitch (wt %) - Ash <sub>p</sub>	0.2%	IAI 2006
hydrogen content in pitch (wt %) - H <sub>2</sub>	3.3%	IAI 2006
sulphur content in calcinated coke (wt %) - S <sub>c</sub>	1.9%	IAI 2006
ash content in calcinated coke (wt %) - Ash <sub>c</sub>	0.2%	IAI 2006

\* HSS = Horizontal Stud Søderberg; VSS = Vertical Stud Søderberg.



to current production. The factors below reflect the considerable progress that has been made over the period from 1990 to 2001 (AAC 2002b; IAI 2006):

Søderberg: EF = 1.7 t CO<sub>2</sub>/t Al produced; and

Pre-baked: EF = 1.6 t CO<sub>2</sub>/t Al produced.

To calculate CO<sub>2</sub> emissions resulting from anode baking (i.e. pitch volatiles combustion and combustion of baking furnace packing material), the following equations are used (AAC 2002a):

#### Equation 4-13: for Pitch Volatiles Combustion

$$CO_2 \text{ Emissions (t)} = (GAW - BAP - HW - RT) \times \left(\frac{44}{12}\right)$$

where:

GAW	=	green anode weight (t)
BAP	=	baked anode production (t)
HW	=	weight of hydrogen from pitch (t) = %H <sub>2</sub> / 100 * PC / 100 * GAW
H <sub>2</sub>	=	hydrogen content in pitch (wt%)
PC	=	average pitch content in green anode (wt%)
RT	=	waste tar collected (t)
44/12	=	ratio of the molecular weight of CO <sub>2</sub> to the molecular weight of carbon

#### Equation 4-14: For Packing Coke

$$CO_2 \text{ Emissions(t)} = \left[ PCC \times BAP \times \frac{(100 S_{pc} Ash_{pc})}{100} \right] \times \left[ \frac{44}{12} \right]$$

where:

PCC	=	packing coke consumed (t coke/ t of baked anode)
BAP	=	baked anode production (t)
S <sub>pc</sub>	=	sulphur content in packing coke (wt%)
Ash <sub>pc</sub>	=	ash content in packing coke (wt%)
44/12	=	ratio of the molecular weight of CO <sub>2</sub> to the molecular weight of carbon

As in the case of anode consumption, the use of Equation 4-13 and Equation 4-14 with actual plant-specific data is considered a Tier 3 type methodology. A Tier 2 type technique involves applying some measured data in combination with industry-typical values to these equations. Shown in Table 4-6 are Tier 2 industry-typical values that can be applied by facilities to estimate CO<sub>2</sub> emissions arising from anode baking.

According to a communication with representatives of the Canadian aluminium industry,<sup>16</sup> one of the three aluminium companies has only relied on plantspecific values to develop its process CO<sub>2</sub> estimates (Tier 3), whereas the other two companies have used default parameter values shown in Table 4-5 and Table 4-6 above for estimates of some earlier years of the time series.

It should be noted that the use of petroleum coke in anodes for the production of aluminium was also reported by Statistics Canada with all other non-energy uses of petroleum coke. To avoid double counting, the CO<sub>2</sub> emissions from the consumption of anodes in the aluminium smelting process were therefore subtracted from the total non-energy emissions associated with the consumption of petroleum coke.

#### Calculating PFC Emissions:

CF<sub>4</sub> and C<sub>2</sub>F<sub>6</sub> emitted during anode effects can be calculated by smelters using either the Slope Method or the Pechiney Overvoltage Method, depending on the smelter technology (AAC 2002a):

16 Chaput P. and Dubois C. 2007. Personal communications (emails from Chaput P. and Dubois C. to A. Au, Greenhouse Gas Division, dated October 12, 2007). Aluminium Association of Canada and Alcoa.

Table 4-6 Default Tier 2 Parameter Values for the Estimation of CO<sub>2</sub> Emissions from Anode Baking

Parameter	Industry-Typical Value	Source
<b>For Pitch Volatiles Combustion:</b>		
hydrogen content in pitch (wt%) - %H <sub>2</sub>	0.5%	IAI 2006
waste tar collected (t) - RT	For Riedhammer furnaces only; all others are insignificant	IAI 2006
<b>For Packing Coke:</b>		
packing coke consumed (t coke/ t of baked anode) - PCC	0.015 t/ t	IAI 2006
sulphur content in packing coke (wt%) - S <sub>pc</sub>	2%	IAI 2006
ash content in packing coke (wt%) - Ash <sub>pc</sub>	2.5%	IAI 2006

**Equation 4–15: for Slope Method**

$$PFC \text{ Emissions (tCO}_2\text{eq)} = \frac{\text{slope} \times AEF \times AED \times MP \times GWP}{1000}$$

where:

Slope	=	slope (for CF <sub>4</sub> or C <sub>2</sub> F <sub>6</sub> ) of the emission relationship ([kg PFC/t Al]/[AE-minutes/cell-day])
AEF	=	number of anode effects per pot per day (AE/cell-day)
AED	=	anode effect duration (minutes)
MP	=	total aluminium production (t)
GWP	=	global warming potential for CF <sub>4</sub> or C <sub>2</sub> F <sub>6</sub>

**Equation 4–16: for Pechiney Overvoltage Method**

$$PFC \text{ Emissions (tCO}_2\text{eq)} = \frac{\text{overvoltage coefficient} \times AEO/CE \times GWP \times MP}{1000}$$

where:

overvoltage coefficient	=	([kg PFC/t Al]/[mV/cell-day])
AEO	=	anode effect overvoltage (mV/cell-day)
CE	=	aluminium production process current efficiency expressed as a fraction
GWP	=	global warming potential for CF <sub>4</sub> or C <sub>2</sub> F <sub>6</sub>
MP	=	total aluminium production (t)

The use of the above equations with actual process data to estimate PFC emissions is considered a Tier 3 type

methodology. The estimation technique is considered as Tier 2 type when the default coefficients shown in Table 4–7 (IAI 2006) are used together with smelter-specific operating parameters. In a Tier 2 approach, one would first estimate emissions of CF<sub>4</sub> using the slope or overvoltage coefficients as per Equation 4–15 and Equation 4–16. Emissions of C<sub>2</sub>F<sub>6</sub> are then calculated by multiplying the CF<sub>4</sub> estimates by the CF<sub>4</sub>/C<sub>2</sub>F<sub>6</sub> weight fraction.

If only production statistics are available (i.e. no data on anode effect frequency, anode effect duration, or anode effect overvoltage), the Tier 1 emission factors shown in Table 4–8 can be used by smelters (IAI 2006).

Based on recent information provided by the Canadian aluminium industry,<sup>17</sup> one of the three aluminium companies has solely relied on plant-specific values to develop its process PFC estimates (Tier 3), whereas the other two companies have used default parameter values shown in Table 4–7 and Table 4–8 above for estimates of some earlier years of the time series.

Calculating SF<sub>6</sub> emissions:

According to the methodology documents supplied by the AAC, SF<sub>6</sub> emissions are equal to consumption in the aluminium industry. This method is consistent with the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997).

17 Chaput P. 2007. Personal communication (email from Chaput P. to A. Au, Greenhouse Gas Division, dated October 12, 2007). Aluminum Association of Canada.

**Table 4–7 Tier 2 Default Slope and Overvoltage Coefficients (IAI 2006)**

Type of Cell	Slope Coefficients for CF <sub>4</sub> ([kg PFC/t Al]/ [AE-minutes/cell-day])	Overvoltage Coefficients for CF <sub>4</sub> ([kg PFC/t Al]/ [mV/cell-day])	Weight Fraction CF <sub>4</sub> / C <sub>2</sub> F <sub>6</sub>
Centre Worked Pre-baked	0.143	1.16	0.121
Side Worked Pre-baked	0.272	3.65	0.252
Vertical Stud Søderberg	0.092	NA	0.053
Horizontal Stud Søderberg	0.099	NA	0.085

Note: NA = not applicable

**Table 4–8 PFC Emission Factors**

Type of Cell	Emission Factors (kg PFC/t Al)	
	CF <sub>4</sub>	C <sub>2</sub> F <sub>6</sub>
Centre Worked Pre-Baked	0.4	0.04
Side Worked Pre-Baked	1.6	0.4
Vertical Stud Søderberg	0.8	0.04
Horizontal Stud Søderberg	0.4	0.03

### 4.17.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has been performed for the category of Aluminium Production (i.e. for the CO<sub>2</sub>, PFC and SF<sub>6</sub> emission estimates). It took into account the uncertainties associated with all the parameters used in the equations stated above. The Aluminium Sector Greenhouse Gas Protocol published by the IAI (IAI 2006) was the main source of the parameters' uncertainty values. The uncertainties for the CO<sub>2</sub>, PFC and SF<sub>6</sub> estimates were ±7%, ±9% and ±3%, respectively. For the CO<sub>2</sub> and PFC estimates, it should be noted that the uncertainty assessment was done for only one year of the time series (2006 for CO<sub>2</sub> and 2007 for PFC). It is expected that emission estimates of more recent years would have similar uncertainties, while older estimates would have slightly higher uncertainties. For the SF<sub>6</sub> estimate, it was assumed that the uncertainty would be the same as that of the Magnesium Casting category, since the method used to develop SF<sub>6</sub> emission estimates is the same for both Aluminium Production and Magnesium Casting.

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 of the 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.

### 4.17.4. Category-Specific QA/QC and Verification

CO<sub>2</sub> and PFC emissions from Aluminium Production were key categories that have undergone Tier 1 QC checks as elaborated in the QA/QC plan (see Annex 6). The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC 2000). No issues of importance were detected from the Tier 1 QC process.

### 4.17.5. Category-Specific Recalculations

The Kitimat plant's production value for 2011 was updated.

### 4.17.6. Category-Specific Planned Improvements

There are currently no improvements planned for this category.

## 4.18. Magnesium Metal Production and Casting (CRF Categories 2.C.5.1 & 2.C.4.2)

### 4.18.1. Source Category Description

SF<sub>6</sub> is emitted during magnesium production and casting, where it is used as a cover gas to prevent oxidation of the molten metals. Although emitted in relatively small quantities, SF<sub>6</sub> is an extremely potent GHG, with a 100-year GWP of 23 900. SF<sub>6</sub> is not manufactured in Canada. All SF<sub>6</sub> is imported.

During the 1990–2006 period, there were two major magnesium producers in Canada: Norsk Hydro and Timminco Metals. Norsk Hydro was shut down in the first quarter of 2007. Another magnesium producer, Métallurgie Magnola, existed between 2000 and 2003, but was shut down in April 2003. Between 1990 and 2004, Norsk Hydro had invested in research and development projects having as objectives finding a substitute for SF<sub>6</sub> and eventually eliminating the use of SF<sub>6</sub> as cover gas at its plant.<sup>18</sup> This research, as well as the use of substitute gas mixtures, produced significant reductions in SF<sub>6</sub> emissions in the mid-1990s to late 1990s. For the years 2005–2007, Norsk Hydro's SF<sub>6</sub> emissions were significantly reduced as a result of gradual production reduction and the plant's closure in 2007. Timminco was also closed in August 2008.

There were in total 11 magnesium casting facilities in operation during the 1990–2004 period (Cheminfo Services 2005b). Only a few of them had used SF<sub>6</sub> every year during the entire period. Some casters started using SF<sub>6</sub> towards the mid- or late 1990s, whereas others replaced it with an alternative gas, such as SO<sub>2</sub>. Two facilities have ceased their casting operations over the last few years. During the 2005–2008 period, only seven facilities were in operation and had used SF<sub>6</sub>. Two companies shut down their magnesium casting operations in different times of 2009 (one in June and one in December). In 2010, another facility moved its operations to the United States.

### 4.18.2. Methodological Issues

For SF<sub>6</sub> emissions from magnesium production, data for 1999–2007 were directly reported by the companies (Norsk Hydro, Timminco Metals and Métallurgie Magnola Inc.) through a mandatory emissions reporting program known as the National Pollutant Release Inventory (NPRI). Emission estimates used in this report were obtained from the NPRI's online database ([http://www.ec.gc.ca/pdb/querysite/query\\_e.cfm](http://www.ec.gc.ca/pdb/querysite/query_e.cfm)). For previous years (i.e.

<sup>18</sup> Laperrière J. 2004. Personal communication (email from Laperrière J. to A. Au, Greenhouse Gas Division, dated October 27, 2004). Norsk Hydro.

1990–1998), the data were provided voluntarily by the producers to the GHG Division over the telephone. Since there were no reported 2008 data for Timminco, its 2008 SF<sub>6</sub> value was estimated based on its 2007 data and number of months of operation in 2008 (i.e. 7 months). For 2009 onwards, since there have been no magnesium production plants operating in Canada, there has been no need to perform any data collection.

Representatives from both Norsk Hydro and Timminco were contacted in 2006, so that the methodology they had applied to estimate SF<sub>6</sub> emissions could be understood. Both companies reported that they used the IPCC default method (Emissions of SF<sub>6</sub> = Consumption of SF<sub>6</sub>), as recommended in the IPCC Good Practice Guidance (IPCC 2000). However, they have used different ways for estimating their SF<sub>6</sub> consumption. Norsk Hydro confirmed the use of the weight difference method.<sup>19</sup> This method is based on measuring the weight of gas cylinders used at the facility at the time when these were purchased and when these were returned to suppliers at the end of the usage. The accounting method was reported as being used by Timminco for estimating its SF<sub>6</sub> use.<sup>20</sup> In this method, accounting of delivered purchases and inventory changes of SF<sub>6</sub> used are recorded. The purchases must be the actual volumes received in the calendar period; therefore, beginning-of-year and end-of-year inventories are taken into account.

The technique applied to estimate emissions from magnesium production is considered to be a Tier 3 type method, as it is based on the reporting of facility-specific emission data.

For calculating SF<sub>6</sub> emissions from casters, the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997) provide one general equation that assumes that all SF<sub>6</sub> used as a cover gas is emitted to the atmosphere. To estimate SF<sub>6</sub> emissions for 1990–2004 using this equation, attempts had been made, through a study (Cheminfo Services 2005b) in 2005, to collect data on SF<sub>6</sub> consumption from casting facilities. A couple of facilities indicated that they did not hold any historical records of their past SF<sub>6</sub> consumption. Therefore, to estimate SF<sub>6</sub> use for the entire time series, results of a previous study (Cheminfo Services 2002) were used in combination with the data received from the Cheminfo Services (2005b) study and some assumptions. For casters that had SF<sub>6</sub> data for only a year, it was assumed that their SF<sub>6</sub> use stayed constant, during the other operating years, at the level of the year for which the actual SF<sub>6</sub> data were obtained. For casters that had data for more than one year, linear interpolation between two data points was applied to estimate SF<sub>6</sub> consumption for the other years.

For 2005–2007, consumption data were provided by all seven operating casting facilities through a voluntary data submission process. They were used for the calculation of emissions. For

2008, data were made available by six out of the seven casting facilities through the voluntary data submission process. For the remaining facility, it was assumed that its 2008 SF<sub>6</sub> use stayed at the 2007 level. For 2009, communication was established with all seven companies. Two of the companies, for which magnesium casting operations were shut down in 2009, were not able to report their 2009 SF<sub>6</sub> use data, but provided reasonable assumptions that could be used to estimate the 2009 SF<sub>6</sub> use. SF<sub>6</sub> use data for 2009 were provided by the other five facilities. No 2010 or 2011 data were obtained from these facilities. The reported 2009 SF<sub>6</sub> use data were taken to be the 2010 and 2011 use data.

The technique applied to estimate emissions from magnesium casting for 1990–2004 and 2008–2009 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 2005–2007, the method used is considered as a Tier 3 type.

### 4.18.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has been performed for the category of Magnesium Casting. It took into account the uncertainty associated with the SF<sub>6</sub> data reported by each facility. The uncertainty for the category as a whole was estimated at  $\pm 4.0\%$ . It should be noted that the uncertainty assessment was done for only one year of the time series (2007). As such, it is expected that emission estimates of more recent years (2005 onwards) would have a similar uncertainty value, while older estimates would have a slightly higher uncertainty.

As the last magnesium production facility was closed in August 2008, it became difficult to gather the data needed for the Tier 1 uncertainty assessment of the Magnesium Production category. Hence, based on the fact that the same emission estimation method (i.e. emissions = consumption of SF<sub>6</sub>) was applied to both categories of Magnesium Casting and Magnesium Production, it was assumed that the Magnesium Production category would have the same uncertainty ( $\pm 4.0\%$ ) as the Magnesium Casting category.

The data source remains consistent over the time series. The methodology, which equates consumption of SF<sub>6</sub> as a cover gas by magnesium casters to emissions of SF<sub>6</sub>, is applied over the time series with some assumptions for some historical years, as discussed in the methodology section.

### 4.18.4. Category-Specific QA/QC and Verification

Magnesium Production and Magnesium Casting have both undergone Tier 1 QC checks as elaborated in the QA/QC plan (see Annex 6). The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good

<sup>19</sup> Laperrière J. 2006. Personal communication (email from Laperrière J. to A. Au, Greenhouse Gas Division, dated October 4, 2006). Norsk Hydro.

<sup>20</sup> Katan R. 2006. Personal communication (emails from Katan R. to A. Au, Greenhouse Gas Division, dated March 16–22, 2006). Timminco.

Practice Guidance (IPCC 2000). No issues of importance were detected from the Tier 1 QC process.

#### 4.18.5. Category-Specific Recalculations

Recalculations were made in the subcategory of Magnesium Casting to reflect the new information respecting transfer of operations of a plant to the United States in 2010 (affecting 2010 and 2011 emissions), and to reflect the extrapolation (based on GDP output) of another plant's estimates for 2010 and 2011 from the 2009 estimate.

#### 4.18.6. Category-Specific Planned Improvements

Efforts will be made to obtain the up-to-date SF<sub>6</sub> use data from magnesium casting.

### 4.19. Production of Halocarbons (CRF Category 2.E)

#### 4.19.1. Source Category Description

Chlorodifluoromethane (HCFC-22 or CHClF<sub>2</sub>) is produced when reacting chloroform (CHCl<sub>3</sub>) with hydrogen fluoride (HF), in the presence of antimony pentachloride (SbCl<sub>5</sub>) as catalyst. During the manufacture of HCFC-22, trifluoromethane (HFC-23 or CHF<sub>3</sub>) is generated as a by product (IPCC 2002).

The reaction is carried out in a continuous flow reactor, usually under high pressure (up to 500 psig) and temperatures in the order of 45 to 200°C. Although the reaction is exothermic, heat is added to increase the flow of vapours leaving the reactor. The vapour stream contains HCFC 22 (CHClF<sub>2</sub>), HFC-21 (CHCl<sub>2</sub>F), HFC-23 (CHF<sub>3</sub>), HCl, excess CHCl<sub>3</sub>, HF and some entrained catalyst. Subsequent processing of the vapour stream involves several separations to remove/recover by-products and to purify HCFC-22. Unreacted chloroform, entrained catalyst and underfluorinated intermediates (i.e. HCFC-21) from the vapour stream are condensed and returned to the reactor. The major emission point for HFC-23 is the condenser vent, where HFC 23 is discharged into the atmosphere after being separated from HCFC-22 (IPCC 2002).

Two HCFC-22 producers (Dupont Canada and Allied-Signal) operated in Canada during the 1980s and early 1990s. They ceased their HCFC-22 production between 1990 and 1993. According to the data records transferred from the Use Patterns and Control Implementation Section (UPCIS) of Environment Canada to the GHG Division, Dupont Canada produced some HCFC-22 in 1989, Canada's 2014 UNFCCC Submission

but none in the years 1990 and after. Allied-Signal only submitted its 1990–1992 production data to UPCIS because it stopped its operation in 1993.<sup>21</sup>

HCFC-22 can be used as refrigerant, as a blend component in foam blowing and as a chemical feedstock for manufacturing synthetic polymers (IPCC 2002). However, due to its ozone-depleting properties, developed countries have scheduled the phase-out of HCFC-22 for the coming years. In Canada, there has been no more manufacturing or import of equipment containing HCFC-22 as of Jan. 1, 2010 (HRAI 2008).

#### 4.19.2. Methodological Issues

To estimate HFC-23 emissions from HCFC-22 production, the total HCFC-22 production was multiplied by the IPCC Tier 1 default emission factor of 0.04 t HFC-23 / t HCFC-22 produced (IPCC/OECD/IEA 1997). It was assumed that destruction (through thermal oxidation) or transformation of HFC-23 was not practiced in Canada. The 1990–1992 production data were collected by the UPCIS from HCFC producers.<sup>22</sup>

#### 4.19.3. Uncertainties and Time-Series Consistency

Uncertainty in the HFC-23 emission estimates has not been assessed. However, it was believed that the production data reported by HCFC-22 producers were reasonably accurate. The major source of uncertainty could be the Tier 1 default emission factor, because the correlation between the quantity of HFC-23 emitted and the HCFC-22 production rate can vary with plant infrastructure and operating conditions (IPCC 2002).

#### 4.19.4. Category-Specific QA/QC and Verification

Informal checks (such as data transcription checks, calculation checks, and unit conversion checks) were done on the category of HCFC-22 Production. No issues of importance were detected.

#### 4.19.5. Category-Specific Recalculations

There were no recalculations for this category.

#### 4.19.6. Category-Specific Planned Improvements

There are currently no improvements planned for this category.

21 Bovet Y. 2007. Personal communication (email from Bovet Y. to A. Au, Greenhouse Gas Division, dated November 8, 2007). Environment Canada, UPCIS.

22 Bovet Y. and Y. Guilbault. 2004–2006. Personal communications (emails received from Bovet Y. and Guilbault Y. to A. Au, Greenhouse Gas Division, during the years 2004–2006). UPCIS.



## 4.20. Consumption of Halocarbons (CRF Category 2.F)

Hydrofluorocarbons (HFCs) and, to a very limited extent, perfluorocarbons (PFCs) are serving as alternatives to ozone-depleting substances being phased out under the Montreal Protocol. Application areas of HFCs and PFCs include refrigeration and air conditioning, fire suppression, aerosols, solvent cleaning, foam blowing, and other applications (such as semiconductor manufacturing in the case of PFCs).

Before the ban on the production and use of CFCs came into effect in 1996, as a result of the Montreal Protocol, very few HFCs were produced and used. The only HFCs produced were HFC 152a, a component of the refrigerant blend R-500; and HFC-23, a by-product of HCFC-22 production (discussed in the previous section). As such, emissions from HFC consumption were considered negligible for the 1990–1994 period. HFC-134a began to be produced in 1991 and a variety of other HFCs are now also being produced (IPCC/OECD/IEA 1997). All HFCs consumed in Canada are imported in bulk or in products (e.g. refrigerators). There is no known production of HFCs in Canada.

PFCs have been primarily used as cooling/heating agents in specialized market segments and in electronic safety testing. However, emissions from the consumption of PFCs are minor relative to the by-product emissions of PFCs from aluminium production (discussed in the section on aluminium production). Like HFCs, all PFCs consumed in Canada are imported in bulk or in products. There is no known PFC manufacturing in Canada.

### 4.20.1. Methodological Issues

HFC emission estimates for 1995 were based on data gathered from an initial HFC survey conducted by the Use Patterns and Control Implementation Section (UPCIS) of Environment Canada in 1996. Environment Canada has revised subsequent surveys to obtain more detailed activity data. The 1998, 1999, 2001 and 2005 HFC surveys were the source of activity data for emission estimates for the years 1996–2000 and 2004 (2004–2006 emails from Y. Bovet and Y. Guilbault).<sup>23</sup> 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.

HFC import and sales data for 2005–2010<sup>24</sup> were collected by the GHG Division through a voluntary data submission process. In this process, requests for data were sent to the main importers of bulk HFCs and to companies that import/export HFC-containing products. For 2009, the distribution list for data collection was expanded, as the Division became aware of other players (either importers of bulk HFCs or importers/exporters of items with HFCs) in the market by looking at HFC import data collected by the Canadian Border Services Agency (CBSA).<sup>25</sup>

In terms of data on imports of bulk HFCs, since the 2007 and 2008 data were not provided by one of the major importers, it was assumed that the company would have the same 2006–2007 and 2006–2008 growth rates (%) in its imports as the other reporting companies. The same company also did not respond to the voluntary data submission survey for 2009 and 2010 data. As such, its 2009 and 2010 HFC import was assumed to stay at the 2008 level. As mentioned above, there were other companies added to the distribution list of the 2009 data collection, and some of these companies that reported their data in 2009 decided not to participate in the 2010 voluntary data collection. For these companies it was assumed that their 2009 value would be applicable for 2010.

For 2011, there was no voluntary collection of HFC data arranged due to the expectation that such data would later on be acquired through a CEPA section 71 (mandatory environmental reporting) initiative. The initiative, currently underway, would collect import and distribution data on bulk HFCs from 2008 to 2012. In respect of 2011 and 2012 HFC emissions, a trend line has been used to extrapolate consumption values for these two years, from the trend observed for 2008 to 2010. Methodology used for estimation of the 2011 and 2012 HFC emissions has been the same as the one used for the 1995–2010 data years.

In terms of data on import/export of HFC-containing products, in the cases where data were not available from companies, it was assumed that the non-reported quantities stayed at the levels of the most recent years for which data were available, or data were linearly interpolated. For instance, 1995 data on the quantities of HFCs contained in imported and exported products, except imported and exported vehicles, were not available. As such, 1995 HFC quantities in imported and exported products were assumed to be zero. For 1999–2003, these quantities were linearly interpolated from the data available in 1998 and 2004. Similar to the situation for data on bulk HFCs, the distribution list

23 Bovet Y. and Y. Guilbault. 2004–2006. Personal communications (emails received from Bovet Y. and Guilbault Y. to A. Au, Greenhouse Gas Division, during the years 2004–2006). UPCIS.

24 Except for 2010, data collection by the GHG Division on bulk HFCs only covered “Sales.” However, with no Canadian production existing for HFCs, and an insignificant amount of exports, the import values should theoretically be close to the sales values. In fact import values were added to the 2010 data collection in order to verify the sales values.

25 It should be noted that HFC data from the CBSA cannot be used for GHG inventory purposes, as these HFC data are collected and categorized only under three types: HFC-134a, HFC-152a and others. Also, the data are not presented by use type. However, company-specific data from the CBSA are a useful tool for expanding the distribution list for the HFC data collection conducted by the GHG Division and for cross-checking the data submitted to the Division.



for HFC item data collection has been expanded for 2009 data, and this list was used for the 2010 data collection.

Since detailed 1995 HFC data were not available, the IPCC Tier 2 method could not be applied. Instead, a modified Tier 1 methodology was used to obtain a representative estimate of the actual 1995 HFC emissions for the following groups: aerosols, foams, air conditioning original equipment manufacture (AC OEM), AC service, refrigeration, and total flooding systems. To estimate 1996–2008 HFC emissions at the national level, an IPCC Tier 2 methodology was applied. A more detailed description of the Tier 1 and Tier 2 methods used is provided in the following subsections.

Once the emission estimates at the national level were obtained, they were distributed by province/territory based on proxy variables, such as gross output of accommodation and food services for commercial refrigeration and number of households for residential refrigeration. The details of the proxy variables used and assumptions made can be made available upon request.

The IPCC Tier 2 methodology was used to estimate emissions from the consumption of PFCs for the years 1995–2011. Details of the method are found in the following subsections. The 1995–2000 activity data were obtained through the 1998 and 2001 PFC surveys conducted by Environment Canada. As 2001–2004 data were unavailable, emission estimates were developed, by and large, based on the assumption that the use quantities in various applications stayed constant since 2000. The GHG Division conducted a collection of 2003–2007 PFC use data from major distributors of PFCs in 2008 and 2009. The data from the major distributors were then integrated with existing PFC use data. The 2008 and 2009 PFC use data from major distributors were collected in 2009 and 2010. No collection of 2010 and 2011 PFC use data occurred; instead, the 2010 PFC use data were extrapolated from the 2009 PFC use data using 2009 and 2010 GO (gross output) data of applicable economic sectors. These PFC use data were used in the emission estimation. The poor data collection responses from PFC use companies prompted to the switch to collect data from the major distributors of PFCs.

#### 4.20.1.1. 1995 HFC Emission Estimates

The following subsections provide explanations on the emission factors used and the assumptions made to develop 1995 HFC emission estimates for AC OEM, AC service, refrigeration, foam blowing, aerosol products and total flooding systems.

##### Air Conditioning Original Equipment Manufacture (AC OEM)

To estimate emissions from AC OEM, the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997) suggest a 2–5% loss rate. For Canada, a rate of 4% was assumed.

##### AC Service

Since it was assumed that for AC systems, HFCs were mostly used to replace operating losses, a loss rate of 100% was applied.

##### Refrigeration

It was assumed that all refrigeration in Canada falls under the “commercial and industrial” category, since it was the dominant emission source. It was also assumed that the quantity of HFCs reported under “refrigeration” represented the amount used for initial and subsequent recharging of equipment. Therefore,

**Equation 4–17:**

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

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,

$$HFC(\text{refrig}) = \text{Charge} + 0.17 (\text{Charge}) = 1.17 (\text{Charge})$$

or

$$\text{Charge} = \frac{HFC(\text{refrig})}{1.17}$$

Assuming assembly leakage was minimal,

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

Thus,

**Equation 4–18:**

$$\text{Emissions} = 0.17 \times \left( \frac{HFC(\text{refrig})}{1.17} \right)$$

##### Foam Blowing

For 1995, it was assumed that all foam blowing was of open cell type. In other words, an emission factor of 100% was applied.

##### Aerosol Products

For aerosol products, the IPCC Good Practice Guidance (IPCC 2000) suggests a default EF of 50% of the initial charge per year. It was assumed that 1994 production was 50% of that of 1995. Hence, emissions from aerosol products manufactured in 1994, occurring in 1995, would be equivalent to approximately 25% of the 1995 consumption level. Therefore, a factor of 80% was applied to the 1995 consumption to estimate HFC emissions from aerosol products in 1995.

Fire Suppression – Total Flooding Systems

For 1995, it was assumed that all fire suppression equipment to which HFCs were introduced was of the total flooding type. Hence, a factor of 35% (IPCC/OECD/IEA 1997) was applied to estimate HFC emissions from fire suppression.

4.20.1.2. 1996–2011 HFC and 1995–2009 PFC Emission Estimates

The following subsections provide explanations on the emission factors used and the assumptions made to develop 1996–2011 HFC and 1995–2009 PFC emission estimates.

Refrigeration and AC System Assembly

The Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997) recommend the use of the following equation for the estimation of emissions from the assembly of residential refrigeration, commercial refrigeration, stationary AC, and mobile AC systems:

Equation 4–19:

$$E_{assembly,t} = Charge_t \times k$$

where:

- $E_{assembly,t}$  = emissions during system manufacture and assembly in year t
- $Charge_t$  = quantity of refrigerant charged into new systems in year t
- $k$  = assembly losses in percentage of the quantity charged

The k value was chosen from a range of values that were provided for each equipment category in the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997) (Table 4–9).

Annual Leakage

The equation below, given in the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997), was used to calculate HFC and PFC emissions from leakage:

Equation 4–20:

$$E_{operation,t} = Stock_t \times x$$

where:

- $E_{operation,t}$  = quantity of HFCs/PFCs emitted during system operations in year t
- $Stock_t$  = 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 term “Stock<sub>t</sub>” includes the amount of HFCs/PFCs contained in equipment manufactured in Canada, the amount of HFCs/PFCs in imported equipment, and the amount of HFCs used for servicing equipment and excludes the amount of HFCs/PFCs in exported equipment. It was assumed that no leakage occurred in the year of manufacturing. The Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997) give a range of values for the annual leakage rate (x) for each of the different equipment categories. The annual leakage rate chosen for each category is shown in Table 4–10.

Table 4–9 Percentage of Losses during Assembly (k) for Various Applications

For HFC estimates		For PFC estimates	
Application Type	k Values (%)	Application Type	k Values (%)
Residential Refrigeration	2.0	Refrigeration (including ultra low temperature refrigeration)	3.5
Commercial Refrigeration	3.5	Stationary AC	3.5
Stationary AC	3.5	Mobile	4.5
Mobile AC	4.5		

Table 4–10 Annual Leakage Rates (x) for Various Applications

For HFC estimates:		For PFC estimates:	
Application Type	x Values (%)	Application Type	x Values (%)
Residential Refrigeration	1	Refrigeration (including ultra low temperature refrigeration)	17
Commercial Refrigeration	17	Stationary AC	17
Stationary AC	17	Mobile AC	30
Mobile AC	15		

## System Disposal

It was assumed that there were no HFC/PFC emissions from the disposal of refrigeration and stationary AC systems during 1995–2009, since these systems have a lifetime of 15 years (IPCC default value) and HFC use began only in 1995. For the disposal of mobile AC systems with a slightly shorter lifetime of 12 years (the IPCC default average value), it was assumed that there were no recovery and recycling technologies in place and, therefore, 100% of the quantities remaining in systems built in 1995 would be emitted in 2008. This is a conservative assumption because various regulatory requirements currently existing in Canada would prohibit release of HFCs.

## Foam Blowing

The IPCC Tier 2 methodology presented in the revised 1996 IPCC guidelines (IPCC/OECD/IEA 1997) was used to estimate HFC (1996–2011) and PFC (1995–2009) emissions from foam blowing. Foams are grouped into two main categories: open cell and closed cell.

### Open Cell Foam Blowing

In the production of open cell foam, 100% of the HFCs used are emitted (IPCC/OECD/IEA 1997). There has been no known PFC use in open cell foam blowing. Open cell foam production categories that release HFC emissions include the following:

- 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 4–21:

$$E_{\text{foam},t} = 10\% \times Q_{\text{ty}_{\text{manufacturing},t}} + 4.5\% \times \text{Orig. Charge}$$

where:

$E_{\text{foam},t}$	=	emissions from closed cell foam in year t
$Q_{\text{ty}_{\text{manufacturing},t}}$	=	quantity of HFCs/PFCs used in manufacturing closed cell foam in year t
Orig. Charge	=	original charge blown into the foam

The following are closed cell foam production categories that emit HFC emissions:

- Thermal Insulation—Home and Building;
- Thermal Insulation—Pipe;
- Thermal Insulation—Refrigerator and Freezer; and
- Thermal Insulation—Other.

## Fire Extinguishers

The IPCC Tier 2 methodology of the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997) was used to calculate HFC emissions from portable fire extinguishers and total flooding systems from 1996 onward. There has been no known PFC use in fire-extinguishing equipment.

### Portable Fire-Extinguishing Equipment

The IPCC Tier 2 methodology in the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997) estimated emissions as 60% of HFCs used in newly installed equipment.

### Total Flooding Systems

The IPCC Tier 2 methodology provided in the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997) estimated emissions from total flooding systems as 35% of the HFCs used in newly installed fire extinguishing systems.

## Aerosols/Metered Dose Inhalers

The IPCC Tier 2 methodology presented in the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997) was used to calculate HFC emissions from aerosols for 1996 onwards. The emission estimate for the current year is equal to half of the HFCs used in aerosols in the current year plus half of the HFCs used in aerosols in the previous year. The amount of HFCs used each year is equal to the amount of HFCs used to produce aerosols and the amount of HFCs in imported aerosol products and excludes the amount of HFCs in exported aerosol products.

Since no data on PFCs used in aerosols were gathered from Environment Canada's PFC surveys, it was assumed that PFC emissions coming from the use of PFCs in aerosols were negligible.

## Solvents

The IPCC Tier 2 methodology presented in the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997) was used to estimate HFC and PFC emissions from solvents. The emission estimate for the current year is equal to half of the HFCs/PFCs used as solvents in the current year plus half of the HFCs/PFCs used as solvents in the previous year. The amount of HFCs/PFCs used each year is equal to the amount of HFCs/PFCs produced and imported as solvents and excludes the amount of HFCs/PFCs exported as solvents. HFCs/PFCs used as solvents include the following categories:

- electronics industries;
- laboratory solvents; and
- general cleaning.

## Semiconductor Manufacture

There are two main uses of PFCs in the semiconductor manufacturing industry: plasma etching of silicon wafers and plasma cleaning of chemical vapour deposition chambers.

IPCC Tier 2b methodology, as shown below, was used to estimate PFC emissions from the semiconductor manufacturing industry:

### Equation 4–22:

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

where:

- $E_{SC}$  = total PFC emissions from semiconductor
- $E_{FC}$  = emissions resulting from the use of PFCs (see Equation 4–23 below)
- $E_{CF_4}$  =  $CF_4$  emitted as a by-product during the use of PFCs (see Equation 4–24 below)

### Equation 4–23:

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

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 4–24:

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

where:

- $B_{i,p}$  = fraction of gas  $i$  transformed into  $CF_4$  for each process type  $p$

and other terms are as defined above.

Default values for variables used in the above equations are shown in Table 4–11 (IPCC 2000).

As no information on emission control technologies for these processes was available,  $a_{i,p}$  was assumed to be 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 PFC use in the electronics industry for emissive applications, including reliability testing (inert liquids), coolants (direct evaporative cooling for electric and electronic apparatuses and indirect coolants in closed-circuit electronic apparatuses), and precision cleaning (IPCC 2000). These emissions can be classified into two types of sources: *emissive* and *contained*.

*Emissive* sources include the following:

- electrical environmental testing;
- gross leak testing; and
- thermal shock testing.

Unidentified and miscellaneous PFC uses reported in the PFC survey were also considered as part of *emissive* sources. According to the IPCC Tier 2 methodology, 50% of PFCs used for the above purposes would be released during the first year and the remaining 50% released in the following year.

*Contained* sources consist of PFCs used as an electronic insulator and a dielectric coolant for heat transfer in the electronics

Table 4–11 PFC Emission Rates<sup>1</sup>

Process	IPCC Default Emission Fractions			
	CF <sub>4</sub>	C <sub>2</sub> F <sub>6</sub>	C <sub>3</sub> F <sub>8</sub>	c-C <sub>4</sub> F <sub>8</sub>
(1-C) Plasma Etching	0.7	0.4	0.4	0.3
(1-C) Chemical Vapour Deposition Chamber	0.8	0.7	0.4	ND
B Plasma Etching	NA	0.1	ND	NA
B Chemical Vapour Deposition Chamber	NA	0.1	0.2	NA

Notes:

1. Tier 2b, from IPCC (2000) Table 3-15

NA = not applicable.

ND = no data.

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 4-25:

$$E_{\text{contained},t} = (k \times Qty_1) + (x \times Stock_t) + (d \times Qty_t)$$

where:

$E_{\text{contained},t}$	=	emissions from contained sources
$Qty_t$	=	quantity of PFC sale for use or manufacturing of contained sources in year t
$Stock_t$	=	quantity of PFCs in stock in year t
$k$	=	manufacturing emission rate (1% of annual sales)
$x$	=	leakage rate (2% of stock)
$d$	=	disposal emission factor (5% of annual sales)

### 4.20.2. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has been performed for the category of HFC Consumption. It took into account the uncertainties associated with all the subcategories, such as residential/commercial refrigeration, stationary/mobile AC, etc. To determine the uncertainty for a subcategory, the uncertainties related to activity data (Cheminfo 2005c) and emission factors (Japan's Ministry of the Environment 2009) were used. It should be noted that the category uncertainty can vary throughout the time series because it is dependent on the magnitude of each of the subcategory emission estimates, which changes from year to year. The uncertainty associated with the category as a whole for the time series ranged from  $\pm 34\%$  to  $\pm 50\%$ .

Maintaining the consumption of HFCs constant between 2010 and 2011 is expected to increase the uncertainty of the category. Considering that 2010 was the year that brought with it the ban on the production and import of HCFC-containing equipment, it is expected that the surge seen in the use of HFCs (as replacements to HCFCs) would subside for 2011 and after.

A Tier 1 uncertainty assessment has also been performed for the category of PFC Consumption. Similar to HFC Consumption, the uncertainties related to activity data (IPCC 2006) and emission factors (Japan's Ministry of the Environment 2009) were taken into account in the assessment for PFC Consumption. The uncertainty associated with the category as a whole for the time series ranged from  $\pm 10\%$  to  $\pm 24\%$ .

### 4.20.3. Category-Specific QA/QC and Verification

Consumption of Halocarbons resulting in HFC emissions was a key category that has undergone Tier 1 QC checks as developed in the QA/QC plan (see Annex 6). The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC 2000). Some transcription errors (for 1999–2008 estimates) were detected from the Tier 1 QC process.

### 4.20.4. Category-Specific Recalculations

The 2011 HFC use data, which were kept constant at 2010 values, are now extrapolated based on the 2008 to 2010 trend in values.

### 4.20.5. Category-Specific Planned Improvements

Environment Canada, in the course of 2012 and early 2013, conducted a contract to research emission factors associated with Canadian refrigeration and AC equipment, for all the stages of its life cycle. This study has produced more practical (and lower) EF values that will suit Canadian circumstances. The new EFs are being confirmed by the inventory agency. Once confirmed for implementation, they will be used in the NIR 2015 estimations.

As mentioned earlier, the inventory agency is also collaborating with EC's regulatory group for a comprehensive collection of HFC importation and distribution data from 2005 to 2012. It is expected that these data will allow updates to the 2012 and 2011 estimates, as well as improvements to some of the historical data.

## 4.21. Production and Consumption of SF<sub>6</sub> (CRF Categories 2.E & 2.F)

### 4.21.1. Source Category Description

In addition to magnesium production and casting, electrical equipment in electric utilities and semiconductor manufacturing are known sources of SF<sub>6</sub> emissions. In electric utilities, SF<sub>6</sub> is used as an insulating and arc-quenching medium in high-tension electrical equipment, such as electrical switchgear, stand-alone circuit breakers and gas-insulated substations.

There is currently no production of SF<sub>6</sub> in Canada; therefore, all Canadian supply of SF<sub>6</sub> is obtained through imports. From 1990 to 1996, more than 95% of total SF<sub>6</sub> imports came from the United States; however, in recent years, this percentage has declined,



with an increase in SF<sub>6</sub> imports from Germany (Cheminfo Services 2002).

## 4.21.2. Methodological Issues

### SF<sub>6</sub> Emissions from Electrical Equipment

A modified Tier 3 method was used to estimate SF<sub>6</sub> emissions from electrical equipment in utilities for certain years (i.e. 2006–2011) of the time series, in place of the previous top-down approach (which assumed that all SF<sub>6</sub> purchased from gas distributors replaces SF<sub>6</sub> lost through leakage). The SF<sub>6</sub> emission estimates by province for 2006–2011 were provided by the Canadian Electricity Association (CEA)—which represents electricity companies across Canada, except for the province of Quebec—and Hydro Quebec (HQ). The emission data submitted by the CEA and HQ were prepared following the *SF<sub>6</sub> Emission Estimation and Reporting Protocol for Electric Utilities* (“the Protocol”) (Environment Canada and Canadian Electricity Association 2008). The national SF<sub>6</sub> estimate for each year of 2006–2011 was the sum of all provincial estimates. The *Protocol* is the result of a collaborative effort between the GHG Division, the CEA and HQ. It is also part of the memorandum of understanding between the GHG Division and the CEA, and of the voluntary data submission agreement of HQ.

In summary, the *Protocol* explains how the (country-specific) modified Tier 3 method was derived from the IPCC Tier 3 life cycle methodology. It also explains the different options available for estimating the equipment life cycle emissions. These are equal to the sum of SF<sub>6</sub> used to top up the equipment and the equipment disposal and failure emissions (which are equal to nameplate capacity less recovered quantity for disposal emissions or to simply nameplate capacity for failure emissions). The options for the tracking of SF<sub>6</sub> consumed for top-ups are mass flow meters, weigh scales and cylinder count. For further details on the methodology, data uncertainty, data quality control, data verification by third party, transfer of information and data to the GHG Division, documentation and archiving, new information or data updates, and protocol reviews and amendments, please refer to the *Protocol* (available upon request at <http://www.ec.gc.ca/Publications/default.asp?lang=En&xml=5926D759-36A6-467C-AE05-077C5E6C12A2>). A more detailed description of the methodology is also provided in Annex 3.2.

Estimates were not available from the CEA and HQ for the years 1990–2005 because a systematic manner for taking inventory of the quantities of SF<sub>6</sub> used was only started in 2006. Hence, the application of the *Protocol* was not possible. Section 7.3.2.2 of the 2000 IPCC Good Practice Guidance suggests four approaches for such a situation: 1) overlap, 2) surrogate method, 3) interpolation, and 4) trend extrapolation. Each of these techniques has been evaluated for its applicability in this particular situation. The surrogate and trend extrapolation methods could not be used

because, according to the 2000 IPCC Good Practice Guidance, it is NOT good practice to use these approaches for a long period. The interpolation approach could not be used because data for intermittent years were needed. The overlap approach was determined to be the most appropriate option in this case for the following reasons:

- The overlap between two or more sets of annual emission estimates could be assessed. (In this case, the overlap was assessed between four sets of annual estimates – 2006, 2007, 2008 and 2009.)
- There was a consistent and proportional relationship between the estimates developed using the “old” (i.e. used in the previous submission) and the modified Tier 3 methods. (In this case, the national estimates developed using the modified Tier 3 method were consistently around 10–20% of those developed using the old method.)

Emissions at provincial/territorial levels were estimated based on the national emission estimates (obtained from the use of the overlap approach) and the percent of provincial shares (based on the reported 2006–2009 data).

### SF<sub>6</sub> Emissions from Semiconductor Manufacturing

The method applied to estimate SF<sub>6</sub> emissions from semiconductor manufacturing was similar to the one used for calculating PFC emissions. However, as there is no by-product CF<sub>4</sub> created during the use of SF<sub>6</sub> in the process, Equation 4–24 is not needed. Hence,

#### Equation 4–26:

$$SF_6 \text{ Emissions} = (1 - h) \times [FC \times (1 - C) \times (1 - a \times d)]$$

where:

h	=	fraction of SF <sub>6</sub> remaining in shipping container (heel) after use (%)
FC	=	quantity of SF <sub>6</sub> fed into the process (or sales) (t)
C	=	use rate (fraction destroyed or transformed) (%)
a	=	fraction of gas volume fed into the process with emission control technologies
d	=	fraction of SF <sub>6</sub> destroyed in the process by the emission control technologies

The value of “h” provided and confirmed by two major SF<sub>6</sub> gas distributors, Air Liquide and Praxair, was 12%.<sup>26</sup> The IPCC default value of 0.5 for “(1 – C)” was used. As it was assumed that there has been no emission control technology applied by this industry, the values of “a” and “d” were 0 and 1, respectively. The estimation technique is considered as Tier 2 type. It should be noted that efforts have been made during the preparation of this inventory to obtain country-specific (1 – C), a and d values. How-

26 Rahal H. and Tardif A. 2006. Personal communications (emails from Rahal H. and Tardif A. to A. Au, Greenhouse Gas Division, dated November 22, 2006, and November 13, 2006, respectively). Praxair and Air Liquide, respectively.



ever, due to the scarcity of the collected data, the development of country specific parameter values has not been possible.

Since only 1995–2000 sales data were obtained from major Canadian gas suppliers through a study conducted in 2005 (Cheminfo Services 2005a), it was assumed that the quantity sold per year during 1990–1994 was at the 1995 level. The sales per year for 2001–2003 were assumed to be the average value between 1995 and 2000. The SF<sub>6</sub> sales to semiconductor manufacturers in 2004–2009 were estimated by multiplying the SF<sub>6</sub> import (data purchased from Statistics Canada) by the sales distribution (in %) to semiconductor manufacturers. No SF<sub>6</sub> sales data were collected for the 2010 and 2011 data years. The 2009 SF<sub>6</sub> sales data were therefore used to determine the amount of SF<sub>6</sub> used by semiconductor manufacturers. As explained above, sales data by market segment provided by some of the major SF<sub>6</sub> gas distributors were used to establish the percentage of sales attributed to each user/market type. It is noteworthy to mention that attempts have been made to collect SF<sub>6</sub> use data directly from manufacturers, but the response rate for the data-gathering exercise was rather low and the small amount of collected data would not bring in any improvement to the current estimation method.

### 4.21.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment was conducted for the category of SF<sub>6</sub> from Electrical Equipment. It should be noted, though, that the uncertainty assessment was done using 2007 data from the previous submission. Therefore, it is expected that emission estimates of this submission would have much lower uncertainty values. The uncertainty for the category as a whole was estimated at  $\pm 32.0\%$ .

A Tier 1 uncertainty assessment has also been performed for the category of Semiconductor Manufacturing. Although the assessment took into account uncertainties associated with the parameters of Equation 4–24, it should be mentioned that the most of these uncertainties were assumed values due to data unavailability. The uncertainty for the category as a whole was estimated at  $\pm 45\%$ . The uncertainty value is applicable to all years of the time series.

Depending on the years, the data source and methodology used for SF<sub>6</sub> from electrical equipment could vary, as explained in the section above. For SF<sub>6</sub> from semiconductor manufacturing, both data source and methodology used were consistent throughout the time series.

### 4.21.4. Category-Specific QA/QC and Verification

SF<sub>6</sub> Consumption in Electrical Equipment was a key category that has undergone Tier 1 QC checks as developed in the QA/QC plan

(see Annex 6). The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC 2000). No issues of importance were detected.

Informal checks (such as data transcription checks, calculation checks and unit conversion checks) were done on the category of Semiconductor Manufacturing. No issues of importance were detected.

### 4.21.5. Category-Specific Recalculations

There were no recalculations applied to this category.

### 4.21.6. Category-Specific Planned Improvements

There are no improvements planned for the category of SF<sub>6</sub> from Electrical Equipment.

## 4.22. Other and Undifferentiated Production (CRF Category 2.G)

### 4.22.1. Source Category Description

The Other and Undifferentiated Production category includes emissions from the non-energy use of fossil fuels that are not accounted for under any of the other subsectors of the Industrial Processes Sector. The following are examples of fuels in non-energy applications: the use of natural gas liquids (NGLs) and refinery output as feedstocks in the chemical industry, and the use of lubricants such as engine oil and grease in transportation and industrial applications, with “use” defined as “close-to-production” consumption of fuel, e.g., burning of motor oil in the engine’s combustion chamber (excludes waste oil incineration, which is allocated to the Waste Sector). All of these activities result in varying degrees of oxidation of the fuel, producing CO<sub>2</sub> emissions. Also included in this category are emissions from the use of hydrocarbons (such as coal) as reductants for base metal smelting, and petroleum-based solvents, cleaners and paint thinners.

The use of fossil fuels as feedstock or for other non-energy purposes is reported in an aggregated manner by Statistics Canada (#57-003) under “Non-Energy Use” for each individual fuel. In the event that CO<sub>2</sub> emissions resulting from non-energy fuel use are allocated to another category of the Industrial Processes Sector (as is the case for ammonia production, iron and steel produc-

tion, and aluminium production), those emissions are subtracted from the total non-energy emissions to avoid double counting.

4.22.2. Methodological Issues

Emission factors for non-energy use of fuels were developed based on the total potential CO<sub>2</sub> emission rates and the IPCC 1996 Energy Sector’s default percentages of carbon stored in products (IPCC/OECD/IEA 1997). The total potential CO<sub>2</sub> emission factors were derived from the carbon emission factors shown in Jaques (1992), McCann (2000) and CIEEDAC (2006), which are EFs based on natural units of fuel; the IPCC provides for energy units-based EFs.

Table 4–12 shows the types of non-energy fuels used by Canadian industry that are included in the estimation model for the Other and Undifferentiated Production category.

Table 4–12 PFC Emission Rates<sup>1</sup>

GASEOUS Fuels	SOLID Fuels	LIQUID Fuels
Natural gas	Canadian bituminous	Refined petroleum products
	Sub-bituminous	Petroleum coke
	Lignite	Petroleum feedstocks
	Anthracite	Natural gas liquids
	Foreign bituminous	Propane
		Butane
		Ethane

Fuel quantity data for non-energy fuel usage were reported by the *Report on Energy Supply Demand in Canada* (RESO – Statistics Canada #57-003). It should be noted that the RESO data for any given year are preliminary and subject to revisions in subsequent publications. These data were multiplied by the emission rates shown in Annex 3 to estimate CO<sub>2</sub> emissions for this subsector.

This technique is considered to be a Tier 1 type method, as it is based on the use of national consumption data and average national emission factors. Methodological issues for calculating CO<sub>2</sub> emissions from the non-energy use of fossil fuels are not addressed specifically in the IPCC Good Practice Guidance (IPCC 2000). However, and as noted previously, the IPCC Guidelines 1996 provide a method of estimating non energy use of fuels, based on the amount of carbon stored in the products resulting from the process. The CO<sub>2</sub> emissions are derived from the amount of residual carbon that is released during the production process (residual carbon = total carbon minus amounts stored in product).

4.22.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has also been performed for the subsector of Other and Undifferentiated Production. The assessment took into account uncertainties associated with the activity data and emission factors (ICF Consulting 2004). The uncertainty for the category as a whole was estimated at ±21%. It should be noted that the uncertainty assessment was done for only one year of the time series (2007).

The non-energy fuel data, for the time series 1996 to 2003, have been revised in this NIR. This has removed the inconsistency that existed in the time series (1996–2003 and 2004–2011) in the last NIR.

4.22.4. Category-Specific QA/QC and Verification

Other and Undifferentiated Production was a key category that has undergone Tier 1 QC checks as developed in the QA/QC plan (see Annex 6). The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC 2000). No issues of importance were detected.

4.22.5. Category-Specific Recalculations

New values from RESO resulted in the recalculation of emissions from 1996 to 2003. Also, for consistency purposes, the EFs for solid fuels used as non-energy were made equivalent to the EFs of corresponding fuels in the Energy Sector; this caused recalculations across the time series.

4.22.6. Category-Specific Planned Improvements

In preparation for the adoption of the IPCC 2006 Guidelines in the NIR 2015, it is intended to move towards a production-based estimation methodology for the sources included in the Other and Undifferentiated Production category.

# Chapter 5

## Solvent and Other Product Use (CRF Sector 3)

### 5.1. Overview

Although the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997) mentions that solvents and related compounds can be significant sources of emissions of non-methane volatile organic compounds (NMVOCs), the Solvent and Other Product Use Sector accounts only for direct greenhouse gas (GHG) emissions. Annex 10 of the NIR provides details on emissions of NMVOCs and other indirect GHG emissions.

This Sector specifically includes emissions that are related to the use of N<sub>2</sub>O as an anaesthetic and propellant. Emissions from use of solvents in dry cleaning, printing, metal degreasing and a variety of industrial applications, as well as household use, are not estimated because, according to the Revised 1996 IPCC Guidelines, GHGs are not emitted in significant amounts from these types of uses (IPCC/OECD/IEA 1997). Process CO<sub>2</sub> emissions associated with the production of solvents are included in the Industrial Processes Sector.

As shown in Table 5–1, the GHG emissions from the Solvent and Other Product Use Sector contributed 0.25 Mt CO<sub>2</sub> eq to the 2011 national GHG inventory, compared with 0.18 Mt CO<sub>2</sub> eq in 1990. These emissions represented 0.04% of the total Canadian GHG emissions in 2011. The emission trends, either long term or short term, were driven mainly by the domestic demand for N<sub>2</sub>O for anaesthetic or propellant purposes.

Most of the N<sub>2</sub>O sold in Canada is used as an anaesthetic. The second major application of N<sub>2</sub>O is as a propellant to generate pressure in aerosol products, with the largest application being pressure-packaged whipped cream. Demand for N<sub>2</sub>O in Canada for manufacturing of this food product has been relatively stable since 1995 (Cheminfo Services 2006).

Although not a key category (KC), this category that forms a Sector underwent Tier 1 quality control checks like a KC to ensure correctness of estimates. Further details on quality assurance and quality control and uncertainty assessment can be found in sections 5.1.4 and 5.1.3, respectively.

### 5.1.1. Source Category Description

N<sub>2</sub>O is a clear, colourless, oxidizing liquefied gas with a slightly sweet odour, and is stable and inert at room temperature. Steam (H<sub>2</sub>O) and N<sub>2</sub>O are formed in a low-pressure and low-temperature reaction that decomposes ammonium nitrate (NH<sub>4</sub>NO<sub>3</sub>). While steam is condensed out, “crude” N<sub>2</sub>O is further purified, compressed, dried and liquefied for storage and distribution. Nitrous Oxide of Canada (NOC) in Maitland, Ontario, is the only known producer of compressed N<sub>2</sub>O for commercial sales in Canada. It supplies N<sub>2</sub>O to two of the three primary N<sub>2</sub>O gas distributors that essentially account for the total commercial market in Canada. These companies sell cylinders of N<sub>2</sub>O to a relatively large number of sub-distributors. It is estimated that there may be 9000 to 12 000 final end-use customers for N<sub>2</sub>O in Canada, including dental offices, clinics, hospitals and laboratories (Cheminfo Services 2006).

N<sub>2</sub>O is used in a limited number of applications, with anaesthetic use representing the vast majority of consumption in Canada. Use as a propellant in food products is the second largest type of end use in Canada. Other areas where N<sub>2</sub>O can be used include production of sodium azide<sup>1</sup> (a chemical that is used to inflate automobile airbags), atomic absorption spectrometry and semiconductor manufacturing. According to the distributors that were surveyed during the recent study, approximately 82% of

<sup>1</sup> N<sub>2</sub>O was used by ICI Chemicals between 1990 and 1997 as a reactant for producing sodium azide. However, a different raw material has been used in its place since 1998.

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

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)							
	1990	2000	2005	2008	2009	2010	2011	2012
Solvent and Other Product Use TOTAL	179	450	378	342	260	242	247	310
Use of N <sub>2</sub> O as an anaesthetic	151	384	319	289	220	204	209	262
Use of N <sub>2</sub> O as a propellant	27	66	59	53	40	38	38	48

Note: The sums of anaesthetic and propellant use may not add up to the solvent total due to rounding.

their N<sub>2</sub>O sales volume is used in dentistry/medical applications, 15% in food processing propellants and only 3% for the other uses (Cheminfo Services 2006).

It is important to note that, of all applications in which N<sub>2</sub>O can be used, only the two major types are emissive. When N<sub>2</sub>O is used as an anaesthetic, it is assumed that none of the N<sub>2</sub>O is metabolized (IPCC 2006). In other words, the used N<sub>2</sub>O quickly leaves the body in exhaled breath (i.e. is emitted) as a result of the poor solubility of N<sub>2</sub>O in blood and tissues. When N<sub>2</sub>O is used as a propellant, only emissions coming from N<sub>2</sub>O used in whipped cream are estimated, because the amounts of N<sub>2</sub>O employed in other food products and in non-food products are considered negligible, according to the food industry and the gas producer and distributors. When the cream escapes from the can, the N<sub>2</sub>O gas expands and whips the cream into foam. As none of the N<sub>2</sub>O is reacted during the process, it is all emitted to the atmosphere (Cheminfo Services 2006).

### 5.1.2. Methodological Issues

Estimation of N<sub>2</sub>O emissions from this Sector was done based on sales data, following the consumption-based approach presented in the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997). Because it was virtually impossible to collect data from all end users, it was assumed that domestic sales equal domestic consumption.

Attempts were made to collect sales data, instead of purchase or consumption data, for all years. To obtain the sales volumes by end-use type, for 1990–2005, Canada's single N<sub>2</sub>O producer and the three major N<sub>2</sub>O gas distributors were surveyed through a study (Cheminfo Services 2006). NOC was contacted to obtain its annual production and domestic sales data, but it was able to provide only rough estimates of historical data. NOC provided its production, import, export and domestic sales data for 2012.

N<sub>2</sub>O import data for 2012 were not available from Statistics Canada. This is due to a decision by Statistics Canada to make N<sub>2</sub>O imports part of a larger import data set that includes other substance import activities. The 2012 N<sub>2</sub>O import data were hence assessed based on a trend line built upon the N<sub>2</sub>O imports of 2008 to 2011. The domestic sales of the sole Canadian producer, and the trended N<sub>2</sub>O import data, were used to estimate the domestic sales (or consumption) of N<sub>2</sub>O in 2012. 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 (Cheminfo Services 2006). The sales pattern for 2006–2012 was assumed to be the same as the one for 2005, which was determined during the study in 2006 (Cheminfo Services 2006). To calculate the amounts of N<sub>2</sub>O sold for anaesthetic and propellant purposes, the total domestic sales volume was multiplied by the percentage of each of these provided in the sales patterns.

To estimate emissions coming from usage of anaesthetic at the national level, it was assumed that 100% of the quantity used in anaesthetic applications was emitted, as explained previously in the source category description section. This is the recommended emission rate as per the 2006 IPCC guidelines.

To estimate emissions coming from N<sub>2</sub>O use in food products (i.e. whipped cream cans) at the national level, it was assumed that 100% of the quantity used in the whipped cream manufacturing was emitted, as explained previously in the source category description section. The same assumption was also made by the U.S. EPA.

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

The national emission estimates were divided by the national total population to yield an emissions per capita factor. This factor was then multiplied by the population in each province and territory to estimate emissions at provincial/territorial levels. The 1990–2012 annual population statistics were obtained from Statistics Canada (2013).

### 5.1.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has been performed for the Solvent Sector. It took into account the uncertainties associated with domestic sales, import, sales patterns and emission factors. The uncertainty associated with the Sector as a whole was evaluated at ±19%. It should be noted, though, that the uncertainty assessment was done for only one year of the time series (2007). However, it is expected that the uncertainty for this Sector would not vary considerably from year to year as the data sources and methodology applied were the same.

### 5.1.4. Quality Assurance, Quality Control and Verification

This Sector was treated as a key category and has undergone Tier 1 quality control checks as developed in the quality assurance/quality control plan (see Annex 6). The checks performed were consistent with the Tier 1 general inventory level quality control procedures outlined in the IPCC good practice guidance (IPCC 2000). No issues of importance were detected from the Tier 1 quality control process.

### 5.1.5. Recalculations

No recalculations were performed on this category.

### 5.1.6. Planned Improvements

The Sector activity data, i.e., the imported/distributed amounts, will be examined to find alternative sources of data. This is because Statistics Canada has ceased to provide N<sub>2</sub>O import data as a single substance. A survey on the N<sub>2</sub>O importer/distributor companies in Canada will more likely be the vehicle that Environment Canada will use for the acquisition of data.

# Chapter 6

## Agriculture (CRF Sector 4)

### 6.1. Overview

Emission sources from the Agriculture Sector include enteric fermentation ( $\text{CH}_4$ ) and manure management ( $\text{N}_2\text{O}$  and  $\text{CH}_4$ ) categories from animal production and the agricultural soils ( $\text{N}_2\text{O}$ ) and field burning of crop residues ( $\text{CH}_4$  and  $\text{N}_2\text{O}$ ) categories that occur during crop production. Carbon dioxide emissions from, and removals by, agricultural lands are reported in the Land Use, Land-use Change and Forestry (LULUCF) Sector under the Cropland category (see Chapter 7).

The largest sectors in Canadian agriculture are beef cattle (non dairy), swine, and cereal and oil seed production. There is also a large poultry industry and a large dairy industry. Sheep are raised, but production is highly localized and small compared to the beef, swine, dairy and poultry industries. Other animals are produced for commercial purposes, namely buffalo,<sup>1</sup> llamas, alpacas, horses and goats, but production is small.

Canadian agriculture is highly regionalized due to historic and climatic influences. Approximately 75% of beef cattle and more than 90% of wheat, barley and canola are produced on the Prairies in a semi-arid to subhumid ecozone. On the other hand, approximately 75% of dairy cattle, 60% of swine and poultry, 95% of corn and 90% of soybeans are produced on the humid mixed-wood plains ecozone in Eastern Canada.

In 1990 there were 10.5 million non-dairy cattle in Canada, 1.4 million dairy cattle, 10 million swine and 100 million poultry. Beef cattle and swine populations peaked in 2005 at 15 million head each but have since decreased to 12 and 13 million head, respectively. Since 1990, poultry populations have increased to 140 million. Dairy cattle populations have decreased steadily since 1990 to less than 1 million head in 2012.

Since 1990, cropping practices have changed in Canada, with increasing canola production from 3 Mt to 14 Mt, corn production from 7 Mt to 13 Mt, and soybean production from 1.3 Mt to 5 Mt, and decreasing wheat production from 32 Mt to 25 Mt.

Synthetic nitrogen consumption has increased from 1.2 Mt N in 1990 to 2.3 Mt N in 2012, while the area under summerfallow has decreased by 5.4 million hectares (Mha) and the regions using conservation tillage have increased by 12.9 Mha.

As a result of those changes, total greenhouse gas (GHG) emissions from the Canadian Agriculture Sector have increased from 47 Mt  $\text{CO}_2$  eq in 1990, to 56 Mt  $\text{CO}_2$  eq in 2012 (Table 6–1). This difference represents an increase of 19% from 1990, mainly due to higher populations of beef cattle and swine (13% and 25% increases, respectively), as well as an increase in the use of synthetic nitrogen fertilizers (93%).

Emissions of  $\text{CH}_4$  from livestock accounted for 19 Mt  $\text{CO}_2$  eq in 1990 and 20 Mt  $\text{CO}_2$  eq in 2012, and mean estimates lie within an uncertainty range of -16 to +20%. Over the time series of 1990 to 2012, mean  $\text{CH}_4$  emissions are estimated to have increased by 1.6 Mt  $\text{CO}_2$  eq, a 9% increase. The observed increase in emissions falls within an uncertainty range of 4% to 12%. Emissions of  $\text{N}_2\text{O}$  from agricultural soils and livestock accounted for 28 Mt  $\text{CO}_2$  eq in 1990 and 35 Mt  $\text{CO}_2$  eq in 2012; mean estimates lie within an uncertainty range of -36 to +52%. Over the time series, mean  $\text{N}_2\text{O}$  emissions increased by 7.1 Mt  $\text{CO}_2$  eq, an increase of 25%.

Emissions from the Agriculture Sector peaked in 2005 and, until 2008, there were no significant changes in total emissions, as increases in emissions due to increased use of nitrogen fertilizer and crop residue decomposition were offset by reductions in emissions from animal production as major livestock populations decreased (Enteric Fermentation and Manure Management, Table 6-1). Since 2008, fertilizer emissions have continued to increase. Livestock populations decreased from 2005 to 2011, but did not continue this decline in 2012; crop production and the resulting crop residual emissions in 2012 were lower than their peak in 2008, but increased slightly relative to 2011. As a result of these short-term changes, total agricultural emissions were lower in 2012 than peak levels in 2005–2008, by less than 3 Mt  $\text{CO}_2$  eq.

Recalculations were 1.7% in this submission, with an increase in emissions of less than 0.2 Mt  $\text{CO}_2$  eq for 1990 and a decrease of -0.9 Mt  $\text{CO}_2$  eq in 2011, reducing the emission trend reported in the 2013 NIR by 2%, from 15% to 13%. Recalculation resulted from a number of changes in activity data based on the 2011 *Census of Agriculture*, due to revisions to animal population estimates by Statistics Canada and revisions to crop areas by Agriculture and Agri-Food Canada (AAFC), as well as an improvement to ecodistrict-level climate data (Table 6–2).

Emissions from biological nitrogen fixation by the legume-rhizobium association are reported as not occurring. This decision is supported by Rochette and Janzen (2005), who concluded that there is no evidence that measurable amounts of  $\text{N}_2\text{O}$  are produced during the nitrogen fixation process. Rice is not produced in Canada and is not a source of  $\text{CH}_4$  emissions. Prescribed

<sup>1</sup> The Intergovernmental Panel on Climate Change (IPCC) category “buffalo” is being used in Canada to represent the North American bison (*Bison bison*) that is raised for meat production using methods similar to beef cattle.



Table 6-1 Short- and Long-Term Changes in GHG Emissions from the Agriculture Sector<sup>1</sup>

GHG Source Category		GHG Emissions (kt CO <sub>2</sub> eq)							
		1990	2000	2005	2008	2009	2010	2011	2012
Agriculture TOTAL		47 000	56 000	58 000	58 000	56 000	55 000	53 000	56 000
Enteric Fermentation		16 000	20 000	22 000	20 000	19 000	18 000	17 000	18 000
—CH <sub>4</sub>	Dairy Cattle	3 100	2 800	2 700	2 600	2 500	2 600	2 600	2 600
	Beef Cattle <sup>2</sup>	12 000	16 000	18 000	16 000	15 000	15 000	14 000	14 000
	Others <sup>3</sup>	610	910	1 100	960	920	900	890	890
Manure Management		5 700	7 000	7 500	6 900	6 600	6 500	6 300	6 400
—CH <sub>4</sub>	Dairy Cattle	660	600	580	560	550	560	560	560
	Beef Cattle <sup>2</sup>	670	760	840	760	730	700	670	670
	Swine	660	1 400	1 600	1 400	1 300	1 300	1 300	1 300
	Poultry	130	150	160	150	150	150	150	150
	Others <sup>4</sup>	20	30	40	40	30	30	30	30
—N <sub>2</sub> O	All Animal Types	3 200	4 000	4 300	4 000	3 800	3 700	3 600	3 600
Agricultural Soils		25 000	29 000	29 000	31 000	30 000	30 000	29 000	32 000
Direct Sources		14 000	15 000	15 000	17 000	16 000	17 000	16 000	17 000
	Synthetic Nitrogen Fertilizers	5 900	7 700	7 100	8 600	8 600	8 800	9 100	10 000
	Manure Applied as Fertilizers	1 800	2 100	2 200	2 000	1 900	1 900	1 800	1 800
	Crop Residue Decomposition	4 800	4 800	5 200	6 200	5 600	5 800	5 000	5 300
	Cultivation of Organic Soils	60	60	60	60	60	60	60	60
	Conservation Tillage <sup>5</sup>	-300	-740	-880	-1 100	-1 000	-1 000	-1 100	-1 300
	Summerfallow	1 400	1 100	820	730	620	540	500	490
	Irrigation	280	330	330	360	340	360	370	400
Pasture, Range, and Paddock Manure		2 200	3 100	3 400	3 100	2 900	2 800	2 600	2 700
Indirect Sources		8 700	10 000	10 000	11 000	11 000	11 000	11 000	12 000
Crop Residue Burning (CH <sub>4</sub> & N <sub>2</sub> O)		210	120	40	40	40	30	30	30

Notes:

1. Totals may not add up due to rounding.

2. Beef Cattle includes dairy heifers.

3. Others, Enteric Fermentation, includes buffalo, goat, horse, lamb, llama/alpaca, sheep and swine.

4. Others, Manure Management, includes buffalo, goat, horse, lamb, llama/alpaca and sheep.

5. The negative values reflect a reduced N<sub>2</sub>O emission due to the adoption of conservation tillage.

burning of savannas is not practised in Canada. Finally, emissions of GHG from on-farm fuel combustion are included in the Energy Sector (Chapter 3).

For each emission source category, a brief introduction and a brief description of methodological issues, uncertainties and time-series consistency, quality assurance / quality control (QA/QC) and verification, recalculations, and planned improvements are provided in this chapter. The detailed inventory methodologies and sources of activity data are described in Annex 3.3.

## 6.2. Enteric Fermentation (CRF Category 4.A)

### 6.2.1. Source Category Description

In Canada, animal production varies from region to region. In western Canada, beef production dominates, combining both intensive production systems with high animal densities finished

in feedlots, and low density, ranch-style, pasturing systems for cow-calf operations. Most dairy production occurs in eastern Canada in high-production, high-density facilities. Eastern Canada also has traditionally produced swine in high-density, intensive production facilities. Over the past 20 years, some swine production has shifted to western Canada. Other animals that produce CH<sub>4</sub> by enteric fermentation are raised as livestock, such as buffalo, goats, horses, llamas/alpacas and sheep; however, populations of these animals have traditionally been low.

Methane (CH<sub>4</sub>) is produced during the normal digestive process of enteric fermentation by herbivores. Microorganisms break down carbohydrates and proteins into simple molecules for absorption through the gastro-intestinal tract and CH<sub>4</sub> is produced as a by-product. This process results in an accumulation of CH<sub>4</sub> in the rumen that is emitted by eructation and exhalation. Some CH<sub>4</sub> is released later in the digestive process by flatulence, but this accounts for less than 5% of total emissions. Ruminant animals, such as cattle, generate the most CH<sub>4</sub>.

Table 6–2 Corrections and Improvements Carried Out for Canada's 2014 Submission

Correction or Improvement	Years affected
1. Correction by Statistics Canada of biannual livestock surveys to the 2011 census values.	2006–2011
2. Recalculation and re-levelling of crop areas to integrate values from 2011 census.	Complete time series
3. Improvements to the estimate of the precipitation/potential evapotranspiration ratio (P/PE) used in the calculation of N <sub>2</sub> O emission factors for ecodistricts without long-term climate data, using nearest neighbour analysis as opposed to provincial averages.	Complete time series
4. Correction of populations of llamas and alpacas, interpolating from a zero value for certain provinces that reported no populations in the 1991 <i>Census of Agriculture</i> .	1992–1995
5. Small modifications to the number of significant digits carried in rounding animal population interpolations to ecodistricts between census years.	1990, 1992–1995, 1997–2000, 2001–2005, 2007–2010
6. Changes in the distribution of animals to ecodistricts based on 2011 <i>Census of Agriculture</i> population numbers and correction of ecodistrict population numbers for poultry at the ecodistrict level, with linear interpolation between censuses of 2006 and 2011.	2007–2011
7. Correction of data transfer error in soil texture data for certain ecodistricts for 2011.	2011

## 6.2.2. Methodological Issues

The diversity of animal production systems and regional differences in production facilities complicate emission estimation. For each animal category/subcategory, CH<sub>4</sub> emissions are calculated, by province, by multiplying the animal population of a given category/subcategory by its corresponding emission factor.

For cattle, CH<sub>4</sub> emission factors are estimated using the Intergovernmental Panel on Climate Change (IPCC) Tier 2 methodology, based on the equations provided by IPCC Good Practice Guidance (IPCC 2000). A national study by Boadi et al. (2004) broke down cattle subcategories, by province, into subannual production stages and defined their physiological status, diet, age class, sex, weight, growth rate, activity level and production environment. These data were integrated into IPCC Tier 2 equations to produce annual emission factors for each individual animal subcategory that take into account provincial production practices. The data describing each production stage were obtained by surveying beef and dairy cattle specialists across the country.

Increased milk production in dairy cattle herds over the 1990–2011 time period are reflected in a 17% increase in CH<sub>4</sub> emission factors from this animal category. Increased milk production increases the requirement of energy for lactation (NE<sub>l</sub>) and requires greater food consumption. In beef cattle, changes in mature body weight influence maintenance and growth energy (NE<sub>m</sub> and NE<sub>g</sub>) requirements and as a consequence feed consumption. From 1990 to 2003 large breeds were popular and emission factors increased from 1990 to 2003 by 7%, but have since decreased from their peak by 5% (see Table A3-18, Annex 3.3).

For non-cattle animal categories, CH<sub>4</sub> emissions from enteric fermentation continue to be estimated using the IPCC Tier 1

methodology. Poultry are excluded from enteric fermentation estimates, since no emission factors are available.

Activity data consist of domestic animal populations for each animal category/subcategory, by province, and are obtained from Statistics Canada (Annex 3.3, Table A3-11). The data are based on the **Census of Agriculture**, conducted every five years and updated annually by semi-annual or quarterly surveys for cattle, swine and sheep.

## 6.2.3. Uncertainties and Time-Series Consistency

An uncertainty analysis using the Monte Carlo technique was carried out on the methodology used to estimate emissions of methane from agricultural sources. The analysis considered the uncertainty in the parameters defined in Boadi et al. (2004) as they are used within the IPCC Tier 2 methodology equations. Details of this analysis can be found in Annex 3.3, Section A3.3.2.3. Uncertainty distributions for parameters were taken from Karimi-Zindashty et al. (2012), though some additional parameters and updates were included in this analysis.

The uncertainty ranges for CH<sub>4</sub> emissions from enteric fermentation were similar in 1990 and 2012, and mean estimates lie within an uncertainty range of -17 to +22% (Table 6–3). Over the time series of 1990 to 2012, mean emissions are estimated to have increased by 1.5 Mt CO<sub>2</sub> eq, a 9% increase. The observed increase falls within an uncertainty range of 4% to 14%.

The uncertainty in emissions was mainly associated with the calculation of the emission factor. The range of uncertainty around the calculation of the Tier 2 emission factors was the highest (43%) in the case of beef cattle. Calculations of uncertainty in emissions and emission factors were the most sensitive to the use

**Table 6–3 Uncertainty in Estimates of Emissions of CH<sub>4</sub> from Enteric Fermentation**

Animal Category	Uncertainty Source	Mean Value <sup>1</sup>	2.5% Prob <sup>2,3</sup>	97.5% Prob
Dairy Cattle	Population (1000 head)	955	905 (-5.2%)	1 005 (+5.2%)
	Tier 2 Emission Factor (kg/head/year)	128	108 (-16%)	155 (+21%)
	Emissions (Mt CO <sub>2</sub> eq)	2.6	2.1 (-17%)	3.1 (22%)
Non-dairy Cattle	Population (1000 head)	11 913	11 700 (-1.8%)	12 138 (+1.9%)
	Tier 2 Emission Factor (kg/head/year)	56.4	46.1 (-19%)	70.1 (+22%)
	Emissions (Mt CO <sub>2</sub> eq)	14.1	11.4 (-19%)	17.6 (+25%)
Other Animals	Emissions (Mt CO <sub>2</sub> eq)	0.89	0.74 (-18%)	1.1 (+17%)
Total Emissions	Emissions (Mt CO <sub>2</sub> eq) 1990	16.1	13.4 (-17%)	19.6 (+22%)
	2012	17.6	14.6 (-17%)	21.4 (+22%)
	Trend 1990–2012	1.5 (9%)	0.72 (+4%)	2.2 (+14%)

Notes:

1. Mean value reported from database, with the exception of Trend, which is the difference between 1990 and 2012.

2. Values in parentheses represent the uncertain percentage of the mean, with the exception of the Trend, where values in parentheses represent the percentage change between 1990 and 2012.

of IPCC default parameters in the Tier 2 calculation methodology, in particular the methane conversion rate (Y<sub>m</sub>) and the factor associated with the estimation of the net energy of maintenance (C<sub>fi</sub>) (Karimi-Zindashty et al. 2012). The uncertainty in the estimates of average national livestock populations for all livestock categories were low (under 6%), including uncertainty in minor livestock populations due to the fact that population estimates were based on the recent (2011) census.

The methodology and parameter data used in the calculation of emission factors are consistent throughout the entire time series (1990–2012) with the exception of milk production for dairy cattle. The time series of milk production from 1990 to 1998 is estimated. Two milk production data sets exist in Canada: i) publishable records that represent production data for genetically elite animals within the Canadian herd from 1990 to present, and ii) management records that provide a more accurate estimate of production from the entire Canadian dairy herd from 1999 to present. An estimate of real milk production for the entire Canadian herd from 1990 to 1998 was calculated based on the average ratio between the publishable and the management data from 1999 to 2007.

The weight of bulls was kept constant in this submission, due to inconsistencies in national slaughter weights and regional averages, depending on a review of the data published on the AAFC website.

## 6.2.4. QA/QC and Verification

Enteric Fermentation, as a key category, has undergone Tier 1-level QC checks as elaborated in the QA/QC plan (Annex 6) in a manner consistent with IPCC (2000) Good Practice Guidance. The activity data, methodologies and changes are documented and archived in both paper and electronic forms. The IPCC Tier 2 emis-

sion factors for cattle, derived from Boadi et al. (2004), have been reviewed by independent experts (McAllister and Basarab 2004).

Internal Tier 2-level QC checks carried out in 2010–2011 included a complete review and rebuild of calculation methodology, input data, and a review and compilation of Canadian research on enteric fermentation (MacDonald and Liang 2011). The literature review suggested that no specific bias can be clearly identified in the enteric emission estimate. Based on the sensitivity analyses carried out in the uncertainty analysis and the review of literature, improvements to the cattle model require the development of country-specific parameters that take into account specific regional management influences on emissions, replacing IPCC defaults currently used in the emission model. Details of this review can be found in Annex 3.3.

## 6.2.5. Recalculations

For major livestock categories, i.e., cattle, swine and sheep, annual population estimates come from bi annual surveys. After the 2011 *Census of Agriculture* (Statistics Canada 2012), Statistics Canada corrected bi-annual survey data for the inter-census period based on the new census data, resulting in a new time series of cattle, swine and sheep populations for the period 2006 to 2011. Estimates of cattle populations for 2011 increased by 300 000 head, and swine and sheep decreased by 800 000 and 70 000 head, respectively. These corrections were integrated into the estimate of emissions from 2006 to 2011, resulting in recalculations of enteric fermentation emission estimates of -0.6 Mt CO<sub>2</sub> eq in 2011 (Table 6–4).

## 6.2.6. Planned Improvements

In general, the enteric fermentation methodology is robust; improvements are mainly dependent on the ability to collect

**Table 6–4 Recalculations of Estimates of Emissions and Their Impact on Emissions Trend and Total Agricultural Emissions from Enteric Fermentation, Manure Management CH<sub>4</sub> and Manure Management N<sub>2</sub>O**

Emission Source	Year	Submission Year	Category Emissions (Mt CO <sub>2</sub> eq)	Trend of Source Category Emissions (% Change)	Change in Emissions (kt CO <sub>2</sub> eq)	Relative Change Category Emissions (%)	Change Agricultural Emissions Total (%)
Pasture, Range and Paddock Emissions	2011	2013	2.72	23	-87	-3.2%	-0.16%
	2011	2014	2.64	19			
Indirect Emissions, Volatilization and Redeposition	2011	2013	2.60	30	-7	-0.3%	-0.01%
	2011	2014	2.59	29			
Indirect Emissions, Leaching, Erosion and Runoff	1990	2013	6.67	24 (2013)	27	0.4%	0.05%
		2014	6.69				
	2011	2013	8.24	22 (2014)	-54	-0.7%	-0.10%
		2014	8.19				

Notes:

1. Numbers in parentheses indicate submission year in which the change in trend is calculated.

more complete data on diet composition fed to livestock that will facilitate the development of parameters specific to animal subcategories within different regions of Canada.

At present, data have been collected to develop a time series that accounts for changes in feed ration digestibility. The methodology is currently being refined and documented. Implementation of new data and methodologies will occur over the short term.

A study has begun with Canadian experts in the beef industry to update and improve the beef production model, intended to characterize variability in animal management strategies in different regions across Canada.

The time series of carcass weight data will be reviewed in collaboration with AAFC, to determine whether carcass weights reported on their website are accurate.

## 6.3. Manure Management (CRF Category 4.B)

In Canada, the animal waste management systems (AWMS) typically used in animal production include 1) liquid storage, 2) solid storage and drylot, and 3) pasture and paddock. To a lesser extent, AWMS also include other systems such as composting and biodigestors. No manure is burned as fuel.

Both CH<sub>4</sub> and N<sub>2</sub>O are emitted during handling and storage of livestock manure. The magnitude of emissions depends upon the quantity of manure handled, its characteristics, and the type of manure management system. Generally, poorly aerated manure management systems generate high CH<sub>4</sub> emissions but relatively low N<sub>2</sub>O emissions, whereas well-aerated systems generate high N<sub>2</sub>O emissions but relatively low CH<sub>4</sub> emissions.

Manure management practices vary regionally and also by animal category. Dairy, poultry and swine production occur in mod-

ern high-density production facilities. Dairy and swine produce large volumes of liquid manure while poultry produces solid manure, both of which are spread on a limited landbase. Feedlot beef production results in large volumes of drylot and solid manure, whereas low-density pasturing systems for beef result in widely dispersed manure in pastures and paddocks. Production systems for other animals, such as buffalo, goats, horses, llamas/alpacas and sheep are generally in pastured or medium-density production facilities producing mainly solid manure.

### 6.3.1. CH<sub>4</sub> Emissions from Manure Management (CRF Category 4.B (a))

#### 6.3.1.1. Source Category Description

Shortly after manure is excreted, the decomposition process begins. In well-aerated conditions, decomposition is an oxidation process producing CO<sub>2</sub>; however, if little oxygen is present, carbon is reduced, resulting in the production of CH<sub>4</sub>. The quantity of CH<sub>4</sub> produced depends on manure characteristics and on the type of manure management system. Manure characteristics are in turn linked to animal category and animal nutrition.

#### 6.3.1.2. Methodological Issues

Methane emissions from manure management are calculated for each animal category/subcategory by multiplying its population by the corresponding emission factor (see Annex 3.3 for detailed methodology). The animal population data are the same as those used for the enteric fermentation emission estimates (Section 6.2.2) Methane emission factors for manure management are estimated using the IPCC Tier 2 methodology (IPCC 2006).

All Tier 2 parameters were taken from expert consultations described in Boadi et al. (2004) and Marinier et al. (2004, 2005)

**Table 6–5 Uncertainty in Estimates of Emissions of CH<sub>4</sub> from Manure Management**

Animal Category	Uncertainty Source	Mean Value <sup>1</sup>	2.5% Prob <sup>2</sup>	97.5% Prob
Dairy Cattle	Population (1000 head)	955	905 (-5.2%)	1 005 (+5.2%)
	Tier 2 Emission Factor (kg/head/year)	27.8	11 (-60%)	42 (+50%)
	Emissions (Mt CO <sub>2</sub> eq)	0.56	0.22 (-61%)	0.83 (+50%)
Non-dairy Cattle	Population (1000 head)	11 913	11 700 (-1.8%)	12 138 (+1.9%)
	Tier 2 Emission Factor (kg/head/year)	2.7	4.4 (-34%)	4.6 (+62%)
	Emissions (Mt CO <sub>2</sub> eq)	0.67	0.44 (-34%)	1.1 (+65%)
Swine	Population (1000 head)	12 791	11 453 (-2.7%)	13 136 (+2.7%)
	Tier 2 Emission Factor (kg/head/year)	5.0	2.4 (-51%)	7.1 (+43%)
	Emissions (Mt CO <sub>2</sub> eq)	1.3	0.65 (-51%)	1.9 (+44%)
Other Animals	Emissions (Mt CO <sub>2</sub> eq)	1.06	0.12 (-35%)	0.21 (+15%)
Total Emissions	Emissions (Mt CO <sub>2</sub> eq) 1990	2.6	1.7 (-33%)	3.5 (+38%)
	Emissions (Mt CO <sub>2</sub> eq) 2012	2.8	1.9 (-32%)	3.5 (+27%)
	Trend 1990–2012	0.20 (7.5%)	-0.20 (-7.6%)	0.25 (+10%)

Notes:

1. Mean value reported from database, with the exception of Trend, which is the difference between 1990 and 2012.

2. Values in parentheses represent the uncertain percentage of the mean, with the exception of the Trend, where values in parentheses represent the percentage change between 1990 and 2012.

or from the IPCC (2006) Guidelines. For dairy and beef cattle, the Boadi et al. (2004) Tier 2 animal production model was used to derive gross energy of consumption (GE) from which volatile solids (VS) were estimated using Equation 4.16 of the Good Practice Guidance and manure ash contents from Marinier et al. (2004). All other livestock used VS taken from Marinier et al. (2004) based on ash content and digestible energy derived from expert consultations. For swine, sheep and poultry, different parameters were used for subcategories based on size class for swine and sheep as well as for turkeys, broilers and layers in the poultry category.

Emission factors were derived using the CH<sub>4</sub> producing potential (B<sub>0</sub>) and CH<sub>4</sub> conversion factors (MCF) taken from the IPCC (2006) Guidelines. Manure management systems (AWMS) for each animal category were taken from Marinier et al. (2005) for each province, taking into account regional differences in production practices and manure storage systems. A more complete description of the derivation of the distribution factor for manure management systems is contained in Annex 3.3, Section A3.3.3.3.

An increase in emission factors over the period of 1990 to 2012 (see Table A3-25 in Annex 3.3) reflects higher gross energy intake for dairy cattle due to increased milk productivity and for beef cattle due to changes in live body weights (see Section 6.2.2).

### 6.3.1.3. Uncertainties and Time-Series Consistency

The uncertainty analysis of emissions of methane from agricultural sources using the Monte Carlo technique included methane emissions from manure management. The analysis used parameter estimates and uncertainty distributions from Marinier et al.

(2004) supplemented with information from Karimi Zindashty et al. (2012) and additional and updated parameters specific to this analysis. Details of this analysis can be found in Annex 3.3, Section A3.3.3.8.

The estimate of 2.8 Mt CO<sub>2</sub> eq from manure management CH<sub>4</sub> emissions from Canadian livestock in 2012 lies within an uncertainty range of -32% to +27% (Table 6–5). The emission estimate from manure management in 1990, 2.6 Mt CO<sub>2</sub> eq, has a slightly larger uncertainty range, -33% to +38%, due to greater uncertainty associated with the type of manure management systems in 1990. The estimate of a +7.5% increase in mean emissions between 1990 and 2012 lies within an uncertainty range of a possible decrease of -8% to a maximum increase of +10%.

As was the case with enteric fermentation, most uncertainty in the emission estimate was associated with the calculation of the emission factor. The uncertainty range around the mean emission factor was as high as 110% in the case of dairy cattle. The uncertainty in emissions was most sensitive to the use of IPCC default parameters in the Tier 2 calculation methodology, in particular the methane conversion factor (MCF) that was applied to all regions of Canada and all animal types and the maximum methane production capacity (B<sub>0</sub>) (Karimi-Zindashty et al. 2012).

The methodology and parameter data used in the calculation of emission factors are consistent for the entire time series (1990–2012) with the exception of milk production for dairy and bull weights. Milk production from 1990 to 1999 in Ontario and the western provinces, and bull carcass weights, were estimated as described in Section 6.2.3.



#### 6.3.1.4. QA/QC and Verification

Methane emissions from manure management have undergone Tier 1-level QC checks as elaborated in the QA/QC plan (Annex 6) in a manner consistent with IPCC good practice. The activity data and methodologies are documented and archived in both paper and electronic forms. The IPCC Tier 2 CH<sub>4</sub> emission factors for manure management practices by all animal categories derived from Marinier et al. (2004) have been reviewed by independent experts (Patni and Desjardins 2004). These documents have been archived in both paper and electronic form.

Internal Tier 2-level QC checks carried out in 2010–2011 included a complete review and rebuild of calculation methodology, input data and review and compilation of Canadian research on manure management (MacDonald and Liang 2011). No specific bias can be clearly identified in the IPCC Tier 2 model parameters due to the high variability in research results and the lack of supporting information for research carried out on manure storage installations. There is no clear standard to evaluate if IPCC parameters are appropriate for estimating emissions from manure management systems in the Canadian context. More standardized and detailed research is required in Canada to improve upon the current Tier 2 methodology. Details of this review can be found in Annex 3.3, Section A3.3.3.7.

#### 6.3.1.5. Recalculations

The integration of 2011 Census of Agriculture (Statistics Canada 2012) population numbers noted in Section 6.2.5 resulted in an increase in emissions from 2006 to 2011, with a maximum recalculation in 2011 of 31 kt CO<sub>2</sub> eq (Table 6–4). Unlike enteric fermentation emissions, the increase in swine populations resulted in a net increase in overall CH<sub>4</sub> emissions from manure management, due to the large proportion of liquid storage systems used in swine production.

#### 6.3.1.6. Planned Improvements

Analysis of the manure management model suggested that improvements could be made to the values used for the distribution of manure management systems (AWMS) based on Statistics Canada's farm environmental management surveys (FEMS). Those data, combined with recent publications on livestock management (Sheppard et al. 2009a, 2009b, 2010, 2011a, 2011b; Sheppard and Bittman 2011, 2012) may provide the basis for new manure management time series over the medium term.

As noted in Section 6.2.6, data have been collected to develop a time series that accounts for changes in feed ration digestibility. Methodology will be developed to incorporate a time series for digestible energy used in the calculation of volatile solids for certain animal categories and will be incorporated over the medium term.

### 6.3.2. N<sub>2</sub>O Emissions from Manure Management (CRF Category 4.B (b))

#### 6.3.2.1. Source Category Description

The production of N<sub>2</sub>O during storage and treatment of animal waste occurs during nitrification and denitrification of nitrogen contained in the manure. Nitrification is the oxidation of ammonium (NH<sub>4</sub><sup>+</sup>) to nitrate (NO<sub>3</sub><sup>–</sup>), and denitrification is the reduction of NO<sub>3</sub><sup>–</sup> to N<sub>2</sub>O or N<sub>2</sub>. Manure from beef cattle, sheep, lamb, goats and horses are mainly handled with a solid and dry lot system, which is the manure management system that emits the most N<sub>2</sub>O. Nitrous oxide emissions from manure excreted on pasture, range and paddock by grazing animals are reported separately (see Section 6.4.2, Manure on Pasture, Range and Paddock).

#### 6.3.2.2. Methodological Issues

Emissions of N<sub>2</sub>O from manure management are estimated using the IPCC Tier 1 methodology. Emissions are calculated for each animal category by multiplying the animal population of a given category by its nitrogen excretion rate and by the emission factor associated with the animal waste management system (AWMS).

The animal characterization data are the same as those used for the Enteric Fermentation category estimates (Section 6.2) and CH<sub>4</sub> Emissions from Manure Management (Section 6.3.1). The average annual nitrogen excretion rates for domestic animals are taken from the 2006 IPCC Guidelines. The amount of manure nitrogen subject to losses because of leaching and volatilization of NH<sub>3</sub> and NO<sub>x</sub> during storage is adjusted by animal type and manure management system according to the default values provided in the 2006 IPCC Guidelines.

The fraction of nitrogen available for conversion into N<sub>2</sub>O is estimated by applying system-specific emission factors to the manure nitrogen handled by each management system. The 2006 IPCC default emission factors for a developed country with a cool climate are used to estimate manure nitrogen emitted as N<sub>2</sub>O for each type of AWMS.

#### 6.3.2.3. Uncertainties and Time-Series Consistency

An uncertainty analysis using the Monte Carlo technique was carried out to estimate emissions of N<sub>2</sub>O from agricultural sources (Karimi-Zindashty et al. 2014). For N<sub>2</sub>O emissions from manure management, the uncertainty in the parameters defined in the Tier 1 methodology of the 2006 IPCC Guidelines and all uncertainty in AWMS systems, animal populations and characterizations were identical to those used in the analysis of enteric fermentation and manure management CH<sub>4</sub> defined in Sections



6.2.3 and 6.3.1.3. Details of this analysis can be found in Annex 3.3, Section A3.3.7.

The estimate of N<sub>2</sub>O emissions of 3.6 Mt CO<sub>2</sub> eq from manure management of Canadian livestock wastes in 2012 lies within an uncertainty range of 2.1 Mt CO<sub>2</sub> eq (-43%) to 5.5 Mt CO<sub>2</sub> eq (+51%) (Table 6–6). Most uncertainty is associated with the IPCC Tier 1 emission factor (+/-100% uncertainty). Due to the size of the N<sub>2</sub>O model, the initial uncertainty analysis was limited to providing sound estimates of uncertainty for emission source categories and a basic sensitivity analysis. A complete analysis of the trend uncertainty has not yet been completed, due to limitations in software capabilities.

The same methodology, emission factors and data sources are used for the entire time series (1990–2012), with the exception that bull weights were maintained constant as noted in Section 6.2.3.

#### 6.3.2.4. QA/QC and Verification

This category has undergone Tier 1-level QC checks as elaborated in the QA/QC plan (Annex 6) in a manner consistent with IPCC Good Practice Guidance. The activity data, methodology and changes to methodologies are documented and archived in both paper and electronic form. A complete Tier 2 QC was carried out on all calculation processes and parameters during rebuilding of the agricultural N<sub>2</sub>O emission database.

There have been very few published data on N<sub>2</sub>O emissions from manure management storage in Canada or in regions with practices and climatic conditions comparable to those of Canada. More standardized and detailed research is required in Canada to improve upon the current methodology.

#### 6.3.2.5. Recalculations

The integration of 2011 Census of Agriculture (Statistics Canada 2012) population numbers noted in Section 6.2.5 resulted in a decrease in emissions from 2006 to 2011, with a maximum recalculation in 2011 of -92 kt CO<sub>2</sub> eq (Table 6–4), driven by the decrease in populations of cattle. Other small recalculations resulted in a change of less than 0.1 kt CO<sub>2</sub> eq.

#### 6.3.2.6. Planned Improvements

Data from direct measurements of N<sub>2</sub>O emissions from manure management in Canada are scarce. Recent scientific advances in analytical techniques allow direct measurements of N<sub>2</sub>O emissions from point sources. However, it will likely take several years before N<sub>2</sub>O emissions can be reliably measured and verified for various manure management systems in Canada.

As noted in Section 6.3.1.6, plans are in place to analyze whether improvements could be made to the values used for the distribu-

tion of manure management systems (AWMS) based on Statistics Canada farm environmental management surveys.

As noted in Section 6.2.6, data have been collected to develop a time series that accounts for changes in animal nutrition, and country-specific nitrogen excretion rates will be calculated and incorporated over the medium term.

Further uncertainty work will be carried out to establish trend uncertainty over the medium term.

### 6.4. N<sub>2</sub>O Emissions from Agricultural Soils (CRF Category 4.D)

Emissions of N<sub>2</sub>O from agricultural soils consist of direct and indirect emissions as well as emissions from animal manure deposited on pasture, range and paddock. The emissions of N<sub>2</sub>O from anthropogenic nitrogen inputs occur directly from the soils to which the nitrogen is added, and also indirectly through two pathways: i) volatilization of nitrogen from synthetic fertilizer and manure as NH<sub>3</sub> and NO<sub>x</sub> and its subsequent deposition off-site; and ii) leaching and runoff of synthetic fertilizer, manure and crop residue N. Changes in crop rotations and management practices such as summerfallow, tillage and irrigation, can also affect direct N<sub>2</sub>O emissions by altering mineralization of organic nitrogen, nitrification and denitrification.

#### 6.4.1. Direct N<sub>2</sub>O Emissions from Soils (CRF Category 4.D.1)

Direct sources of N<sub>2</sub>O from soils include the application of synthetic nitrogen fertilizers and animal manure, crop residue decomposition, and cultivation of histosols. In addition, Canada also reports three country-specific sources of emissions/removals driven by soil organic matter decay from tillage practices, summerfallow and irrigation. Emissions/removals from these sources are estimated similarly based on nitrogen inputs from the application of synthetic nitrogen fertilizers and animal manure and crop residue nitrogen.

##### 6.4.1.1. Synthetic Nitrogen Fertilizer

###### 6.4.1.1.1. Source Category Description

Synthetic fertilizers add large quantities of nitrogen to agricultural soils. This added nitrogen undergoes transformations, such as nitrification and denitrification, which can release N<sub>2</sub>O. Emission factors associated with fertilizer application depend on many factors, such as soil types, climate, topography, farming practices and environmental conditions (Gregorich et al. 2005; Rochette et al. 2008b).

### 6.4.1.1.2. Methodological Issues

Canada has developed a country-specific, Tier 2 methodology to estimate N<sub>2</sub>O emissions from synthetic nitrogen fertilizer application on agricultural soils, which takes into account moisture regimes and topographic conditions. Emissions of N<sub>2</sub>O are estimated by ecodistrict and are scaled up at provincial and national levels. The amount of nitrogen applied is obtained from yearly fertilizer sales, which are available from regional fertilizer associations and compiled at the national level. All synthetic nitrogen fertilizers sold by retailers are assumed to be applied for crop production in Canada; the quantity of fertilizers applied to forests is deemed negligible. More details on the inventory method can be found in Annex 3.3.

### 6.4.1.1.3. Uncertainties and Time-Series Consistency

The uncertainty analysis, using the Monte Carlo technique on the methodology used to estimate emissions of N<sub>2</sub>O from agricultural sources noted in Section 6.3.2.3, included all direct and indirect emissions from soils (Table 6–6). For N<sub>2</sub>O emissions from fertilizer, the analysis considered the uncertainty in the parameters defined in the country-specific methodology (Rochette et al. 2008b) used to develop N<sub>2</sub>O emission factors, the uncertainty in provincial fertilizer sales, and the uncertainty in crop areas and production at the ecodistrict level.

The estimate of N<sub>2</sub>O emissions of 10 Mt CO<sub>2</sub> eq from application of fertilizers on agricultural soils in 2012 lies within an uncertainty range of 6.4 Mt CO<sub>2</sub> eq (–35%) to 15 Mt CO<sub>2</sub> eq (+43%) (Table 6–6). The main source of uncertainty in the calculation is associated with the parameters (slope and intercept) of the regression equation relating emission factors to the precipitation to potential evapotranspiration ratio (P/PE).

The same methodology and emission factors are used for the entire time series (1990–2012).

### 6.4.1.1.4. QA/QC and Verification

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

While Statistics Canada conducts QC checks before the release of synthetic nitrogen fertilizer consumption data, the Pollutant Inventories and Reporting Division of Environment Canada carries out its own Tier 2 QC checks through historical records and consultations with regional and provincial agricultural industries.

Emissions of N<sub>2</sub>O associated with synthetic fertilizer nitrogen applications on agricultural soils in Canada vary on a site-by-site basis, but there is a close agreement between the IPCC default emission factor of 1% (IPCC 2006) and the measured emission factor of 1.2% in eastern Canada, excluding emissions during the spring thaw period (Gregorich et al. 2005).

### 6.4.1.1.5. Recalculations

In this year's submission, changes to calculations of the direct emissions of N<sub>2</sub>O from fertilizer application to agricultural soils included i) the recalculation and re-leveling of crop areas to integrate values from the 2011 *Census of Agriculture*, which modified the distribution of fertilizer N among ecodistricts; ii) the improvements to the estimate of the precipitation/potential evapotranspiration (P/PE) ratio for ecodistricts without long-term climate data; and iii) a correction to soil texture for a series of ecodistricts in the 2011 input data.

**Table 6–6 Uncertainty in Estimates of Emissions of N<sub>2</sub>O from Manure Management and Agricultural Soils**

Emission Source		Mean Value <sup>1</sup>	2.5% Prob. <sup>2</sup>	97.5% Prob
		Mt CO <sub>2</sub> eq		
Manure Management	All Animal Types	3.6	2.1 (–43%)	5.5 (+51%)
Agricultural Soils (N <sub>2</sub> O)		31	20.2 (–36%)	47.8 (+52%)
Direct Sources		17	12.3 (–28%)	22.9 (+34%)
	Synthetic Nitrogen Fertilizers	10	6.4 (–35%)	15 (+43%)
	Manure Applied as Fertilizers	1.8	1.2 (–33%)	2.6 (+41%)
	Crop Residue Decomposition	5.3	3.4 (–35%)	7.7 (+45%)
	Cultivation of Organic Soils	0.06	0.01 (–79%)	0.12 (+96%)
	Soil N Mineralization/Immobilization	–0.39	–0.61 (–44%)	–0.22 (+55%)
Pasture, Range and Paddock Manure		2.7	1.1 (–60%)	4.7 (+75%)
Indirect Sources		12	4.0 (–66%)	23 (+99%)
	Atmospheric Deposition	2.8	0.71 (–74%)	5.7 (110%)
	Leaching and Runoff	8.9	1.8 (–80%)	20 (120%)

Notes:

1. Mean value reported from database.

2. Values in parentheses represent the uncertain percentage of the mean.

**Table 6–7 Recalculations of Estimates of N<sub>2</sub>O Emissions and their Impact on Emissions Trend, and Total Agricultural Emissions from Fertilizer Application, Manure Spreading and Crop Residue Decomposition**

Emission Source	Year	Submission Year	Category Emissions (Mt CO <sub>2</sub> eq)	Change in Emissions (kt CO <sub>2</sub> eq)	Relative Change Category Emissions (%)	Change Agricultural Emissions Total (%)	Trend of Source Category Emissions (%) <sup>1</sup>
Synthetic Nitrogen Fertilizers	1990	2013	5.88	34	0.6%	0.06%	56 (2013)
		2014	5.91				
	2011	2013	9.17	-22	-0.2%	-0.04%	55 (2014)
		2014	9.15				
Manure Applied as Fertilizers	1990	2013	1.78	-0.2	0.0%	0.00%	6.2 (2013)
		2014	1.78				
	2011	2013	1.89	-61	-3.2%	-0.11%	2.8 (2014)
		2014	1.83				
Crop Residue Decomposition	1990	2013	4.74	29	0.6%	0.05%	6.9 (2013)
		2014	4.77				
	2011	2013	5.06	-36	-0.7%	-0.07%	5.5 (2014)
		2014	5.03				

Notes:

1. Numbers in parentheses indicate submission year in which the change in trend is calculated.

Total recalculations consisted of a decrease of 34 kt CO<sub>2</sub> eq in 1990 (Table 6–7); approximately 50% of the recalculation was due to the redistribution of fertilizer N among ecodistricts based on changes in crop areas, and 50% was due to the correction in P/PE ratio. In 2011, the small increase in emissions associated with the redistribution of fertilizer N and the corrections to the P/PE ratio partially attenuated the decrease in emissions due to the correction of errors in soil texture in the 2011 input data, resulting in a small decrease in emissions of 22 kt CO<sub>2</sub> eq.

#### 6.4.1.1.6. Planned Improvements

There is no immediate plan in place aimed at improving emission estimates for this source; in the mid term, research efforts will be made to differentiate between N<sub>2</sub>O emission factors from organic and inorganic N sources. Further uncertainty work will be carried out to establish trend uncertainty over the medium term.

### 6.4.1.2. Manure Applied as Fertilizer

#### 6.4.1.2.1. Source Category Description

The application of animal manure as fertilizer to agricultural soils can increase the rate of nitrification and denitrification and result in enhanced N<sub>2</sub>O emissions. Emissions from this category include all the manure managed by drylot, liquid and other animal waste management systems. Manure deposited on pasture by grazing animals is accounted for in Section 6.4.2.

#### 6.4.1.2.2. Methodological Issues

Similar to the methodology used to estimate emissions from synthetic nitrogen fertilizers, the method used to estimate N<sub>2</sub>O

emissions from animal manure applied to agricultural soils is a country-specific IPCC Tier 2 method that takes into account moisture regimes (long-term growing season precipitation and potential evapotranspiration) and topographic conditions. Emissions are calculated by multiplying the amount of manure nitrogen applied to agricultural soils by an emission factor for each ecodistrict, and summed at the provincial and national levels. All manure that is handled by AWMS, except for the manure deposited on pasture, range and paddock from grazing animals, is assumed to be subsequently applied to agricultural soils (see Section 6.4.2).

#### 6.4.1.2.3. Uncertainties and Time-Series Consistency

In the case of N<sub>2</sub>O emissions from manure application, the uncertainty analysis considered the uncertainty in the parameters used in producing estimates of manure N noted in Section 6.3.2.3, and the uncertainty defined in the country-specific methodology (Rochette et al. 2008b) used to develop N<sub>2</sub>O emission factors, as noted in Section 6.4.1.1.3.

The estimate of N<sub>2</sub>O emissions of 1.8 Mt CO<sub>2</sub> eq from manure spreading of Canadian livestock wastes in 2012 lies within an uncertainty range of 1.2 Mt CO<sub>2</sub> eq (-33%) to 2.6 Mt CO<sub>2</sub> eq (+41%) (Table 6–6). The main source of uncertainty in the calculation of emissions from manure includes the slope of the P/PE regression equation, P/PE animal N excretion rates, and emission factor modifiers for texture (RF<sub>TEXTURE</sub>) and tillage (RF<sub>TILL</sub>).

The same methodology and emission factors are used for the entire time series (1990–2012).

#### 6.4.1.2.4. QA/QC and Verification

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

#### 6.4.1.2.5. Recalculations

In this year's submission, changes to calculations of the direct emissions of N<sub>2</sub>O from spreading of manure on agricultural soils included the integration of 2011 Census of Agriculture (Statistics Canada 2012) population numbers noted in Section 6.2.5, and the modifications to input data that altered the N<sub>2</sub>O emission factor noted in Section 6.4.1.1.5.

Total recalculations consisted of a decrease of 0.2 kt CO<sub>2</sub> eq in 1990 (Table 6–7); the redistribution of manure N among ecodistricts increased emissions by 1.2 kt CO<sub>2</sub> eq, and the correction in P/PE ratio decreased emissions by 1 kt CO<sub>2</sub> eq. The correction of errors in soil texture in the 2011 input data resulted in a larger decrease in emissions of 61 kt CO<sub>2</sub> eq in that year.

#### 6.4.1.2.6. Planned Improvements

There is no immediate plan in place aimed at improving emission estimates for this source. Further uncertainty work will be carried out to establish trend uncertainty over the medium term.

### 6.4.1.3. Biological Nitrogen Fixation

#### 6.4.1.3.1. Source Category Description

Biological nitrogen fixation by the legume-rhizobium association is not considered a source of N<sub>2</sub>O emissions by Canada. The decision to exclude this category as an emission source is supported by the findings of Rochette and Janzen (2005) that there is no evidence that measurable amounts of N<sub>2</sub>O are produced during the nitrogen fixation process. Canada reports this source as “not occurring.” However, the contribution of legume nitrogen to N<sub>2</sub>O emissions from crop residue decomposition is still included (see Section 6.4.1.4).

#### 6.4.1.4. Crop Residue Decomposition (CRF Category 4.D.4)

##### 6.4.1.4.1. Source Category Description

When a crop is harvested, a portion of the crop is left on the field to decompose. The remaining plant matter is a nitrogen source for nitrification and denitrification and thus can contribute to N<sub>2</sub>O production.

#### 6.4.1.4.2. Methodological Issues

Emissions are estimated using an IPCC Tier 2 approach based on the amount of nitrogen contained in crop residue multiplied by the emission factor at the ecodistrict level and scaled up to the provincial and national levels. The amount of nitrogen contained in crop residues from both nitrogen-fixing and non nitrogen-fixing crops is estimated using country-specific crop characteristics (Janzen et al. 2003). Emission factors are determined using the same approach as for synthetic fertilizer nitrogen application based on moisture regimes and topographic conditions.

#### 6.4.1.4.3. Uncertainties and Time-Series Consistency

For N<sub>2</sub>O emissions from crop residue decomposition, the uncertainty analysis considered the uncertainty in crop production, as well as the uncertainty defined in the country-specific methodology (Rochette et al. 2008b) used to develop N<sub>2</sub>O emission factors as noted in Section 6.4.1.1.3.

The estimate of N<sub>2</sub>O emissions of 5.3 Mt CO<sub>2</sub> eq from crop residue decomposition in 2012 lies within an uncertainty range of 3.4 Mt CO<sub>2</sub> eq (–35%) to 7.7 Mt CO<sub>2</sub> eq (+45%) (Table 6–6). The main sources of uncertainty in the calculation of emissions from crop residue decomposition include the slope of the P/PE regression equation and emission factor modifiers for texture (RF<sub>TEXTURE</sub>) and tillage (RF<sub>TILL</sub>).

The same methodology and emission factors are used for the entire time series (1990–2012).

#### 6.4.1.4.4. QA/QC and Verification

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

#### 6.4.1.4.5. Recalculations

In this year's submission, changes to calculations of the direct emissions of N<sub>2</sub>O from decomposition of crop residues are due to the modifications to input data that affected the N<sub>2</sub>O emission factors noted in Section 6.4.1.1.5.

Total recalculations consisted of an increase of 29 kt CO<sub>2</sub> eq in 1990; the redistribution of crop production among ecodistricts increased emissions by approximately 34 kt CO<sub>2</sub> eq, and the correction in P/PE ratio decreased emissions by approximately 5 kt CO<sub>2</sub> eq. In 2011, the small increase in emissions associated with the redistribution of fertilizer N was partially attenuated by the decrease in emissions due to the corrections to the P/PE ratio and the correction of errors in soil texture in the 2011 input

data, resulting in a small decrease in emissions of 36 kt CO<sub>2</sub> eq (Table 6–7).

#### 6.4.1.4.6. Planned Improvements

There is no immediate plan in place aimed at improving emission estimates for this source. Further uncertainty work will be carried out to establish trend uncertainty over the medium term.

### 6.4.1.5. Cultivation of Organic Soils (Histosols)

#### 6.4.1.5.1. Source Category Description

Cultivation of organic soils (histosols) for crop production usually involves drainage, lowering the water table and increasing aeration, which enhance the decomposition of organic matter and nitrogen mineralization. The enhancement of decomposition upon the cultivation of histosols can result in greater denitrification and nitrification, and thus higher N<sub>2</sub>O production (Mosier et al. 1998).

#### 6.4.1.5.2. Methodological Issues

The IPCC Tier 1 methodology (IPCC 2000) is used to estimate N<sub>2</sub>O emissions from cultivated organic soils. Emissions of N<sub>2</sub>O 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 surveyed in the *Census of Agriculture*. Consultations with numerous soil and crop specialists across Canada have resulted in an estimated area of 16 kha of cultivated organic soils in Canada, a constant level for the period 1990–2012 (Liang et al. 2004a).

#### 6.4.1.5.3. Uncertainties and Time Series Consistency

For N<sub>2</sub>O emissions from organic soils, the uncertainty analysis considered the uncertainty in organic soil areas and the uncertainty in the default emission factor.

The estimate of N<sub>2</sub>O emissions of 0.06 Mt CO<sub>2</sub> eq from organic soils in 2012 lies within an uncertainty range of 0.01 Mt CO<sub>2</sub> eq (–79%) to 0.12 Mt CO<sub>2</sub> eq (+96%) (Table 6–6). The main source of uncertainty is in the IPCC Tier 1 default emission factor.

The same methodology and emission factors are used for the entire time series (1990–2012).

#### 6.4.1.5.4. QA/QC and Verification

This category has undergone Tier 1-level QC checks as elaborated in the QA/QC plan (Annex 6) in a manner consistent with IPCC

Good Practice Guidance. The activity data, methodologies, and changes to methodologies are documented and archived in both paper and electronic form.

#### 6.4.1.5.5. Recalculations

There were no recalculations in this source of emission estimates over the last two years.

#### 6.4.1.5.6. Planned Improvements

There is no immediate plan in place aimed at improving emission estimates from this source. Further uncertainty work will be carried out to establish trend uncertainty over the medium term.

### 6.4.1.6. Changes in N<sub>2</sub>O Emissions from Adoption of No-Till and Reduced Tillage

#### 6.4.1.6.1. Source Category Description

This category is not derived from additional nitrogen inputs (i.e. fertilizer, manure or crop residue); rather, it is implemented as modifications to N<sub>2</sub>O emission factors due to the change from conventional to conservation tillage practices—namely, reduced tillage (RT) and no-tillage (NT).

#### 6.4.1.6.2. Methodological Issues

Compared with conventional or intensive tillage (IT), direct seeding or NT as well as RT change several factors that influence N<sub>2</sub>O production, including decomposition of soil organic matter, soil carbon and nitrogen availability, soil bulk density, and water content (McConkey et al. 1996, 2003; Liang et al. 2004b). As a result, compared with conventional tillage, conservation tillage (i.e. RT and NT) generally reduces N<sub>2</sub>O emissions for the Prairies (Malhi and Lemke 2007), but increases N<sub>2</sub>O emissions for the non-Prairie regions of Canada (Rochette et al. 2008a). The net result across the country amounts to a small reduction in emissions. This reduction is reported separately, as a negative estimate (Table 6–1).

Changes in N<sub>2</sub>O emissions resulting from the adoption of NT and RT are estimated through modifications of emission factors for synthetic fertilizers, manure nitrogen applied to cropland, and crop residue nitrogen decomposition. This subcategory is kept separate from the fertilizer and crop residue decomposition source categories to preserve the transparency in reporting; however, this separation causes negative emissions to be reported. An empirically derived tillage factor ( $F_{TILL}$ ), defined as the ratio of mean N<sub>2</sub>O fluxes on NT or RT to mean N<sub>2</sub>O fluxes on IT ( $N_{2O_{NT}}/N_{2O_{IT}}$ ), represents the effect of NT or RT on N<sub>2</sub>O emissions (see Annex 3.3).



### 6.4.1.6.3. Uncertainties and Time-Series Consistency

For N<sub>2</sub>O emissions from adoption of conservation tillage practices, the uncertainty analysis considered the uncertainty in tillage practice areas, manure management factors defined in Sections 6.3.2.3 and 6.4.1.2.3, and the uncertainty defined in the country-specific methodology (Rochette et al. 2008b) used to develop N<sub>2</sub>O emission factors as noted in Section 6.4.1.1.3.

The estimate of N<sub>2</sub>O emission reductions of -1.3 Mt CO<sub>2</sub> eq from conservation tillage practices in 2012 lies within an uncertainty range of -44% to +55% based on the uncertainty range of combined emissions of tillage, irrigation and summerfallow practices (Table 6–6). Tillage practice calculations are dependent on all soil emission calculations, and uncertainty is therefore influenced by all factors denoted in previous uncertainty sections, in particular the emission factor modifier for tillage (RF<sub>TILL</sub>).

The same methodology and emission factors are used for the entire time series (1990–2012).

### 6.4.1.6.4. QA/QC and Verification

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

### 6.4.1.6.5. Recalculations

Re-levelling of crop areas as a result of integrating values from the 2011 census, which modified the distribution of fertilizer N among ecodistricts, resulted in the recalculation of conservation

tillage areas for the entire time series. Furthermore, conservation tillage areas after 2006 had been extrapolated based on the 2001 to 2006 areas, and these areas were recalculated for the 2006 to 2011 period based on the 2011 census. As noted above, tillage practice calculations are dependent on all soil emission calculations, and recalculations are a function of all factors denoted in previous recalculation sections. These changes resulted in a very small recalculation of -5.6 kt CO<sub>2</sub> eq in 1990 and a larger recalculation of 111 kt CO<sub>2</sub> eq in 2011. Although there are large changes in the trend for this emission source category, there is little impact on the total agricultural emission estimates (Table 6–8).

### 6.4.1.6.6. Planned Improvements

There is no immediate plan in place aimed at improving emission estimates from this source. However, work is ongoing to develop level and trend uncertainty estimates using the IPCC Tier 2 method. Further uncertainty work will be carried out to establish trend uncertainty over the medium term.

## 6.4.1.7. N<sub>2</sub>O Emissions Resulting from Summerfallowing

### 6.4.1.7.1. Source Category Description

This category is not derived from additional nitrogen input but reflects changes in soil conditions that affect N<sub>2</sub>O emissions. Summerfallow (SF) is a farming practice typically used in the Prairie region to conserve soil moisture by leaving the soil unseeded for an entire growing season in a crop rotation. During the fallow year, several soil factors may stimulate N<sub>2</sub>O emissions relative to a cropped situation, such as higher soil water content, higher soil temperature, and greater availability of soil carbon and nitrogen (Campbell et al. 1990, 2005).

**Table 6–8 Recalculations of Estimates of N<sub>2</sub>O Emissions and Their Impact on Emissions Trend, and Total Agricultural Emissions from Conservation Tillage Practices, Summerfallow and Irrigation**

Emission Source	Year	Submission Year	Category Emissions (Mt CO <sub>2</sub> eq)	Change in Emissions (kt CO <sub>2</sub> eq)	Relative Change Category Emissions (%)	Change Agricultural Emissions Total (%)	Trend of Source Category Emissions (%) <sup>1</sup>
Conservation Tillage Practices	1990	2013	-0.30	-5.6	1.9%	-0.01%	310 (2013)
		2014	-0.30				
	2011	2013	-1.21	111	-9.2%	0.21%	260 (2014)
		2014	-1.10				
Summerfallow	1990	2013	1.36	20	1.5%	0.04%	58 (2013)
		2014	1.38				
	2011	2013	0.57	-75	-13%	-0.14%	63 (2014)
		2014	0.50				
Irrigation	1990	2013	0.28	-0.2	-0.1%	0.00%	44 (2013)
		2014	0.28				
	2011	2013	0.41	-33	-8.1%	-0.06%	32 (2014)
		2014	0.37				

Notes:

1. Numbers in parentheses indicate submission year in which the change in trend is calculated.



#### 6.4.1.7.2. Methodological Issues

Experimental studies have shown that N<sub>2</sub>O emissions in fallow fields are not statistically different from emissions on continuously cropped fields (Rochette et al. 2008b). Omitting areas under SF in calculations of N<sub>2</sub>O emissions because no crops are grown or fertilizer applied could lead to underestimating total N<sub>2</sub>O emissions. The emissions from SF land are therefore calculated through a country-specific method by summing emissions from fertilizer nitrogen, manure nitrogen application to annual crops and crop residue nitrogen for a given ecodistrict and multiplying the sum by the proportion of that ecodistrict area under SF (Rochette et al. 2008b). A more detailed description of the approach is provided in Annex 3.3. This subcategory is reported separately from the Synthetic Nitrogen Fertilizers, Animal Manure Applied as Fertilizers and Crop Residue Decomposition source categories to enhance the transparency of the reporting process.

#### 6.4.1.7.3. Uncertainties and Time-Series Consistency

For N<sub>2</sub>O emissions from summerfallow, the uncertainty analysis considered the uncertainty in summerfallow areas, manure management factors defined in Sections 6.3.2.3 and 6.4.1.2.3, crop residue decomposition defined in Section 6.4.1.2.3, and the uncertainty defined in the country-specific methodology (Rochette et al. 2008b) used to develop N<sub>2</sub>O emission factors as noted in Section 6.4.1.1.3.

The estimate of N<sub>2</sub>O emissions of 0.49 Mt CO<sub>2</sub> eq from summerfallow land in 2012 lies within an uncertainty range of -44% to +55%, based on the uncertainty range of combined emissions of tillage, irrigation and summerfallow practices (Table 6-6). Summerfallow emission calculations overlie all soil emission calculations, and uncertainty is therefore influenced by all factors denoted in previous uncertainty sections, in particular the emission factor modifier for tillage (RF<sub>TILL</sub>).

The same methodology and emission factors are used for the entire time series (1990–2012).

#### 6.4.1.7.4. QA/QC and Verification

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

#### 6.4.1.7.5. Recalculations

As was the case with tillage, re-leveling of crop areas to integrate values from the 2011 census, which modified the distribution of fertilizer N among ecodistricts, also affected the recalculation

of summerfallow areas for the entire time series, including the extrapolation for the 2006 to 2011 period. Summerfallow calculations are also dependent on all soil emission calculations, and recalculations are a function of all factors denoted in previous recalculation sections. These changes resulted in a recalculation of 20 kt CO<sub>2</sub> eq in 1990 and -75 kt CO<sub>2</sub> eq in 2011, and although there are large changes in the trend for this emission source category, there is little impact on the total agricultural emission estimates (Table 6-8).

#### 6.4.1.7.6. Planned Improvements

There is no immediate plan in place aimed at improving emission estimates from this source. Further uncertainty work will be carried out to establish trend uncertainty over the medium term.

#### 6.4.1.8. N<sub>2</sub>O Emissions from Irrigation

##### 6.4.1.8.1. Source Category Description

Similar to tillage practices and summerfallow, the effect of irrigation on N<sub>2</sub>O emissions is not derived from additional nitrogen input but reflects changes in soil conditions that affect N<sub>2</sub>O emissions. Higher soil water content under irrigation increases the potential for N<sub>2</sub>O emissions through increased biological activity, reducing soil aeration (Jambert et al. 1997) and thus enhancing denitrification.

##### 6.4.1.8.2. Methodological Issues

The methodology is country specific and is based on the assumptions that 1) irrigation water stimulates N<sub>2</sub>O production in a way similar to rainfall water and 2) irrigation is applied at rates such that amounts of precipitation plus those of irrigation water are equal to the potential evapotranspiration at the local conditions. Consequently, the effect of irrigation on N<sub>2</sub>O emissions from agricultural soils was estimated using an EF<sub>BASE</sub> estimated at a P/PE = 1 (precipitation/potential evapotranspiration, EF<sub>BASE</sub> = 0.017 N<sub>2</sub>O-N/kg N) for the irrigated areas of a given ecodistrict. To improve the transparency, the effect of irrigation on soil N<sub>2</sub>O emissions is also reported separately from other source categories.

##### 6.4.1.8.3. Uncertainties and Time-Series Consistency

For N<sub>2</sub>O emissions from irrigation, the uncertainty analysis considered the uncertainty in irrigation areas, manure management factors defined in Sections 6.3.2.3 and 6.4.1.2.3, and the uncertainty defined in the country-specific methodology (Rochette et al. 2008b) used to develop N<sub>2</sub>O emission factors as noted in Section 6.4.1.1.3.

The estimate of N<sub>2</sub>O emissions of 0.4 Mt CO<sub>2</sub> eq from irrigated land in 2012 lies within an uncertainty range of -44% to +55% based on the uncertainty range of combined emissions of tillage, irrigation and summerfallow practices (Table 6–6). The irrigated land emission factor for a given ecodistrict is a function of all soil emission factor calculations, and uncertainty is therefore influenced by all factors denoted in previous uncertainty sections, in particular the slope and intercept of the P/PE regression equation.

The same methodology and emission factors are used for the entire time series (1990–2012).

#### 6.4.1.8.4. QA/QC and Verification

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

#### 6.4.1.8.5. Recalculations

Re-levelling of crop areas to integrate values from the 2011 census also affected the recalculation of irrigation areas for the entire time series, including the extrapolation for the 2006 to 2011 period. Irrigation calculations are also dependent on all soil emission calculations, and recalculations are a function of all factors denoted in previous recalculation sections. These changes resulted in a recalculation of -0.2 kt CO<sub>2</sub> eq in 1990 and -33 kt CO<sub>2</sub> eq in 2011 (Table 6–8).

#### 6.4.1.8.6. Planned Improvements

There is no immediate plan in place aimed at improving emission estimates from this source. Further uncertainty work will be carried out to establish trend uncertainty over the medium term.

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

#### 6.4.2.1. Source Category Description

When manure is excreted on pasture, range and paddock by grazing animals, nitrogen in the manure undergoes transformations, such as ammonification, nitrification and denitrification. During these transformation processes, N<sub>2</sub>O can be emitted.

#### 6.4.2.2. Methodological Issues

The emissions from manure excreted by grazing animals are calculated using the IPCC Tier 1 methodology (IPCC/OECD/IEA 1997). Emissions are calculated for each animal category by

multiplying the number of grazing animals for that category by the appropriate nitrogen excretion rate and by the fraction of manure nitrogen available for conversion to N<sub>2</sub>O.

The animal population data are the same as those used in the Enteric Fermentation category (see Section 6.2). The number of grazing animals for each category or subcategory is calculated using the total population multiplied by the fraction of animals grazed on pasture, range and paddock. The nitrogen excretion rates are based on the IPCC (2006) defaults. The fraction of manure nitrogen available for conversion to N<sub>2</sub>O is calculated as the percentage of total manure nitrogen produced on pasture, range and paddock multiplied by the IPCC (2006) default values of 0.02 kg N<sub>2</sub>O-N/kg N for cattle and swine, and 0.01 kg N<sub>2</sub>O-N/kg N for sheep/lamb, goat and horse.

#### 6.4.2.3. Uncertainties and Time-Series Consistency

For N<sub>2</sub>O emissions from pasture, range and paddock, the uncertainty analysis considered the uncertainty in the parameters defined in the Tier 1 methodology of the 2006 IPCC Guidelines and in the proportion of animals on pasture systems. Animal populations and characterizations were identical to those used in the analysis of enteric fermentation and manure management CH<sub>4</sub> defined in Sections 6.2.3 and 6.3.1.3.

The estimate of N<sub>2</sub>O emissions of 2.7 Mt CO<sub>2</sub> eq from pasturing Canadian livestock in 2012 lies within an uncertainty range of 1.1 Mt CO<sub>2</sub> eq (-60%) to 4.7 Mt CO<sub>2</sub> eq (+75%) (Table 6–6). Most uncertainty is associated with the IPCC Tier 1 emission factor (-100% to +200% uncertainty).

The same methodology and emission factors are used for the entire time series (1990–2012).

#### 6.4.2.4. QA/QC and Verification

The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form. QC checks and cross-checks have been carried out to identify data entry errors and calculation errors. In general, there are very few data available on the quantity of N<sub>2</sub>O emissions from the manure on pasture, range and paddock from grazing animals in Canada. Therefore, it is extremely difficult to verify how well the IPCC emission factors reflect Canadian conditions.

#### 6.4.2.5. Recalculations

The integration of 2011 Census of Agriculture (Statistics Canada 2012) population numbers noted in Section 6.2.5 resulted in a decrease in emissions from 2006 to 2011, with a maximum recalculation in 2011 of -87 kt CO<sub>2</sub> eq (Table 6–9), driven by the decrease in populations of cattle. The increasing trend in emis-

**Table 6–9 Recalculations of Estimates of N<sub>2</sub>O Emissions and Their Impact on Emissions Trend, and Total Agricultural Emissions from Pasture, Range and Paddock Emissions, Indirect Emissions, Volatilization and Redeposition and Leaching, Erosion and Runoff**

Emission Source	Year	Submission Year	Category Emissions (Mt CO <sub>2</sub> eq)	Trend of Source Category Emissions (%) <sup>1</sup>	Change in Emissions (kt CO <sub>2</sub> eq)	Relative Change Category Emissions (%)	Change Agricultural Emissions Total (%)
Pasture, Range and Paddock Emissions	2011	2013	2.72	23			
		2014	2.64	19	-87	-3.2%	-0.16%
Indirect Emissions, Volatilization and Redeposition	2011	2013	2.60	30			
		2014	2.59	29	-7	-0.3%	-0.01%
Indirect Emissions, Leaching, Erosion and Runoff	1990	2013	6.67				
		2014	6.69	24 (2013)	27	0.4%	0.05%
	2011	2013	8.24				
		2014	8.19	22 (2014)	-54	-0.7%	-0.10%

Notes:

1. Numbers in parentheses indicate submission year in which the change in trend is calculated.

sions was reduced by 4%, but overall there was less than a 0.5% decrease in total agricultural emissions.

#### 6.4.2.6. Planned Improvements

Emissions of N<sub>2</sub>O from the Manure Deposited on Pasture, Range and Paddock by grazing animals for Canada are a key source category according to the level assessment. Because of its importance, Canada has initiated a three-year research project, starting in September 2009, to quantify N<sub>2</sub>O emissions from animal manure on pasture, range and paddock by grazing dairy and beef cattle. It is expected that, by the end of this project, Canada will be able to estimate N<sub>2</sub>O emissions for this source using country-specific emission factors. This improvement will also trigger an update of the uncertainty analysis.

### 6.4.3. Indirect Emissions of N<sub>2</sub>O from Soils (CRF Category 4.D.3)

A fraction of the nitrogen from both synthetic fertilizer and manure that are applied to agricultural fields is transported off-site through volatilization in the form of NH<sub>3</sub> and NO<sub>x</sub> and subsequent redeposition or leaching, erosion and runoff. The nitrogen that is transported from the agricultural field in this manner provides additional nitrogen for subsequent nitrification and denitrification to produce N<sub>2</sub>O.

#### 6.4.3.1. Volatilization and Redeposition of Nitrogen

##### 6.4.3.1.1. Source Category Description

When synthetic fertilizer or manure is applied to cropland, a portion of the nitrogen is lost through volatilization in the form of NH<sub>3</sub> or NO<sub>x</sub>, which can be redeposited elsewhere and undergo

further transformation, resulting in N<sub>2</sub>O emissions off-site. The quantity of this volatilized nitrogen depends on a number of factors, such as rates of fertilizer and manure nitrogen application, fertilizer types, methods and time of nitrogen application, soil texture, rainfall, temperature, and soil pH.

#### 6.4.3.1.2. Methodological Issues

There are few published scientific data that actually determine N<sub>2</sub>O emissions from volatilization and redeposition of NH<sub>3</sub> and NO<sub>x</sub>. Leached or volatilized N may not be available for the process of nitrification and denitrification for many years, particularly in the case of N leaching into groundwater. Even though Indirect Soil N<sub>2</sub>O Emissions from Agricultural Soils are a key source category for level and trend assessments for Canada, there are difficulties in defining the duration and boundaries for this source of emissions because no standardized method for deriving the IPCC Tier 2 emission factors is provided by the IPCC Guidelines.

The IPCC Tier 1 methodology is used to estimate indirect N<sub>2</sub>O emissions due to volatilization and redeposition of nitrogen from synthetic N fertilizers and animal manure. The amount of synthetic fertilizer and manure nitrogen is multiplied by the fraction of N that is volatilized as NH<sub>3</sub>-N and NO<sub>x</sub>-N and then by an emission factor. The amount of nitrogen applied is obtained from yearly fertilizer sales data, which are available from Statistics Canada, and from the amounts of manure nitrogen excreted by animals (see Annex 3.3). The amount of nitrogen that volatilizes is assumed to be 10% of the total amount of synthetic fertilizer applied, 20% of the applied manure nitrogen to cropland, and from 12% to 48% of excreted manure nitrogen during handling and storage (IPCC 2006). The default IPCC emission factor, 0.01 kg N<sub>2</sub>O-N/kg N, is used to derive the N<sub>2</sub>O emission estimate (IPCC/OECD/IEA 1997).

### 6.4.3.1.3. Uncertainties and Time-Series Consistency

The Monte Carlo uncertainty analysis of indirect N<sub>2</sub>O emissions from volatilization and redeposition of N considered the uncertainty in the parameters defined in the Tier 1 methodology of the 2006 IPCC Guidelines, and the uncertainty in the estimate of total N.

The estimate of N<sub>2</sub>O emissions of 2.8 Mt CO<sub>2</sub> eq from volatilization and redeposition in 2012 lies within an uncertainty range of 0.7 Mt CO<sub>2</sub> eq (-74%) to 5.7 Mt CO<sub>2</sub> eq (+110%) (Table 6–6). Most uncertainty is associated with the IPCC Tier 1 emission factor of 1% (uncertain range, 0.2% to 5%).

The same methodology and emission factors are used for the entire time series (1990–2012).

### 6.4.3.1.4. QA/QC and Verification

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

### 6.4.3.1.5. Recalculations

The integration of 2011 *Census of Agriculture* (Statistics Canada 2012) population numbers noted in Section 6.2.5 resulted in a decrease in emissions from 2006 to 2011, with a maximum recalculation in 2011 of -7 kt CO<sub>2</sub> eq (Table 6–9), driven by the decrease in populations of cattle, and had very little impact on total agricultural emissions or emission trends.

### 6.4.3.1.6. 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

### 6.4.3.2.1. Source Category Description

When synthetic fertilizer, manure and crop residue are added to cropland, a portion of the nitrogen from these sources is lost through leaching, erosion and runoff. The magnitude of this loss depends on a number of factors, such as application rate and method, crop type, soil texture, rainfall and landscape. This portion of lost nitrogen can further undergo transformations, such as nitrification and denitrification, and can produce N<sub>2</sub>O emissions off-site.

### 6.4.3.2.2. Methodological Issues

There are few published scientific data that determine N<sub>2</sub>O emissions from leaching, erosion and runoff in Canada. Similar to N<sub>2</sub>O emissions from volatilization and redeposition of NH<sub>3</sub> and NO<sub>x</sub>, this source is poorly defined because no standardized method for deriving the IPCC Tier 2 emission factors is provided by the IPCC Guidelines.

A modified IPCC Tier 1 methodology is used to estimate indirect N<sub>2</sub>O emissions from leaching, runoff and erosion of fertilizers, manure and crop residue nitrogen from agricultural soils. Indirect N<sub>2</sub>O emissions from runoff and leaching of nitrogen at the ecodistrict level are estimated using FRAC<sub>LEACH</sub> multiplied by the amount of synthetic fertilizer nitrogen, non-volatilized manure nitrogen and crop residue nitrogen and by an emission factor of 0.025 kg N<sub>2</sub>O-N/kg N (IPCC 2000).

The default value for the fraction of nitrogen that is lost through leaching and runoff (FRAC<sub>LEACH</sub>) in the Revised 1996 Guidelines is 0.3; however, FRAC<sub>LEACH</sub> can reach values as low as 0.05 in regions where rainfall is much lower than potential evapotranspiration (IPCC 2006), such as in the Prairie region of Canada. Accordingly, it is assumed that FRAC<sub>LEACH</sub> would vary among ecodistricts from a low of 0.05 to a high of 0.3. For ecodistricts with no moisture deficit during the growing season (May through October), the maximum FRAC<sub>LEACH</sub> value of 0.3 recommended by the IPCC (2006) Guidelines is assigned. The minimum FRAC<sub>LEACH</sub> value of 0.05 is assigned to ecodistricts with the greatest moisture deficit. For the remaining ecodistricts, FRAC<sub>LEACH</sub> is estimated by the linear extrapolation of the two end-points described above.

### 6.4.3.2.3. Uncertainties and Time-Series Consistency

The Monte Carlo uncertainty analysis of indirect N<sub>2</sub>O emissions from leaching, erosion and runoff of N considered the uncertainty in the parameters defined in the Tier 1 methodology of the Revised 1996 IPCC Guidelines, and the uncertainty in the estimate of total N.

The estimate of N<sub>2</sub>O emissions of 8.9 Mt CO<sub>2</sub> eq from leaching, erosion and runoff of N in 2012 lies within an uncertainty range of 1.8 Mt CO<sub>2</sub> eq (-80%) to 20 Mt CO<sub>2</sub> eq (+120%) (Table 6–6). Most uncertainty is associated with the IPCC Tier 1 emission factor of 2.5% of total N leached (uncertainty range of 0.2%–12%).

The same methodology and emission factors are used for the entire time series (1990–2012).

### 6.4.3.2.4. QA/QC and Verification

This category has undergone Tier 1-level QC checks as elaborated in the QA/QC plan (refer to details and references in Annex 6) in a manner consistent with IPCC Good Practice Guidance. The

activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

#### 6.4.3.2.5. Recalculations

Estimates of indirect emissions from leaching, erosion and runoff were directly affected by improvements to the estimate of the P/PE ratio for ecodistricts and the redistribution of fertilizer N among ecodistricts.

Total recalculations consisted of an increase of 27 kt CO<sub>2</sub> eq in 1990, and a decrease of -54 kt CO<sub>2</sub> eq in 2011, decreasing the category emission trend by 2% but having a very small impact on total agricultural emission estimates (Table 6–9).

#### 6.4.3.2.6. Planned Improvements

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

### 6.5. CH<sub>4</sub> and N<sub>2</sub>O Emissions from Field Burning of Agricultural Residues (CRF Category 4.F)

#### 6.5.1. Source Category Description

Crop residues are sometimes burned in Canada, as a matter of convenience and disease control through residue removals, even though this practice has declined in recent years because of concerns over soil quality and environmental issues. Crop residue burning is a net source of CH<sub>4</sub>, CO, NO<sub>x</sub> and N<sub>2</sub>O (IPCC/OECD/IEA 1997).

#### 6.5.2. Methodological Issues

There are no published data on emissions of N<sub>2</sub>O and CH<sub>4</sub> from field burning of agricultural residues in Canada. Thus, the IPCC default emission factors and parameters from the Good Practice Guidance (IPCC 2000) were used for estimating emissions.

A complete time series of activity data on the type and the percent of each crop residue subject to field burning was developed based on Statistics Canada's *Farm Environmental Management Survey* (FEMS)<sup>2</sup> and on expert consultations (Coote et al. 2008).

Crop-specific parameters, such as moisture content of the crop product and ratio of above-ground crop residue to crop product, required for estimating the amount of crop residue burned, were

obtained from Janzen et al. (2003), and are consistent with the values used to estimate emissions from crop residue decomposition.

#### 6.5.3. Uncertainties and Time-Series Consistency

The uncertainties associated with CH<sub>4</sub> and N<sub>2</sub>O emissions from field burning of agricultural residues were determined using an IPCC Tier 1 method (IPCC 2006).

The uncertain quantities associated with CH<sub>4</sub> and N<sub>2</sub>O emissions from field burning of agricultural residues are the amount of field crop residues burned and emission factors. The uncertainty in the amount of crop residues burned is estimated, based on the area of specific seeded crop, to be ±50% (Coote et al. 2008). The uncertainties associated with the emission factors are not reported in the 2006 IPCC Guidelines but are assumed to be similar to those associated with burning of Savanna and grassland: ±40% for CH<sub>4</sub> and ±48% for N<sub>2</sub>O (IPCC 2006). The level and trend uncertainties for CH<sub>4</sub> emission estimates from 1990 to 2012 were estimated to be ±29% and ±23%, respectively. The level and trend uncertainties for N<sub>2</sub>O emission estimates were estimated to be ±29% and ±23%, respectively.

#### 6.5.4. QA/QC and Verification

CH<sub>4</sub> and N<sub>2</sub>O emissions from field burning of agricultural residues have undergone Tier 1-level QC checks as elaborated in the QA/QC plan (Annex 6) in a manner consistent with IPCC Good Practice Guidance. The activity data and methodologies are documented and archived in both paper and electronic form.

#### 6.5.5. Recalculations

In this submission, there are no recalculations from this emission source.

#### 6.5.6. Planned Improvements

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

<sup>2</sup> <http://www.statcan.gc.ca/cgi-bin/imdb/p2SV.pl?Function=getSurvey&SDDS=5044&lang=en&db=imdb&adm=8&dis=2#a4>



# Chapter 7

## Land Use, Land-use Change and Forestry (CRF Sector 5)

### 7.1. Overview

The Land Use, Land-use Change and Forestry (LULUCF) Sector reports greenhouse gas (GHG) fluxes between the atmosphere and Canada's managed lands, as well as those associated with land-use change. The assessment includes emissions and removals of CO<sub>2</sub>, additional emissions of CH<sub>4</sub>, N<sub>2</sub>O and CO due to wildfires and controlled burning, and N<sub>2</sub>O released following land conversion to cropland. All emissions from and removals by the LULUCF Sector are excluded from the national totals.

In 2012, the estimated net GHG flux in the LULUCF Sector, calculated as the sum of CO<sub>2</sub><sup>1</sup> emissions and removals and non-CO<sub>2</sub> emissions, amounted to emissions of 41 Mt. If these were included in the national totals, they would increase the total Canadian GHG emissions by about 6%. Table 7–1 provides the net flux estimates for 1990 and recent years in the major LULUCF Sector categories and subcategories.

In view of the high interannual variability displayed by some categories and its effect on the sectoral trends, the reader is cautioned against interpreting the figures in Table 7–1 as trends. The full time series of LULUCF Sector estimates is available in Table 10–10 of the common reporting format (CRF) series.

The Forest Land category has the largest influence on sectoral totals. The net fluxes are negative (removals) in 12 of the 23 years of the time series, and positive (emissions) for the remainder. Years with a net positive flux increased in frequency in the latter part of the time series, reflecting the ongoing impact of insect disturbances in western Canada. Net emissions are particularly large in years where large areas of managed forests were burned by wildfire. As a consequence, the interannual variability is high, with net category totals fluctuating between –115 Mt (1992) and 180 Mt (1995) (see Figure 2-12 ). These fluctuations are carried over to the LULUCF Sector totals, which vary between net

1 Unless otherwise indicated, all emissions and removals are in CO<sub>2</sub> equivalents.

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

Sectoral Category	Net GHG Flux (kt CO <sub>2</sub> eq) <sup>4</sup>							
	1990	2000	2005	2008	2009	2010	2011	2012
<b>Land Use, Land-Use Change and Forestry TOTAL<sup>1</sup></b>	<b>-71 000</b>	<b>-52 000</b>	<b>53 000</b>	<b>-17 000</b>	<b>-27 000</b>	<b>76 000</b>	<b>77 000</b>	<b>41 000</b>
<b>a. Forest Land</b>	<b>-98 000</b>	<b>-65 000</b>	<b>44 000</b>	<b>-26 000</b>	<b>-35 000</b>	<b>68 000</b>	<b>69 000</b>	<b>32 000</b>
Forest Land Remaining Forest Land	-97 000	-64 000	45 000	-25 000	-34 000	69 000	69 000	33 000
Land Converted to Forest Land	-1 000	-1 000	-900	-800	-800	-700	-700	-700
<b>b. Cropland</b>	<b>12 000</b>	<b>280</b>	<b>-3 800</b>	<b>-4 900</b>	<b>-4 900</b>	<b>-5 000</b>	<b>-4 800</b>	<b>-4 900</b>
Cropland Remaining Cropland	-1 000	-7 000	-10 000	-10 000	-10 000	-10 000	-10 000	-10 000
Land Converted to Cropland	13 000	7 000	6 000	5 500	5 500	5 400	5 700	5 600
<b>c. Grassland</b>	<b>600</b>	<b>900</b>	<b>800</b>	<b>400</b>	<b>400</b>	<b>300</b>	<b>600</b>	<b>1 400</b>
Grassland Remaining Grassland	600	900	800	400	400	300	600	1 400
Land Converted to Grassland	NO	NO	NO	NO	NO	NO	NO	NO
<b>d. Wetlands</b>	<b>5 000</b>	<b>3 000</b>	<b>3 000</b>	<b>3 000</b>	<b>3 000</b>	<b>3 000</b>	<b>3 000</b>	<b>3 000</b>
Wetlands Remaining Wetlands	1 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000
Land Converted to Wetlands	4 000	700	900	800	800	700	700	700
<b>e. Settlements</b>	<b>9 000</b>	<b>9 000</b>	<b>10 000</b>	<b>10 000</b>	<b>9 000</b>	<b>10 000</b>	<b>10 000</b>	<b>10 000</b>
Settlements Remaining Settlements	-100	-200	-200	-200	-200	-200	-200	-200
Land Converted to Settlements	9 000	9 000	10 000	10 000	10 000	10 000	10 000	10 000
<b>Forest conversion (memo item)<sup>2</sup></b>	<b>25 000</b>	<b>18 000</b>	<b>19 000</b>	<b>19 000</b>	<b>18 000</b>	<b>18 000</b>	<b>18 000</b>	<b>18 000</b>
<b>Grassland conversion (memo item)<sup>2,3</sup></b>	<b>200</b>	<b>200</b>	<b>200</b>	<b>200</b>	<b>200</b>	<b>200</b>	<b>200</b>	<b>200</b>

Notes:

1. Totals may not add up due to rounding. Annex 9 describes the rounding protocol.

2. Already included in land converted to cropland, land converted to wetlands, and land converted to settlements; and in cropland remaining cropland and wetlands remaining wetlands (for residual emissions post-20 years, 10 years for reservoirs).

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

4. Negative sign indicates net removals of CO<sub>2</sub> from the atmosphere.

NE = Not estimated, NO=Not Occurring



emissions and net removals, depending on the net flux from managed forests.

The Cropland category displays a steady trend towards decreasing emissions in the period 1990–2006, from emissions of 12 Mt in 1990 to net removals of 5 Mt in 2006. This trend is the result of changes in agricultural land management practices in western Canada, such as the extensive adoption of conservation tillage practices and reduction in summerfallow. Since 2006, net removals have tended to remain constant around 5 Mt, as the adoption of conservation tillage and reduction of summerfallow begin to level off and the soil sink approaches equilibrium. In addition, higher emissions resulting from an increase in the proportion of annual crops within crop production systems in more recent years partially offset the removals. A decline in emissions from the conversion of forest to cropland also contributes to this trend.

Over the 1990–2012 period, net fluxes in the Wetlands category (managed peatlands and flooded lands) fluctuate between 2.5 Mt and 5.4 Mt. Emissions from land converted to wetlands declined from 4 Mt to 0.7 Mt during the period. Current emissions from flooded lands account for 55% of all emissions in the Wetlands category, compared to a share of 84% in 1990.

The LULUCF Sector continues to draw on the best Canadian expertise within Canada's national multidisciplinary framework for monitoring, accounting and reporting emissions and removals in managed lands. The Monitoring, Accounting and Reporting System (MARS) framework<sup>2</sup> 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. Planned improvements include incorporating carbon storage in harvested wood products, the completion of formal and documented uncertainty estimates in all LULUCF categories, and quantification of missing land use and land-use change categories. Expert Review Teams (ERTs) that examined Canada's previous inventory submissions have made various recommendations for the

LULUCF Sector. Table 7–2 lists recommendations that have been addressed in this submission. This submission does not incorporate any change in response to the recommendations of the ERTs that reviewed Canada's 2013 submission, as the review report was not yet available at the time this submission was prepared.

This year's submission includes several changes to forest-related estimates, including a new forest model version, revisions to forest areas affected by natural disturbances, incorporation of a new provincial forest inventory and updated harvest activity data. There was also integration of Cropland activity data from the 2011 Census of Agriculture, inclusion for the first time in this submission of a new source of emissions from Grassland burning, refined land allocation of areas converted to peat extraction, and new peatland restoration data (Table 7–3). Uncertainty values for the land converted to the Forest Land category are presented for the first time, and forest-related uncertainty estimates have been also updated in this submission.

The remainder of this chapter highlights the salient features of each LULUCF Sector category. Section 7.2 gives an overview of the representation of managed lands; each subsequent section provides a short description of a land category (Sections 7.3–7.7). Section 7.8 is devoted to the cross category estimates of forest conversion to other lands.

## 7.2. Land Category Definition and Representation of Managed Lands

In order to harmonize all land-based estimates, a common definitional framework was elaborated and adopted by all groups involved in estimate preparation. Definitions are consistent with the IPCC (2003) land categories, while remaining relevant to land management practices, prevailing environmental conditions and available data sources in Canada. This framework applies to all LULUCF estimates reported under the Convention.

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*.

<sup>2</sup> First described in the NIR of the 2004 submission and implemented in the 2006 submission.

**Table 7–2 Expert Review Team Recommendations and Actions Taken by Canada**

Expert Review Team Recommendation	Location
Provide information in the NIR on carbon stock changes in areas reported as confidential (ARR 2012)	New footnote in CRF Table 5.B
Provide supporting data to justify the assumption that differences in above-ground biomass before and after grassland conversion to cropland are negligible (ARR 2012)	New data from Bailey and Liang (2013) in Annex 3.4.3.2, Grassland Converted to Cropland
Provide methods and emission estimates from burning of managed grasslands in Canada (ARR 2011)	New section on burning of managed grassland in Section 7.5.1 of NIR, Grassland Remaining Grassland; and Annex 3.4.4, Grassland

Table 7–3 Summary of Changes in the LULUCF Sector

List of Changes	Years Affected
<b>Forest Land</b>	
New model version	Complete time series
Natural disturbances area revisions	Complete time series
Alberta Forest Inventory Update	Complete time series
Revisions to official harvest activity data	2009–2011
<b>Cropland</b>	
Inclusion of 2011 Census of Agriculture	Complete time series
<b>Grassland</b>	
Managed grassland burning	Complete new time series
<b>Wetland</b>	
Change in land allocation for managed peatlands	Complete time series
New peatland restoration activity	2005–2011

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 managed for timber and non-timber resources (including parks) or subject to fire protection. Annex 3.4 provides more detail on the implementation of the “managed forests” definition.

Agricultural land comprises both cropland and agricultural grassland. Cropland includes all lands in annual crops, summerfallow and perennial crops (mostly forage, but also including berries, grapes, nursery crops, vegetables, and fruit trees and orchards). Agricultural grassland is defined as “unimproved” pasture or rangeland that is used only for grazing domestic livestock. It occurs only in geographical areas where the grassland would not naturally regrow to forest if abandoned: the natural 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 un-managed grassland.

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. Managed wetlands are those where human interventions have altered the water table—for example, peatlands drained for peat extraction or flooded lands (IPCC 2003).

Settlements include all built-up land: urban, rural residential, land devoted to industrial and recreational use; roads, rights-of-way and other transportation infrastructure; and resource exploration, extraction and distribution (mining, oil and gas). The diversity of this category has so far precluded an assessment of its extent in the Canadian landscape; however, it is often involved in land conversion, and the impact of forest land conversion to settlements is assessed in this GHG inventory.

Other land comprises areas of rock, ice or bare soil, and all land areas that do not fall into any of the other five categories. Currently, only emissions from the conversion of other land to reservoirs and peatlands are reported, under the Wetlands category.

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 7–4 illustrates the land-use areas (diagonal cells) and cumulative land-use change areas (non-diagonal cells) in 2012. 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 grassland, whereas grassland converted to settlements refers to land conversion of un-managed tundra to settlements in northern Canada. Column totals equal the total land area as reported in the CRF for each category.

The MARS land monitoring system includes the conversion of un-managed forests and grassland to other land categories. Un-managed land converted to any use always becomes

Table 7-4 Land Use and Land-use Change Matrix for the 2012 Inventory Year (Areas in kha)<sup>1</sup>

Initial Land Use	Final Land Use					
	Forest	Cropland	Grassland	Wetlands	Settlements	Other
Forest	231 683	414	NO	66	508	NO
Cropland	72	46 370	NO	NE	NE	NO
Grassland	NO	5	19 <sup>2</sup>	NE	1	NO
Wetlands	NO	NE	NO	414 <sup>2</sup>	NE	NE
Settlements	NO	NE	NO	NO	NE	NO
Other	NO	NO	NO	62	NE	NE

Notes:

1. Non-diagonal cells refer to cumulative areas, i.e., total land converted over the last 20 years (10 years for reservoirs).

2. Only includes areas for which emissions are reported in the CRF.

NE = Not estimated.

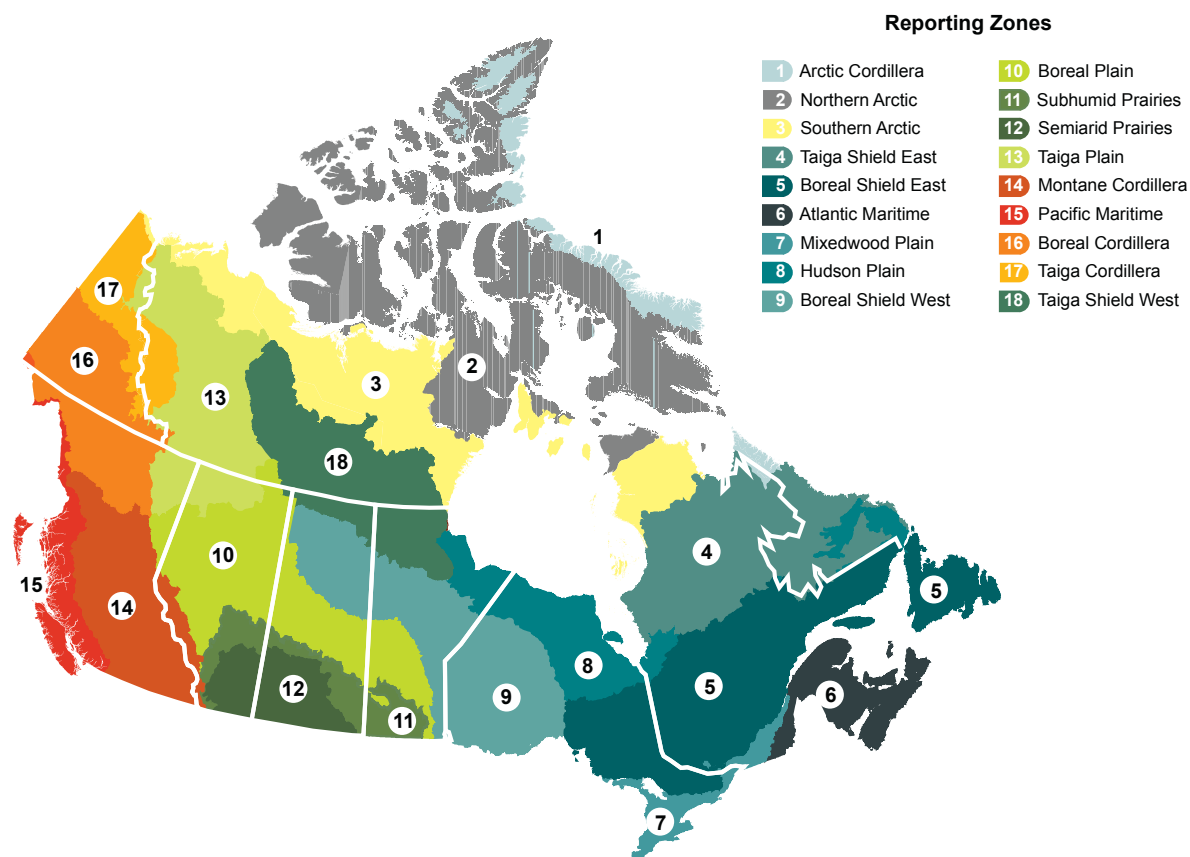
NO = Not occurring.

“managed”; once land has become managed, it does not revert to “un-managed” status, even if management practices are discontinued. Parks and protected areas are included in managed lands.

With a few exceptions (e.g. emissions due to liming), the LULUCF estimates as reported in the CRF tables are spatially attached to “reporting zones” (Figure 7-1). These reporting zones are essentially the same as Canada’s terrestrial ecozones (Marshall

and Shut 1999), with three exceptions: the Boreal Shield and Taiga Shield ecozones are split into their east and west components to form four reporting zones; and the Prairies ecozone is divided into a semi-arid and a subhumid component. Estimates are reported for 17 of the 18 reporting zones, leaving out the northernmost ecozone of Canada: the Arctic Cordillera, where no direct human-induced LULUCF GHG emissions and removals are detected for this sector. More details on the spatial estimation and reporting framework can be found in Annex 3.4.

Figure 7-1 Reporting Zones for LULUCF Estimates



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 of land converted to wetlands (reservoirs) represent a fraction of total reservoir areas (those flooded for 10 years or less), not the total area of reservoirs in Canada.

Similarly, the areas of land conversion reported in the CRF tables refer to the cumulative total land area converted over the last 20 years (10 years for reservoirs) and should not be confused with annual rates of land-use change. The trends observed in the land conversion categories of the CRF (e.g. land converted to forest land, land converted to cropland) result from the balance between land area newly converted to a category and the transfer of lands converted more than 20 years ago (10 years for reservoirs) into the “land remaining land” categories.

## 7.3. Forest Land

Forest and other wooded lands cover 389 million hectares (Mha) of Canadian territory; forest lands alone occupy 348 Mha (NRCan 2010). Managed forests, those under direct human influence, extend to 232 Mha, or 67% of all forests. Four reporting zones (Boreal Shield East, Montane Cordillera, Boreal Plains and Boreal Shield West) account for 68% of managed forests (Table 7–5).

In 2012, the net GHG balance of managed forest land amounted to emissions of 32 Mt (Table 7–1 and CRF Table 7–5). This estimate includes net emissions and removals of CO<sub>2</sub>, as well as N<sub>2</sub>O,

CO and CH<sub>4</sub> emissions from wildfires in managed forests. For the purpose of UNFCCC reporting, managed forest lands are divided into forest land remaining forest land (232 Mha, net emissions of 33 Mt) and land converted to forest land (0.07 Mha, net removals of 0.7 Mt) in 2012.

The managed forest GHG balance is not spatially homogeneous. In 2012, managed forests in the Boreal Plains, Montane Cordillera, Pacific Maritime and Taiga Plain reporting zones were four large net sources of GHGs, while those in the Atlantic Maritime, Boreal Shield East, Boreal Shield West, and Mixedwood Plains were net sinks (Table 7–5). Note that the spatial distribution of emissions and removals is influenced by the occurrence and location of disturbances and would therefore not necessarily be constant in successive years.

### 7.3.1. Forest Land Remaining Forest Land

#### 7.3.1.1. Methodological Issues

Vegetation absorbs CO<sub>2</sub> from the atmosphere through photosynthesis, and some of this carbon is sequestered in standing vegetation (biomass), dead organic matter and soils. CO<sub>2</sub> is returned to the atmosphere by vegetation respiration and the decay, through heterotrophic respiration, of organic matter. The natural CO<sub>2</sub> exchanges between the atmosphere and biota are

Table 7–5 GHG Balance of Managed Forests by Reporting Zone, 2012<sup>1</sup>

Reporting Zone Number	Reporting Zone Name	Managed Forest Area (kha)	Net GHG Balance (Mt CO <sub>2</sub> eq)
1	Arctic Cordillera	–	NA
2	Northern Arctic	–	NA
3	Southern Arctic	–	NA
4	Taiga Shield East	1 100	3
5	Boreal Shield East	55 600	- 38
6	Atlantic Maritime	15 400	- 9
7	Mixedwood Plains	2 700	- 8
8	Hudson Plains	300	-0.60
9	Boreal Shield West	28 800	- 8
10	Boreal Plains	37 800	12
11	Subhumid Prairies	1 800	- 0.4
12	Semiarid Prairies	40	- 0.02
13	Taiga Plains	20 500	30
14	Montane Cordillera	35 500	64
15	Pacific Maritime	13 200	10
16	Boreal Cordillera	16 600	- 22
17	Taiga Cordillera	400	- 0.2
18	Taiga Shield West	1 800	0.4

Notes:

1. Negative sign indicates removal of CO<sub>2</sub> from the atmosphere.

NA = Not applicable.

large fluxes, globally recycling on the order of one seventh of the total atmospheric CO<sub>2</sub> content annually. These large gross fluxes result from the accumulation of minute processes dispersed over vast land areas. Only a small fraction of the carbon (C) taken up by photosynthesis accumulates in ecosystem C pools after all respiratory and disturbance C losses (Stinson et al. 2011).

Human interactions with the land can 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 intended 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, including natural disturbances. Untangling the various cause-and-effect relationships in the long term and short term is still the object of complex scientific inquiries.

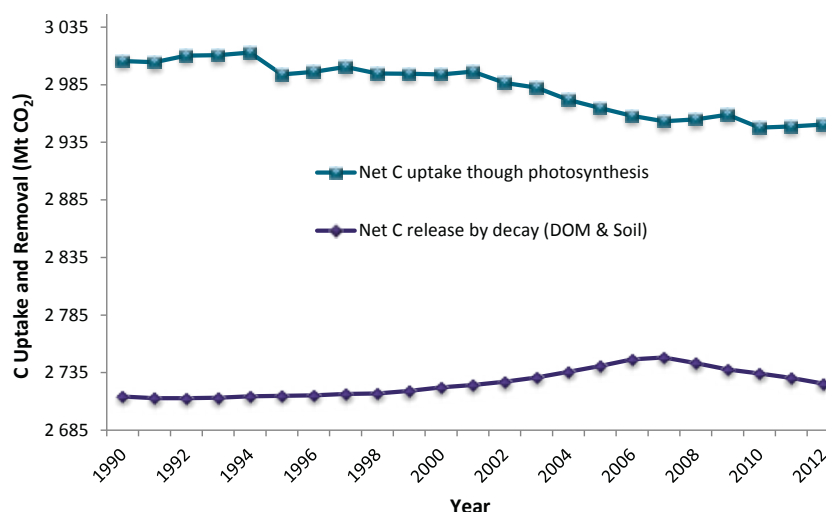
Canada emphasizes that while all efforts are made to provide IPCC-compliant GHG estimates, such estimates may not truly account for direct human effects or accurately reflect where and when emissions occur (Stinson et al. 2011).

Canada applies a Tier 3 methodology for estimating GHG emissions and removals in managed forests. Canada's National Forest Carbon Monitoring, Accounting and Reporting System (NFC-

MARS – Kurz and Apps 2006) includes a model-based approach (Carbon Budget Model of the Canadian Forest Sector, CBM-CFS<sub>3</sub> – Kull et al. 2011; Kurz et al. 2009). This model integrates forest inventory data and yield curves with spatially referenced activity data on forest management and natural disturbances (fires, insect infestations) to estimate forest carbon stocks, stock changes and CO<sub>2</sub> emissions and removals. The model uses regional ecological and climate parameters to simulate carbon transfers among pools, to the forest product sector and to the atmosphere. The conceptual approach remains that recommended by the IPCC (2003), in which net removals or emissions are calculated as the difference between CO<sub>2</sub> uptake by growing trees and emissions from forest management activities (harvesting), heterotrophic respiration and natural disturbances. The interested reader will find additional information on estimation methodology in Annex 3.4.

Carbon stock changes in managed forests are reported in CRF Table 5A, by reporting zone. For any given pool, carbon stock changes include not only exchanges of GHG with the atmosphere, but also the carbon transfers to and from pools, for example its transfer from living biomass to dead organic matter upon stand mortality. Therefore individual carbon stock changes give no indication of the net fluxes between carbon pools in managed forests and the atmosphere. The largest carbon fluxes to and from managed forests consist of net carbon uptake by growing trees and its release due to the decay of organic matter (–3000 and 2700 Mt, respectively, in 2012; see Figure 7–2). The upward trend in dead organic matter (DOM) decay and decline in C uptake over the years 2000–2007 reflect the long-term effect of past disturbances, especially insect epidemics that have left substantial quantities of decaying DOM. Over the last decade,

**Figure 7–2 Large Annual Carbon Fluxes to and from the Atmosphere in Managed Forests, 1990–2012: Net Carbon Uptake (or Net Primary Production) and Release Due to Decay (from Heterotrophic Respiration)**



insect epidemics have affected a total of over 49 Mha<sup>3</sup> of managed forests, with 83% being located in the Montane Cordillera reporting zone and corresponding to the epidemics of Mountain Pine Beetle. In contrast, much of the interannual variability of the GHG budget of managed forests hinges on the occurrence, location and severity of fires. During the 1990–2012 period, annual wildfire emissions fluctuated between 11 and 275 Mt. The consumption of DOM by fires accounts for 77% of immediate emissions; much biomass is killed by forest fires and is thus transferred to the DOM pool, but is not immediately burned. Hence, a large amount of the actual fuel load consists of dead wood and litter on the forest floor. On average, 8% of immediate fire emissions in CO<sub>2</sub> equivalents are in the form of CO, 7% as CH<sub>4</sub>, and 4% in the form of N<sub>2</sub>O.

In order to avoid double counting, estimates of C stock changes in CRF Table 5A exclude carbon emissions emitted as CO<sub>2</sub>, CH<sub>4</sub> and CO due to biomass burning, which are reported in Table 5 (V). Emissions and removals are automatically tallied in CRF Table 5.

In keeping with the IPCC default methodology (IPCC 2003), forest land estimates reflect the assumption that all carbon transferred out of forests in the form of wood products is deemed an immediate emission. Under this assumption, in 2012 the transfer of carbon from forests to harvested wood products (HWP) from forest management activities amounts to emissions of 126 Mt, a decrease of 17% compared to 1990 and of 35% from the peak of 2004. However, this assumption introduces significant temporal inaccuracies in emission patterns, as it omits the long-term C storage in HWP in use and subsequently in landfills, followed by its eventual release (IPCC 2006). This section presents preliminary estimates of the impact of incorporating the long-term C storage in HWP in use.

Estimates presented here were developed using the general framework of the “Production” approach, one of the four approaches to incorporate long-term C storage in HWPs (IPCC 2006). A country-specific model, the Carbon Budget Model Framework for Harvest Wood Products (CBM-FHWP), was developed to monitor and quantify the fate of carbon off-site from the point of harvest. The CBM-FHWP tracks HWP sub-pools and carbon flows between sub-pools through the action of events (e.g. manufacturing, use, trade and disposal). More information on Canada’s application of the production approach and the CBM-FHWP is available in Annex 3.4.

Emissions associated with HWP using both the default and production approach are presented in Table 7–6. The column “Net GHG Flux excluding C removed off-site” shows the net forest flux excluding carbon taken off-site in harvested material (but

including the on-site decay of harvest residues). The next two sets of columns contrast emissions from HWP under two different approaches, and the resulting net emissions or removals in Forest land remaining forest land (FLFL).

In general, incorporating the delay in emissions from HWP due to C storage in commodities increases the net sink or reduces the net source in forest land remaining forest land. It does not remove the interannual variability created by natural disturbances. Under the instant oxidation approach, emissions from HWP simply equal the quantity of C harvested. In contrast, the temporal pattern of emissions under the production approach results from historical commodity production combined with the duration of the economic lives of various commodities. The impact of any significant changes in harvest levels, or in the mix of products, is therefore spread out over several subsequent years and decades as commodities are gradually retired from use. A portion of harvested carbon nevertheless continues to be emitted in the harvest year. In any one year, between 19% and 38% of C in domestically harvested fibre is not stored in commodities and is presumed lost in the processing stream, for simplicity identified as “milling waste.” These emissions can fluctuate with harvest levels, variations in product mix and changes in processing technologies.

The difference in FLFL estimates due to changing the HWP estimation approach is not constant over time; the impact is larger at the beginning of the time series, and decreases over time. This is to be expected, since the HWP pool starts in 1990 and at that time contains no C from historically produced commodities. Over time, C accumulates in the pool of HWP in use, and so emissions from the pool increase (from 57 Mt CO<sub>2</sub> in 1990 to 106 Mt CO<sub>2</sub> in 2012).

### 7.3.1.2. Uncertainties and Time-Series Consistency

#### Uncertainty Estimates

Conducting uncertainty analysis is a significant challenge in complex modelling frameworks such as the one used for modelling forest carbon dynamics, with multiple interactions and dependencies between current and historical events, and among the very large number of model inputs and parameters required to simulate carbon dynamics.

Numerical techniques are used to quantify uncertainties about the outputs of the CBM-CFS3 (Metsaranta et al. 2014). Careful consideration is given to the identification and representation of uncertainty sources in the analysis (see Annex A3.4.2.4 for additional information). Modelling of the entire managed forests of Canada is not done as a single run, but in separate “project runs” whose output is subsequently assembled. For each “project,” 100

3 May include areas repeatedly infested, e.g., a hectare infested in three successive years is counted as three hectares towards the 49 Mha.



**Table 7-6 Net GHG Flux in Forest Land Remaining Forest Land with Two Harvested Wood Products (HWP) Estimation Approaches (Mt CO<sub>2</sub> equivalent<sup>1</sup>)**

Inventory Year	Net GHG Flux excluding C removed off-site	Instant Oxidation Approach <sup>2</sup>		Production Approach <sup>3</sup>	
		Emissions from HWP	Total Net GHG Flux <sup>4,6</sup>	Emissions from HWP	Total Net GHG Flux <sup>5,6</sup>
1990	-250	150	-100	60	-190
1991	-220	150	-70	70	-150
1992	-270	160	-110	80	-190
1993	-220	160	-60	90	-130
1994	-220	170	-50	100	-120
1995	4	180	180	110	110
1996	-220	170	-40	110	-110
1997	-260	180	-80	110	-150
1998	-50	170	120	100	50
1999	-190	190	-4	110	-80
2000	-250	190	-60	120	-140
2001	-230	170	-60	100	-130
2002	-70	180	110	110	40
2003	-120	170	50	100	-20
2004	-70	190	120	120	50
2005	-150	190	40	120	-30
2006	-100	170	70	110	3
2007	-100	150	50	100	-3
2008	-150	130	-20	100	-60
2009	-140	110	-30	100	-50
2010	-60	130	70	110	40
2011	-70	140	70	110	40
2012	-90	130	30	110	10

**Notes:**

1. Negative sign indicates net removals from the atmosphere.
2. Instant oxidation is the default approach in IPCC (2003) to estimate emissions from HWP.
3. The production approach accounts for the HWP from domestically harvested wood, both within and outside Canada; imported HWP are excluded (IPCC 2006).
4. Values should match total estimates reported under Forest land remaining forest land in CRF Table 5 and NIR Table 7-1.
5. Total emissions and removals in Forest land remaining forest land, using the production approach for HWP.
6. Totals may not add up due to rounding. Annex 9 describes the rounding protocol.

Monte Carlo runs are conducted using the base input data for the 2014 submission (covering the entire 1990–2012 time series). Confidence intervals are obtained for each inventory year, by randomly sampling 10 000 combinations of all the project runs for that year. Separate uncertainty estimates are produced for each gas.

Throughout the entire time series the uncertainties about annual estimates are expressed as a 95% confidence interval, bound by 2.5th and 97.5th percentiles of the Monte Carlo run outputs (see Table 7-7 for CO<sub>2</sub> fluxes, and Table 7-8 and Table 7-9 for CH<sub>4</sub> and N<sub>2</sub>O emissions, respectively).

Over the entire time series, the range of the 95% confidence interval about the median CO<sub>2</sub> estimates averaged 56 Mt. Expressing this range in relative terms (as % of the estimate) can be misleading, as the relative uncertainty will be largest when the net CO<sub>2</sub> balance is closest to neutrality, and increasingly smaller

as the net flux departs from neutrality. This does not represent varying uncertainty levels; it is an artefact of the combination of large fluxes cancelling each other while their respective uncertainties do not. Also note the very small contribution of non-CO<sub>2</sub> emissions to total uncertainty.

More information is provided in Annex A3.4.2.4 on the general approach used to conduct this analysis.

The uncertainty sources included in this analysis were essentially errors about input data and model parameters, as opposed to the model structure itself. Given the nature of these sources, the results of the uncertainty analysis are better understood as expressions of precision than estimates of accuracy. These results will be used, among other factors, to analyze and prioritize improvements in the estimation of anthropogenic emissions and removals in this category.

## Time-Series Consistency

All estimates have been developed in a consistent manner, but some sources of activity data do not provide full coverage for the reporting period. Estimates for wildfire areas in 2004–2012 were derived from a composite of real-time, remotely sensed imagery and monitoring data collected by provincial resource management agencies, known as the National Burned Area Composite.<sup>4</sup> Estimates for 1990–2003 were derived solely from the Canadian National Fire Database,<sup>5</sup> which comprises information from provincial resource management agencies.

The forest inventory data incorporated in the analyses were not all collected in the same year across the country; Annex 3.4 explains how forest inventory data from various sources were processed to provide complete, coherent and consistent forest data for 1990.

### 7.3.1.3. QA/QC and Verification

Tier 2 quality control (QC) checks (White and Dymond 2008; Dymond 2008) specifically address estimate development in the Forest Land category. Systematic and documented quality assurance / quality control (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 category-specific Tier 2 checks for estimates obtained from partners, as well as for all estimates and activity data contained in the LULUCF geodatabase and entered into the CRF reporter. These procedures and their outcome are fully documented in the centralized archives.

### 7.3.1.4. Recalculations

Significant recalculations have occurred in this category. Recalculations are due to the combined effects of an updated model version, revisions to areas affected by natural disturbances, incorporation of a new provincial forest inventory and updated harvesting activity data. The cumulative impacts of changes are presented in Figure 7–3. Details on these changes are presented in the following four categories:

**New Model Version:** The model used to produce forest estimates (CBM-CFS3) was upgraded to correct errors in the way that the model manages multi-component growth curves.

**Table 7–7 Estimates of the Net Annual CO<sub>2</sub> Fluxes for Forest Land Remaining Forest Land, 1990–2012, with 2.5<sup>th</sup> and 97.5<sup>th</sup> Percentiles**

Inventory Year	Net CO <sub>2</sub> Flux (Gg)	2.5 <sup>th</sup> Percentile (Gg)	97.5 <sup>th</sup> Percentile (Gg)
1990	-101 000	-184 000	-86 000
1991	-74 000	-165 000	-56 000
1992	-117 000	-207 000	-98 000
1993	-61 000	-151 000	-36 000
1994	-53 000	-138 000	-25 000
1995	148 000	63 000	192 000
1996	-50 000	-142 000	-27 000
1997	-83 000	-177 000	-57 000
1998	101 000	19 000	177 000
1999	-6 000	-96 000	26 000
2000	-65 000	-162 000	-36 000
2001	-58 000	-150 000	-27 000
2002	95 000	7 000	151 000
2003	33 000	-39 000	74 000
2004	105 000	41 000	146 000
2005	35 000	-36 000	64 000
2006	53 000	-6 000	82 000
2007	35 000	-26 000	71 000
2008	-32 000	-97 000	330
2009	-45 000	-96 000	-10 000
2010	40 000	-20 000	70 000
2011	55 000	-10 000	119 000
2012	16 000	-40 000	52 000

**Table 7–8 Estimates of the Annual CH<sub>4</sub> Emissions from Forest Land Remaining Forest Land, 1990–2012, with 2.5<sup>th</sup> and 97.5<sup>th</sup> Percentiles**

Inventory Year	Net CH <sub>4</sub> Flux (Gg CO <sub>2</sub> eq)	2.5 <sup>th</sup> Percentile (Gg)	97.5 <sup>th</sup> Percentile (Gg)
1990	3 000	2 700	4 200
1991	5 000	4 100	7 200
1992	1 600	1 400	2 200
1993	5 500	4 400	7 700
1994	5 700	4 800	8 000
1995	19 000	16 000	25 000
1996	4 500	3 700	6 100
1997	1 800	1 400	2 500
1998	16 000	13 000	25 000
1999	6 000	5 500	8 500
2000	1 300	1 100	1 800
2001	3 000	2 200	5 200
2002	13 000	10 000	19 000
2003	8 900	7 800	13 000
2004	11 000	9 500	16 000
2005	5 300	4 300	7 400
2006	7 100	6 000	9 700
2007	6 700	5 500	9 500
2008	3 900	3 100	5 200
2009	5 200	4 000	7 900
2010	9 300	6 200	13 000
2011	10 400	7 500	17 000
2012	8 800	6 900	13 000

<sup>4</sup> <http://www.nrcan.gc.ca/node/13159>

<sup>5</sup> <http://www.nrcan.gc.ca/node/13159>

**Table 7-9 Estimates of the Annual N<sub>2</sub>O Emissions from Forest Land Remaining Forest land, 1990–2012, with 2.5th and 97.5th Percentiles**

Inventory Year	Net N <sub>2</sub> O Flux (Gg CO <sub>2</sub> eq)	2.5 <sup>th</sup> Percentile (Gg)	97.5 <sup>th</sup> Percentile (Gg)
1990	1 800	1 700	2 600
1991	3 200	2 500	4 500
1992	1 000	870	1 400
1993	3 400	2 700	4 700
1994	3 500	3 000	5 000
1995	12 000	10 000	15 000
1996	2 800	2 200	3 700
1997	1 100	900	1 500
1998	10 000	8 400	16 000
1999	3 900	3 400	5 600
2000	790	690	1 100
2001	1 900	1 400	3 300
2002	8 200	6 600	12 000
2003	5 500	4 900	8 000
2004	7 000	5 900	10 000
2005	3 300	2 700	4 500
2006	4 400	3 600	6 200
2007	4 200	3 400	6 100
2008	2 400	1 900	3 200
2009	3 200	2 200	5 000
2010	5 800	3 700	8 200
2011	6 500	4 800	11 000
2012	5 500	4 300	8 100

**Natural Disturbances Area Revisions:** Wildfire disturbance activity for all provinces except Ontario and insect activity data for British Columbia (Mountain Pine Beetle) and Alberta (aspen defoliator) were revised. These revisions captured updates to datasets on natural disturbances monitoring, and corrected data processing errors, including the assignment of insect impact classes.

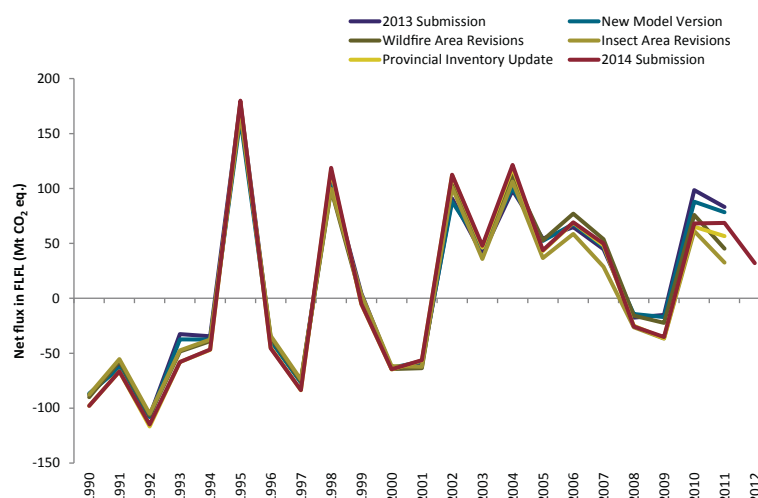
**Alberta Forest Inventory Update:** The Alberta provincial forest inventory and associated spatial stratification, growth and yield information and wildfire disturbance matrices were updated, based on digital information on provincial forest management areas provided by the provincial government. This new information was augmented with data from Canada's Forest Inventory (CANFI 2001)<sup>6</sup> for the remaining managed forest area in the province. As a result of the new data compilation, the number of forest analysis units for Alberta rose from 70 to 181. New inventory information also altered the age-class distribution in Alberta forests.

**Harvesting Activity Updates:** Harvest activity data for 2009–2011 were updated according to changes in statistics from the National Forestry Database Program.

Total recalculations, resulting from a combination of all changes, range from -30 Mt (2010) to + 23 Mt (2004). The largest recalculations affect emissions and removals in the Boreal Plains and Taiga Plains reporting zones, which largely lie in Alberta, and in the Montane Cordillera reporting zone, where forests were severely affected by the Mountain Pine Beetle infestation that began in the early 2000s. Recalculations in immediate emissions from wildfires are mainly due to wildfire activity data revisions and the updated Alberta inventory, as many wildfires occur in this province. Recalculations in burned areas ranged from a 15% decrease in 2010 (173 kha) to a 27% increase in 2004 (201 kha). There was an increase in net removals in annual ecosystem processes, averaging 7 Mt and largely occurring in the Boreal Plains, Montane Cordillera and Taiga Plains, which is attributed mainly to the Alberta inventory update and the residual impacts of changes to natural disturbances such as insects.

6 <https://nfi.nfis.org/index.php>

**Figure 7-3 Impact of Incremental Changes on FLFL Estimates**



Harvesting recalculations occur due to both the combined effects of previously implemented changes, which alter the pool of candidate forest inventory records available for harvest, and harvest activity data updates. The indirect effects of changes in forest modelling lead to an average downward recalculation of 184 kt (0.11%). Updated harvesting data led to increased emissions, especially in 2011 (by 8 Mt or 6%).

### 7.3.1.5. Planned Improvements

Long-term planned improvements include enhancing the quality of forest inventory data and greater focus on drivers of anthropogenic emissions and removals. A more systematic approach for implementing improvements will reduce the frequency of recalculations.

Although already more realistic spatially and temporally than the official estimates, the HWP estimates provided in this submission should be considered as preliminary. Further elaboration of the production approach for HWP is planned for future submissions, including an examination of the appropriateness of IPCC default half-lives to Canadian circumstances, the feasibility of including pre-1990 HWP production, incorporating long-term storage at solid waste disposal sites (SWDS), and representing the use of milling waste and end-of-life products as bioenergy feedstocks.

## 7.3.2. Land Converted to Forest Land

### 7.3.2.1. Category Description

This category includes all lands converted to forest land through direct human activity. Post-harvest tree planting is not included, nor is abandoned farmland where natural vegetation is allowed to establish; hence, the category more precisely refers to forest establishment where the previous land use was not forest (typically, abandoned farmland).

The total cumulative area of land converted to forest land declined from 174 kha in 1990 to 72 kha in 2012. The trend reflects the gradual transfer of lands afforested more than 20 years ago to the Forest land remaining forest land category, and a dearth of recent data on current rates of forest establishment. Eighty four percent of all farmland converted to forest land over the last 20 years is in eastern Canada (Atlantic Maritime, Mixed-wood Plains and Boreal Shield East reporting zones) and only 9% in the Prairies (Boreal Shield West, Boreal Plains and Subhumid Prairies reporting zones). However, caution must be exerted in regard to analysis of afforestation trends due to the absence of a reliable and comprehensive data source.

Net removals consequently declined throughout the period, from 1.0 Mt in 1990 to 0.7 Mt in 2012. Net carbon accumulation

largely occurs in biomass (155 Gg C in 2012 – CRF Table 5A); soil carbon sequestration is negligible and will remain so because this category is restricted to plantations that are younger than 20 years. For the same reason, and considering the relatively low net increment of planted trees in the early years, the subcategory as a whole is not expected to contribute significantly to the net greenhouse gas balance of forest lands.

### 7.3.2.2. Methodological Issues

The Feasibility Assessment of Afforestation for Carbon Sequestration (FAACS) initiative collected and compiled afforestation records for 1990–2002 (NRCan 2005a). In this period, softwood plantations, especially spruce and pine, accounted for 90% of the area planted. Activities for 1970–1989 and 2003–2008 were estimated based on activity rates observed in the FAACS data, complemented with information from the Forest 2020 Plantation Demonstration Assessment (NRCan 2005b). No new afforestation activity data were collected for the 2009–2012 inventory years.

GHG emissions and removals on lands newly converted to forests were estimated using CBM-CFS3, as described in Annex 3.4. Changes in soil carbon stocks are highly uncertain because of difficulties in locating data about the carbon stocks prior to plantation. It was assumed that the ecosystem would generally accumulate soil carbon at a slow rate; the limited time frame of this analysis and the scale of the activity relative to other land use and land-use change activities suggest that the impact of this uncertainty, if any, is minimal.

### 7.3.2.3. Uncertainties and Time-Series Consistency

Uncertainty estimates are provided for this category for the first time in this submission. Significant challenges remain in estimating uncertainty for this category due to the lack of a consistent national system for tracking afforestation, and because it is currently not possible to run a Monte Carlo simulation using the model data input structure for this category. Given these limitations, initial uncertainty estimates were developed based on expert judgement. It was assumed that the 95% confidence intervals for this category could be estimated at 10% smaller or 200% larger than the reported value.

### 7.3.2.4. QA/QC and Verification

Tier 2 QC checks (Dymond 2008) specifically address estimate development in the Forest Land category. Environment Canada, while maintaining its own QA/QC procedures for estimates developed internally (refer to Annex 6), has implemented specific 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.

### 7.3.2.5. Recalculations

Although afforestation activity data have not changed, recalculations are due to the indirect effects of changes in forest modelling (e.g. corrections to growth curves in the new model version). The impacts of indirect modelling effects lead to an average recalculation of 5 kt CO<sub>2</sub> eq (0.5% of the category total) for the 1990–2011 period. For more detailed information on changes to forest-related modelling, refer to Section 7.3.1.4

### 7.3.2.6. Planned Improvements

There is currently limited access to information on afforestation activity. Efforts are underway to obtain data on afforestation activities in recent years from provincial and territorial resource management agencies. As more information becomes available in the future, uncertainty estimates will be further refined.

## 7.4. Cropland

Cropland covers approximately 48 Mha of the Canadian territory. In 2012, the net GHG balance in the Cropland category amounted to removals of 4.9 Mt CO<sub>2</sub> eq (Table 7–1 and CRF Table 7–5). For the purpose of reporting under the Convention (UNFCCC), Cropland is divided into cropland remaining cropland (net removals of 10 Mt CO<sub>2</sub> eq in 2012) and land, either forest or grassland, converted to cropland (net emissions of 5.5 Mt CO<sub>2</sub> eq and 0.017 Mt CO<sub>2</sub> eq, respectively, in 2012). The estimates in land “converted to cropland” include net emissions and removals of CO<sub>2</sub>, as well as N<sub>2</sub>O and CH<sub>4</sub> emissions.

### 7.4.1. Cropland Remaining Cropland

Cultivated agricultural land in Canada includes areas of field crops, summerfallow, hayland, and tame or seeded pasture. Cropland is found mainly in the nine southernmost reporting zones. About 84% of Canada’s cropland is in the interior plains of western Canada, made up of the Semi-arid Prairies, the Sub humid Prairies and the Boreal Plains reporting zones.

Cropland remaining cropland includes CO<sub>2</sub> emissions/removals in mineral soils, CO<sub>2</sub> emissions from agricultural lime application and cultivation of organic soils, and CO<sub>2</sub> emissions/removals resulting from changes in woody biomass from specialty crops. An enhanced Tier 2 approach is used for estimating CO<sub>2</sub> emissions from and removals by mineral soils triggered by changes in land management practices. Table 7–10 summarizes the trend in emissions and removals for these categories.

### 7.4.1.1. CO<sub>2</sub> Emissions and Removals in Mineral Soils

Mineral soils constitute the majority of cropland areas (> 99%). The amount of organic carbon retained in these soils is a function of primary production and rate of decomposition of soil organic carbon (SOC). Cultivation and management practices can lead to an increase or decrease in the organic carbon stored in soils. This change in SOC results in a CO<sub>2</sub> emission to or removal from the atmosphere.

In 1990, changes in mineral soil management amounted to a net CO<sub>2</sub> removal of about 2.0 Mt CO<sub>2</sub> eq (Table 7–10). This net sink steadily increased to about 11 Mt CO<sub>2</sub> eq in 2006, remaining relatively constant around this value over the subsequent years. The increasing trend in removals in the first 17 years partly reflects continuous efforts in reducing summerfallow and increasing conservation tillage (Campbell et al. 1996; Janzen et al. 1998; McConkey et al. 2003), while in more recent years net removals tend to stabilize as the adoption of conservation tillage and decreases in summerfallow begin to level off and the soil sink approaches equilibrium. Higher emissions due to an increasing proportion of annual crops within the total crop mixture also contribute to stabilization of the net soil sink by partially offsetting soil carbon gains. The area of summerfallow declined by 76% over the 1990–2012 period, resulting in a net sink that increased from 3.1 Mt CO<sub>2</sub> eq in 1990 to 7.3 Mt CO<sub>2</sub> eq in 2012. The increase in net sink due to the adoption of conservation tillage practices (from 1.4 Mt CO<sub>2</sub> eq in 1990 to 5 Mt CO<sub>2</sub> eq in 2012) is substantiated by a net increase of 13 Mha in areas under no-till and reduced tillage over the 1990–2012 period. The net change in crop mixture resulted in a change from a source of 2.3 Mt CO<sub>2</sub> eq in 1990 to a sink of 0.3 Mt CO<sub>2</sub> eq in 2012.

The net increase in sink from changes in management practices over time was partially offset by an increase since 1990 in net residual CO<sub>2</sub> emissions from the decay of dead organic matter and SOC 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 under land converted to cropland. The increase since 1990 in these residual emissions is due to a methodological artefact. Since forest conversion monitoring goes back only to 1970, post-20-year residual emissions in 1990 only accounted for the land converted in 1970. Residual emissions display an apparent increase because the temporal coverage increases with each inventory year. In the CRF tables, these emissions are split among the dead organic matter and soil pools.

### Methodological Issues

Following the IPCC Good Practice Guidance for LULUCF (IPCC 2003), the premise is that the changes in SOC are driven by changes in soil management practices. Where no change in

**Table 7–10 Base and Recent Year Emissions and Removals Associated with Various Land Management Changes on Cropland Remaining Cropland**

Categories	Land Management Change (LMC)	Emissions/Removals (Gg CO <sub>2</sub> ) <sup>1</sup>							
		1990	2000	2005	2008	2009	2010	2011	2012
Total Cropland Remaining Cropland		-1 500	-7 000	-10 000	-10 000	-10 000	-10 000	-10 000	-10 000
<i>Cultivation of Histosols</i>		300	300	300	300	300	300	300	300
<i>Liming</i>		200	270	290	290	290	290	290	290
<i>Perennial Woody Crops</i>		60	90	40	30	30	20	20	- 10
<i>Total Mineral Soils</i>		-2 000	-7 400	-10 000	-11 000	-11 000	-11 000	-11 000	-11 000
Change in Crop Mixture	Increase in Perennial	-1 200	-3 000	-4 500	-4 700	-4 700	-4 700	-4 600	-4 600
	Increase in Annual	3 500	3 800	3 700	3 900	4 000	4 100	4 200	4 300
Change in Tillage	Conventional to Reduced Tillage	- 870	- 960	- 860	- 790	- 760	- 730	- 710	- 680
	Conventional to No-till	- 540	-2 500	-3 500	-3 700	-3 800	-3 800	-3 800	-3 900
	Other	- 1	- 250	- 600	- 720	- 750	- 770	- 800	- 820
Change in Summerfallow (SF)	Increase in SF	1 700	1 400	1 300	1 200	1 200	1 100	1 100	1 100
	Decrease in SF	-4 800	-7 100	-7 700	-8 000	-8 100	-8 200	-8 300	-8 400
<i>Land Conversion—Residual Emissions<sup>2</sup></i>		170	1 400	1 700	1 800	1 900	1 900	1 900	1 900

Notes:

1. Negative sign indicates removal of CO<sub>2</sub> from the atmosphere.2. Net residual CO<sub>2</sub> emissions from the conversion of forest land and grassland to cropland that occurred more than 20 years prior to the inventory year, including emissions from the decay of woody biomass and DOM.

NO = Not occurring

management is detected, it is assumed that mineral soils are neither sequestering nor losing carbon.

VandenBygaart et al. (2003) compiled published data from long-term studies in Canada to assess the effect of agricultural management on SOC. This compendium provided the basis for selecting the key management practices and management changes likely to cause changes in soil carbon stocks. The availability of activity data (time series of management practices) from the Census of Agriculture was also taken into account. 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 re-establishment of perennial vegetation (Janzen et al. 1997; Bruce et al. 1999). Other land management changes, such as changes in irrigation, manure application and fertilization, are also known to have positive impacts on SOC. Lack of activity data for these land management changes (LMCs) associated with specific crops prevented their inclusion in the inventory at this time. Estimates of CO<sub>2</sub> changes in mineral soils were derived from the following LMCs:

- change in the proportion of annual and perennial crops;
- change in tillage practices; and
- change in area of summerfallow.

Carbon emissions and removals were estimated by applying country-specific carbon emission and removal factors multiplied by the relevant area of land that underwent a management change. Calculations were performed at a high degree of spatial

disaggregation, namely by Soil Landscapes of Canada (SLC) polygons (see Annex 3.4.1). The carbon emission/removal factors represent the rate of SOC change per year and per unit area that underwent an LMC. The annual CO<sub>2</sub> emissions/removals by mineral soils undergoing a specific LMC are expressed as:

**Equation 7–1:**

$$\Delta C = F \times A$$

where:

$\Delta C$	=	change in soil carbon stock, Mg C
$F$	=	average change in SOC subject to LMC, Mg C/ha
$A$	=	area of LMC, ha

In reality, the impact of LMC on SOC varies with initial conditions. The most accurate estimate of soil carbon stock change would therefore be derived by individually considering the cumulative effects of the long-term management history of each piece of land or farm field. Limits are imposed by the availability of activity data within the modelling framework. At this point, the inventory relies extensively on the Census of Agriculture for estimates of areas of LMC (i.e. changes in tillage, types of crop and fallow). The area of LMC was determined individually for 3269 SLC polygons having agricultural activities, each one with an agricultural area in the order of 1000–1 000 000 ha. This is the finest possible



**Table 7–11 Uncertainty about Components of the Total CO<sub>2</sub> Fluxes from Forest Land Converted to Cropland for the 2012 Inventory Year**

Flux Component	Net CO <sub>2</sub> Flux (kt CO <sub>2</sub> eq)	Uncertainty (kt CO <sub>2</sub> eq)
Immediate emissions	3,160	± 683
Residual emissions from the DOM pool	1,893	± 392
Residual emissions from the soil pool	295	± 183

**Table 7–12 Uncertainty about Non-CO<sub>2</sub> Emissions from Forest Land Converted to Cropland for the 2012 Inventory Year**

Flux Component	Emissions (kt CO <sub>2</sub> eq)	Uncertainty (kt CO <sub>2</sub> eq)
CH <sub>4</sub> emissions	105	± 29
N <sub>2</sub> O emissions	64	± 18

resolution of activity data, given the limitations imposed by confidentiality requirements of census data. The census provides information about the area of each practice for each census year, so only the net area of change for each land management practice can be estimated. Estimates of these LMCs are as close to gross area of LMC as is feasible for regional or national analyses.

The validity of LMC estimates using census data relies on two key assumptions: additivity and reversibility of carbon factors. Additivity assumes that the combined effects of different LMCs or LMCs at different times would be the same as the sum of the effect of 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.

A more detailed description of methodologies for determining carbon factors and other key parameters can be found in Annex 3.4.

## Uncertainties and Time-Series Consistency

Uncertainty was estimated analytically with a Tier 1 approach. The uncertainties associated with estimates of CO<sub>2</sub> emissions or removals involve estimates of uncertainties for area and carbon factors of management changes for fallow, tillage and annual/perennial crops (McConkey et al. 2007).

The uncertainty about the area in a management practice for an ecodistrict varied inversely with the relative proportion it occupied of the total area of agricultural land in that ecodistrict. The relative uncertainty of the area of management practice (expressed as standard deviation of an assumed normal population) decreased from 10% to 1.25% of the area as the relative area of that practice increased.<sup>7</sup>

The uncertainties associated with carbon change factors for fallow, tillage and annual/perennial crops were partitioned in two main sources: 1) process uncertainty in carbon change due to inaccuracies in predicting carbon change even if the situation of management practice was defined perfectly, and 2) situational uncertainty in carbon change due to variation in the location or timing of the management practice. More details about estimating process and situational uncertainties are presented in Annex 3.4. Uncertainty estimates associated with emissions/removals of CO<sub>2</sub> from mineral soils were developed by McConkey et al. (2007), who reported uncertainty values at ±19% for the level and ±27% for the trend. These uncertainty estimates have not been updated since the 2011 annual submission, but should still be applicable because there has been no change in the inventory method over the last two submissions.

Consistency in the CO<sub>2</sub> estimates is ensured through the use of the same methodology for the entire time series of estimates (1990–2012).

## QA/QC and Verification

Tier 1 QC checks, implemented by Agriculture and Agri-Food Canada (AAFC), specifically address estimate development in the cropland remaining cropland subcategory. Environment Canada, while maintaining its own QA/QC procedures for estimates developed internally (see Annex 6), has implemented additional QC checks for estimates obtained from partners, as well as for all estimates and activity data contained in its LULUCF geodatabase and entered into the CRF reporter. In addition, the activity data, methodologies and changes are documented and archived in both paper and electronic form.

Carbon change factors for LMCs used in the inventory were compared with empirical coefficients in VandenBygaart et al. (2008). The comparison showed that empirical data on changes in SOC in response to no tillage were highly variable, particularly for eastern Canada. Nonetheless, the modelled factors were still within the range derived from the empirical data. For the switch from annual to perennial cropping, the mean empirical factor was 0.59 Mg C/ha per year, and this compared favourably with the range of 0.46–0.56 Mg C/ha per year in the modelled factors in western Canadian soil zones. For eastern Canada, only two empirical change factors were available, but they fell within

<sup>7</sup> T. Huffman, Agriculture and Agri-Food Canada, personal communication to Brian McConkey, 2007.

the range of the modelled values (0.60–1.07 Mg C/ha per year empirical versus 0.74–0.77 Mg C/ha per year modelled). For conversion of crop fallow to continuous cropping, the modelled rate of carbon storage obtained (0.33 Mg C/ha per year) was more than twice the average rate of  $0.15 \pm 0.06$  Mg C/ha per year derived from two independent assessments of the literature. This difference led to the decision to use empirically based factors for changes in summerfallow in the inventory. More details can be found in Annex 3.4.

In February 2009, Canada convened an international team of scientists and experts from Denmark, France, Japan, Sweden, the Russian Federation and the United States, to conduct a quality assurance assessment of the Canadian Agricultural Monitoring, Accounting and Reporting System (Can Ag-MARS). Some limitations of the current system were found with respect to activity data, which could possibly create some bias in the current carbon stock change estimates. In particular, the lack of a complete and consistent set of land-use data, and issues with the concept and application of pseudo-rotations, will be addressed in the next generation of Can Ag-MARS.

## Recalculations

The size of the agricultural soil C sink was reduced by up to 2.7 Mt annually between 2007 and 2011 because of updates to cropland management practice data from the 2011 *Census of Agriculture*. Previous estimates of the agricultural soil C sink for these years were projected based on information in the 2006 *Census of Agriculture*. The use of the most recent Census of Agriculture resulted in downward recalculations of the area estimates of cropland management practices in the period 1993–2011. These recalculations show a growing trend, in particular after 2006, going from a reduction of only 33 kha in 1993 to 1.7 Mha in 2011. Consequently, recalculations were also carried out with a similar trend in net removals, going from a reduction of 107 kt CO<sub>2</sub> eq for 1990 to 2.7 Mt in 2011.

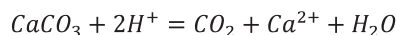
## Planned Improvements

Improvements to the CENTURY model and the use of alternative models such as DAYCENT and RothC are also being explored, to improve the simulation of Canadian agricultural conditions. The quality of area statistics collected through the Census of Agriculture will be improved using land cover information.

### 7.4.1.2. CO<sub>2</sub> Emissions from Lime Application

In eastern Canada, limestone and dolomite are often used for certain crops such as alfalfa to neutralize acidic soils; increase the availability of soil nutrients, in particular phosphorus; reduce the toxicity of heavy metals, such as aluminium; and improve the crop growth environment. During this neutralization process, CO<sub>2</sub>

is released in bicarbonate equilibrium reactions that take place in the soil:



The rate of release will vary with soil conditions and the compounds applied. In most cases where lime is applied, applications are repeated every few years. For the purposes of the inventory, it is assumed that the rate of lime addition is in near equilibrium with the rate of lime consumed from previous applications.

## Methodological Issues

Emissions associated with the use of lime were calculated from the amount and composition of the lime applied annually—specifically, the respective stoichiometric relationships that describe the breakdown of limestone and dolomite into CO<sub>2</sub> and other minerals. Methods and data sources are outlined in Annex 3.4.

## Uncertainties and Time-Series Consistency

The 95% confidence limits about data on the annual lime consumption in each province were estimated to be  $\pm 50\%$  (McConkey et al. 2007). This uncertainty was assumed to include the uncertainty about lime sales, uncertainty in proportion of dolomite to calcite, uncertainty of when lime sold is actually applied, and uncertainty in the timing of emissions from applied lime. The uncertainty in the emission factor was not considered because the chemical conversion is deemed complete, and the maximum value of the emission factor was used. The overall mean and uncertainties were estimated to be  $0.3 \pm 0.25$  Mt CO<sub>2</sub> eq for the level uncertainty and  $0.09 \pm 0.30$  Mt CO<sub>2</sub> eq for the trend uncertainty (McConkey et al. 2007).

The same methodology is used for the entire time series of emission estimates (1990–2012).

## QA/QC and Verification

This category has undergone Tier 1 QC checks (see Annex 6) in a manner consistent with IPCC Good Practice Guidance (IPCC 2000). The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

## Recalculations

There was no recalculation involved in emission estimates for this source category.

## Planned Improvements

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

### 7.4.1.3. CO<sub>2</sub> Emissions from Cultivation of Organic Soils

#### Category Description

In Canada, cultivated organic soils are defined as the conversion of organic soils to agriculture for annual crop production, normally accompanied by artificial drainage, cultivation and liming. Organic soils used for agricultural production in Canada include the Peaty Phase of Gleysolic soils, Fibrisols over 60 cm thick, and Mesisols and Humisols over 40 cm thick (AAFC 1998).

#### Methodological Issues

The emissions from the cultivation of organic soils were calculated by multiplying the total area of cultivated histosols by the default emission factor of 5 Mg C/ha per year (IPCC 2006).

Areas of cultivated histosols are not provided by the *Census of Agriculture*; area estimates were based on the expert opinion of soil and crop specialists across Canada (Liang et al. 2004). The total area of cultivated organic soils in Canada (constant for the period 1990–2012) was estimated to be 16 kha, or 0.03% of the cropland area. The area of cultivated histosols is mainly located in the Atlantic Maritime, Mixedwood Plains and Pacific Maritime reporting zones.

#### Uncertainties and Time-Series Consistency

The uncertainty associated with emissions from this source is due to the uncertainties from the area estimates for the cultivated histosols and the emission factor. The 95% confidence limits associated with the area estimate of cultivated histosols are assessed to be  $\pm 50\%$  (Hutchinson et al. 2007). The 95% confidence limits of the default emission factor are  $\pm 90\%$  (IPCC 2006). The overall mean and uncertainties associated with this source of emissions were estimated to be  $0.3 \pm 0.09$  Mt CO<sub>2</sub> eq for the level uncertainty and  $0 \pm 0.13$  Mt CO<sub>2</sub> eq for the trend uncertainty (McConkey et al. 2007).

The same methodology and emission factors are used for the entire time series of emission estimates (1990–2012).

#### QA/QC and Verification

This category has undergone Tier 1 QC checks (see Annex 6) in a manner consistent with IPCC Good Practice Guidance (IPCC 2000). The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

#### Recalculations

There was no recalculation involved in emission estimates for this source category.

#### Planned Improvements

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

### 7.4.1.4. CO<sub>2</sub> Emissions and Removals in Woody Biomass

#### Category Description

Perennial woody biomass is found on cropland planted with vineyards, fruit orchards and Christmas trees. It also accumulates on abandoned cropland allowed to revert to natural vegetation. In the definitional framework adopted in Canada for LULUCF reporting, abandoned cropland is still considered “cropland” until there is evidence of a new land use; however, there is little information on the dynamics of cropland abandonment or recultivation. Owing to these data limitations, only vineyards, fruit orchards and Christmas trees are considered; for the time being 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 is 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 Annex 3.4.

#### Uncertainties and Time-Series Consistency

Upon a loss of area with perennial woody crops, all carbon in woody biomass is assumed to be immediately released. It is assumed that the uncertainty for carbon loss equals the uncertainty about mass of woody biomass carbon. The default uncertainty of  $\pm 75\%$  (i.e. 95% confidence limits) for woody biomass on cropland from the IPCC Good Practice Guidance (IPCC 2003) was used.

If the loss in area of fruit trees, vineyards or Christmas trees is estimated to have gone to annual crops, there is also a deemed perennial to annual crop conversion with associated uncertainty that contributes to carbon change uncertainty. For area of gain in fruit trees, vineyards or Christmas trees, the uncertainty in annual

carbon change was also assumed to be the default uncertainty of  $\pm 75\%$  (i.e. 95% confidence limits) (IPCC 2003).

The overall mean and uncertainties associated with emissions or removals of CO<sub>2</sub> from woody specialty crops were estimated to be  $-10 \pm 1$  kt CO<sub>2</sub> eq for the level uncertainty and  $-70 \pm 105$  kt CO<sub>2</sub> eq for the trend uncertainty (McConkey et al. 2007).

The same methodology was used for the entire time series of emission estimates (1990–2012).

### QA/QC and Verification

This category has undergone Tier 1 QC checks (see Annex 6) in a manner consistent with IPCC Good Practice Guidance (IPCC 2000). The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

### Recalculations

There were small changes in area statistics resulting from an update in the Census of Agriculture in 2011. As a result, recalculations were carried out, with an increase in emissions of 7 kt CO<sub>2</sub> eq in 1990 and 65 kt CO<sub>2</sub> eq in 2011.

### Planned Improvements

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

## 7.4.2. Land Converted to Cropland

This subcategory includes the conversion of forest land and grassland to cropland. Emissions from the conversion of forest land to cropland account for nearly 100% of the total emissions in this category, which have decreased from 13 Mt CO<sub>2</sub> eq in 1990 to 5.6 Mt CO<sub>2</sub> eq in 2012. Emissions from the conversion of grassland are relatively insignificant.

### 7.4.2.1. Forest Land Converted to Cropland

Clearing forest for use as agricultural land is an ongoing but declining practice in Canada, although agriculture remains an important cause of forest conversion (accounting for 41% of forest area conversion in 2012). The cumulative area of forest land converted to cropland since 1971 was 1331 kha in 1990; in 2012, the cumulative area converted since 1993 was 444 kha. Methods to determine the area converted annually are common to all forest conversion to other land-use categories; they are outlined in Section 7.8 of this chapter, under the heading “Forest Conversion.” In 2012, immediate emissions from this year’s forest conversion accounted for 3.3 Mt CO<sub>2</sub> eq, or 60% of all emissions from forest land converted to cropland, while residual emissions from events that occurred in the last 20 years accounted for the remaining

2.2 Mt CO<sub>2</sub> eq. Ninety five percent of emissions originate from the biomass and dead organic matter pools during and after conversion, with the remainder being attributed to the soil pool.

### Methodological Issues – Dead Organic Matter and Biomass Pools

As stated above, emissions from the dead organic matter (DOM) and biomass pools account for almost all emissions due to the conversion of forests to cropland. Their estimation is performed in the same modelling environment as that used for forest land remaining forest land. A general description of this modelling environment was provided in Section 7.3.1.1; more information is provided in Annex 3.4.

### Methodological Issues – Soils

Emissions from soils in this category include the net C stock change due to the actual conversion, a very small net CO<sub>2</sub> source from change in management practices in the 20 years following conversion, and the N<sub>2</sub>O emissions from the decay of soil organic matter. The soil emissions from forest land conversion to cropland were calculated by multiplying the total area of conversion by the empirically derived emission factor along with modelling-based SOC dynamics (see Annex 3.4). As explained below, patterns of change in SOC after the conversion of forest to cropland clearly differ between eastern and western Canada.

### Eastern Canada

All agricultural land in the eastern part of the country was forested before its conversion to agriculture. Many observations, either in the scientific literature or the Canadian Soil Information System, of forest SOC comparisons with adjacent agricultural land in eastern Canada show a mean loss of carbon of 20% at depths to approximately 20–40 cm (see Annex 3.4). Average nitrogen change was  $-5.2\%$ , equivalent to a loss of approximately 0.4 Mg N/ha. For those comparisons where both nitrogen and carbon losses were determined, the corresponding carbon loss was 19.9 Mg C/ha. Therefore, it was assumed that nitrogen loss was a constant 2% of carbon loss.

The CENTURY model (Version 4.0) is used to estimate the 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 Annex 3.4.

Following a Tier 2-type methodology, as was done for direct N<sub>2</sub>O emissions from agricultural soils (see Agriculture Sector, Chapter 6), emissions of N<sub>2</sub>O from forest conversion to cropland were estimated by multiplying the amount of carbon loss by the fraction of nitrogen loss per unit of carbon and by an emission factor (EF<sub>BASE</sub>). EF<sub>BASE</sub> was determined for each ecodistrict based on topographic and climate conditions (see Annex 3.3).



## Western Canada

Much of the current agricultural land in western Canada (Prairies and British Columbia) was grassland in the native condition. Hence, forest land converted to cropland has been primarily of forest that lies on the fringe of former grassland areas.

The Canadian Soil Information System (CanSIS) represents the best available data source for SOC under forest and agriculture. On average, these data suggest that there is no loss of SOC from forest conversion 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 forest conversion is occurring, the land is marginal for arable agriculture; pasture and forage crops are the dominant management practices.

For western Canada, no loss of SOC over the long term was assumed from forest land converted to cropland managed exclusively for seeded pastures and hayland. The carbon loss from forest conversion in western Canada results from the loss of above- and below-ground tree biomass and from loss or decay of other above- and below-ground coarse woody DOM that existed in the forest at the time of forest conversion. The average nitrogen change in western Canada for sites at least 50 years from breaking was +52% (see Annex 3.4), reflecting substantial added nitrogen in agricultural systems compared with forest management practices. However, recognizing the uncertainty about actual carbon-nitrogen dynamics for forest conversion, loss of forest land to cropland in western Canada was assumed not to be a source of N<sub>2</sub>O.

## Uncertainties and Time-Series Consistency

Greenhouse gas fluxes from forest land converted to cropland result from the combination of (i) burning or harvesting—immediate emissions from biomass and dead organic matter or transfers to HWP accounted for as immediate emissions, respectively; (ii) the organic matter decay and subsequent CO<sub>2</sub> emissions in the DOM pool; and (iii) the net carbon losses from SOC. Note that immediate CO<sub>2</sub> emissions always refer to area converted in the inventory year; residual emissions, while also occurring on land converted during the inventory year, mostly come from land converted over the last 20 years. Non-CO<sub>2</sub> emissions are produced only by burning, and occur during the conversion process.

Immediate and residual CO<sub>2</sub> emissions from the biomass and DOM pools represent the largest components of this category, and contribute the most to the category uncertainty (Table 7–11 and Table 7–12). In all cases, uncertainty values are presented as the 95% confidence interval about the median (biomass and DOM pools) or mean (soil pool) estimate values.

Reflecting the estimation approach and procedures, uncertainty estimates were derived independently for the biomass and dead organic matter pools, and for soil organic matter. The uncertainty about activity data described in Section 7.8.2 was incorporated in all analyses.

The fate of biomass and DOM upon forest conversion and the ensuing emissions are modelled in the same framework as that used for forest land; the corresponding uncertainty estimates were therefore also developed within this framework and with the same Monte Carlo runs that generated uncertainty estimates in the Forest Land category. The Monte Carlo analysis was carried out for the entire time series for this submission. A description of the general approach is provided in Section 7.3.1.2; more information can be found in Section 3.4.2.4 of Annex 3.4.

The uncertainty about the net CO<sub>2</sub> flux from the soil pool was estimated analytically (McConkey et al. 2007). More information is provided in Annex 3.4.2.4 on the general approach used to conduct this analysis.

## QA/QC and Verification

This category has undergone Tier 1 QC checks (see Annex 6) in a manner consistent with IPCC Good Practice Guidance (IPCC 2000). Quality checks were also performed externally by 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.

To address the question raised by the expert review team during the 2009 annual inventory review, Canada has provided additional materials in Annex 3.4 to support the methodology.

## Recalculations

Recalculations were carried out, with an increase in emissions of 67 kt CO<sub>2</sub> eq in 1990 and 405 kt CO<sub>2</sub> eq in 2011 because of updates from the 2011 Census of Agriculture and some error corrections in the CBM forest modelling system.

## Planned Improvements

Planned improvements described under Section 7.8, Forest Conversion, will also affect this category.

### 7.4.2.2. Grassland Converted to Cropland

Conversion of native grassland to cropland occurs in the Prairie region of the country and generally results in losses of SOC and soil organic nitrogen and emissions of CO<sub>2</sub> and N<sub>2</sub>O to the atmosphere. Carbon losses from the above-ground or below-ground biomass or DOM upon conversion are insignificant, based

on findings from a recent work by Bailey and Liang (2013) on burning of managed grassland in Canada, who reported that the average above-ground biomass was 1100 kg ha<sup>-1</sup> in the Brown Chernozem, and 1700 kg ha<sup>-1</sup> in the Dark Brown Chernozem. The above-ground biomass for the managed grassland would be lower than its respective yield under crop production (Liang et al. 2005). Total emissions in 2012 from soils amounted to 17 kt CO<sub>2</sub> eq, including carbon losses and N<sub>2</sub>O emissions from the conversion.

### Methodological Issues

A number of studies on changes of SOC and soil organic nitrogen in grassland converted to cropland have been carried out on the Brown, Dark Brown and Black soil zones of the Canadian Prairies. The average loss of SOC was 22%, and the corresponding average change in soil organic nitrogen was 0.06 kg N lost/kg C (see Annex 3.4).

The CENTURY model (Version 4.0) is used to estimate the SOC dynamics from breaking of grassland to cropland for the Brown and Dark Brown Chernozemic soils. More details of methodologies for determining the maximal carbon loss and its rate constant associated with the breaking of grassland can be found in Annex 3.4.

Similar to N<sub>2</sub>O emissions in forest converted to cropland, emissions of N<sub>2</sub>O in grassland converted to cropland were estimated by a Tier 2 methodology, multiplying the amount of carbon loss by the fraction of nitrogen loss per unit of carbon by a base emission factor (EF<sub>BASE</sub>). EF<sub>BASE</sub> is determined for each ecodistrict based on climate and topographic characteristics (see Annex 3.3.3).

### Uncertainty and Time-Series Consistency

The conversion from agricultural grassland to cropland occurs, but within the land definitional framework the conversion in the other direction is not occurring (see Section 7.2). Therefore, the uncertainty in absolute value of the area of this conversion cannot be larger than the uncertainty about the area of cropland or grassland. Hence, the uncertainty of the area of conversion was set to the lower of the uncertainties of the area of either cropland or grassland in each ecodistrict. The uncertainty of SOC change was estimated as in forest land conversion to cropland. The overall mean and uncertainty associated with emissions due to SOC losses on grassland conversion to cropland were estimated to be 17 ± 20 kt CO<sub>2</sub> eq for the level uncertainty, and -42 ± 28 kt CO<sub>2</sub> eq for the trend uncertainty.

The same methodology and emission factors are used for the entire time series of emission estimates (1990–2012).

### QA/QC and Verification

This category has undergone Tier 1 QC checks (see Annex 6) in a manner consistent with IPCC Good Practice Guidance (IPCC

2000). The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

### Recalculations

Because of updates from the 2011 Census of Agriculture, recalculations were carried out, with a decrease in emissions of 19 kt CO<sub>2</sub> eq in 1990 and an increase of 8 kt CO<sub>2</sub> eq in 2011.

### Planned Improvements

Canada plans to validate the modelled soil carbon change factors with the measured and published soil carbon change factors from grassland conversion as these become available.

## 7.5. Grassland

Agricultural grassland is defined under the Canadian LULUCF framework as pasture or rangeland on which the only agricultural land management activity has been the grazing of domestic livestock (i.e. the land has never been cultivated). It occurs only in geographical areas where the grassland would not naturally grow into 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 three reporting zones: Semi-arid Prairies (5207 kha), Montane Cordillera (199 kha), and Pacific Maritime (2 kha). As with cropland, the change in management triggers a change in carbon stocks (IPCC 2003). Very little information is available on management practices on Canadian agricultural grassland, and it is unknown whether grazed land is improving or degrading. Therefore, Canada reports this grassland remaining grassland category using the IPCC Tier 1 method based on no change in management practices since 1990. The subcategory land converted to grassland, within the current definitional framework as explained in Section 7.2, is reported either as not estimated (wetlands converted to grassland) or as not occurring (Table 7–4).

### 7.5.1. Grassland Remaining Grassland

#### 7.5.1.1. Category Description

Managed grassland is sometimes burned in Canada, naturally by lightning, by accidental ignition, as a management tool to control invasive plants and stimulate the growth of native species, or as part of military training exercises. Burning from managed grassland is a net source of CH<sub>4</sub>, CO, NO<sub>x</sub> and N<sub>2</sub>O (IPCC 1997).

#### 7.5.1.2. Methodological Issues

The emissions of CH<sub>4</sub> and N<sub>2</sub>O from burning of managed agricultural grassland were estimated using the IPCC Tier-1 method by



taking into consideration the area of burn, fuel load and combustion efficiency for each burning event. Emission factors of CH<sub>4</sub> (2.7 g CH<sub>4</sub> kg<sup>-1</sup> dry matter burned and 0.07 g N<sub>2</sub>O kg<sup>-1</sup> dry matter burned) were taken from the 2006 IPCC Guidelines (IPCC 2006).

Activity data on area, fuel load and combustion efficiency for each burning event for managed agricultural grassland were collected through consultations (Bailey and Liang 2013).

### 7.5.1.3. Uncertainties and Time-Series Consistency

The uncertainty associated with emissions from this source is due to the uncertainties from the area estimate, average fuel load per hectare and combustion efficiency, along with emission factors. The 95% confidence limits associated with the amount of burned materials based on expert judgement are assessed to be ±50%. The 95% confidence limits of the default emission factors are ±40% for CH<sub>4</sub> and ±48% for N<sub>2</sub>O (IPCC 2006). The overall uncertainties associated with this source of emissions using a simple error propagation were estimated to be ±64% for CH<sub>4</sub>, and ±69% for N<sub>2</sub>O, respectively.

The same methodology and emission factors are used for the entire time series of emission estimates (1990–2012).

### 7.5.1.4. QA/QC and Verification

This category has undergone Tier 1 QC checks (see Annex 6) in a manner consistent with IPCC Good Practice Guidance (IPCC 2000). The activity data and methodologies are documented and archived in both paper and electronic form.

### 7.5.1.5. Recalculations

Given that this is the first time that Canada reports emissions from this source, there is no recalculation involved.

### 7.5.1.6. Planned Improvements

There is no immediate plan in place to improve emission estimates for this source.

## 7.6. Wetlands

In Canada, a wetland is land that is saturated with water long enough to promote anaerobic processes, as indicated by poorly drained soils, hydrophytic vegetation and various kinds of biological activity that are adapted to a wet environment—in other words, any land area that can keep water long enough to let wetland plants and soils develop. As such, wetlands cover about 14% of the land area of Canada (Environment Canada 2003). The Canadian Wetland Classification System groups wetlands into five

broad categories: bogs, fens, marshes, swamps and shallow water (National Wetlands Working Group 1997).

However, for the purpose of this report and in compliance with land categories as defined in IPCC (2003), the Wetlands category should be restricted to those wetlands that are not already in the Forest, Cropland or Grassland categories. There is no corresponding area estimate for these wetlands in Canada.

In accordance with IPCC guidance (IPCC 2003), two types of managed wetlands are considered, where human intervention has directly altered the water table level and thereby the dynamics of GHG emissions/removals: peatlands drained for peat harvesting; and flooded land (namely, the creation of reservoirs). Owing to their differences in nature, GHG dynamics and the general approaches to estimating emissions and removals, these two types of managed wetlands are considered separately.

## 7.6.1. Managed Peatlands

### 7.6.1.1. Source Category Description

Of the estimated 123 Mha of peatlands in Canada,<sup>8</sup> approximately 26 kha are, or were at some point in the past, drained for peat extraction. Some 14 kha are currently being actively managed. The other 11 kha consist of 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). Peat production is concentrated in the provinces of New Brunswick, Quebec, Alberta and Manitoba. Canada produces only horticultural peat.

Since the 1980s, virtually all peat extraction in Canada has relied on vacuum harvest technology; approximately 100 t/ha (wet basis) of horticultural peat is extracted with this technology (Cleary 2003). A drawback of the technology, as opposed to the traditional cut-block method, is poor natural vegetation regrowth in the post-production phase. Since the 1990s, peatland restoration activities have been pursued with greater interest.

Peat extraction activities expanded during the 1990–2000 period, with a 47% increase in the land area under active peat extraction, from 9.5 kha in 1990 to 14 kha at the turn of the century. 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 first half of the assessment period. Since then, emissions have declined (Figure 7-4), from 1.5 Mt in 2000 to 1.1 Mt in 2012. Emissions from managed peatlands are reported under land

<sup>8</sup> This area includes peatlands that would be classified as Forest, Cropland and Grassland in the IPCC land classification.

converted to wetlands for the first 20 years after conversion and under wetlands remaining wetlands thereafter.

### 7.6.1.2. Methodological Issues

The general phases of peat extraction are 1) drainage, 2) vegetation clearing, 3) extraction, 4) stockpiling, 5) abandonment and 6) peatland restoration and establishment of natural vegetation. Due to drainage, CO<sub>2</sub> is the dominant GHG emitted from commercial peatlands and the only gas reported under this category. The main sources of emissions are vegetation clearing upon conversion, the continuing decay of dead organic matter and the rapid oxidation of exposed peat, resulting in a threefold increase in CO<sub>2</sub> emission rates compared to natural peatlands (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 Annex 3.4.

Note that the methodology does not include carbon losses from the peat transported off-site; should these be included, total emissions from managed peatlands would significantly increase.

### 7.6.1.3. Uncertainty and Time-Series Consistency

There was no formal uncertainty assessment for carbon emissions and removals in managed peatlands. The most important sources of uncertainty are discussed below.

Emission factors were derived from flux measurements made mostly over abandoned peatlands, which introduces significant uncertainty when applied to actively managed peatlands, and peat stockpiles. All measurements were conducted in eastern Canada, adding uncertainties to estimates for western Canada. Preconversion biomass carbon densities of 20 t C/ha for forest land and 2.8 t C/ha for other land (open bogs) were determined from a literature review. An average of 63% of above-ground forest land biomass was deemed harvested at clearing.

Spatially referenced information on the areas of managed peatlands is currently not available; therefore these are modelled based on general information provided by the industry.<sup>9</sup> This introduces significant uncertainty about activity data. In addition, the fate of abandoned peatlands is not monitored in Canada; there is no information on older peat fields that could have been converted to other uses. Therefore, the area estimate of abandoned peatlands is probably conservative.

### 7.6.1.4. QA/QC and Verification

Annex 6 describes the general QA/QC procedures being implemented for Canada's GHG inventory; they apply to this category as well. Areas were derived in collaboration with the Canadian Sphagnum Peat Moss Association.

### 7.6.1.5. Recalculations

Contrary to the assumption used in previous submissions that all land converted to peat extraction is forest land, geospatial analysis of peat extraction sites across Canada indicated that, on average, only 5% of land converted can be considered forest land. Therefore, land converted to managed peatlands was broken down into the subcategories other land converted to wetlands and forest land converted to wetlands. Separate preconversion above-ground biomass density parameters of 20 t C/ha and 2.8 t C/ha were used for forest and other land, respectively.

Modelled managed peatland areas were updated due to additional information on peatland restoration for 2005–2011. These data were determined based on a survey of members of the Canadian Sphagnum Peat Moss Association.

Recalculations were largest for the 1990–2000 period, with estimates decreasing, on average, by 47 kt CO<sub>2</sub> per year. These recalculations were largely due to the change in land allocation and the use of land category-specific biomass density parameters that had a greater impact during the period of expansion of areas under peat extraction (1990–2000). Overall for the 1990–2012 period, downward recalculations for the managed peatland category were, on average, 30 kt CO<sub>2</sub> per year (2% of the total category).

### 7.6.1.6. Planned Improvements

Efforts are being made to develop an appropriate methodology to estimate the emissions associated with the decay of offsite-harvested peat, as recommended in the 2006 IPCC guidelines.

## 7.6.2. Flooded Lands (Reservoirs)

This category includes in theory all lands that have been flooded regardless of purpose. Owing to methodological 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, 7, 8, 10 and 14. The total land area flooded for 10 years or less declined from 900 kha in 1990 to 120 kha in 2012. In 2012, 55% of the 120 kha of reservoirs flooded for 10 years or less were previously forested (mostly un-managed forests).

<sup>9</sup> Gerry Hood, Canadian Sphagnum Peat Moss Association, personal communication to D. Blain, Environment Canada, 2006.

Total emissions from reservoirs declined from 4.4 Mt in 1990 to 1.4 Mt CO<sub>2</sub> in 2012.

### 7.6.2.1. Methodological Issues

Two concurrent estimation methodologies were used to account for GHG fluxes from flooded lands—one for forest clearing and the other for flooding. When there was evidence of forest biomass clearing and removal prior to flooding, the corresponding carbon stock changes for all non-flooded carbon pools were estimated as in all forest conversion events, using the CBM-CFS3 (refer to Section 7.8 below and Annex 3.4). Emissions from the burning and decay of all non-flooded dead organic matter are reported under land converted to wetlands for the first 10 years post-clearing and in wetlands remaining wetlands beyond this period. The construction of large reservoirs in northern Quebec (Toulustuc, Eastmain 1, Peribonka), whose impoundments were completed in 2005, 2006 and 2008, respectively, resulted in this type of forest clearing prior to flooding. Note that emissions from forest clearing in the general area surrounding future reservoirs (e.g. for infrastructure development) are reported under forest conversion to settlements.

The second methodology is applied to estimate CO<sub>2</sub> emissions from the surface of reservoirs whose flooding has been completed. The default approach to estimate emissions from flooding assumes that all forest biomass carbon is emitted immediately (IPCC 2003). In the Canadian context, this approach would overestimate emissions from reservoir creation, since the largest proportion of any submerged vegetation does not decay for an extended period. A domestic approach was developed and used to estimate emissions from reservoirs based on measured CO<sub>2</sub> fluxes above reservoir surfaces, consistent with the descriptions of IPCC Tier 2 methodology (IPCC 2003, 2006) and following the guidance in Appendix 3a.3 of IPCC (2003). Annex 3.4 of this National Inventory Report contains more detail on this estimation methodology. The assessment includes CO<sub>2</sub> emissions only. Emissions from the surface of flooded lands are reported for a period of 10 years after flooding, in an attempt to minimize the potential double counting of dissolved organic carbon lost from the watershed and subsequently emitted from reservoirs. Therefore, only CO<sub>2</sub> emissions are calculated for hydroelectric reservoirs where flooding had been completed between 1981 and 2012.

For each reservoir, the proportion of pre-flooding area that was forest is used to apportion the resulting emissions to the subcategories forest land converted to wetlands and other land converted to wetlands.

It is important to note that fluctuations in the area of lands converted to wetlands (reservoirs) reported in the CRF tables are not indicative of changes in current conversion rates, but reflect the difference between land areas recently flooded (less than 10 years before the inventory year) and older reservoirs (more

than 10 years before the inventory year), whose areas are thus transferred out of the inventory. The reporting system does not encompass all the reservoir areas in Canada.

### 7.6.2.2. Uncertainties and Time-Series Consistency

For forest land converted to wetlands, refer to the corresponding subheading in Section 7.8, Forest Conversion. Annex 3.4 discusses the uncertainty associated with the Tier 2 estimation methodology.

Owing to current limitations in LULUCF estimation methodologies, it is not possible to fully monitor the fate of dissolved organic carbon (DOC) 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. Much of the DOC in these zones originate from unmanaged lands, and are not a reporting requirement.

### 7.6.2.3. QA/QC and Verification

Annex 6 describes the general QA/QC procedures being implemented for Canada's GHG inventory; they apply to this category as well.

Additional Tier 2 QC checks were performed on activity data, emission factors and methodology (for further explanation see Section 7.6.2.4, Recalculations).

For forest land converted to wetlands, also refer to the corresponding subheading in Section 7.8, Forest Conversion.

Canada's approach to estimating emissions from forest flooding is more realistic temporally than the default approach (IPCC 2003), which assumes that all biomass carbon on flooded forests is immediately emitted. Canada's method is more refined in that it distinguishes forest clearing and flooding; emissions from the former are estimated as in all forest clearing associated with land-use change. Further, in Canada's approach, emissions from the surface of reservoirs are derived from measurements, rather than from an assumption (immediate decay of all submerged biomass) that clearly is not verified.

### 7.6.2.4. Recalculations

Recalculations in the flooded lands category are due to the indirect effects of changes in forest modelling. Although activity data for flooded lands have not changed, the changes to activity data for one forest disturbance type alter the pool of candidate forest inventory records available for subsequent simulation of disturbances in the CBM-CFS. The impact of indirect modelling effects

leads to an average downward recalculation of 14 kt CO<sub>2</sub> eq (less than 1% of the category total) for the 1990–2012 period.

#### 7.6.2.5. Planned Improvements

Further refining estimates of CO<sub>2</sub> emissions from the surface of reservoirs partly rests upon the quantification of lateral transfers of dissolved carbon from the watershed. The monitoring of dissolved organic carbon as it travels through the landscape to the point of emission or long-term storage is beyond current scientific capabilities, and will require long-term investments in research. Efforts to ensure activity data are updated and validated will continue on an ongoing basis.

### 7.7. Settlements

The Settlements category is very diverse, and includes 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. Estimates for 2012 indicate modest removals of less than 0.2 Mt.

For the purpose of this inventory, two types of land conversion to settlements were estimated: forest land conversion to settlements, and non-forest land conversion to settlements in the Canadian north. In 2012, 510 kha of lands converted to settlements accounted for emissions of a little less than 10 Mt. Forest land conversion to settlements represents 98% of these emissions. The conversion of cropland to settlements is known to occur in Canada; an approach to developing activity data and an estimation methodology is under development.

#### 7.7.1. Settlements Remaining Settlements

This category includes estimates of carbon sequestration in urban trees. No modification has been made in activity data or methods since the last submission. The current approach considers only the removal activity of urban trees on the non-built-up portion of urban areas. This component, although approximate, makes a very minor contribution to the LULUCF Sector and represents a low priority for improvement.

##### 7.7.1.1. 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.

#### 7.7.1.2. Planned Improvements

Future efforts to improve estimates for this category will focus on improving activity data estimates of the area and extent of urban trees, as well as an update to the modelling approach. These improvements will be based on approaches outlined in the 2006 IPCC Guidelines.

### 7.7.2. Land Converted to Settlements

#### 7.7.2.1. Source Category Description

In 2012, emissions from land conversion to settlements amounted to a little less than 10 Mt CO<sub>2</sub> eq. While there are potentially several land categories, including forests that have been converted to settlements, there are currently insufficient data to quantify areas or associated emissions for all types of land-use change. Significant efforts were invested in quantifying the areas of forest land converted to settlements; this is the leading forest conversion type since 1998. On average, during the 1990–2012 period, 25 kha of forest land are converted annually to settlements, predominantly in the Boreal Plains, Boreal Shield East, Atlantic Maritime and Mixedwood Plains reporting zones. Forest land conversion accounts for 98% of emissions reported under this category. A consistent methodology was developed for all forest conversion, which is outlined in Section 7.8.

The remainder of this section covers non-forest land conversion to settlements in the Canadian north, primarily the Arctic and Sub-Arctic regions and reporting zones 4 and 8. In 2012, the conversion of non forest land to settlements in the Canadian north accounted for emissions of 150 kt CO<sub>2</sub> eq; this value is very similar in the entire trend from 1990. The major source of emissions in this category is associated with conversion of grassland to settlement land in reporting zone 13, the Taiga Plains.

#### 7.7.2.2. Methodological Issues (Non-forest Land Converted to Settlements)

Resource development in Canada's vast northern ecumene is the dominant driver of land-use change. An accurate estimation of this direct human impact in northern Canada requires that activities be geographically located and the preconversion vegetation known—a significant challenge, considering that the area of interest extends over 557 Mha, intersecting with eight reporting zones (2, 3, 4, 8, 10, 13, 17 and 18). For all reporting zones except 4 and 8, various information sources and geographic data sets were used to identify areas of high land-use change potential and narrow down the geographical domain of interest. These areas were targeted for change detection analysis using 23 Worldwide Reference System Landsat frames from circa 1985, 1990 and



2000. The scenes cover more than 8.7 Mha, or 56% of the area with high potential for land-use change. Lack of available imagery prevented the implementation of the system beyond 2000.

For reporting zones 4 and 8, a change enhancement and manual delineation approach was implemented for the 1975–2000 time period for the entire area.

Emissions include only the carbon in preconversion above-ground biomass. In spite of the existing relevant literature, the estimation of actual or average biomass density over such a large area is challenging and remains fraught with uncertainty.

### 7.7.2.3. Uncertainties and Time-Series Consistency

For forest land converted to settlements, refer to the corresponding subheading in Section 7.8, Forest Conversion.

The uncertainty about the area of non-forest land converted to settlements in the Canadian north is estimated at 20%; the uncertainty about the preconversion standing biomass varies between 35% and 50%. Annex 3.4 provides more information.

### 7.7.2.4. QA/QC and Verification

Annex 6 describes the general QA/QC procedures being implemented for Canada's GHG inventory; they apply to this category as well.

For forest land converted to settlements, refer to the corresponding subheading in Section 7.8, Forest Conversion.

### 7.7.2.5. Planned Improvement

Future efforts to improve estimates for this category will focus on improving estimates of above-ground biomass for preconversion condition for land-use change events in the Arctic and Sub-Arctic regions, by updating estimates of activity data for land-use change in these regions for the post 2000 time period.

In addition, planned improvements described under Section 7.8, Forest Conversion, will also affect this category (see Section 7.8.5, Planned Improvements).

## 7.8. Forest Conversion

Forest conversion is not a reporting category, since it overlaps with the subcategories of land converted to cropland, land converted to wetlands and land converted to settlements; it is nevertheless reported as a memo item. This section will briefly discuss methodological issues specific to this type of land-use change and outline the general approach taken to estimate its extent, location and impact. A consistent approach was applied for all

types of forest conversion, minimizing omissions and overlaps, while maintaining spatial consistency as much as possible.

In 2012, forest conversion to cropland, wetlands and settlements amounted to total emissions of 18 Mt, down from 25 Mt in 1990. This decline includes a 6.2 Mt decrease in immediate and residual emissions due to forest conversion to cropland and a 1.6 Mt decrease in emissions from forest conversion to reservoirs. There was, however, a slight increase of 0.8 Mt in immediate and residual emissions due to forest conversion to settlement lands. Note that the above values include residual emissions more than 20 years after conversion (10 years for reservoirs) that are included in the "land remaining..." categories.

Care should be taken to distinguish annual forest conversion rates (64 kha in 1990 and 46 kha in 2012) from the total area of forest land converted to other uses as reported in the CRF tables for each inventory year. The CRF figures encompass all forest land conversion for 20 years including the current inventory year (10 years for reservoirs) and hence are significantly higher than the annual rates of forest conversion to other land use.

It is also important to note that immediate emissions from forest conversion, which occur upon the conversion event, are only a fraction of the total emissions due to current and previous forest conversion activities reported in any inventory year; some of these "immediate" emissions are carbon transferred to forest products. In 2012, immediate emissions (7.9 Mt) represented only 43% of the total reported emissions due to forest conversion; the balance is accounted for by residual emissions due to current and prior events. Decay rates for dead organic matter are such that residual emissions continue beyond 20 years (10 years for reservoirs), after which they are reported in the carbon stock changes in cropland remaining cropland and wetlands remaining wetlands.

With a current annual conversion rate of 27 kha, forest conversion to settlements accounts for the largest share of forest losses to other land categories, i.e., 59% in 2012. Conversion to cropland (19 kha), meanwhile, is the second most important cause of forest conversion, representing 41% of all forest area lost. The occasional impoundment of large reservoirs (e.g. La Forge 1 in 1993 and Eastman 1 in 2006) may also convert large forest areas to wetlands (flooded land); because much of the pre-conversion C stocks are flooded, these punctual events may not release commensurate quantities of greenhouse gases.

Geographically, the highest rates of forest conversion occur in the Boreal Plains (reporting zone 10), which accounts for 51% of the total forest area lost in 2012.

Forest conversion affects both managed and un-managed forests. Losses of un-managed forests occur mainly in reporting zones 4 (Taiga Shield East) and 5 (Boreal Shield East), and are

caused mostly by reservoir impoundment; they occur to a smaller extent in reporting zones 8 and 9.

### 7.8.1. Methodological Issues

Forest conversion to other land categories is still a prevalent practice in Canada. This phenomenon is driven by a great variety of circumstances across the country, including policy and regulatory frameworks, market forces and resource endowment. The economic activities causing forest losses are very diverse; they result in heterogeneous spatial and temporal patterns of forest conversion, which, until recently, were not systematically documented. The challenge has been to develop an approach that would integrate a large variety of information sources to capture the various forest conversion patterns across the Canadian landscape, while maintaining a consistent approach in order to minimize omissions and overlap.

The approach adopted for estimating forest areas converted to other uses is based on three main information sources: systematic or representative sampling of remote sensing imagery, records, and expert judgement. The core method involves mapping of forest conversion on samples from remotely sensed Landsat images dated circa 1975, 1990, 2000 and 2008. For implementation purposes, all permanent forest removal wider than 20 m from tree base to tree base and at least 1 ha in area was considered forest conversion. This convention was adopted as a guide to consistently label linear patterns in the landscape. The other main information sources consist of databases or other documentation on forest roads, power lines, oil and gas infrastructure, and hydroelectric reservoirs. Expert opinion was called upon when the remote sensing sample was insufficient, to resolve differences among records and remote sensing information, and to resolve apparent discrepancies across the 1975–1990, 1990–2000 and 2000–2008 area estimates. A more detailed description of the approach and data sources is provided in Annex 3.4.

All estimates of emissions from biomass and dead organic matter pools due to forest conversion were generated using the CBM-CFS3 (Section 7.3.1.1), except when forests were flooded without prior clearing. Emissions from the soil pool were estimated in different modelling frameworks, except for land conversion to settlements where CBM-CFS3 decay rates were used. Hence, methods are in general consistent with those used in the forest land remaining forest land subcategory. Annex 3.4 summarizes the estimation procedures.

### 7.8.2. Uncertainties and Time-Series Consistency

An overall uncertainty estimate of  $\pm 30\%$  bounds the estimate of the total forest area converted annually in Canada (Leckie 2011), placing with 95% confidence the true value of this area for

2012 between 35 kha and 66 kha. Care should be taken not to apply the 30% range to the cumulative area reported in the CRF tables for forest land converted to another category over the last 20 years (10 years for reservoirs). Annex 3.4 describes the main sources of uncertainty about area estimates derived from remote sensing

### 7.8.3. QA/QC and Verification

Annex 6 describes the general QA/QC procedures being implemented for Canada's GHG inventory; they apply to this category as well. In addition, detailed Tier 2 QA/QC procedures were carried out during estimate development procedures, involving documented QC of imagery interpretation, field validation, cross-calculations and detailed examination of results (Dyk et al. 2011). The calculations, use of records data, and expert judgement are traceable through the compilation system and documented. More information is available in Annex 3.4.

### 7.8.4. Recalculations

Recalculations occurred throughout the entire forest conversion estimation time period (1970–2011). These recalculations were the result of a combination of a fix to the way CBM manages multi-component yield curves, the integration of the new forest inventory of Alberta, and improvements in the allocation of areas converted to peat extraction. Complexities in the processing and estimation development system currently do not enable a complete breakdown of each of these recalculation components. For more detailed information on changes to forest-related modelling, refer to Section 7.3.1.4.

For the 1990–2011 period, the recalculations on area rates show a different trend between the two decades: a decrease of less than 1 kha/yr on average over the first decade, with important peak decreases in 1993 and 1996–1998 of around 1.5 kha/year; and a slightly constant small decrease over the second decade of 56 kha/year on average. However, in terms of the resulting emissions, the recalculations show a different pattern: highly variable decreases over the entire time-series that fluctuate between 0.2 Mt in 1994 and 1.3 Mt in 2008.

### 7.8.5. Planned Improvements

Planned improvements emphasize extension of the time period of mapping, QA/QC review and assessments, increased mapping coverage in areas with high uncertainty, field validation, use of additional records, and efforts to enhance the efficiency in the data compilation process.



# Chapter 8

## Waste (CRF Sector 6)

### 8.1. Overview

This sector includes emissions from the treatment and disposal of wastes. Sources include solid waste disposal on land (landfills), wastewater treatment and waste incineration. The categories evaluated are CH<sub>4</sub> emissions from solid waste disposal on land, CH<sub>4</sub> and N<sub>2</sub>O emissions from wastewater treatment, and CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O emissions from waste incineration.

Much of the waste treated or disposed of is biomass or biomass-based. CO<sub>2</sub> emissions attributable to such wastes are not included in inventory totals but are reported in the inventory as a memo item. CO<sub>2</sub> emissions of biogenic origin are not reported if they are reported elsewhere in the inventory or if the corresponding CO<sub>2</sub> uptake is not reported in the inventory (e.g. annual crops). Therefore, under these circumstances, the emissions are not included in the inventory emission totals, since the absorption of CO<sub>2</sub> by the harvested vegetation is not estimated by the Agriculture Sector and, thus, the inclusion of these emissions in the Waste Sector would result in an imbalance. Also, CO<sub>2</sub> emissions from wood and wood products are not included, because these emissions are accounted for in the Land Use, Land-use Change and Forestry (LULUCF) Sector at the time of tree harvesting. In contrast, CH<sub>4</sub> emissions from anaerobic decomposition of wastes are included in inventory totals as part of the Waste Sector.

If carbon is lost from forests at an unsustainable rate (i.e. faster than annual re-growth), the carbon budget for forest lands will be negative for net emissions.

In 2012, the greenhouse gas (GHG) emissions from the Waste Sector contributed 21 Mt to the national inventory, compared with 19 Mt for 1990—an increase of 8.2%. The national total emissions increased by 18.2% over the same time interval. The emissions from this sector represented 3.2% and 2.9% of the overall Canadian GHG emissions in 1990 and 2012, 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 19 Mt or 92% of the emissions from this sector in 2012. The chief contributor to the Waste Sector emissions is the CH<sub>4</sub> released from MSW landfills, which for 2012 amounted to 19 Mt (0.90 Mt CH<sub>4</sub>). This net emission value is determined by subtracting the amount of CH<sub>4</sub> captured from the total estimated CH<sub>4</sub> generated within the landfill by the Scholl Canyon model, then adding the quantity of the captured CH<sub>4</sub> that was not combusted by the flaring operation, where applicable. From our 2012 biennial survey of Canadian landfills, which collected 2010 and 2011 year data, approximately 35% of the CH<sub>4</sub> generated in Canadian MSW landfills, as estimated by the Scholl-Canyon model, was captured and combusted (either for energy recovery, or flared). The next Environment Canada biennial landfill gas collection and utilization survey will be held in the spring/summer of 2014 for the data years 2012 and 2013; for the purposes of the present submission, the landfill gas collection and utilization data for 2012 were assumed the same as 2011.

Overall, the increase in the CH<sub>4</sub> generation rate from MSW landfills is primarily dependent on population growth and on average household disposable income, which has been steadily increasing since the 1980s. Other factors, such as types and patterns of consumption (which influence volume of packaging materials) and rates of urbanization also play a part. This upward influence 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 2010, nearly 33 Mt of non hazardous waste

Table 8–1 Waste Sector GHG Emission Summary, Selected Years

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)							
	1990	2000	2005	2008	2009	2010	2011	2012
Waste Sector	19 000	21 000	22 000	22 000	22 000	20 000	20 000	21 000
Solid Waste Disposal on Land	17 000	19 000	20 000	20 000	20 000	19 000	19 000	19 000
Wastewater Handling	830	920	950	970	980	990	990	1 000
Waste Incineration	740	750	700	710	680	680	670	670

Note: Totals may not add up due to rounding.

(residential, institutional, commercial, industrial, construction and demolition) were generated. Waste diversion initiatives began in the early 1990s and, based upon the national figures for 2010, approximately 24% of the waste generated is diverted from disposal (landfill or incineration) (Statistics Canada 2013a). Nationally since 2000, the portion of the waste generated that has been diverted from final disposal has slowly but steadily increased, from 21% in 2000 to 24% in 2010. Municipal and provincial government initiatives have resulted in significant quantities of residential wastes being diverted from final disposal. From 2000 to 2010, the percentage of diverted residential waste increased from 19% to 33%. The same, however, cannot be said of the diversion of non-residential waste, which decreased from 22% to 19% over this period (Statistics Canada 2003, 2004, 2007a, 2008a, 2010b, 2003a).

Table 8–1 summarizes the Waste Sector and subsector GHG contributions for the following inventory years: 1990, 2000, 2005, 2008, 2009, 2010, 2011 and 2012.

## 8.2. Solid Waste Disposal on Land (CRF Category 6.A)

### 8.2.1. Source Category Description

Emissions are estimated from two types of landfills in Canada:

- MSW landfills; and
- wood waste landfills.

In Canada, most waste disposal on land occurs in managed municipal or privately owned landfills. Very few, if any, unmanaged waste disposal sites exist. Therefore, it has been assumed that all waste is disposed of in managed facilities. Residential, institutional, commercial and industrial wastes are disposed of in MSW landfills. Over the past 15 years, dedicated construction and demolition (C & D) landfills were established. Typically, these landfills do not require CH<sub>4</sub> collection systems, as the CH<sub>4</sub> generation rate is very low due to the minimal organic content in the waste stream. However, for completeness of this emission source and accuracy of emissions from MSW landfills, the waste quantities now include C & D wastes.

Wood waste landfills are mostly privately owned and operated by forest industries, such as saw mills and pulp and paper mills. These industries use the landfills to dispose of surplus wood residue, such as sawdust, wood shavings, bark and sludges. Some industries have shown increasing interest in waste-to-energy projects that produce steam and/or electricity by combusting these wastes. In recent years, residual wood previously regarded as a waste is now being processed as a value-added product—

e.g., wood pellets for residential and commercial pellet stoves and furnaces, and hardboard, fibreboard and particle board. Wood waste landfills have been identified as a source of CH<sub>4</sub> emissions; however, there is a great deal of uncertainty in the estimates. These landfills are a minor source of CH<sub>4</sub> emissions in comparison with MSW landfills.

The *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997) provides two methodologies for estimating emissions from landfills: a default method and a first-order kinetics method, also known as the Scholl Canyon model. The default method relates emissions to the quantity of waste landfilled in the previous year, whereas the Scholl Canyon model relates emissions to the cumulative biologically available waste that has been landfilled in previous years.

The composition and amount of waste landfilled in Canada have significantly changed over the past several decades, primarily as a result of waste diversion initiatives and population growth, respectively. For this reason, a static model such as the default method is not felt to be appropriate. Therefore, emissions from MSW landfills and wood waste landfills are estimated using the Scholl Canyon model. The Scholl Canyon model, used to estimate Canada's CH<sub>4</sub> emissions from landfills, has been validated independently through a study conducted by the University of Manitoba (Thompson et al. 2006).

Landfill gas, which is composed mainly of CH<sub>4</sub> and CO<sub>2</sub>, is produced by the anaerobic decomposition of organic wastes. The first phase of this process typically begins after waste has been in a landfill for 10 to 50 days. Although the majority of the CH<sub>4</sub> and CO<sub>2</sub> gases are generated within 20 years of landfilling, emissions can continue for 100 years or more (Levelton 1991).

A number of important site-specific factors contribute to the generation of gases within a landfill, including the following:

*Waste composition:* Waste composition is probably the most important factor affecting landfill gas generation rates and quantities. The amount of landfill gas produced is dependent on the amount of organic matter landfilled. The rate at which gas is generated is dependent on the distribution and type of organic matter in the landfill.

*Moisture content:* Water is required for anaerobic degradation of organic matter; therefore, moisture content within a landfill significantly affects gas generation rates.

*Temperature:* Anaerobic digestion is an exothermic process. The growth rates of bacteria tend to increase with temperature until an optimum is reached. Therefore, landfill temperatures may be higher than ambient air temperatures. The extent to which ambient air temperatures influence the temperature of the landfill and gas generation rates depends mainly on the depth of the landfill. Temperature variations can affect microbial activity,

subsequently affecting their ability to decompose matter (Maurice and Lagerkvist 2003).

*pH and buffer capacity:* The generation of CH<sub>4</sub> in landfills is greatest when neutral pH conditions exist. The activity of methanogenic bacteria is inhibited in acidic environments.

*Availability of nutrients:* Certain nutrients are required for anaerobic digestion. These include carbon, hydrogen, nitrogen and phosphorus. In general, MSW contains the necessary nutrients to support the required bacterial populations.

*Waste density and particle size:* The particle size and density of the waste also influences gas generation. Decreasing the particle size increases the surface area available for degradation and therefore increases the gas production rate. The waste density, which is largely controlled by compaction of the waste as it is placed in the landfill, affects the transport of moisture and nutrients through the landfill, which also affects the gas generation rate.

## 8.2.2. Methodological Issues

CH<sub>4</sub> produced from the decomposition of waste in landfills is calculated using the Scholl Canyon model, which is a first-order decay model. This reflects the fact that waste degrades in landfills over many years. Data pertaining to landfill gas capture were obtained directly from the owners/operators of specific landfills with landfill gas collection systems.

CH<sub>4</sub> emissions are determined by calculating the amount of CH<sub>4</sub> generated from landfill waste decomposition through the Scholl Canyon model, subtracting the CH<sub>4</sub> captured through landfill gas recovery systems, then adding the quantity of uncombusted CH<sub>4</sub> emitted by the flares for those locations where a portion or all of the recovered landfill gas is burned without energy recovery. The GHG emissions associated with the combustion of that portion of the landfill gas that is captured and utilized for energy generation purposes are accounted for in the Energy Sector. Annex 3.5 provides detailed information on the methodologies used for various categories covered by this subsector.

### 8.2.2.1. CH<sub>4</sub> Generation

The Scholl Canyon model was used to estimate the quantity of CH<sub>4</sub> generated. The model is based upon the following first-order decay equation (IPCC/OECD/IEA 1997):

Equation 8–1:

$$Q_{T,x} = kM_xL_0e^{-k(T-x)}$$

where:

Q <sub>T,x</sub>	=	amount of CH <sub>4</sub> generated in the current year (T) by the waste M <sub>x</sub> , kt CH <sub>4</sub> /year
x	=	the year of waste input
M <sub>x</sub>	=	the amount of waste disposed of in year x, Mt
k	=	CH <sub>4</sub> generation rate constant, year <sup>-1</sup>
L <sub>0</sub>	=	CH <sub>4</sub> generation potential, kg CH <sub>4</sub> /t waste
T	=	current year

Equation 8–2:

$$Q_T = \sum Q_{T,x}$$

where:

Q <sub>T</sub>	=	amount of CH <sub>4</sub> generated in the current year (T), kt CH <sub>4</sub> /year
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In order to estimate CH<sub>4</sub> emissions from landfills, information on several of the factors described above is needed. To calculate the net emissions for each year, the sum of Q<sub>T,x</sub> for every section of waste landfilled in past years was obtained (Equation 8–2), from which the captured gas was subtracted for each province. A computerized model has been developed to estimate aggregate emissions on a regional basis (by province and territory) in Canada. The national CH<sub>4</sub> emission value is the summation of emissions from all regions.

## Waste Disposed of Each Year or the Mass of Refuse (M<sub>x</sub>)

### MSW Landfills

For the purposes of the inventory, MSW includes residential; institutional, commercial and industrial; and construction and demolition wastes. 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 B.H. Levelton (1991). For the years 1998, 2000, 2002, 2004, 2006, 2008 and 2010, MSW disposal data were obtained from the *Waste Management Industry Survey* that is conducted by Statistics Canada on a biennial basis (Statistics Canada 2000, 2003, 2004, 2007a, 2008a, 2010b, 2013a). For the intervening odd years (1999, 2001, 2003, 2005, 2007 and 2009), the MSW disposal values, including both landfilled and incinerated MSW, were obtained by taking an average of the adjacent even years.

Quantities of waste landfilled for 2011 and 2012 were trended from values derived from the Statistics Canada survey. Incinerated and exported waste quantities were subtracted from the Statistics Canada disposal values in order to obtain the amounts of MSW landfilled for 1998–2012. Exported waste quantities are provided in Annex 3.5. For the years 1991–1997, with the exception of Prince Edward Island, the Northwest Territories, Nunavut and Yukon, the quantities of waste disposed of were estimated from an interpolation using a multiple linear regression approach applied to the B.H. Levelton (1991) and Statistics Canada (2000, 2003, 2004) MSW landfill values. MSW landfill values for Prince Edward Island, the Northwest Territories, Nunavut and Yukon for the period 1991–2012 are obtained by trending historical landfill data with the provincial populations for 1971–2012 (Statistics Canada 2006, 2013). Waste quantities imported into Canada are accounted for within the Statistics Canada *Waste Management Industry Survey* since the facilities report all wastes being disposed of in their facility, whether of domestic or international origin.

### 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 an exponential extrapolation was used for 1999–2012.

### CH<sub>4</sub> Generation Rate Constant (k)

The CH<sub>4</sub> kinetic rate constant (k) represents the first-order rate at which CH<sub>4</sub> is generated after waste has been landfilled. The value of k is affected by four major factors: moisture content, temperature, availability of nutrients and pH. It is assumed that, in a typical MSW landfill, the nutrient and pH conditions are attained and that, therefore, these factors are not limiting. In many parts of Canada, subzero conditions exist for up to seven months of the year, with temperatures dropping below –30°C (Thompson et al. 2006); however, evidence suggests that ambient temperature does not affect landfill decay rates (Maurice and Lagerkvist 2003; Thompson and Tanapat 2005). In addition, seasonal temperature variations in the waste are minimal when compared with atmospheric temperature variations (Maurice 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 CH<sub>4</sub> production occurs between the winter and summer seasons (Bingemer and Crutzen 1987; Thompson and Tanapat 2005). Therefore, of all these factors, moisture content is the most

influential parameter for Canadian landfills and is largely determined by the annual precipitation received at the landfills.

### MSW Landfills

The k values used to estimate emissions from MSW landfills were obtained from a study conducted by Environment Canada's Greenhouse Gas Division that employed provincial precipitation data from 1941 to 2007 (Environment Canada 1941–2007). The provincial locations at which the average annual precipitations were calculated were those indicated in the Levelton study where major landfills were located over the 1941–1990 period (Levelton 1991). Since the k values are related to precipitation, and assuming that the moisture content of a landfill is a direct function of the annual precipitation, from these precipitation values, the associated k values were determined using a relationship prepared by the Research Triangle Institute (RTI) for the U.S. EPA (RTI 2004). The RTI assigns default decay values of less than 0.02/year, 0.038/year and 0.057/year to areas with an annual precipitation of less than 20 inches/year (< 500 mm), between 20 and 40 inches/year (500 to 1000 [average 750 mm]) and greater than 40 inches/year (> 1000 mm), respectively. The plot of these decay values and precipitation data showed a linear relationship. Using this relationship and Environment Canada's average provincial precipitation data for 1941–2007, average provincial landfill decay rates were calculated for three time periods that match those used to derive the methane generation potentials (L<sub>0</sub>), i.e., 1941–1975, 1976–1989 and 1990–2007 (Environment Canada 1941–2007). It is assumed that the provincial k values determined for 1990–2007 are also applicable from 2008 to 2011.

These values are provided in Table 8–2.

### Wood Waste Landfills

Based upon the default value for estimating wood products industry landfill CH<sub>4</sub> emissions recommended by the National Council for Air and Stream Improvement, Inc., a k value of 0.03/year was assumed to represent the CH<sub>4</sub> generation rate constant k for all of the wood waste landfills in Canada (NCASI 2003).

### CH<sub>4</sub> Generation Potential (L<sub>0</sub>)

#### MSW Landfills

The values of theoretical and measured L<sub>0</sub> range from 4.4 to 194 kg CH<sub>4</sub>/t of waste (Pelt et al. 1998). Over the time series used by the MSW portion of the emission estimation model, i.e., 1941 to 2012, three different L<sub>0</sub>s were used to represent discrete time periods where studies showed significant changes in waste composition from one period to the next. L<sub>0</sub> is a function of degradable organic carbon (DOC), which is in turn determined from the composition of the waste, as described below. For consistency with the quantities of MSW used in the Scholl Canyon model, the calculation of the L<sub>0</sub> accounted for the characteristics of the

Table 8–2 MSW Landfill k Value Estimates for Each Province/Territory

Time Series	Provinces and Territories											
	N.L.	P.E.I.	N.S.	N.B.	Que.	Ont.	Man.	Sask.	Alta.	B.C.	N.W.T. & Nvt.	Yk.
1941–1975	0.075	0.056	0.076	0.06	0.053	0.041	0.020	0.01	0.012	0.082	0.001	0.001
1976–1989	0.080	0.062	0.079	0.063	0.057	0.047	0.017	0.009	0.012	0.082	0.002	0.001
1990–2012	0.078	0.061	0.075	0.059	0.059	0.046	0.019	0.012	0.012	0.083	0.003	0.002

three MSW sources: residential; institutional, commercial and industrial; and construction and demolition wastes. Each of the percentage fractions (A, B, C and D; refer to Equation 8-4) is calculated from the combined quantities of the three aforementioned waste sources for the respective fraction, in the derivation of the aggregated DOC.

The provincial and territorial DOC values were calculated from waste disposal composition values for three distinct time periods: 1941–1975, 1976–1989 and 1990–2012. These time intervals coincide with those employed for the calculation of the CH<sub>4</sub> generation rate constant k. Using waste composition data obtained from a Natural Resources Canada (NRCan) study, which was based on the 2002 data year (NRCan 2006), DOC values were derived and assumed to be constant over the period 1990–2012. Since waste diversion programs were not significant prior to 1990, a second set of DOC values was developed to represent the waste composition at disposal from 1976 to 1989 by adding the NRCan landfill to the 2004 Statistics Canada recycled waste composition data (Statistics Canada 2007a). A third set of DOC values was developed from a 1967 national study to cover the period from 1941 to 1975 (CRC Press 1973). A summary of the L<sub>0</sub> values for the provinces and territories over the three time periods is given in Table 8–3. The percentages of organic waste diverted in 2002 for all Canadian provinces are also given as a reference for that year. As waste disposal practices in Canada change and as new information is made available, the L<sub>0</sub> values will be adjusted accordingly.

L<sub>0</sub> was determined employing the methodology provided by the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997) (Equation 8–3) using the provincial waste composition data as input to the degradable organic carbon (DOC) calculation:

#### Equation 8–3:

$$L_o = MCF \times DOC \times DOC_F \times F \times \frac{16}{12} \times \frac{1000 \text{ kg CH}_4}{\text{t CH}_4}$$

where:

L <sub>0</sub>	=	CH <sub>4</sub> generation potential (kg CH <sub>4</sub> /t waste)
MCF	=	CH <sub>4</sub> methane correction factor (fraction)
DOC	=	degradable organic carbon (t C/t waste)
DOC <sub>F</sub>	=	fraction DOC dissimilated
F	=	fraction of CH <sub>4</sub> in landfill gas
16/12	=	stoichiometric factor

According to the Revised 1996 IPCC Guidelines, the methane correction factor (MCF) for managed landfill sites has a value of 1.0 (IPCC/OECD/IEA 1997). The fraction (F) of CH<sub>4</sub> emitted from a landfill ranges from 0.4 to 0.6 and was assumed to be 0.5. From the *IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (2000), a DOC<sub>F</sub> value of 0.6 was selected from a default range of 0.5 to 0.6. This DOC<sub>F</sub> value best reflects the lower concentration of lignin in the MSW waste, since the majority of wood wastes from pulp and paper industries and saw mills are disposed of in dedicated wood waste landfills.

The DOC calculation is derived from the biodegradable portion of the MSW (Equation 8–4):



Table 8–3 CH<sub>4</sub> Generation Potential (L<sub>0</sub>) from 1941 to Present

Province/Territory	2002 Organic Waste Diversion (%)	1941 to 1975		1976 to 1989		1990 to Present	
		DOC	L <sub>0</sub> (kg CH <sub>4</sub> /t waste)	DOC	L <sub>0</sub> (kg CH <sub>4</sub> /t waste)	DOC	L <sub>0</sub> (kg CH <sub>4</sub> /t waste)
Newfoundland	N/A	0.30	121.01	0.18	71.60	0.18	71.50
Prince Edward Island	N/A	0.28	111.20	0.16	63.82	0.15	60.34
Nova Scotia	29.7	0.26	105.92	0.15	60.24	0.15	60.56
New Brunswick	19.8	0.24	97.53	0.16	63.23	0.15	59.98
Quebec	13.7	0.38	153.06	0.20	79.71	0.19	77.43
Ontario	16.4	0.37	147.61	0.20	79.19	0.20	78.34
Manitoba	4.9	0.34	137.60	0.19	74.28	0.18	73.41
Saskatchewan	4.3	0.37	149.93	0.21	82.63	0.21	82.33
Alberta	16.7	0.28	111.53	0.17	69.25	0.17	67.95
British Columbia	23.3	0.27	109.62	0.17	66.34	0.15	59.58
Territories (Yk., N.W.T. and Nvt.)	N/A	0.23	91.70	0.14	56.68	0.16	62.36

Sources: All values are derived from data obtained from NRCan (2006), Statistics Canada (2007a) and CRC Press (1973), with the exception of the 2002 Organic Waste Diversion figures, which were obtained from Thompson et al. (2006).

N/A = Unavailable categorical information.

#### Equation 8–4:

$$DOC = (0.4 \times A) + (0.17 \times B) + (0.15 \times C) + (0.3 \times D)$$

where:

- A = fraction of MSW that is paper and textiles
- B = fraction of MSW that is garden or park waste
- C = fraction of MSW that is food waste
- D = fraction of MSW that is wood or straw

#### Wood Waste Landfills

Equation 8–3 generated an L<sub>0</sub> value of 80 kg CH<sub>4</sub>/t of wood waste, which was used to estimate emissions from wood waste landfills by the Scholl Canyon model. IPCC defaults were used for MCF in unmanaged deep landfills (MCF = 0.8); the fraction of CH<sub>4</sub> in the landfill gas (F = 0.5); and the fraction of DOC dissimilated (DOC<sub>F</sub> = 0.5), where the lower end of the default range for wastes containing lignin was selected (IPCC/OECD/IEA 1997). A composition of 100% wood waste was assumed in calculating the fraction of DOC in Equation 8–4.

#### 8.2.2.2. Captured Landfill Gas

Some of the CH<sub>4</sub> that is generated in MSW landfills is captured as landfill gas and combusted, either by flaring or burning the gas for energy recovery. Combustion of the landfill gas converts CH<sub>4</sub> to CO<sub>2</sub>, thus reducing the CH<sub>4</sub> emissions. To calculate the net CH<sub>4</sub> emissions from landfills, the amount of CH<sub>4</sub> captured, as provided

by the landfill facilities, is subtracted from the quantity of CH<sub>4</sub> generated, as estimated by the Scholl Canyon model. Added to this value, to account for the combustion inefficiency of the flares, is the quantity of captured CH<sub>4</sub> that passes through the flare uncombusted. The captured gas is wholly or partially flared or combusted for electricity or heat generation. GHG emissions affiliated with the use of landfill gas for energy recovery are accounted for in the Energy Sector.

Flaring combustion efficiency for CH<sub>4</sub> in landfill gas of 99.7% was used to determine the quantity of CH<sub>4</sub> that circumvented the flare. This value was obtained from Table 2.4-3 of Chapter 2.4 of the U.S. EPA AP 42 (U.S. EPA 1995). The quantities of landfill gas collected from 1983 to 1996 were obtained from a personal communication.<sup>1</sup> Data for the 1997 to 2003 period were collected directly from individual landfill operators biennially by Environment Canada's National Office of Pollution Prevention (Environment Canada 1997, 1999b, 2001, 2003a). As of 2006, beginning with the 2005 data year, this survey is now being conducted by Environment Canada's Pollutant Inventories and Reporting Division (Environment Canada 2007, 2009, 2011a, 2013a). 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 adjacent odd years starting from 1997. However, since the 2008 survey, the Division has been collecting two years' data biennially, i.e., 2006–2007, 2008–2009 and 2010–2011 data from the 2008, 2010 and 2012 facility surveys, respectively (Environment Canada 2009, 2011a, 2013a). The 2011 captured landfill gas data were assumed constant for 2012.

<sup>1</sup> Personal communication with ME Perkin of Environment Canada's National Office of Pollution Prevention in 1998.

### 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 NIR by ICF Consulting (2004). This Tier 2 evaluation of uncertainty employed values from the 2001 inventory year (Environment Canada 2003b). However, there have been modifications made to the methodology, emission factors and sources of information as a consequence of the findings of this uncertainty study. Therefore, the results of this study may not be an accurate representation of the current uncertainty around the emissions from this subsector and the model inputs. However, in the absence of a follow-up Tier 2 study, it is expected that the improvements made would result in a reduction of the uncertainty for this subsector.

The CH<sub>4</sub> emissions from this key category include CH<sub>4</sub> emissions from MSW landfills and wood waste landfills. The level of uncertainty associated with the CH<sub>4</sub> emissions from the combined subsectors was estimated to be in the range of -35% to +40%, which closely resembles the uncertainty range of -40% to +35% estimated in this study for the CH<sub>4</sub> emissions from MSW landfills. The level uncertainty range provided by the ICF Consulting study (2004) is only slightly larger than the  $\pm 30\%$  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 uncertainty range of the ICF Consulting study (2004) is quoted for a 95% confidence interval, which would typically be larger than the range quoted for a 90% confidence interval.

The MSW landfills contributed to over 90% of the total CH<sub>4</sub> emissions from this key category in 2001 (Environment Canada 2003b). The uncertainty estimates for CH<sub>4</sub> emissions from MSW landfills seem to have been largely influenced by the uncertainty in the inventory values for L<sub>0</sub> for 1941–1989 and 1990–2001 and the CH<sub>4</sub> generation rate constant k, where the uncertainty for both k and L<sub>0</sub> were based upon an estimate from one expert elicitation. A simplified model of the Scholl Canyon method was used for the Monte Carlo simulation, which may have had a bearing on relevancy of the uncertainty values. An error was introduced in the calculation of the MSW landfill CH<sub>4</sub> emission uncertainty by the use of the year 2000 value (instead of the 2001 value) for the total CH<sub>4</sub> captured in Canada, resulting in an uncertainty range of +20% to +24% for these activity data. The actual uncertainty for this activity data entry should have been  $\pm 2\%$ .

Although the uncertainty range estimated in this study for wood waste landfills was significantly higher (i.e. -60% to +190%) than that for MSW landfills, its contribution to the uncertainty in the key category was much lower, owing to its relatively low contribution of emissions (i.e. less than 10%) (Environment Canada 2003b). The uncertainty estimate for wood waste landfills seems

to have been largely influenced by the CH<sub>4</sub> generation rate, carbon content of the waste landfilled, and the biodegradable fraction of the waste, where the uncertainties were assumed by ICF Consulting (2004) based upon the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997) and/or the *IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000), where available.

The estimates are calculated in a consistent manner over time.

### 8.2.4. QA/QC and Verification

A linkage error in the Waste Sector model was identified; however, it was only identified after the emission values were confirmed for the present submission. The error affects the calculation of MSW landfill emissions from Quebec and British Columbia, and only for the year 2012. This error results in an overestimation of 1% of the national emissions from Solid Waste Disposal on Land. The error will be corrected in the 2015 submission.

### 8.2.5. Recalculations

Emission estimations from MSW landfills were recalculated over the 1994–2011 time series, to account for corrections to model linkages related to the new provincial waste export data over the 1998–2011 time series as well as updates to the CH<sub>4</sub> recovery data from the 2012 CH<sub>4</sub> collection and utilization survey (Environment Canada 2013a). Significant recalculations for 2010 and 2011 were due to the incorporation of Statistics Canada (2013a) waste disposal values from its biennial waste management survey. Slight recalculations were conducted for Prince Edward Island and the three territories from 2006 to 2011, to account for population revisions by Statistics Canada (2013b). Overall, these recalculations resulted in a slight reduction over the 1994–2009 time series, ranging from 0.01% to 4.5%; and then increases of 6.3% and 6.8% for 2010 and 2011, respectively, from the 2013 submission.

### 8.2.6. Planned Improvements

A multi-year study is being considered to provide a current review of recent MSW waste composition values for all provinces and territories for urban and rural areas to update L<sub>0</sub>. The study is planned to start in the summer of 2014. Results from the study are tentatively expected for incorporation into the submission in 2016, upon review and approval of the data.

The in-house biennial landfill gas capture and utilization survey is planned for the summer of 2014.

## 8.3. Wastewater Handling (CRF Category 6.B)

### 8.3.1. Source Category Description

Emissions from municipal and industrial wastewater treatment were estimated. Both municipal and industrial wastewater can be aerobically or anaerobically treated. When wastewater is treated anaerobically, CH<sub>4</sub> is produced; however, it is typical that systems with anaerobic digestion in Canada contain and combust the produced CH<sub>4</sub>. CH<sub>4</sub> emissions from aerobic systems are assumed to be negligible. Both types of treatment system generate N<sub>2</sub>O through the nitrification and denitrification of sewage nitrogen (IPCC/OECD/IEA 1997).

CO<sub>2</sub> is also a product of aerobic and anaerobic wastewater treatment. However, as detailed in Section 8.1, CO<sub>2</sub> emissions originating from the decomposition of organic matter are not included with the national total estimates, in accordance with the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997).

The emission estimation methodology for municipal wastewater handling is divided into two areas: CH<sub>4</sub> from anaerobic wastewater treatment and N<sub>2</sub>O from human sewage.

### 8.3.2. Methodological Issues

Annex 3.5 provides for detailed information on the methodologies used for various categories covered by this subsector.

#### 8.3.2.1. CH<sub>4</sub> Emissions

##### Municipal Wastewater Treatment

The IPCC default method was not used because the required data were not available. A method developed for Environment Canada (AECOM Canada 2010) was used to calculate an emission factor. This country specific methodology provides for the accurate estimation of provincial methane emissions that best suits the available related activity data. Based on the amount of organic matter generated per person in Canada and the conversion of organic matter to CH<sub>4</sub>, it was estimated that 1.97 kg CH<sub>4</sub>/person per year could potentially be emitted from anaerobically treated wastewater. Additional information on the incorporated methodology is provided in Annex 3.5.

CH<sub>4</sub> emissions were calculated by multiplying the emission factor by the population of the respective province (Statistics Canada 2006, 2013b) and by the fraction of wastewater that is treated anaerobically.

##### Industrial Wastewater Treatment

A survey was conducted by the Greenhouse Gas Division to obtain methane emissions from facilities that treated their effluent anaerobically on-site over the 1990–2011 time series. Where actual measured facility data were not provided, design specifications particular to that site were used to estimate maximum emissions expected. In the absence of current data, the values for 2012 are assumed constant from 2011. A complete description of the methodology is provided in Annex 3.5.

#### 8.3.2.2. N<sub>2</sub>O Emissions

##### Municipal Wastewater Treatment

The N<sub>2</sub>O emissions from municipal wastewater treatment facilities were calculated using the IPCC default method (IPCC/OECD/IEA 1997). This method estimates the N<sub>2</sub>O emission factor as the product of the annual per capita protein consumption, the assumed protein nitrogen content (16%), the quantity of N<sub>2</sub>O-N produced per unit of sewage nitrogen (0.01 kg N<sub>2</sub>O-N/kg sewage nitrogen) and the N<sub>2</sub>O/N<sub>2</sub>O-N conversion factor (1.57). Protein consumption estimates, in kg/person per year, were obtained from an annual Food Statistics report published by Statistics Canada (2007b, 2008b, 2010a). The protein consumption values used are those adjusted to account for retail, household, cooking and plate loss, as recommended by AECOM Canada (2012). Data are provided for the years 1991, 1996 and 2001 to 2009. Protein consumption data for missing years are estimated by applying a multiple linear regression application to the Statistics Canada data. Protein consumption values for 2010–2012 were assumed constant from 2009 in the absence of current data due to the discontinuation by Statistics Canada of the Food Statistics publication. Emissions were calculated by multiplying the emission factor by the population of the respective provinces (Statistics Canada 2006, 2013b). A summary of the values for these two parameters over the time series is given in Table 8–4.

##### Industrial Wastewater Treatment

The *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997) do not address the methodology for the estimation of N<sub>2</sub>O emissions from industrial wastewater treatment. Owing to a lack of activity data, the N<sub>2</sub>O emissions from this category have not been evaluated.

### 8.3.3. Uncertainties and Time-Series Consistency

##### Municipal Wastewater Treatment

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 NIR (ICF Consulting 2004). This Tier 2 evaluation of uncertainty employed values from the 2001 inven-

**Table 8–4 N<sub>2</sub>O Emission Factors**

Year	Annual Per Capita Protein Consumption (kg protein/person per year)	N <sub>2</sub> O Emission Factor (kg N <sub>2</sub> O/person per year)
1990	23.82	0.060
1991	24.16	0.061
1992	24.29	0.061
1993	24.53	0.062
1994	24.77	0.062
1995a	25.01	0.063
1996a	25.04	0.063
1997a	25.50	0.064
1998a	25.75	0.065
1999a	26.01	0.065
2000a	26.26	0.066
2001b	26.63	0.067
2002b	26.57	0.067
2003b	26.19	0.066
2004b	26.35	0.066
2005c	25.96	0.065
2006c	25.93	0.065
2007c	26.20	0.066
2008c	25.64	0.064
2009c	25.50	0.064
2010c	25.50	0.064
2011c	25.50	0.064
2012c	25.50	0.064

Sources: <sup>a</sup>Statistics Canada (2007b), <sup>b</sup>Statistics Canada (2008b) and <sup>c</sup>Statistics Canada (2010a). The data have been adjusted to account for retail, household, cooking and plate loss.

tory year (Environment Canada 2003b). However, there have been modifications made to the methodology, emission factors and sources of information as a consequence of the findings of this uncertainty study. Therefore, the results of this study may not be an accurate representation of the current uncertainty around the emissions from this subsector and the model inputs. However, in the absence of a follow-up Tier 2 study, it is expected that the improvements made would result in a reduction of the uncertainty for this subsector.

The overall level uncertainty associated with the wastewater treatment subsector was estimated to be in the range of –40% to +55%. The level uncertainty range provided by the ICF Consulting (2004) study is less than the  $\pm 60\%$  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 Consulting (2004) for a 95% confidence interval should typically show a larger value than that quoted for a 90% confidence interval. Based on 2001 data, the trend uncertainty associated with the total GHG emissions (comprising CH<sub>4</sub> and N<sub>2</sub>O) from the wastewater treatment systems was estimated to be in the range of about +12% to +13%. The

extrapolation of trend uncertainty in 2001 to the 2011 inventory should be made with caution, as trend uncertainty is more sensitive than level uncertainty to the changes in the inventory estimate values for the more recent years.

Since the methods and data sources have remained unchanged over the time series, the estimates for this category are consistent over time.

### Industrial Wastewater Treatment

The IPCC *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000) provide for default uncertainties ranging from –25% to +25%. Since these data were for the most part obtained directly from the facility operators, based upon expert opinion, the uncertainty is estimated to be in the range of –15% to +15% or less.

### 8.3.4. QA/QC and Verification

No significant anomalies were identified.

### 8.3.5. Recalculations

Minor recalculations were conducted for wastewater treatment to account for revised Statistics Canada population data from 2006 to 2011 (Statistics Canada 2013b). Emission increases on the order of 0.01% to 0.74% from the 2013 submission were noted for this subsector.

### 8.3.6. Planned Improvements

The next biennial industrial wastewater treatment facility survey will be conducted during the summer of 2014. It is expected that these values will be used to update emissions for the 2015 submission.

## 8.4. Waste Incineration (CRF Category 6.C)

### 8.4.1. Source Category Description

Emissions from MSW, hazardous wastes and sewage sludge incineration are included in the inventory. Some municipalities in Canada utilize incinerators to reduce the quantity of MSW sent to landfills and to reduce the amount of sewage sludge requiring land application.

GHG emissions from incinerators vary, depending on factors such as the amount of waste incinerated, the composition of the waste, the carbon content of the non-biomass waste and the facilities' operating conditions.

### 8.4.1.1. MSW Incineration

A combustion chamber of a typical mass-burn MSW incinerator is composed of a grate system on which waste is burned and is either water-walled (if the energy is recovered) or refractory-lined (if it is not). GHGs that are emitted from MSW incinerators include CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O.

As per the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997), CO<sub>2</sub> emissions from biomass waste combustion are not included in the inventory totals. The only CO<sub>2</sub> emissions detailed in this section are from fossil fuel-based carbon waste, such as plastics and rubber.

CH<sub>4</sub> emissions from Canadian MSW incinerators are negligible, based on the findings from a recent report commissioned by Environment Canada (CRA 2011).

### 8.4.1.2. Hazardous Waste Incineration

There are five hazardous waste incinerators in Canada located in Quebec, Ontario and Alberta. CO<sub>2</sub>, N<sub>2</sub>O and CH<sub>4</sub> are the greenhouse gases emitted from this source. The emissions are derived from the quantities of hazardous wastes incinerated that were provided directly by the facilities in a series of surveys summarized in a report (Environment Canada 2011b). A preliminary survey was conducted in 2006, which was followed by surveys in 2008, 2010 and 2012 (Environment Canada 2013b) to improve completeness of the coverage and data accuracy.

### 8.4.1.3. Sewage Sludge Incineration

Two different types of sewage sludge incinerators are used in Canada: multiple hearth and fluidized bed. In both types of incinerators, the sewage sludge is partially de-watered prior to incineration. The de-watering is typically done in a centrifuge or using a filter press. Currently, municipalities in Ontario and Quebec operate sewage sludge incinerators. GHGs emitted from the incineration of sewage sludge include CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O, as in the case of MSW incinerators; however, since the carbon present in the wastewater sewage sludge is of biological origin, the CO<sub>2</sub> emissions are not accounted for in the inventory totals from this source.

## 8.4.2. Methodological Issues

The emission estimation methodology depends on waste type and gas emitted. A more detailed discussion of the methodologies is presented in Annex 3.5.

### 8.4.2.1. CO<sub>2</sub> Emissions

#### MSW Incineration

The *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997) do not specify a method to calculate CO<sub>2</sub> emissions from the incineration of fossil fuel-based waste (such as plastics and rubber). Therefore, the following three-step method was developed for MSW incineration:

- *Calculating the amount of waste incinerated:* The amount of waste incinerated each year was estimated based on a regression analysis using data from an Environment Canada (1996) study, which contains detailed provincial incineration data for the year 1992, and from a study performed by A.J. Chandler & Associates Ltd. for Environment Canada, which provided incineration data for 1999, 2000 and 2001 (Environment Canada 2003c).
- *Developing emission factors:* Provincial CO<sub>2</sub> emission factors are founded on the assumption that the carbon contained in waste undergoes complete oxidation to CO<sub>2</sub>. The amount of fossil fuel-based carbon available in the waste incinerated has been determined using typical percent weight carbon content values (Tchobanoglous et al. 1993). The amount of carbon per tonne of waste is estimated and converted to tonnes of CO<sub>2</sub> per tonne of waste by multiplying by the ratio of the molecular mass of CO<sub>2</sub> to that of carbon.
- *Calculating CO<sub>2</sub> emissions:* Emissions were calculated on a provincial level by multiplying the amount of waste incinerated by the appropriate emission factor.

#### Hazardous Waste Incineration

CO<sub>2</sub> emissions were estimated from the quantities of hazardous wastes combusted over the 1990–2012 time series, where the emissions for 2012 were assumed to be constant from 2010 since they were not included within the last survey. The emission estimation method used the IPCC default carbon content and fossil carbon percent of total carbon of 50% and 90%, respectively, for hazardous waste as presented in Table 5.6 of the IPCC Good Practice Guidance (IPCC 2000).

#### Sewage Sludge Incineration

CO<sub>2</sub> generated from the incineration of sewage sludge is not reported in the inventory emission totals, since the sludge consists solely of biogenic matter.

### 8.4.2.2. N<sub>2</sub>O and CH<sub>4</sub> Emissions

#### MSW Incineration

Emissions of N<sub>2</sub>O from MSW incineration were estimated using the IPCC default method (IPCC/OECD/IEA 1997). An average emission factor was calculated assuming that the IPCC five-stoker facility factors were most representative. To estimate emissions, the calculated emission factor was multiplied by the amount of waste incinerated by each province. CH<sub>4</sub> emissions from



Canadian MSW incinerators are negligible, based on the findings from a recent report commissioned by Environment Canada (CRA 2011).

### Hazardous Waste Incineration

N<sub>2</sub>O and CH<sub>4</sub> emissions were estimated from emission factors derived from site-specific data provided by a facility rather than from IPCC defaults because of the relatively small emission contribution of these two gases, the availability of country-specific data, and the number of sites involved in this process. Site specific data consisted of the quantities of hazardous waste processed at the facility and the cumulative measured N<sub>2</sub>O and CH<sub>4</sub> emissions for 2009 (Environment Canada 2011b). The resulting emission factors were  $3.16 \times 10^{-3}$  kt N<sub>2</sub>O/kt waste and  $1.69 \times 10^{-4}$  kt CH<sub>4</sub>/kt of waste.

### Sewage Sludge Incineration

Emissions generated from the incineration of sewage sludge are dependent on the amount of dried solids incinerated. To calculate the CH<sub>4</sub> emissions, the amount of dried solids incinerated is multiplied by an appropriate emission factor. Estimates of the amount of dried solids in the sewage sludge incinerated in the years 1990–1992 are based on a study completed in 1994, as related in a personal communication with W. Fettes in February of 1994 from an interchange between Senes Consultants and Puitan Bennet. Data for the years 1993–1996 were acquired through telephone surveys of facilities that incinerate sewage sludge. Data for the years 1997 and 1998 were obtained from a Compass Environmental Inc. study prepared for Environment Canada (Environment Canada 1999a). Activity data for 1999, 2000 and 2001 were taken from a study conducted by A.J. Chandler and Associates Ltd. for Environment Canada (Environment Canada 2003c). To estimate the amount of sewage sludge incinerated in the years 2002–2012, a regression analysis was completed using the Chandler and Compass Environmental Inc. incineration values.

CH<sub>4</sub> emissions are estimated based on emission factors obtained from the U.S. EPA publication *Compilation of Air Pollutant Emission Factors* (U.S. EPA 1995). It is assumed that sewage sludge incineration is conducted with fluidized bed incinerators. Therefore, the emission factor is 1.6 t CH<sub>4</sub>/kt of total dried solids for fluidized bed sewage incinerators equipped with venture scrubbers. To estimate emissions, the emission factor was multiplied by the amount of waste incinerated by each province. The national emissions were then determined as the summation of these emissions for all provinces.

Emissions of N<sub>2</sub>O from sewage sludge incineration were estimated using the IPCC default emission factor for fluidized beds, 0.8 kg N<sub>2</sub>O/t of dried sewage sludge incinerated (IPCC 2000). To estimate emissions, the emission factor was multiplied by the amount of waste incinerated by each province. The national

emissions were then determined as the summation of these emissions for all provinces.

### 8.4.3. Uncertainties and Time-Series Consistency

The following discussion on uncertainty for the categories within this subsector is based upon the results as reported in an uncertainty quantification study of the Canadian NIR (ICF Consulting 2004). This Tier 2 evaluation of uncertainty employed values from the 2001 inventory year (Environment Canada 2003b). However, there have been modifications made to the methodology, emission factors and sources of information as a consequence of the findings of this uncertainty study. Therefore, the results of this study may not be an accurate representation of the current uncertainty around the emissions from this subsector and the model inputs. However, in the absence of a follow-up Tier 2 study, it is expected that the improvements made would result in a reduction of the uncertainty for this subsector.

The overall level uncertainty associated with the waste incineration source category was estimated to be in the range of –12% to +65%. For 2001 inventory estimates, the overall trend uncertainty associated with the total GHG emissions (comprising CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O) from incineration of wastes (comprising MSW and sewage sludge) was estimated to be in the range of about +10% to +11%. The inventory trend uncertainty was estimated at +10%. The extrapolation of trend uncertainty in 2001 to the 2012 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.

### 8.4.4. QA/QC and Verification

No significant anomalies were identified.

### 8.4.5. Recalculations

Minor recalculations were conducted for MSW incineration to account for revised Statistics Canada population data from 2006 to 2011 (emission increases of 0.01% to 0.74% from the 2013 submission for this subsector) (Statistics Canada 2013b).

### 8.4.6. Planned Improvements

The next biennial incineration survey is planned for the summer of 2014. Facility-level incineration surveys had been conducted in 2008, 2010 and 2012. The data from these preliminary surveys are to be reviewed for completeness and accuracy with the results from the 2014 biennial incineration survey, before they are to be considered for incorporation into the Waste Sector model, and into the Energy Sector methodologies. It is noted from the surveys that several sites have energy recovery units, emissions from

which are presently accounted for in the Waste Sector. Once the data have been reviewed by both sectors and found complete and reliable, emissions from these units will be reported in the Energy Sector.

# Chapter 9

## Recalculations and Improvements

Canada's greenhouse gas (GHG) inventory undergoes a continuous process of updates and improvements in order to ensure that the most complete, consistent, comparable, accurate and transparent information possible is reported. Section 9.1 of this chapter summarizes the recalculations implemented in Canada's national GHG inventory since its 2013 submission, in order to facilitate an integrated view of changes in, and impacts on, emission levels and trends. A description of improvements to the 2014 submission due to methodological changes or refinements, or to address recommendations made by the Expert Review Teams (ERTs) as part of the annual review process, can be found in Section 9.2 along with a list of planned improvements for future inventories.

Although the quantification of uncertainty for the emission estimates (Annex 7) helps prioritize improvements of future inventories, uncertainty is not an indicator of potential future changes resulting from continual improvement activities.

### 9.1. Explanations and Justifications for Recalculations

The United Nations Framework Convention on Climate Change (UNFCCC) requires all Annex I Parties to continually improve their national GHG inventories. As new information and data become available and more accurate methods are developed, previous estimates are updated to provide a consistent and comparable trend in emissions and removals. As such, recalculations are

expected to occur annually, reflecting the principle of continuous improvement. The nature, rationale and impact of these recalculations are documented in this national inventory report and associated data tables. Recalculations can result for any number of reasons, including the following:

- i. Correction of errors detected by quality control procedures;
- ii. Incorporation of updates to activity data including changes in data sources;
- iii. Reallocation of activities to different categories (although this will only affect sub-totals);
- iv. Refinements of methodologies and emission factors;
- v. Inclusion of categories previously not estimated (which improves inventory completeness); and
- vi. Recommendations from UNFCCC reviews.

On a continuous basis, Environment Canada consults and works jointly with key federal and provincial partners along with industry stakeholders, research centres and consultants to improve the quality of the underlying variables and scientific information for use in the compilation of the national inventory. Where necessary, Environment Canada revises and recalculates the emission and removal estimates for all years in the inventory, as good inventory preparation practice requires that methodological improvements and updates be applied to the entire time series of annual estimates (i.e. from 1990 to the most recent year reported). A consistent time series is required to avoid confounding a methodological change with an actual change in GHG emissions or removals.

Table 9-1 provides a summary of all recalculations that occurred due to methodological changes or refinements since the previous submission, with a brief description, justification and summary of individual impacts on emissions and trends. In addition to the changes listed in Table 9-1, further recalculations may have occurred due to updates in activity data, reallocations of emissions, the correction of errors discovered since the previous submission, or minor incremental enhancements. Details on sectoral recalculations may also be found within the individual chapters for each sector. Estimated impacts on levels and trends at a national level are presented in Sections 9.1.1 and 9.1.2.

**Table 9-1 Summary of Recalculations Due to Methodological Change or Refinement**

CRF # and gas	Category	Description	Justification	Impact on Emissions
1.A.3.b CO <sub>2</sub>	Energy - Fuel Combustion - Transport	Corrections to emissions factor for, propane. Refer to Section 3.2.1.5 for specific details.	Increase accuracy	Emission factor updates to the fuel combustion - Transport Category(1.A.3.b) resulted in an decrease of 0.18% for CO <sub>2</sub> (1.43 kt) for the 2011 data year.
2.A.2 CO <sub>2</sub>	Lime Production	Revised activity data for 2011.	NRCan provided revised value for production of lime in 2011.	Recalculation resulted in 2.9% increase in 2011 emission.

Table 9-1 Summary of Recalculations Due to Methodological Change or Refinement (cont'd)

CRF # and gas	Category	Description	Justification	Impact on Emissions
2.A.3 CO <sub>2</sub>	Limestone and Dolomite Use	Revised activity data for 2011.	NRCAN provided revised value for consumption of limestone and dolomite in 2011.	Recalculation resulted in 31% reduction in 2011 emission.
2.A.7.2 CO <sub>2</sub>	Magnesite Use	Revised activity data for 2011.	Updates to activity data for 2011 resulted in the recalculation of emissions for the year.	Recalculation resulted in 5% increase in 2010 emission.
2.G	Other and Undifferentiated Production	Revised activity data for 1996–2003	Statistics Canada provided revised data for these years related to non-energy consumption of fuels.	Recalculations increased emissions, in the range of 14% to 30%, for aforementioned years.
5.A.1, 5.A.2, 5.B.2, 5.D.2, 5.E.2	LULUCF - Forest Land: FLFL, LFL, LCL, LWL, LSL	Improvements in Forest-related categories were implemented in the following 4 categories: 1) New version of the Carbon Budget Model (CBM-CFS3) 2) Natural disturbances area revisions 3) New Alberta forest inventory 4) Harvesting activity updates	1) To correct errors in the way the model manages multi-component growth curves 2) Revisions captured updates to natural disturbance monitoring datasets and corrected data-processing errors 3) To incorporate the most up to date provincial forest information 4) Activity data update	Total recalculations, resulting from a combination of all changes, range from -30 Mt (2010) to + 23 Mt (2004).
5.B.2.	LULUCF - Grassland Remaining Grassland (GLGL) - CH <sub>4</sub> and N <sub>2</sub> O	To fill a reporting gap compelled by the Good Practice Guidance (IPCC 2003) for burning of managed grasslands in Canada.	Data on the area extent of burning from managed agricultural grasslands have been obtained through consultations. It is now possible to estimate emissions of CH <sub>4</sub> and N <sub>2</sub> O from burning of managed grassland in Canada (GLGL) along with all necessary documentation and archive.	For 1990, 2005 and 2012 emissions from burning of managed grassland (GLGL) are estimated at 571, 756, and 1378 kt CO <sub>2</sub> eq, respectively
5.D.2	LULUCF - Land Converted to Wetland	Land Converted to Wetlands (managed peatlands) was broken down into the Subcategories Other Land Converted to Wetlands and Forest Land Converted to Wetlands.	Geospatial analysis of peat extraction sites across Canada indicated that on average only 5% of land converted can be considered forest land	Overall for the 1990–2012 period downward recalculations for the managed peatland category were on average 30 kt CO <sub>2</sub> per year (2% of the total category).
6.A.1 CH <sub>4</sub>	Waste, Solid Waste Disposal on Land	Exported non-hazardous waste to the U.S.	A linkage error in the model resulted in only those exports from Ontario being accounted for. The error was corrected in the present submission to include exports from Quebec and B.C.	As a consequence of this error being corrected, for the 1989 to 2012 time period, the missing MSW waste quantities, which varied from 27 kt to 789 kt, were subtracted from the quantities being landfilled in Canada. The combination of the revised waste landfilled quantities, the corrected waste export values and the new landfill gas capture values resulted in a 6.8% (1360 kt CO <sub>2</sub> eq.) decrease in the Solid Waste Disposed on Land-Methane category for 2011.
6.A.1 CH <sub>4</sub>	Waste, Solid Waste Disposal on Land	Updated Statistics Canada data	Waste landfilled quantities are derived from the data on quantities of waste disposed of obtained from Statistics Canada's biennial survey: Waste Management Industry Survey: Business and Government Sectors. These data were not available in time for inclusion in last year's submission. The 2013 report from the Waste Management Industry	The combination of the revised waste landfilled quantities, the corrected waste export values and the new landfill gas capture values resulted in a 6.8% (1360 kt CO <sub>2</sub> eq.) decrease in the Solid Waste Disposed on Land-Methane category for 2011. The emission value for 2010 decreased by a similar amount (6.3% or 1250 kt CO <sub>2</sub> eq.). The revision of the 2008 data by Statistics

Table 9-1 Summary of Recalculations Due to Methodological Change or Refinement (cont'd)

CRF # and gas	Category	Description	Justification	Impact on Emissions
6.A.1 CH <sub>4</sub> (cont'd)	Waste, Solid Waste Disposal on Land  (cont'd)	Updated Statistics Canada data  (cont'd)	Survey: Business and Government Sectors includes data on quantities of non-hazardous waste disposed of for the 2010 data year. In last year's submission, waste quantities were extrapolated for 2009-2011. The 2013 report also provided revised data on quantities of waste disposed of for 2008.	Canada resulted in small increases to the emission estimates for 2008 and 2009 (1.9% and 1.6%, respectively).
6.A.1 CH <sub>4</sub>	Waste, Solid Waste Disposal on Land	Updated landfill gas collection and utilization data.	The present submission includes data from the last Environment Canada landfill gas collection and utilization survey for the data years 2010 and 2011. In the previous submission, the provincial values for 2009 from the last survey were assumed constant for 2010 and 2011.	The combination of the revised waste landfilled quantities, the corrected waste export values and the new landfill gas capture values resulted in a 6.8% (1360 kt CO <sub>2</sub> eq.) decrease in the Solid Waste Disposed on Land/ Methane category for 2011.

Table 9-2 Summary of Recalculations

	GHG Emissions per Year							
	1990	2000	2005	2008	2009	2010	2011	2012
<b>National Total</b>								
Current (Mt CO <sub>2</sub> eq)	591	721	736	731	689	699	701	699
2013 submission (Mt CO <sub>2</sub> eq)	591	718	737	731	689	701	702	-
Change (%)	-0.03%	0.53%	-0.22%	0.02%	0.04%	-0.22%	-0.08%	-
<b>LULUCF</b>								
Current (Mt CO <sub>2</sub> eq)	-71	-52	53	-17	-27	76	77	41
2013 submission (Mt CO <sub>2</sub> eq)	-62	-52	63	-11	-10	103	87	-
Change (%)	15.2%	-1.3%	-14.8%	55.6%	179.2%	-26.6%	-12.0%	-

### 9.1.1. Implications for Emission Levels

Overall GHG emissions (excluding the Land Use, Land-use Change and Forestry [LULUCF] Sector) were revised by relatively small amounts for all years. Recalculations had the largest implications for 2000, 2005 and 2010, which showed changes of +0.53% (718 Mt to 721Mt), -0.22% (737 Mt to 736 Mt) and -0.22% (701 Mt to 699 Mt), respectively. See Table 9-2 for additional details. In comparison, recalculations performed in last year's NIR (2013), due to revisions to the underlying 2003–2010 historical energy data carried out by Canada's statistics agency (Statistics Canada), resulted in revisions to emission totals for 2010, 2004 and 2005 of +1.32%, -0.92% and -0.32%, respectively, relative to the original 2012 submission.

This year, significant recalculations occurred in the LULUCF Sector (Table 9-2), due mainly to several changes to forest related estimates—including a new forest model version, revisions to forest areas affected by natural disturbances, incorporation of a new provincial forest inventory, and updated harvest activity data. Chapter 7 provides further information on recalculations and improvements associated with the LULUCF Sector.

### 9.1.2. Implications for Emission Trends

Overall, the recalculations of the total GHG estimates (excluding the LULUCF Sector) had a negligible effect on the trend between 1990 and 2010, now reported as an 18.7% increase in total GHG emissions since 1990 instead of the previously reported 18.6% increase. The trend between 1990 and 2012 shows an 18.2% increase in GHG emissions.

## 9.2. Planned Improvements

Canada's inventory submission is reviewed annually by an ERT following agreed-upon UNFCCC review guidelines. Reviews are coordinated by the UNFCCC Secretariat, and the ERT is composed of inventory experts from developed and developing countries. The purpose of the in-depth review, performed by the ERT, is to provide a thorough and comprehensive technical assessment of the implementation of the Convention and adherence to its Reporting Guidelines; the review's outcome is reflected in an annual review report (ARR).



In the 2012 ARR,<sup>1</sup> the ERT outlined several recommendations and ways to enhance and improve the inventory and the NIR. Table 9–3 summarizes the improvements implemented in the 2014 NIR based on recommendations from the ERT. Further

details on sectoral improvement plans can be found in chapters for each sector. Annual improvements to the national inventory must be applied to all estimation years, in order to maintain time series consistency. The 2013 ARR was finalized after development of the inventory and preparation of the NIR, and recommendations arising from last year's review will be considered for the 2015 submission.

1 The 2012 ARR, *Report of the individual review of the annual submission of Canada submitted in 2012*, can be found at [http://unfccc.int/documentation/documents/advanced\\_search/items/6911.php?preref=600007434](http://unfccc.int/documentation/documents/advanced_search/items/6911.php?preref=600007434).

**Table 9–3 Improvements Based on Recent ERT Recommendations (2012 ARR)**

Sector	Category	Summary of ERT Recommendation*	Status
Energy	Energy – Sector overview	50. Transparency improvements	Addressed in the 2014 NIR: 1) Imported natural gas - see Annex 8 of NIR 2) Coal production data - see Annex 3.1 of NIR
	Stationary Fuel Combustion: Solid, Liquid and Gaseous Fuels – CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O	62. Provide an explanation for the differences between the data in the energy balance and in the CRF tables in the next NIR, in order to improve transparency.	Addressed in 2014 submission: A2.4.2.1 - Road Transportation (CRF Category 1.A.3.b)
	Road Transportation: Liquid Fuels and Biomass – CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O	63. Provide additional information on the activity data (AD) for biofuels in the NIR.	Addressed in 2014 submission: A2.4.2.1 - Road Transportation (CRF Category 1.A.3.b)
	Road Transportation: Liquid Fuels and Biomass – CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O	64. Canada calculates the GHG emissions from road transportation following a Tier 3 approach, and the fuel consumption is calculated using both top-down and bottom-up approaches. Results of the bottom-up and top-down approaches to calculating fuel consumption in the NIR should be presented, and an explanation should be provided in the NIR that all fuel is accounted for in accordance with the IPCC good practice guidance.	Addressed in 2014 submission: A2.4.2.1 - Road Transportation (CRF Category 1.A.3.b)
Industrial Processes and Solvent and Other Product Use	Lime Production – CO <sub>2</sub>	72. Provide the following additional information in the next annual submission: clarification as to whether the AD presented in the CRF tables are the corrected or original values; time-series AD for the production of high-calcium and dolomitic lime; and an explanation of the large decline in the share of dolomitic lime during the periods 1999–2000 and 2008–2009.	The AD presented in the CRF tables are the total national lime production, including the water content in the hydrated lime. The AD in the 2014 CRF have been provided on a "Dry" basis and indicated as so in the NIR. Additional information regarding the split between the dolomitic and high-calcium lime production has been provided in Chapter 4 of the 2014 NIR, as has information on the reasons for reduction of dolomitic lime's portion of overall lime production in the 1999–2000 and 2008–2009 periods. Information on the large decline in the share of dolomitic lime during the periods 1999–2000 and 2008–2009 is also provided in Chapter 4, Section 4.3.2.
	Iron and Steel Production – CO <sub>2</sub>	73. Increase transparency with regard to the use of metallurgical coke and other reductants for iron and steel production in the Industrial Processes and Energy sectors in the next annual submission.	Additional information has been provided in Chapter 4 of the 2014 NIR, Industrial Processes. Additional information on use of reductants other than coke for iron and steel production is provided in NIR 2014, Section 4.16.2. An Annex 3.2 component on other reductants' details has been added.
	Iron and Steel Production – CO <sub>2</sub>	74. Correct the identification of confidential pig iron production data; enhance its QC procedures to prevent this type of error from occurring in future.	Only 2009 data are considered confidential, and this has been indicated in the CRF table. The 2014 NIR text in Chapter 4 has been adjusted accordingly.
	Iron and Steel Production – CO <sub>2</sub>	75. Implement a recommendation made in the previous review report to improve the transparency of its reporting relating to the technologies used by the four major integrated iron and steel plants in Canada, as reflected in the IPCC Tier 2 method.	This has been addressed in the 2014 NIR. Additional information on iron and steel production processes is provided in Section 4.16.1. An Annex 3.2 component on technology details has been added.

Table 9-3 Improvements Based on Recent ERT Recommendations (2012 ARR) (cont'd)

Sector	Category	Summary of ERT Recommendation*	Status
<b>Industrial Processes and Solvent and Other Product Use</b>  (cont'd)	Consumption of Halocarbons and SF <sub>6</sub> – HFCs, PFCs and SF <sub>6</sub>	77. The NIR provides explanations of emission factors (EFs) and underlying assumptions used to develop emission estimates for HFCs (1996–2009) and PFCs (1995–2009), but clarification is required as to whether the same method had been used to estimate HFC and PFC emissions for 2010 as for the other years.	This has been addressed in the 2014 NIR, Chapter 4, Section 4.20.1.2
	Limestone and Dolomite use – CO <sub>2</sub>	79. Include a breakdown of limestone and dolomite use in the next annual submission.	Additional information is provided in Section 4.4.2, Chapter 4, of the 2014 NIR. Table 4-3 provides for the consumption split for limestone and dolomite in the Iron and Steel sector (the major consumer of dolomite).
<b>LULUCF</b>	Sector overview	89. Improvements to the QA/QC system are needed and should be documented in the next annual submission.	Canada has improved documentation of QC processes in the 2014 NIR, specifically in the "QA/QC and Verification" subsections in: 7.3.1.3, 7.3.2.4, 7.4.1.1, 7.4.1.2, 7.4.1.3, 7.4.1.4, 7.4.2.2, 7.5.1.4, 7.6.1.4, 7.6.2.3, 7.7.1.1, 7.7.2.4 and 7.8.3.
	Sector overview	90. Mandatory reporting of pools and areas reported as "NE" in some LULUCF subcategories for which default estimation methods are available in the IPCC good practice guidance for LULUCF, including Land Converted to Grassland and Grassland Remaining Grassland.	Canada has made some progress towards reporting of all mandatory pools and areas reported as "NE" in some LULUCF subcategories for which default estimation methods are available in the good practice guidance for LULUCF. The database, inventory methods, documentation and archives developed for the 2014 NIR include reporting of methods and estimates from Grassland Remaining Grassland and burning of managed grassland. Additional information can be found in Section 7.5.1 of Chapter 7, Grassland Remaining Grassland; Annex 3.4.3.2, Grassland Converted to Cropland, and Annex 3.4.4.1, Grassland Remaining Grassland.
	Sector overview	90. Improve its reporting of the pools in these subcategories currently reported as "NE."	Canada has made efforts to collect activity data AD on burning of managed grassland for the entire time series. With the use of the default IPCC EFs, Canada has provided emission estimates from burning of managed grassland in the 2014 NIR. Additional information can be found in Section 7.5.1 of Chapter 7, Grassland Remaining Grassland, and Annex 3.4.4.1, Grassland Remaining Grassland.
	Land Converted to Cropland – CO <sub>2</sub>	92. Either include an assessment of above-ground biomass changes associated with grassland conversion to cropland using default biomass values, or provide some data supporting the assumption that these stock changes are negligible.	"Canada has provided justifications that there are no significant differences in above-ground biomass before and after grassland conversion to cropland based on recent findings from Barley and Liang (2013) in the 2014 NIR. Additional information can be found in Section 7.4.2.2 of Chapter 7, Grassland Converted to Cropland, and Annex 3.4.3.2, Grassland Converted to Cropland.
	Biomass Burning – CH <sub>4</sub> and N <sub>2</sub> O	94. Include estimates in the next annual submission for Biomass Burning – Grassland.	A study to provide the AD required for reporting biomass burning on grassland has recently been carried out, and Canada has reported on emission estimates from burning of managed grasslands in the 2014 NIR. Additional information can be found in Section 7.5.1 of Chapter 7, Grassland Remaining Grassland, and Annex 3.4.4.1, Grassland Remaining Grassland.
<b>Waste</b>	Wastewater Handling – CH <sub>4</sub>	99. Methane emissions from industrial wastewater sludge and domestic and commercial wastewater sludge should be reported as "Not Occurring (NO)" instead of "Not Estimated (NE)", and the relevant information should be updated accordingly in the CRF tables of its next annual submission.	Methane emissions from industrial wastewater sludge and domestic and commercial wastewater sludge are assumed as NO. Changes to the notations have been made in the CRF, and further details are provided in Annex A.3.5.4 in the 2014 NIR.

\* The number indicated in this column refers to the paragraph in the *Report of the Individual Review of the Annual Submission of Canada Submitted in 2012*, where the specific recommendation can be found.

In addition, Canada has identified planned improvements in Table 9–4 that, when implemented, will impact the inventory time series from 1990 onwards. The planned improvement activities are based on recommendations from both internal sources and external review processes such as the UNFCCC expert reviews, and collaborative work between inventory sector experts and industry, other government departments, and academia. As part of Canada's National System, improvement activities and work plans are developed on a continuous basis to further refine and increase the transparency, completeness, accuracy, consistency and comparability of the Canadian GHG inventory. Improvement activities are developed by sector experts and prioritized by a prioritization and planning committee (P&PC) using key category contributions, quality assurance/quality control (QA/QC) activities, uncertainty assessments, resource availability and potential impacts as primary considerations.

Starting in the 2015 NIR, Annex I inventories will be prepared using the revised *Guidelines for the preparation of national com-*

*munications by Parties included in Annex I to the Convention, Part I: UNFCCC reporting guidelines on annual greenhouse gas inventories* (Reporting Guidelines), which were adopted by the nineteenth Conference of the Parties to the UNFCCC (COP 19<sup>2</sup>) in Warsaw in November 2013. The revised Reporting Guidelines will require the use of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*<sup>3</sup> for the development of inventory estimates, as well as require reporting on new GHGs and the use of global warming potentials from the *IPCC Fourth Assessment Report*.<sup>4</sup>

2 Decision 24/CP.19 can be found at <http://unfccc.int/resource/docs/2013/cop19/eng/10a03.pdf#page=2>.

3 The *2006 IPCC Guidelines for National Greenhouse Gas Inventories* can be found at <http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html>.

4 Global Warming Potentials in the *IPCC Fourth Assessment Report: Climate Change 2007* can be found at [http://www.ipcc.ch/publications\\_and\\_data/ar4/wg1/en/ch2s2-10-2.html](http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html).

**Table 9–4 Principal Planned Improvements**

Category	Improvement	Description	Basis of Planned Improvement
Energy – General	Improve accuracy of the annual submission with respect to coke in CRF table 1.A(d).	A coke study is in progress to investigate the EF for combustion of coal coke.	UNFCCC ERT recommendation
Energy – General	Reallocation of waste incineration with energy recovery emissions to the Energy Industries category	A waste incineration survey is underway for recent historical years. The incorporation of the resulting data, as well as data from previous surveys, and the subsequent reallocation of the relevant estimated emissions to the Energy Sector, will be reviewed by the Party for completeness and accuracy before incorporation in its future annual submissions.	UNFCCC ERT recommendation
Energy – Oil and Natural Gas (CRF 1.A.1, 1.B.2)	To update the conventional oil and gas model with the latest knowledge and information on GHG emissions for the industry	A multi-year study to update GHG emissions for the conventional upstream crude oil and natural gas industry with new information and knowledge is being conducted. Results from the study will be required to go through a review process prior to incorporation into the national inventory.	Continuous improvement
Energy – Road Transportation (CRF 1.A.3.B)	Development of better on-road activity data	Ongoing on-road fleet descriptions (make, model, model year, vehicle counts) and performance data (fuel consumption ratios, annual mileage accumulation rates) continue to evolve as new data and knowledge become available.	UNFCCC ERT recommendation / continuous improvement
Industrial Processes – Cement Production – CO <sub>2</sub>	Develop a country-specific emission factor (EF) based on the Canadian industry's data provided to EC.	The Cement Association of Canada (CAC) has provided its operational data (CO <sub>2</sub> emissions and clinker production levels) at national aggregated levels, for 1990–2011, based on which a new country-specific EF will be developed for Canada.	UNFCCC ERT recommendation
Industrial Processes – Consumption of Halocarbons and SF <sub>6</sub> – HFCs, PFCs and SF <sub>6</sub>	Increase the accuracy of its reporting of HFC emissions from consumption of halocarbons by developing country-specific EFs.	A study has been undertaken to determine country-specific HFC EFs. Before implemented in the NIR, the country-specific EFs from the study need to be confirmed by the Canadian inventory agency in consultation with the industry and	UNFCCC ERT recommendation

Table 9-4 Principal Planned Improvements (cont'd)

Category	Improvement	Description	Basis of Planned Improvement
Industrial Processes – Consumption of Halocarbons and SF <sub>6</sub> – HFCs, PFCs and SF <sub>6</sub>  (cont'd)		other similar jurisdictions. As well, a workshop will be organized to further firm up the EFs of the report before the final EFs are implemented. Therefore, the results of that study will likely be incorporated in its 2015 annual submission.	
Industrial Processes – Other (Industrial Processes) – CO <sub>2</sub>	Introduce new CO <sub>2</sub> estimation methodology, based on IPCC GL 2006, for estimating of emissions from carbide production, and other petrochemicals (ethylene, styrene, methanol, etc.) that involve the use of hydrocarbons as raw materials, in its 2015 annual submission.	There is currently no production of carbide in Canada. Carbide (only for CH <sub>4</sub> ) is reported separately in the CRF in the 2014 NIR under the Chemicals subsector (2.B.4). The CO <sub>2</sub> estimation methodology for carbide and other feedstock uses of hydrocarbons in production processes will be implemented from the 2015 submission onwards.	UNFCCC ERT recommendation
Agriculture – Enteric Fermentation/Manure Management (CRF 4.A/4B)	Improve capacity to capture change in farm practices in emission estimates.	Integration of the time series of nutrition data for certain animal categories	Continuous improvement
Agriculture – Manure Management (CRF 4B)	Integrate new information on manure management systems.	Improve capacity to capture, in emission estimates, changes in farm practices.	Continuous improvement
Agriculture – Agricultural Soils (CRF 4D)	Nitrous oxide emissions from grazing animals on pasture, range and paddock	Research work on collecting N <sub>2</sub> O flux from animal manure on pasture, range and paddock in eastern and western Canada has been carried out since 2009, and the results from this project will be used to provide country-specific EFs, and will be implemented in the 2015 NIR.	Continuous improvement
Agriculture – Agricultural Soils (CRF 4D)	Nitrous oxide emissions from losses of soil organic carbon in cropland remaining cropland	Losses of soil organic carbon from cropland remaining cropland are converted into losses of soil nitrogen using either a fixed or variable C:N ratio. In the 2006 IPCC Guidelines, this lost N is considered as a source of nitrogen input, resulting in nitrous oxide emissions (as per the 2006 IPCC guidelines).  When the 2006 IPCC Guidelines are implemented in 2015, the inclusion of this new source will result in an increase of emissions from 0.58 Mt CO <sub>2</sub> eq in 1990, a peak at 0.68 Mt CO <sub>2</sub> eq in 2001, and then a decrease to 0.59 Mt CO <sub>2</sub> eq in 2010 (based on the 2012 NIR submission).	Continuous improvement
LULUCF – Forest Land Conversion LCL, LWL, LSL (CRF 5.B.2, 5.D.2, 5.E.2)	Ongoing efforts to improve estimates of forest conversion, and reduce uncertainty of estimates	Addition of a new mapping time period (circa 2012) will reduce uncertainties associated with extrapolation of activity data. Other efforts such as ongoing quality control activities, addition of new sampling and enhanced mapping will also lead to improved estimates.	Continuous improvement
Cropland Remaining Cropland (CRF 5.B)	CO <sub>2</sub> emissions from carbon-containing N fertilizers	When urea or urea-based nitrogen fertilizer is applied to a soil for crop production, CO <sub>2</sub> is released upon the hydrolysis. The quantity of CO <sub>2</sub> released to the atmosphere should be accounted for as emissions (IPCC 2006). Use of urea-based nitrogen fertilizers increased considerably since 1990, as did emissions of CO <sub>2</sub> , from approximately 0.8 Mt CO <sub>2</sub> eq in 1990 to 1.7 Mt CO <sub>2</sub> eq in 2011.	Continuous improvement

Table 9-5 Principal Planned Improvements (cont'd)

Category	Improvement	Description	Basis of Planned Improvement
LULUCF – Wetlands (CRF 5. D)	Wetlands (Peat Extraction) – Off-site horticultural peat emissions	The <i>2006 IPCC Guidelines</i> provide a Tier 1 approach to estimate peat emissions, where all carbon in horticultural peat is assumed to be emitted during the extraction year. Canada would aim to provide estimates with a Tier 2 approach, with country-specific EFs.	Continuous improvement
LULUCF – Land Converted to Forest Land – CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O	Provide a plan and time frame for estimating and reporting uncertainties for all LULUCF subcategories.	It is expected that uncertainty updates for all LULUCF subcategories will likely occur after the 2015 NIR, taking into consideration the implementation of the <i>2006 IPCC Guidelines</i>	UNFCCC ERT recommendation
Other: Harvested Wood Products (CRF 5.G)	Forest Land Remaining Forest Land – Harvested Wood Products (CO <sub>2</sub> )	Further elaboration of the production approach to incorporate the delayed carbon emissions due to long-term storage in harvested wood products (HWPs)	To comply with future reporting obligations through implementation of the <i>2006 IPCC Guidelines</i>
Waste – Solid Waste Disposal on Land – CH <sub>4</sub> (CRF - 6.A.1)	Update waste composition data and associated degradable organic carbon values, with a view to improving the accuracy of the relevant emission estimates.	A multi-year study is being initiated, and future improvements are likely in the 2016 NIR.	UNFCCC ERT recommendation



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