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# National Inventory Report

1990-2008

Part 1

GREENHOUSE GAS SOURCES  
AND SINKS IN CANADA

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



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# Foreword

Canada ratified the United Nations Framework Convention on Climate Change (UNFCCC) on December 4, 1992, and the Kyoto Protocol to the UNFCCC on December 17, 2002. Under Decisions 3/CP.1, 9/CP.2 and 3/CP.5 of the UNFCCC, national inventories for UNFCCC Annex I Parties should be submitted to the UNFCCC Secretariat each year, by April 15. In addition, in accordance with the Kyoto Protocol, Parties included in Annex I with a commitment inscribed in Annex B shall submit an annual inventory in accordance with Article 5 paragraph 2 and Article 7 paragraph 1. As such, this report represents Canada's annual inventory submission under the Framework Convention and the Kyoto Protocol.

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

Environment Canada, in consultation with a range of stakeholders, is responsible for preparing Canada's official national inventory. This National Inventory Report, prepared by staff of the Greenhouse Gas Division of Environment Canada, complies with the UNFCCC reporting

guidelines on annual inventories. It represents the efforts of many years of work and builds upon the results of previous reports, published in 1992, 1994, and yearly from 1996 to 2009, and incorporates a number of changes, including recommendations by UN Expert Review Teams that review Canada's National Inventory Report on an annual basis. In addition to the inventory data, the inventory report contains analysis of recent trends in emissions and removals. In this submission, relevant information on Canada's National System, and National Registry, along with information on land use, land-use change and forestry activities under articles 3.3 and 3.4 and minimization of adverse impacts in accordance with article 3.14, are now contained in Annex 11: Supplementary Information Required under Article 7.1 of the Kyoto Protocol.

In an effort to improve Canada's ability to monitor, report, and verify our greenhouse gas emissions, on March 15, 2004, the Government of Canada, in partnership with the provincial and territorial governments, launched a national mandatory greenhouse gas reporting system. The 2010 National Inventory Report contains a summary of the greenhouse gas emissions data reported by industrial facilities in Canada for the year 2008, as well as links to Environment Canada's Internet-based greenhouse gas emissions query site.

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

Art Jaques, P. Eng.  
April 2010

Director, Greenhouse Gas Division  
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# List of Acronyms, Abbreviations and Units

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

DOC	degradable organic carbon
DOCF	degradable organic carbon dissimilated
DOM	dead organic matter
EAF	electric arc furnace
EC	Environment Canada
EF	emission factor
EF <sub>BASE</sub>	basic emission factor
EPA	Environmental Protection Agency (United States)
EPGTD	Electric Power Generation, Transmission and Distribution
eq	equivalent
ERCB	Energy Resources Conservation Board
ERT	Expert Review Team
EU	European Union
FAACS	Feasibility Assessment of Afforestation for Carbon Sequestration
FCR	fuel consumption ratio
FGD	flue gas desulphurization
FLCL	forest land converted to cropland
FLSL	forest land converted to settlement
FLWL	forest land converted to wetland
FTA	fraction of BOD in sludge that degrades anaerobically
FTILL	tillage ratio factor
g	gram
GCV	gross calorific value
GDP	gross domestic product
GE	gross energy
Gg	gigagram
GHG	greenhouse gas
GHGRP	Greenhouse gas reporting program
GHV	gross heating value
GIS	geographic information system
GJ	gigajoule
GL	gigalitre
Gt	gigatonne
GTIS	Global Trade Information Services
GVWR	gross vehicle weight rating
GWP	global warming potential
H <sub>2</sub>	hydrogen
H <sub>2</sub> O	water
ha	hectare
HCFC	hydrochlorofluorocarbon
HCl	hydrochloric acid
HDD	heating degree-day
HDDT	heavy-duty diesel truck
HDDV	heavy-duty diesel vehicle
HDGV	heavy-duty gasoline vehicle
HE	harvest emissions
HFC	hydrofluorocarbon
HHV	higher heating value
HM	heavy metal
HNO <sub>3</sub>	nitric acid
HRAI	Heating, Refrigeration and Air Conditioning Institute of Canada

HSS	horizontal stud Söderberg
HWP	harvested wood product
HWP-C	carbon stored in harvested wood products
IAI	International Aluminium Institute
IE	included elsewhere
IEA	International Energy Agency
I/M	inspection and maintenance
IPCC	Intergovernmental Panel on Climate Change
IT	intensive tillage
ITL	International Transaction Log
k	methane generation rate constant
K <sub>2</sub> CO <sub>3</sub>	potassium carbonate
kg	kilogram
kha	kilohectare
kPa	kilopascal
kt	kilotonne
kWh	kilowatt-hour
L	litre
L <sub>0</sub>	methane generation potential
lb.	pound
LDDT	light-duty diesel truck
LDDV	light-duty diesel vehicle
LDGT	light-duty gasoline truck
LDGV	light-duty gasoline vehicle
LFG	landfill gas
LHV	lower heating value
LMC	land management change
LPG	liquefied petroleum gas
LTO	landing and takeoff
LULUCF	Land Use, Land-Use Change and Forestry
m	metre
m <sup>3</sup>	cubic metre
MAI	mean annual increment
MARS	Monitoring, Accounting and Reporting System
MC	motorcycle
MCED	Manufacturing, Construction and Energy Division of Statistics Canada
MCF	methane conversion factor (Agriculture)
MCF	methane correction factor (Waste)
Mg	magnesium; also megagram
MgCO <sub>3</sub>	magnesite; magnesium carbonate
MGEM	Mobile Greenhouse Gas Emission Model
MGEM07	Mobile Greenhouse Gas Emission Model 2007
MgO	magnesia; dolomitic lime
Mha	megahectare, equivalent to a million hectares
ML	megalitre
mol	mole
MS	manure system distribution factor
MSW	municipal solid waste
Mt	megatonne
mV	millivolt
MW	megawatt

N	nitrogen
N <sub>2</sub>	nitrogen gas
Na <sub>2</sub> CO <sub>3</sub>	sodium carbonate; soda ash
Na <sub>3</sub> AlF <sub>6</sub>	cryolite
NA	not applicable
N/A	not available
NAICS	North American Industry Classification System
NCV	net calorific value
NE	not estimated
NEB	National Energy Board
NGL	natural gas liquid
NH <sub>3</sub>	ammonia
NH <sub>4</sub> <sup>+</sup>	ammonium
NH <sub>4</sub> NO <sub>3</sub>	ammonium nitrate
NIR	National Inventory Report
NM VOC	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
PFC	perfluorocarbon
PJ	petajoule
POP	persistent organic pollutant
ppb	part per billion
ppbv	part per billion by volume
P/PE	precipitation/potential evapotranspiration
ppm	part per million
QA	quality assurance
QC	quality control
RA	reference approach
RES D	Report on Energy Supply and Demand in Canada
RPP	refined petroleum product
RT	reduced tillage
SA	sectoral approach
SCR	selective catalytic reduction
SF <sub>6</sub>	sulphur hexafluoride
SIC	Standard Industrial Classification
SLC	Soil Landscapes of Canada
SMR	steam methane reforming
SO <sub>2</sub>	sulphur dioxide

SO <sub>x</sub>	sulphur oxides
SOC	soil organic carbon
SUV	sport utility vehicle
t	tonne
t-km	tonne-kilometre
TJ	terajoule
TWh	terrawatt-hour
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
UPCIS	Use Patterns and Controls Implementation Section
UOG	upstream oil and gas
VKT	vehicle kilometres travelled
VSS	vertical stud Söderberg
VOC	volatile organic compound
VS	volatile solids
WMO	World Meteorological Organization
wt	weight

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# Executive Summary

## ES.1 Greenhouse Gas Inventories and Climate Change

The United Nations Framework Convention on Climate Change (UNFCCC)—Article 4(1)(a), Article 12(1)(a) and Decision 3/CP.5—requires Annex I Parties to publish, and make available to the Conference of the Parties, national inventories of anthropogenic (human-induced) emissions by sources and removals by sinks of all greenhouse gases (GHGs) not controlled by the Montreal Protocol, using comparable methodologies. Underpinning the UNFCCC is the national GHG inventory, composed of the National Inventory Report (NIR) and Common Reporting Format (CRF) tables. It is the key tool for monitoring and reporting on emissions from sources and removals by sinks and, with respect to the Kyoto Protocol, is the ultimate measure for assessing compliance with Canada's national emissions target. The year 2010 marks the production of Canada's 16th NIR. It is also the sixth inventory since the coming into force of the Kyoto Protocol to the UNFCCC, which Canada ratified in 2002.

The inventory format is based on the framework for international reporting agreed to by the Parties to the UNFCCC, using the procedures of the Intergovernmental Panel on Climate Change (IPCC/OECD/IEA 1997; IPCC 2000; IPCC 2003). This reporting format groups emissions into the following six Sectors: Energy; Industrial Processes; Solvent and Other Product Use; Agriculture; Land Use, Land-Use Change and Forestry (LULUCF); and Waste. Each of these Sectors is further subdivided within the inventory and follows, as closely as possible, the UNFCCC subsector divisions.<sup>1</sup> In developing its inventory, Canada follows IPCC Good Practice Guidelines in the use of quality control and quality assurance procedures and identifies, quantifies and reduces uncertainty of estimates as much as practicable.

<sup>1</sup> Minor differences exist between the UNFCCC and Canada's national inventory sector designations. These are explained in footnotes throughout this report. More details can be found in Chapters 3 to 8, where the methodology used in Canada's inventory is described.

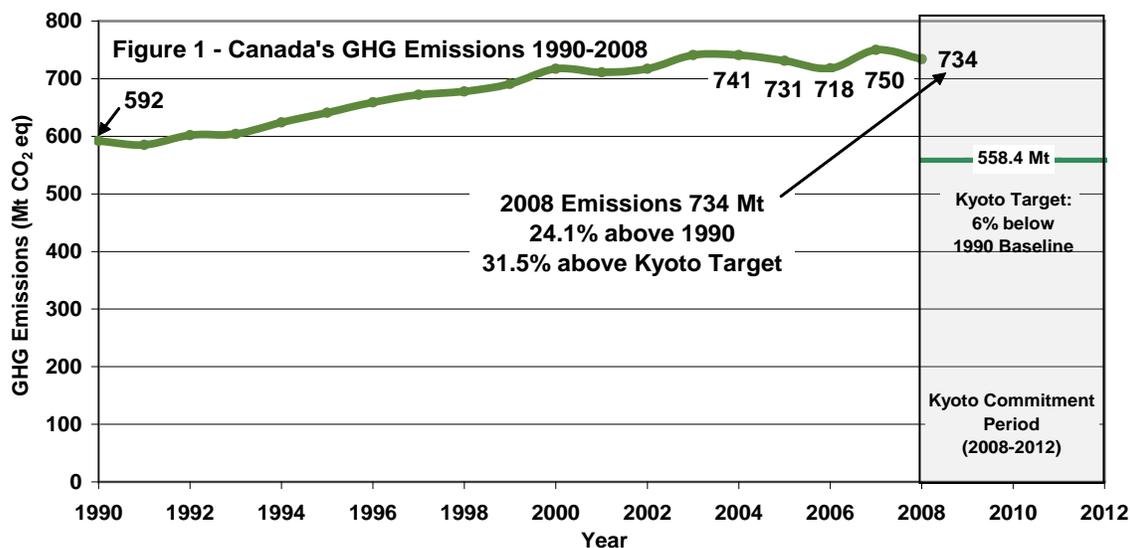
This results in a process of continuous evaluation and improvement of methods, models and documentation.

The report includes an inventory of anthropogenic emissions by sources and removals by sinks, of the six main GHGs—carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), sulphur hexafluoride (SF<sub>6</sub>), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). It is divided into three parts. Part 1 includes this Executive Summary and Chapters 1 to 9. Chapter 1 (Introduction) provides an overview of climate change and GHG emissions in Canada; Canada's legal, institutional and procedural arrangements for producing the inventory (i.e. the national inventory system); a brief description of estimation methodologies as well as quality assurance and quality control procedures; a description of Canada's facility emission reporting system; and assessments of completeness and uncertainty. Chapter 2A provides an analysis of Canada's GHG emission trends in accordance with the UNFCCC reporting structure, while Chapter 2B assesses 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 Common Reporting Format requirements. Chapter 9 presents a summary of recalculations and planned improvements.

Part 2 of the NIR consists of Annexes 1 to 11, 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, a summary of ozone and aerosol precursors, and supplementary information required under Article 7.1 and 3.14 of the Kyoto Protocol. Part 3 comprises Annexes 12–15, 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 and trend analyses by province and territory.

This NIR also includes the first reporting of LULUCF activities under Articles 3.3 and 3.4 of the Kyoto Protocol, with emission and removal estimates for afforestation and deforestation (mandatory), and cropland management (elected by Canada) for the year 2008. These Kyoto estimates do not affect Canada's national emissions total, and will only be accounted for at the end of the five-year commitment period (2012 inventory year). In addition, Chapter 1 and Annex 11 of this report provide supplement-

Figure S-1 Canadian GHG Emission Trend and Kyoto Target



tary information required under Articles 7.1 and 3.14 of the Kyoto Protocol. In February 2010, Canada also submitted its fifth National Communication to the UNFCCC, in order to update Canada's climate change status and related mitigation and adaptation responses.

## ES.2 Summary of National Trends in GHG Emissions and Removals

In 2008, Canadians contributed about 734 megatonnes of CO<sub>2</sub> equivalent<sup>2</sup> (Mt CO<sub>2</sub> eq)<sup>3</sup> of GHGs to the atmosphere (Figure S-1), a 2.1% decrease from 2007. This followed a year of large growth in emissions and two years of declining emissions, such that the overall change from 2004 is a decrease of 0.9%. Since 1990, emissions have increased by 24%, a rate outpacing increases in population (20.3%) but almost identical to the increase in energy use (25.1%). However, the growth in total emissions was well short of the 60% growth in Gross Domestic Product (GDP) between 1990 and 2008. Canada's economic GHG intensity—the amount of GHGs emitted per unit of economic activity—was 2.5% lower in 2008 than in 2007. Overall, economic GHG intensity has decreased by a total of 22%

over the period, an average of 1.2% per year. More goods were manufactured, more commercial activity occurred and more travel took place per unit of GHG emissions. In contrast, GHG emissions per unit of energy used remained relatively unchanged over the period.

Growth in energy production was much larger than energy use between 1990 and 2008. This is a consequence of Canada's large fossil fuel resources and an export-driven economy, with increasing quantities of energy being delivered to the international market (primarily the United States). The resultant sharp growth in energy exports over the period has had a significant impact on the emission trend. (See Section ES.4.1 and Chapter 2B for more details on energy exports and Canadian emission drivers.)

<sup>2</sup> Each of the GHGs has a unique average atmospheric lifetime over which it is an effective climate-forcing agent. The concept of global warming potential has been introduced to equate this climate forcing for different GHGs to that of CO<sub>2</sub>. A more detailed explanation is provided in Section 1.1.5 of this document.

<sup>3</sup> Unless explicitly stated otherwise, all emission estimates given in Mt represent emissions of GHGs in Mt CO<sub>2</sub> eq.

### Changes from the Previous National Inventory Report

Due to updates to the underlying statistical data, estimates for 2007 have been revised. Each year, Statistics Canada revises the preliminary data which were provided the year before. This year, the new data provided by Statistics Canada for 2007 have resulted in more representative estimates for Energy, Industrial Processes and Agriculture. As a result, total GHG emissions previously reported in April 2009 have in this year's inventory been revised upward from 747 Mt to 750 Mt for 2007.

## ES.3 Emission and Removal Estimates and Trends

### ES.3.1 2008 Emissions and Removals

Table S-1 details Canada's emissions and removals for 2008. On an individual GHG basis, CO<sub>2</sub> contributed 78% of the total emissions, while CH<sub>4</sub> accounted for 13%. N<sub>2</sub>O accounted for 7% of the emissions; PFCs, SF<sub>6</sub> and HFCs constituted the remainder (less than 2%).

Approximately 73% of total GHG emissions in 2008 resulted from the combustion of fossil fuels. Another 9% were from fugitive sources, with the result that about 81% of emissions were from the Energy Sector. The Agriculture, Industrial Processes and Waste sectors respectively account for 8.5%, 7.2% and 2.9% of total emissions.

### ES.3.2 Sector Trends

#### ES.3.2.1 Short-Term Changes

Since 2004, total Canadian GHGs have decreased by 6.4 Mt (0.9%), while GDP has risen (see Table S-2). On average, the annual change in emissions was slightly negative (-0.2%) between 2004 and 2008. On the other hand, from 1990 to 2008 emissions showed a significant (1.3%) average annual growth rate, indicating a difference between recent changes and the long-term trend. The largest portion of this decrease can be attributed to the reduced

use of combustion generation for electricity production (as a result of the increased availability of hydropower) and reductions in emissions from manufacturing.

However, emissions did not consistently fall between 2004 and 2008. As can be seen from the emission curve in Figure S-1, levels have fluctuated over the period. The fluctuations are due primarily to changes in the mix of sources used for electricity production (coal use varied with the availability of hydro and nuclear generation); changing emissions from fossil fuel production (as a result of the level of petroleum extraction activities); and varying demand for heating fuels during winters.

The 6.4 Mt decrease in emissions between 2004 and 2008 was the net result of opposing trends in different subsectors. Large increases in areas such as Transportation and Mining & Oil and Gas Extraction were more than offset by the aforementioned declines in Electricity and Industrial Processes and Manufacturing Industries, as well as combustion emissions from the Commercial & Institutional subsector. Emission changes in Transport followed the long-term trends.

In 2008, GHG emissions from the Electricity and Heat Generation subsector shrank by about 6 Mt from 2007 levels. Between 2004 and 2008, however, there were large emission fluctuations. Against a backdrop of increasing coal power usage in some areas, fossil fuel generation varied with the availability of electricity from hydro, nuclear and, to some extent, wind power sources. Hydroelectric power generation increased throughout Canada as a result of increased hydro-generating capacity and higher water levels (precipitation in 2005 was the highest on record). At the same time, efforts have been made in Ontario to decrease coal generation. These efforts were more successful in 2006 and 2008 than 2007, when some nuclear outages necessitated increased coal generation (and hence, emissions). Growing demand for electricity in Alberta has been met primarily through increased generation from coal and natural-gas-fuelled power plants.

Emissions from manufacturing<sup>4</sup> dropped by 11 Mt (10.2%) between 2004 and 2008, due to significantly lowered production. In this period, the GDP for manufacturing dropped by 7%—the decline between 2007 and 2008 alone was 5.7%. Since the late 1990s, the Canadian economy has been experiencing structural shifts away

<sup>4</sup> Manufacturing includes: Manufacturing Industries (Energy Sector) and Industrial Processes.

Table S–1 Canada's GHG Emissions by Gas and Sector, 2008

Greenhouse Gas Categories		Greenhouse Gases								
		CO <sub>2</sub>	CH <sub>4</sub>	CH <sub>4</sub>	N <sub>2</sub> O	N <sub>2</sub> O	HFCs	PFCs	SF <sub>6</sub>	Round Totals
Global Warming Potential		kt	kt	21 kt CO <sub>2</sub> equivalent	kt	310 kt CO <sub>2</sub> equivalent	kt CO <sub>2</sub> equivalent	kt CO <sub>2</sub> equivalent	kt CO <sub>2</sub> equivalent	kt CO <sub>2</sub> equivalent
Unit		kt	kt	kt CO <sub>2</sub> equivalent	kt	kt CO <sub>2</sub> equivalent	kt CO <sub>2</sub> equivalent	kt CO <sub>2</sub> equivalent	kt CO <sub>2</sub> equivalent	kt CO <sub>2</sub> equivalent
<b>TOTAL<sup>1</sup></b>		<b>574 000</b>	<b>4 700</b>	<b>99 000</b>	<b>170</b>	<b>52 000</b>	<b>5 500</b>	<b>2 200</b>	<b>2 200</b>	<b>734 000</b>
<b>ENERGY</b>		<b>535 000</b>	<b>2 500</b>	<b>53 000</b>	<b>30</b>	<b>10 000</b>	–	–	–	<b>597 000</b>
<b>a. Stationary Combustion Sources</b>		<b>328 000</b>	<b>200</b>	<b>4 000</b>	<b>8</b>	<b>3 000</b>	–	–	–	<b>335 000</b>
Electricity and Heat Generation		118 000	4.6	96	2	700	–	–	–	119 000
Fossil Fuel Industries		65 300	100	2 000	1	400	–	–	–	68 000
Petroleum Refining and Upgrading		16 000	–	–	0.4	100	–	–	–	16 000
Fossil Fuel Production		49 100	100	2 000	1	300	–	–	–	52 000
Mining & Oil and Gas Extraction		23 700	0.5	10	0.5	200	–	–	–	23 900
Manufacturing Industries		42 900	3	60	1	500	–	–	–	43 400
Iron and Steel		6 110	0.2	5	0.2	60	–	–	–	6 170
Non Ferrous Metals		3 470	0.08	2	0.05	20	–	–	–	3 480
Chemical		6 650	0.14	2.9	0.1	40	–	–	–	6 690
Pulp and Paper		4 280	2	40	0.7	200	–	–	–	4 540
Cement		4 270	0.1	2	0.03	10	–	–	–	4 280
Other Manufacturing		18 100	0.4	7	0.4	100	–	–	–	18 200
Construction		1 250	0.02	0.5	0.03	10	–	–	–	1 260
Commercial & Institutional		34 600	0.6	10	0.7	200	–	–	–	34 900
Residential		40 400	90	2 000	2	500	–	–	–	43 000
Agriculture & Forestry		2 150	0.04	0.8	0.06	20	–	–	–	2 170
<b>b. Transport<sup>2</sup></b>		<b>190 000</b>	<b>30</b>	<b>600</b>	<b>30</b>	<b>8 000</b>	–	–	–	<b>198 000</b>
Civil Aviation (Domestic Aviation)		8 300	0.5	9	0.8	200	–	–	–	8 500
Road Transportation		132 000	9.2	190	10	3 100	–	–	–	135 000
Light-Duty Gasoline Vehicles		39 600	2.9	61	3.2	1 000	–	–	–	40 600
Light-Duty Gasoline Trucks		43 200	3.2	68	5.0	1 500	–	–	–	44 800
Heavy-Duty Gasoline Vehicles		6 500	0.34	7.2	0.49	150	–	–	–	6 660
Motorcycles		259	0.17	3.6	0.01	1.6	–	–	–	264
Light-Duty Diesel Vehicles		435	0.01	0.2	0.04	10	–	–	–	446
Light-Duty Diesel Trucks		2 310	0.06	1	0.2	60	–	–	–	2 370
Heavy-Duty Diesel Vehicles		39 000	2	40	1	400	–	–	–	39 400
Propane & Natural Gas Vehicles		857	0.8	20	0.02	5	–	–	–	880
Railways		6 290	0.3	7	3	800	–	–	–	7 000
Navigation (Domestic Marine)		5 500	0.4	9	1	300	–	–	–	5 800
Other Transportation		38 000	20	300	10	3 000	–	–	–	41 000
Off-Road Gasoline		6 100	7	200	0.1	40	–	–	–	6 300
Off-Road Diesel		25 000	1	30	10	3 000	–	–	–	28 000
Pipelines		7 240	7.3	150	0.2	60	–	–	–	7 460
<b>c. Fugitive Sources</b>		<b>16 000</b>	<b>2 300</b>	<b>48 000</b>	<b>0.1</b>	<b>40</b>	–	–	–	<b>63 800</b>
Coal Mining		–	40	800	–	–	–	–	–	800
Oil and Natural Gas		16 200	2 230	46 800	0.1	40	–	–	–	63 100
Oil		210	252	5 280	0.1	30	–	–	–	5 520
Natural Gas		67.8	1 010	21 200	–	–	–	–	–	21 300
Venting		10 600	962	20 200	0.01	4	–	–	–	30 800
Flaring		5 400	3.7	78	0.01	4	–	–	–	5 500
<b>INDUSTRIAL PROCESSES</b>		<b>39 000</b>	–	–	<b>11.70</b>	<b>3 640</b>	<b>5 500</b>	<b>2 200</b>	<b>2 200</b>	<b>52 600</b>
<b>a. Mineral Products</b>		<b>8 500</b>	–	–	–	–	–	–	–	<b>8 500</b>
Cement Production		6 600	–	–	–	–	–	–	–	6 600
Lime Production		1 500	–	–	–	–	–	–	–	1 500
Mineral Product Use <sup>3</sup>		365	–	–	–	–	–	–	–	365
<b>b. Chemical Industry</b>		<b>6 700</b>	–	–	<b>11.70</b>	<b>3 640</b>	–	–	–	<b>10 000</b>
Ammonia Production		6 700	–	–	–	–	–	–	–	6 700
Nitric Acid Production		–	–	–	3.96	1 230	–	–	–	1 230
Adipic Acid Production		–	–	–	7.8	2 400	–	–	–	2 400
<b>c. Metal Production</b>		<b>12 600</b>	–	–	–	–	–	<b>2 200</b>	<b>464</b>	<b>15 300</b>
Iron and Steel Production		7 440	–	–	–	–	–	–	–	7 440
Aluminium Production		5 200	–	–	–	–	–	2 200	3.7	7 400
SF <sub>6</sub> Used in Magnesium Smelters and Casters		–	–	–	–	–	–	–	460	460
<b>d. Consumption of Halocarbons and SF<sub>6</sub></b>		–	–	–	–	–	<b>5 500</b>	<b>4</b>	<b>1 800</b>	<b>7 300</b>
<b>e. Other &amp; Undifferentiated Production</b>		<b>11 000</b>	–	–	–	–	–	–	–	<b>11 000</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>		–	–	–	<b>1.1</b>	<b>330</b>	–	–	–	<b>330</b>
<b>AGRICULTURE</b>		–	<b>1 200</b>	<b>25 000</b>	<b>120</b>	<b>37 000</b>	–	–	–	<b>62 000</b>
<b>a. Enteric Fermentation</b>		–	<b>1 100</b>	<b>22 000</b>	–	–	–	–	–	<b>22 000</b>
<b>b. Manure Management</b>		–	<b>140</b>	<b>2 800</b>	<b>15</b>	<b>4 700</b>	–	–	–	<b>7 500</b>
<b>c. Agriculture Soils</b>		–	–	–	<b>100</b>	<b>32 000</b>	–	–	–	<b>32 000</b>
Direct Sources		–	–	–	<b>54</b>	<b>17 000</b>	–	–	–	<b>17 000</b>
Pasture, Range and Paddock Manure		–	–	–	<b>12</b>	<b>3 800</b>	–	–	–	<b>3 800</b>
Indirect Sources		–	–	–	<b>40</b>	<b>10 000</b>	–	–	–	<b>10 000</b>
<b>WASTE</b>		<b>200</b>	<b>990</b>	<b>21 000</b>	<b>2</b>	<b>700</b>	–	–	–	<b>22 000</b>
<b>a. Solid Waste Disposal on Land</b>		–	<b>970</b>	<b>20 000</b>	–	–	–	–	–	<b>20 000</b>
<b>b. Wastewater Handling</b>		–	<b>13</b>	<b>260</b>	<b>2</b>	<b>700</b>	–	–	–	<b>940</b>
<b>c. Waste Incineration</b>		<b>200</b>	<b>0.08</b>	<b>2</b>	<b>0.2</b>	<b>50</b>	–	–	–	<b>250</b>
<b>Land Use, Land-Use Change and Forestry</b>		<b>-19 000</b>	<b>200</b>	<b>4 100</b>	<b>8</b>	<b>2 500</b>	–	–	–	<b>-13 000</b>
<b>a. Forest Land</b>		<b>-25 000</b>	<b>180</b>	<b>3 900</b>	<b>8</b>	<b>2 400</b>	–	–	–	<b>-18 000</b>
<b>b. Cropland</b>		<b>-4 700</b>	<b>7</b>	<b>100</b>	<b>0.3</b>	<b>100</b>	–	–	–	<b>-4 400</b>
<b>c. Grassland</b>		–	–	–	–	–	–	–	–	–
<b>d. Wetlands</b>		<b>2 000</b>	<b>0</b>	–	<b>0</b>	–	–	–	–	<b>2 000</b>
<b>e. Settlements</b>		<b>7 000</b>	<b>4</b>	<b>90</b>	<b>0.1</b>	<b>50</b>	–	–	–	<b>7 000</b>

## Notes:

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

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

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

4. Totals may not add due to rounding.

– Indicates no emissions.

0.0 Indicates emissions truncated due to rounding.

Table S–2 Trends in Emissions and Economic Indicators for Selected Years (1990–2008)

	1990	1995	2000	2004	2005	2006	2007	2008
Total GHGs (Mt)	<b>592</b>	<b>641</b>	<b>717</b>	<b>741</b>	<b>731</b>	<b>718</b>	<b>750</b>	<b>734</b>
Change Since 1990 (%)	N/A	8.3	21.2	25.2	23.5	21.4	26.8	24.1
Annual Change (%)**	N/A	2.8	3.8	-1.3	-1.3	-1.7	4.5	-2.1
Average Annual Change (%)*	N/A	1.7	2.1	1.8	1.6	1.3	1.6	1.3
GDP (Billions 1997\$)***	<b>825</b>	<b>899</b>	<b>1101</b>	<b>1211</b>	<b>1248</b>	<b>1283</b>	<b>1316</b>	<b>1321</b>
Change Since 1990 (%)	N/A	8.9	33.3	46.8	51.2	55.5	59.4	60.1
Annual Change (%)**	N/A	2.8	5.2	3.1	3.0	2.9	2.5	0.4
GHG Intensity (Mt/\$B GDP)	<b>0.72</b>	<b>0.71</b>	<b>0.65</b>	<b>0.61</b>	<b>0.59</b>	<b>0.56</b>	<b>0.57</b>	<b>0.56</b>
Change Since 1990 (%)	N/A	-0.5	-9.1	-14.7	-18.3	-22.0	-20.5	-22.5
Annual Change (%)**	N/A	0.0	-1.4	-3.0	-4.2	-4.5	1.9	-2.5

\*Average annual change since 1990.

\*\*Annual Change: Represents change over previous calendar year.

\*\*\*GDP: Statistics Canada - Table 384-0002 - Expenditure-based, annual (millions) (Jan 13, 2010)

from manufacturing and towards the service industries. The 2004–2008 period showed strong evidence of this trend—GDP for the service industries (e.g. trade, finances, professional services, maintenance, public administration, etc.) rose by 8%.<sup>5</sup> As of 2008, the economic GHG intensity of service industries was about one quarter that of heavy industry and manufacturing, so an economic shift towards services has resulted in overall emission reductions.

The fossil fuel industries,<sup>6</sup> consisting of coal production and oil and gas production, refining and transmission, showed a 2.5 Mt increase (1.7%) in GHG emissions between 2004 and 2008. During this period, crude oil exports increased by 10%, while crude oil production increased by 7.4%. In contrast, domestic consumption of crude decreased by approximately 4.2%. In the same interim, crude prices peaked in 2008 at twice their minimum 2004 value.

Emissions associated with Mining & Oil and Gas Extraction alone increased by 61% (9.0 Mt) between 2004 and 2008, largely due to increased activity at the Alberta oil sands. This was partially offset by a flattening of Canadian natural gas production and decreasing conventional petroleum production, trends which have been in evidence since the turn of the century.

Due to widely varying average winter temperatures, Canadian homes and businesses required fluctuating amounts of energy for heating between 2004 and 2008. In 2006, heating degree-days, an indicator of the necessity for space heating in response to the severity of cold weather,

were down about 10% on a national basis, but were up 10% again (close to the 2004 level) in 2008. This had an impact on fossil fuel consumption, in particular in the Residential and Commercial & Institutional Sectors, where emissions decreased by 9% between 2004 and 2006 and increased by 6% between 2006 and 2008.

### ES.3.2.2 Long-Term Trends

The long-term (1990–2008) subsector emission trends showed both declines and increases, but the increases were well ahead of the declines, for a net growth of 143 Mt, or 24%. The largest portion of the growth is observed in the Energy Sector, where the energy industries (Fossil Fuel Industries plus Electricity & Heat Generation), Road Transportation, Commercial & Institutional, and Mining subsectors made the greatest contributions.

The activities of the fossil fuel industries include combustion sources (Fossil Fuel Industries and Pipelines) and fugitive sources (Coal Mining and Oil and Natural Gas).<sup>7</sup> The fossil fuel industries registered a net increase of about 38 Mt of GHG emissions from 1990 to 2008 (38% growth). These emissions are related to coal mining and the production, transmission, processing, refining and distribution of all oil and gas products.

By 2008, total production of crude oil and natural gas increased 62% over 1990 levels. Elevated demand, particularly in the United States, drove these trends, with the

5 Statistics Canada, October 2009.

6 Fossil fuel industries: Sum of Mining & Oil and Gas Extraction, Fossil Fuel Production and Refining, Pipelines (Transport), and Fugitive sources.

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

export market growing by far the most rapidly<sup>8</sup> (see Section ES.4.1). Although increasing demand provides a large portion of the explanation for the emission trend, it does not paint the complete picture.

Since well before 1990, easily removable reserves of conventional crude have been shrinking. Thus, energy consumption per unit of conventional oil produced has been increasing (Neitzert et al. 1999). At the same time, energy- and GHG-intensive synthetic oil production (i.e. from oil sands) has become increasingly competitive with conventional oil extraction. These trends contributed to the rapidly rising emission increases in the oil and gas industry over the 1990–2008 period.

Emission intensities (emissions per unit energy) vary from year to year and depend upon the product comparisons analyzed. Nevertheless, according to research by Environment Canada,<sup>9</sup> the average GHG intensity for all oil and gas production and processing activities increased by 10% between 1990 and 2008. During this period, the intensity for conventional (light, medium and heavy) oil production increased by 24%.

Oil sands mining, extraction and upgrading activities were about 1.5 times more GHG-intensive than conventional oil production in 2008. However, the oil sands industry has been reducing its per-unit emissions, and in 2008 intensity was actually 39% lower than in 1990.

Electricity and Heat Generation, representing the other portion of the energy industries, also saw large increases in emissions. Rising demand for electricity caused GHG emissions to grow by 23 Mt between 1990 and 2008. Comparatively, in 2008 total electricity demand was approximately 116 TWh (terawatt-hours) above the 1990 level.<sup>10</sup> Although there has been some diminishment in the trend over the last few years, an increasing percentage of high-emitting fossil fuel generation in the mix worsened the average GHG intensity of electricity production over the period. Summaries of provincial electricity intensities can be found in Annex 13.

Of primary importance in this trend is that, starting in the mid-1990s, the GHG emissions associated with coal-fired electricity generation progressively increased. They then

decreased between 2002 and 2006. This was due to the return to service of a number of nuclear units and a commitment to reduced coal-fired electricity generation in Ontario, as well as fuel switching to natural gas in a number of regions of the country. At about 1% of generation by 2008, non-hydro renewable energy sources have had some impact on emission reductions. The impact is predicted to become more significant in future years because installed capacity of wind power in Canada has been rising rapidly. Regardless, fuel and generation costs are likely to continue to play a major role in determining whether coal-fired generation and the associated GHG emissions will be reduced further in the future.

Emissions from Road Transportation rose by 37 Mt (38%) between 1990 and 2008. Of particular interest in this subsector is a 24 Mt (almost 120%) increase in emissions from light-duty gasoline trucks (LDGTs). This was partially offset by 5.2 and 1.3 Mt emission reductions from gasoline-fuelled cars (light-duty gasoline vehicles, or LDGVs) and alternatively fuelled cars (propane and natural gas vehicles), respectively.

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

Research<sup>11</sup> suggests that, between 1990 and 2004, about 10% of the emission increase from automobiles and light trucks could be attributed purely to the shift in the type of private vehicles being driven. Perhaps of greater interest is the overall trend towards increasing horsepower for all classes of passenger vehicles, which has negated the rather substantial efficiency improvements made in internal combustion engines.

Emissions from heavy-duty diesel vehicles (large freight trucks) rose by 18 Mt between 1990 and 2008, a 90% increase. Spurred on by free trade and the deregulation of the trucking industry, the amount of freight shipped grew

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

9 GHG Division, Environment Canada, 2009. Emission intensities based on Statistics Canada data and inventory estimation methods.

10 Statistics Canada, Energy Statistics Handbook, Jan. 2010.

11 Adapted from NRCan (2005).

rapidly over that period. In addition, the quantity shipped by truck (as opposed to other modes of transport, such as rail) increased as a result of customer requirements for just-in-time delivery and cross-border freight (NRCAN 2005).

The Commercial & Institutional subsector displayed a 9 Mt (36%) increase in GHG emissions between 1990 and 2008. Driving this trend was a 25.5% increase in the floor space of commercial and institutional buildings (e.g. offices, schools, stores and government edifices) between 1990 and 2005, a result of Canada's growing economy over that period. Energy demand in commercial buildings is also influenced by weather. In terms of heating degree-days, 2008 was about 2% cooler than 1990, contributing to emission growth.

Mining showed a large increase in emissions between 1990 and 2008—18 Mt (286%)—largely because of increasing economic activity, much of which occurred in the area of unconventional (oil sands) extraction activities.

The Agriculture Sector is the second contributor to the long-term growth in GHG emissions, although to a lesser extent than Energy. Canada's Agriculture Sector is composed of approximately 250 000 farms, 98% of which are family-owned. Agricultural emissions accounted for 62 Mt or 8.5% of total 2008 GHG emissions for Canada. Agriculture accounted for 26% and 71% of the national CH<sub>4</sub> and N<sub>2</sub>O emissions, respectively. All these emissions are from non-energy sources. The 14 Mt increase (29%) in emissions between 1990 and 2008 primarily results from the expansion of the beef cattle (29%), swine (24%) and poultry populations (31%), as well as significant growth (46%) in the consumption of synthetic nitrogen fertilizers, mainly in the Prairies.

In addition to the already-mentioned reduction in emissions from automobiles, three subsectors, all within the Industrial Processes Sector, contributed towards counteracting 1990–2008 emission growth—Adipic Acid Production (chemical industry), Aluminium Production, and SF<sub>6</sub> Used in Magnesium Smelters and Casters (both constituents of Metal Production).

At Canada's sole adipic acid production plant, the installation of an emission-abatement system in 1997 resulted in significant reductions of N<sub>2</sub>O emissions. Although this system was temporarily off-line in 2004 (and therefore N<sub>2</sub>O reductions were not as great that year), emissions in 2008 were down 8.3 Mt (78%) in comparison to 1990.

In the aluminium industry (which emits both CO<sub>2</sub> and PFCs), PFC emissions were reduced as a result of better control of anode events in smelters by increasing the use of electronic monitoring and automated emission controls. As a result, between 1990 and 2008 total GHG process emissions from the aluminium industry decreased by 1.9 Mt (20%), while primary aluminium production increased significantly. Meanwhile, emissions from some subsectors in the Industrial Processes Sector, such as those associated with the production of cement and ammonia, did see sizable increases due to increased construction and agricultural activities, respectively.

The trend in emissions from sources and removals by sinks in LULUCF (i.e. agricultural soils, managed forests, managed wetlands and land-use change) shows that the whole sector can either be a net sink (removing CO<sub>2</sub> from the atmosphere) or a net source of greenhouse gases to the atmosphere. In 2008, the LULUCF Sector amounted to a net sink of 13 Mt. Trends in the Sector are primarily driven by changes occurring in managed forests and cropland.

Net fluxes in managed forests reflect the erratic pattern of forest fires, the trends in management activities such as harvest, and the long-term impact of major forest infestations like the Mountain Pine Beetle in British Columbia. For the first time since 2001 and the beginning of the Mountain Pine Beetle infestation, managed forests acted as net sinks in 2008 (18 Mt), due to the combined effects of the lowest annual harvest rate of the entire period and lowest fire emissions since 2001.

The cropland category includes the effects of agricultural practices on CO<sub>2</sub> emissions and removals from arable soils (soils suitable for growing crops), and the impact of converting forest and grassland to cropland. In 2008, carbon sequestration in arable soils more than made up for emissions from lands converted to cropland with, as a result, a net sink of 4.4 Mt. The continued adoption of no-till and reduced-tillage practices and the reduction of summer fallow have resulted in a steadily increasing ability of cultivated soils to behave like sinks.

Forest land converted to cropland, wetlands and settlements (not shown in the summary table) amounts to emissions of about 19 Mt in 2008, down from 27 Mt in 1990. The conversion of forest and grassland to cropland alone shows a steady decrease in GHG emissions from 14 Mt in 1990 to 7 Mt in 2008.

Table S-3 Canada's GHG Emissions by Sector, 8 Select Years

Greenhouse Gas Categories	1990	1995	2000	2004	2005	2006	2007	2008
<b>TOTAL<sup>1</sup></b>	<b>592 000</b>	<b>641 000</b>	<b>717 000</b>	<b>741 000</b>	<b>731 000</b>	<b>718 000</b>	<b>750 000</b>	<b>734 000</b>
	<i>kt CO<sub>2</sub> equivalent</i>							
<b>ENERGY</b>	<b>469 000</b>	<b>510 000</b>	<b>587 000</b>	<b>603 000</b>	<b>593 000</b>	<b>581 000</b>	<b>614 000</b>	<b>597 000</b>
<b>a. Stationary Combustion Sources</b>	<b>281 000</b>	<b>293 000</b>	<b>344 000</b>	<b>349 000</b>	<b>336 000</b>	<b>324 000</b>	<b>350 000</b>	<b>335 000</b>
Electricity and Heat Generation	95 500	101 000	132 000	127 000	125 000	117 000	125 000	119 000
Fossil Fuel Production and Refining	51 000	54 000	66 000	72 000	66 000	66 000	70 000	68 000
Petroleum Refining and Upgrading	16 000	14 000	14 000	18 000	17 000	16 000	18 000	16 000
Fossil Fuel Production	36 000	40 000	53 000	53 000	49 000	50 000	52 000	52 000
Mining & Oil and Gas Extraction	6 190	7 840	10 400	14 900	15 600	16 800	23 200	23 900
Manufacturing Industries	55 000	53 300	53 400	51 500	47 600	47 000	49 400	43 400
Iron and Steel	6 480	7 020	7 160	6 460	6 450	6 220	6 920	6 170
Non Ferrous Metals	3 190	3 080	3 190	3 230	3 270	3 230	3 490	3 480
Chemical	7 140	8 510	7 910	6 830	6 400	6 820	7 230	6 690
Pulp and Paper	13 700	11 700	11 000	9 400	7 180	5 860	5 870	4 540
Cement	3 830	3 990	4 170	4 620	4 890	5 070	4 750	4 280
Other Manufacturing	20 600	19 000	19 900	20 900	19 400	19 800	21 200	18 200
Construction	1 870	1 170	1 070	1 340	1 360	1 300	1 290	1 260
Commercial & Institutional	25 700	28 900	33 100	37 700	36 700	33 400	34 900	34 900
Residential	43 000	45 000	45 000	43 000	42 000	40 000	44 000	43 000
Agriculture & Forestry	2 390	2 750	2 540	2 090	1 970	1 910	2 240	2 170
<b>b. Transport<sup>2</sup></b>	<b>145 000</b>	<b>159 000</b>	<b>178 000</b>	<b>188 000</b>	<b>192 000</b>	<b>191 000</b>	<b>199 000</b>	<b>198 000</b>
Civil Aviation (Domestic Aviation)	6 400	5 900	6 500	7 800	7 900	7 700	8 800	8 500
Road Transportation	98 400	109 000	119 000	129 000	131 000	133 000	136 000	135 000
Light-Duty Gasoline Vehicles	45 800	44 400	42 100	41 100	39 900	39 900	41 000	40 600
Light-Duty Gasoline Trucks	20 700	27 900	36 800	42 000	43 100	43 600	44 800	44 800
Heavy-Duty Gasoline Vehicles	7 810	6 080	5 290	6 400	6 300	6 430	6 620	6 660
Motorcycles	146	121	158	245	252	256	264	264
Light-Duty Diesel Vehicles	355	327	353	431	432	435	448	446
Light-Duty Diesel Trucks	707	1 330	1 690	1 990	2 130	2 230	2 320	2 370
Heavy-Duty Diesel Vehicles	20 700	26 500	31 300	36 500	38 100	38 900	40 000	39 400
Propane & Natural Gas Vehicles	2 200	2 100	1 100	860	720	790	830	880
Railways	7 000	6 000	7 000	6 000	6 000	6 000	7 000	7 000
Navigation (Domestic Marine)	5 000	4 400	5 100	6 600	6 400	5 800	6 100	5 800
Other Transportation	29 000	34 000	41 000	38 000	41 000	39 000	41 000	41 000
Off-Road Gasoline	6 700	6 400	7 600	7 700	7 300	6 700	7 100	6 300
Off-Road Diesel	15 000	16 000	22 000	22 000	23 000	23 000	25 000	28 000
Pipelines	6 850	11 900	11 200	8 470	10 100	9 610	8 940	7 460
<b>c. Fugitive Sources</b>	<b>42 700</b>	<b>57 000</b>	<b>64 700</b>	<b>65 600</b>	<b>64 700</b>	<b>65 800</b>	<b>64 700</b>	<b>63 800</b>
Coal Mining	2 000	2 000	900	700	700	700	800	800
Oil and Natural Gas	40 700	55 300	63 700	64 900	63 900	65 100	64 000	63 100
Oil	4 180	5 150	5 430	5 940	5 650	5 720	5 810	5 520
Natural Gas	12 900	16 500	19 400	20 400	20 800	21 400	21 300	21 300
Venting	19 300	28 600	33 500	33 000	32 000	32 000	31 600	30 800
Flaring	4 400	5 100	5 400	5 600	5 500	6 000	5 300	5 500
<b>INDUSTRIAL PROCESSES</b>	<b>54 800</b>	<b>56 600</b>	<b>51 100</b>	<b>55 400</b>	<b>55 100</b>	<b>54 600</b>	<b>53 200</b>	<b>52 600</b>
<b>a. Mineral Products</b>	<b>8 300</b>	<b>8 800</b>	<b>9 600</b>	<b>9 500</b>	<b>9 500</b>	<b>9 600</b>	<b>9 300</b>	<b>8 500</b>
Cement Production	5 400	6 100	6 700	7 100	7 200	7 300	7 300	6 600
Lime Production	1 800	1 900	1 900	1 800	1 700	1 600	1 600	1 500
Mineral Product Use <sup>3</sup>	1 090	878	1 020	585	589	660	404	365
<b>b. Chemical Industry</b>	<b>17 000</b>	<b>18 000</b>	<b>8 900</b>	<b>11 000</b>	<b>10 000</b>	<b>9 000</b>	<b>8 900</b>	<b>10 000</b>
Ammonia Production	5 000	6 500	6 800	6 800	6 300	6 600	6 200	6 700
Nitric Acid Production	1 010	1 000	1 230	1 230	1 250	1 230	1 130	1 230
Adipic Acid Production	11 000	11 000	900	3 100	2 600	1 200	1 500	2 400
<b>c. Metal Production</b>	<b>19 500</b>	<b>19 200</b>	<b>18 900</b>	<b>16 700</b>	<b>16 500</b>	<b>16 800</b>	<b>15 500</b>	<b>15 300</b>
Iron and Steel Production	7 060	7 880	7 900	7 200	7 020	7 760	7 720	7 440
Aluminium Production	9 300	9 200	8 200	7 300	8 200	7 700	7 300	7 400
SF <sub>6</sub> Used in Magnesium Smelters and Casters	3 110	2 110	2 780	2 190	1 290	1 390	522	460
<b>d. Production and Consumption of Halocarbons and SF<sub>6</sub></b>	<b>2 300</b>	<b>2 000</b>	<b>4 500</b>	<b>5 500</b>	<b>6 400</b>	<b>6 500</b>	<b>6 700</b>	<b>7 300</b>
<b>e. Other &amp; Undifferentiated Production</b>	<b>8 000</b>	<b>8 400</b>	<b>9 200</b>	<b>13 000</b>	<b>12 000</b>	<b>13 000</b>	<b>13 000</b>	<b>11 000</b>
<b>SOLVENT &amp; OTHER PRODUCT USE</b>	<b>170</b>	<b>210</b>	<b>240</b>	<b>210</b>	<b>180</b>	<b>320</b>	<b>320</b>	<b>330</b>
<b>AGRICULTURE</b>	<b>48 000</b>	<b>55 000</b>	<b>59 000</b>	<b>62 000</b>	<b>62 000</b>	<b>61 000</b>	<b>61 000</b>	<b>62 000</b>
<b>a. Enteric Fermentation</b>	<b>17 000</b>	<b>20 000</b>	<b>21 000</b>	<b>23 000</b>	<b>24 000</b>	<b>23 000</b>	<b>23 000</b>	<b>22 000</b>
<b>b. Manure Management</b>	<b>6 000</b>	<b>6 900</b>	<b>7 400</b>	<b>8 000</b>	<b>8 100</b>	<b>8 000</b>	<b>7 800</b>	<b>7 500</b>
<b>c. Agriculture Soils</b>	<b>26 000</b>	<b>28 000</b>	<b>30 000</b>	<b>30 000</b>	<b>30 000</b>	<b>30 000</b>	<b>31 000</b>	<b>32 000</b>
Direct Sources	14 000	14 000	15 000	15 000	15 000	15 000	16 000	17 000
Pasture, Range and Paddock Manure	2 600	3 300	3 600	4 000	4 100	4 000	3 900	3 800
Indirect Sources	9 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000
<b>WASTE</b>	<b>19 000</b>	<b>20 000</b>	<b>20 000</b>	<b>21 000</b>	<b>21 000</b>	<b>22 000</b>	<b>21 000</b>	<b>22 000</b>
<b>a. Solid Waste Disposal on Land</b>	<b>18 000</b>	<b>19 000</b>	<b>19 000</b>	<b>20 000</b>				
<b>b. Wastewater Handling</b>	<b>740</b>	<b>790</b>	<b>860</b>	<b>900</b>	<b>900</b>	<b>910</b>	<b>930</b>	<b>940</b>
<b>c. Waste Incineration</b>	<b>400</b>	<b>350</b>	<b>250</b>	<b>230</b>	<b>240</b>	<b>240</b>	<b>250</b>	<b>250</b>
<b>LAND USE, LAND-USE CHANGE AND FORESTRY</b>	<b>-52 000</b>	<b>200 000</b>	<b>-80 000</b>	<b>120 000</b>	<b>41 000</b>	<b>41 000</b>	<b>45 000</b>	<b>-13 000</b>
<b>a. Forest Land</b>	<b>-79 000</b>	<b>180 000</b>	<b>-93 000</b>	<b>110 000</b>	<b>32 000</b>	<b>33 000</b>	<b>38 000</b>	<b>-18 000</b>
<b>b. Cropland</b>	<b>13 000</b>	<b>5 800</b>	<b>1 900</b>	<b>-960</b>	<b>-2 100</b>	<b>-2 300</b>	<b>-3 400</b>	<b>-4 400</b>
<b>c. Grassland</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>
<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>2 000</b>
<b>e. Settlements</b>	<b>10 000</b>	<b>9 000</b>	<b>8 000</b>	<b>7 000</b>				
<b>Land Use, Land-Use Change and Forestry - Activities under the Kyoto Protocol</b>								
<b>a. Article 3.3</b>								
Afforestation / reforestation	NA <sup>4</sup>	NA	NA	NA	NA	NA	NA	-738
Deforestation	NA	NA	NA	NA	NA	NA	NA	14 644
<b>b. Article 3.4</b>								
Cropland Management	4 271	NA	NA	NA	NA	NA	NA	-11 503

Notes:

<sup>1</sup>National totals exclude all GHGs from the Land Use, Land-Use Change and Forestry Sector. The estimates for LULUCF activities under the Kyoto Protocol will be accounted for over the five years (2008–2012) of the first commitment period under the Protocol.<sup>2</sup>Emissions from Fuel Ethanol are reported within the gasoline transportation sub-categories.<sup>3</sup>The category Mineral Product Use includes CO<sub>2</sub> emissions coming from the use of limestone & dolomite, soda ash, and magnesite.<sup>4</sup>Totals may not add due to rounding

- Indicates no emissions.

<sup>5</sup>NA = Not Applicable

Table S-4 Crude Oil: Production, Import, Export and GHG Emission Trends, Select Years

<b>Crude Oil Trends</b>	<b>1990</b>	<b>2000</b>	<b>2004</b>	<b>2005</b>	<b>2006</b>	<b>2007</b>	<b>2008</b>
Domestic Production (PJ)	3 765	4 987	5 861	5 754	6 058	6 338	6 264
Growth Since 1990	NA*	32%	56%	53%	61%	68%	66%
Energy Imported (PJ)	1 198	2 042	2 092	2 072	1 899	1 920	1 896
Growth Since 1990	NA	70%	75%	73%	58%	60%	58%
Energy Exported (PJ)	1 516	3 214	3 769	3 762	4 136	4 124	4 151
Growth Since 1990	NA	112%	149%	148%	173%	172%	174%
Apparent Domestic Consumption (PJ)	3 448	3 816	4 184	4 064	3 821	4 134	4 008
Growth Since 1990	NA	11%	21%	18%	11%	20%	16%
Emissions Associated with Gross Exports (Mt CO <sub>2</sub> eq.)	20.9	48.1	54.6	54.4	58.2	58.4	60.7
Growth Since 1990	NA	130%	161%	160%	178%	179%	190%
Emissions Associated with Net Exports <sup>1</sup> (Mt CO <sub>2</sub> eq.)	12.0	33.3	38.3	36.9	41.1	41.0	41.7
Growth Since 1990	NA	177%	218%	207%	241%	241%	246%

Notes:

<sup>1</sup> See box on Net Export Emissions, page 28

\* NA = Not applicable.

Table S-5 Natural Gas: Production, Import, Export and GHG Emission Trends, Select Years

<b>Natural Gas Trends</b>	<b>1990</b>	<b>2000</b>	<b>2004</b>	<b>2005</b>	<b>2006</b>	<b>2007</b>	<b>2008</b>
Domestic Production (PJ)	4 184	7 062	7 118	7 183	7 196	6 994	6 652
Growth Since 1990	NA*	69%	70%	72%	72%	67%	59%
Energy Imported (PJ)	24.2	61.8	416.3	363.9	368.9	503.6	596.1
Growth Since 1990	NA	155%	1 619%	1 403%	1 423%	1 980%	2 361%
Energy Exported (PJ)	1 537	3 846	4 035	4 061	3 901	4 117	3 936
Growth Since 1990	NA	150%	162%	164%	154%	168%	156%
Apparent Domestic Consumption (PJ)	2 671	3 278	3 500	3 486	3 663	3 380	3 313
Growth Since 1990	NA	23%	31%	31%	37%	27%	24%
Emissions Associated with Gross Exports (Mt CO <sub>2</sub> eq.)	12.0	31.5	35.0	35.9	34.2	35.7	34.7
Growth Since 1990	NA	163%	192%	200%	186%	199%	190%
Emissions Associated with Net Exports <sup>1</sup> (Mt CO <sub>2</sub> eq.)	11.7	30.2	30.1	31.5	30.3	30.5	28.7
Growth Since 1990	NA	158%	157%	169%	159%	161%	145%

Notes:

<sup>1</sup> See box on Net Export Emissions, page 28

\* NA = Not applicable.



Table S–6 Combined Crude Oil and Natural Gas: Production, Import, Export and GHG Emission Trends, Select Years

<b>Crude Oil &amp; Natural Gas Trends</b>	<b>1990</b>	<b>2000</b>	<b>2004</b>	<b>2005</b>	<b>2006</b>	<b>2007</b>	<b>2008</b>
Domestic Production (PJ)	7 949	12 049	12 979	12 937	13 254	13 331	12 916
Growth Since 1990	NA*	52%	63%	63%	67%	68%	62%
Energy Imported (PJ)	1 222	2 104	2 509	2 436	2 268	2 424	2 492
Growth Since 1990	NA	72%	105%	99%	86%	98%	104%
Energy Exported (PJ)	3 053	7 060	7 803	7 822	8 037	8 241	8 087
Growth Since 1990	NA	131%	156%	156%	163%	170%	165%
Apparent Domestic Consumption (PJ)	6 119	7 094	7 684	7 550	7 484	7 514	7 321
Growth Since 1990	NA	16%	26%	23%	22%	23%	20%
Emissions Associated with Gross Exports (Mt CO <sub>2</sub> eq.)	32.9	79.6	89.6	90.3	92.4	94.2	95.4
Growth Since 1990	NA	142%	172%	174%	181%	186%	190%
Emissions Associated with Net Exports <sup>1</sup> (Mt CO <sub>2</sub> eq.)	23.7	63.5	68.3	68.4	71.4	71.5	70.4
Growth Since 1990	NA	168%	188%	188%	201%	201%	197%

Notes:

<sup>1</sup> See box on Net Export Emissions, page 28

\* NA = Not applicable.

Table S–7 Conventional Crude Oil: Production Import, Export and GHG Emission Trends, Select Years

<b>Conventional Crude Oil Trends</b>	<b>1990</b>	<b>2000</b>	<b>2004</b>	<b>2005</b>	<b>2006</b>	<b>2007</b>	<b>2008</b>
Domestic Production (PJ)	2 978	3 584	3 572	3 465	3 441	3 534	3 434
Growth Since 1990	NA*	20%	20%	16%	16%	19%	15%
Energy Imported (PJ)	1 198	2 042	2 092	2 072	1 899	1 920	1 896
Growth Since 1990	NA	70%	75%	73%	58%	60%	58%
Energy Exported (PJ)	1 111	2 450	2 365	2 287	2 386	2 233	2 160
Growth Since 1990	NA	121%	113%	106%	115%	101%	94%
Apparent Domestic Consumption (PJ)	3 066	3 176	3 300	3 249	2 954	3 221	3 171
Growth Since 1990	NA	4%	8%	6%	-4%	5%	3%
Emissions Associated with Gross Exports (Mt CO <sub>2</sub> eq.)	11.4	32.6	30.0	30.1	30.2	26.5	27.7
Growth Since 1990	NA	185%	163%	163%	164%	132%	142%
Emissions Associated with Net Exports <sup>1</sup> (Mt CO <sub>2</sub> eq.)	2.6	17.8	13.8	12.7	13.0	9.1	8.7
Growth Since 1990	NA	598%	439%	396%	410%	256%	240%

Notes:

<sup>1</sup> See box on Net Export Emissions, page 28

\* NA = Not applicable.

Table S–8 Unconventional Crude Oil: Production, Import, Export and GHG Emission Trends, Select Years

<b>Unconventional Crude Oil Trends</b>	<b>1990</b>	<b>2000</b>	<b>2004</b>	<b>2005</b>	<b>2006</b>	<b>2007</b>	<b>2008</b>
Domestic Production (PJ)	787	1 403	2 288	2 289	2 617	2 804	2 829
Growth Since 1990	NA	78%	191%	191%	233%	256%	260%
Energy Exported (PJ)	405	763	1 404	1 475	1 750	1 890	1 992
Growth Since 1990	NA	88%	247%	264%	332%	367%	392%
Apparent Domestic Consumption (PJ)	382	640	884	814	867	913	838
Growth Since 1990	NA	67%	131%	113%	127%	139%	119%
Emissions Associated with Gross Exports (Mt CO <sub>2</sub> eq.)	9.5	15.5	24.5	24.3	28.0	31.9	33.0
Growth Since 1990	NA	63%	158%	156%	195%	236%	248%

Notes:

\* NA = Not applicable.

## ES.4 Other Information

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

Canada is rich in fossil fuel resources and the associated industry contributes significantly to the economy. A much greater quantity of Canada's oil and gas production is sold internationally now than in the past. Between 1990 and 2008, oil exports grew by 174% to 4151 petajoules (PJ)<sup>12</sup> (almost three times the rate of growth of oil production) (Table S-4), while exports of natural gas increased 156% to 3936 PJ (approximately two and a half times the rate of growth of natural gas production) (Table S-5).<sup>13</sup> Furthermore, the sum total of oil and gas energy exports increased by 165% over the same period (Table S-6). It is important to note that natural gas exports have not experienced substantial changes since 2000. Future increases in natural gas exports are unlikely, given projected production declines from diminishing reserves in Canada's largest natural gas reservoir (the Western Sedimentary Basin) (Nyboer and Tu 2006).

Whereas natural gas production is declining in Canada, production and exports from Canada's oil sands have been increasing. From 1990 to 2000, exports of conventional crude oil in energy terms increased by 121%, but from 2000 to 2008 exports decreased by 12% (Table S-7). However, exports of unconventional crude oil<sup>14</sup> from Canada's oil sands have been consistently increasing (Table S-8). From 1990 to 2008, exports of unconventional crude oil have increased by 392%.

Increased Canadian fossil fuel exports have been offset, in part, by increased fossil fuel imports. Indeed, 58% more energy from crude oil was imported in 2008 than in 1990. The balance between changes in exports, imports and production reflects an increase of 20% in domestic consumption of crude oil and natural gas between 1990 and 2008 (Table S-6).

Activities associated with the oil and gas industry result in considerable GHG emissions. Between 1990 and 2008, increases in oil and gas production for export (principally to the United States) contributed substantially to emissions growth. Total emissions associated with the production, processing and transmission of all oil and gas destined for export were about 95 Mt in 2008, up 190% from 1990.

#### Net Export Emissions

The production, processing and transmission of oil and gas results in considerable GHG emissions. Since Canada both exports and imports significant quantities of fuel, determination of emissions associated with net exports provides a clearer picture of emissions arising from domestic energy demand. Net export emissions are the Canadian emissions associated with extracting, processing and transporting exported fuels minus the foreign emissions associated with the same activities for imported fuels. The emissions associated with net exports approximate the quantity of GHGs that would be ascribed to Canada if it was responsible only for those above and beyond its own demand. Net exports rose from about 24 Mt in 1990 to 70 Mt in 2008 (a 197% increase; Table S-6).\*

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

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

13 The source for all export and energy production data is Statistics Canada's *Report on Energy Supply and Demand in Canada* (RES-D, #57-003). The 1990–2007 GHG emissions associated with net exports are from Environment Canada (2008).

14 Unconventional crude oil includes crude bitumen from mining and in-situ sources as well as synthetic crude oil.

## ES.4.2 Provincial/Territorial GHG Emissions

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

## ES.4.3 The International Context

Canada contributes about 1.5% of total global GHG emissions. In 2008, Canada emitted 22.0 t of GHGs per capita, which represents 3.1% growth since 1990. Though Canada is one of the highest per capita emitters, largely the result of its size, climate (i.e. energy demands) and resource-based economy, this level is about 4% less than the corresponding rate for the United States.

In terms of growth in total anthropogenic GHG emissions, Canada ranked sixth among the nine Annex I Parties whose emissions increased more than 20% over the 1990–2007 period<sup>15</sup>. Canada, which has a –6% Kyoto target, had a growth of +26% (based on its 2009 inventory submission) compared with Spain's +54% growth (–8% target<sup>16</sup>), Greece's +25% rise (–8% target<sup>16</sup>) and Japan's +8% increase (–6% target<sup>16</sup>). Parties whose emissions decreased by 2007 include the European Union (EU), by –4 (–8% target<sup>16</sup>), the United Kingdom, by –17% (–8% target<sup>16</sup>) and Germany, by –21% (–8% target<sup>16</sup>)<sup>17</sup>.

15 These aggregate estimates are based on data from Parties that submitted inventories to the UNFCCC in 2008. Source: UNFCCC (2009), available online at [http://unfccc.int/ghg\\_data/ghg\\_data\\_unfccc/time\\_series\\_annex\\_i/items/3841.php](http://unfccc.int/ghg_data/ghg_data_unfccc/time_series_annex_i/items/3841.php)

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

17 For further details, see Chapter 2 Part B

# 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.

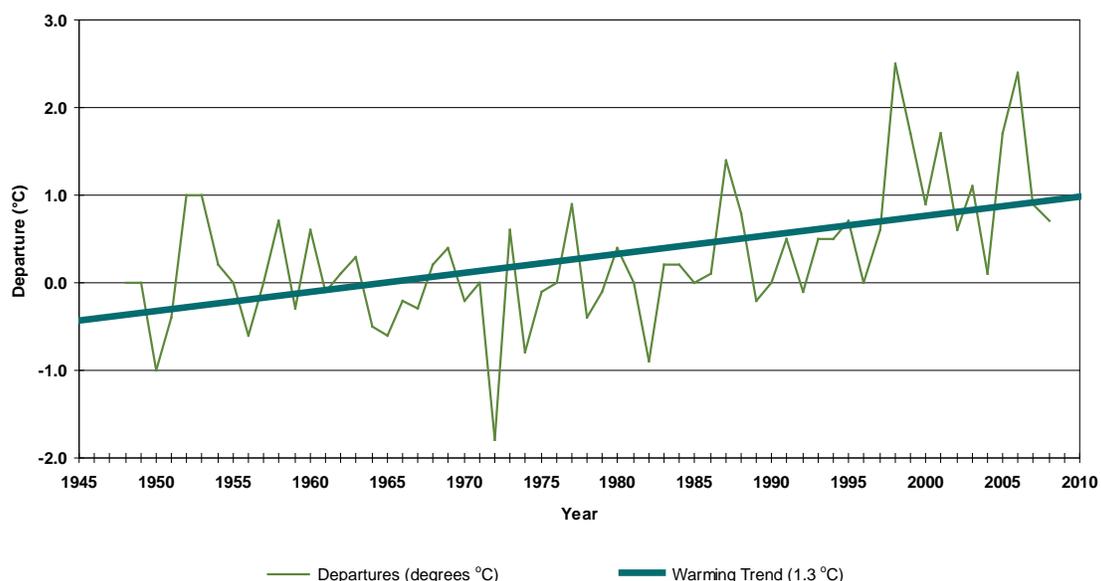
On the other hand, climate is the average pattern of weather (usually taken over a 30-year period) for a particular region. Climatic elements include precipitation, tem-

perature, 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 chemical 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 38%; of methane (CH<sub>4</sub>) by 157%; and of nitrous oxide (N<sub>2</sub>O) by 19% (WMO 2009). Between 1970 and 2004, global GHG emissions due to human activities have increased by approximately 70% (IPCC 2007a). These trends can be largely attributed to fossil fuel use (including energy supply, transportation, residential and commercial buildings and industrial use) and land-use change, including the permanent loss of forest cover.

According to the Intergovernmental Panel on Climate Change’s (IPCC’s) *Fourth Assessment Report* (IPCC 2007b), the impacts of climate change will vary regionally. In general, temperatures and sea levels are expected to rise and the frequency of extreme weather events is expected to increase. In some regions, the impacts could be devastating,

Figure 1–1 Annual Canadian Temperature Departures and Long-Term Trend, 1948–2008 (°C)



Source: Environment Canada (2009)

while other regions could benefit from climate change. The impacts will depend on the form and magnitude of the change and, in the case of adverse effects, the ability of natural and human systems to adapt to the changes. 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 2008 was 0.7°C above normal. Annual temperatures in Canada have remained above or close to normal since 1993, with a warming trend of 1.3°C over the last 61 years (Figure 1–1).

### 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 GHG concentrations in the atmosphere at a level that would prevent dangerous interference with the climate system. In its actions to achieve its objective and to implement its provisions, the UNFCCC lays out a number of guiding principles and commitments. It requires governments to gather and share information on greenhouse gas emissions, national policies and best practices; to launch national strategies for addressing greenhouse gas 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 national inventories of anthropogenic<sup>2</sup> emissions by sources and removals by sinks of all GHGs not controlled by the Montreal Protocol using comparable methodologies.

This National Inventory Report (NIR) provides Canada's annual greenhouse gas emissions estimates for the period 1990–2008. The NIR, along with the Common Reporting Format (CRF) tables comprise Canada's submission to the UNFCCC and have been prepared in accordance with

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

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

Decision 18/CP.8 of the Convention and other relevant decisions.

## 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, 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 ozone precursors oxides of nitrogen (NO<sub>x</sub>), carbon monoxide (CO) non-methane volatile organic compounds (NMVOCs), as well as aerosols produced by sulphur dioxide (SO<sub>2</sub>).

### 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 greenhouse gas. 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 (Environment Canada 2005). Although human-caused releases of CO<sub>2</sub> are relatively small compared to the amounts that enter and leave the atmosphere due to the natural active flow of carbon, and represent approximately 1/20 (Environment Canada 2005), human activities 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. 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 colorless, 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 greenhouse gas. 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 ruminant 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 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 greenhouse gases 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 greenhouse gases. As HFCs do not deplete the ozone layer, they are commonly used as replacements for ozone-depleting substances (ODSs), such as chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs) and halons in various applications including refrigeration, fire-

extinguishing, semi-conductor 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 greenhouse gas 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

It should be noted that greenhouse gases are not equal. In fact, each greenhouse gas has a unique atmospheric lifetime and heat-trapping potential. Therefore, to interpret the emission data presented in this report, it is important to understand that the radiative forcing<sup>3</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 troposphere.

By definition, a global warming potential 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 global warming potential has been developed to allow scientists and policy-makers to compare the ability of each greenhouse gas to trap heat in the atmosphere relative to CO<sub>2</sub>. Often greenhouse gas emissions are calculated in terms of how much CO<sub>2</sub> would be required to produce a similar warming effect. This is called the carbon

<sup>3</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).

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 global warming potential for methane (CH<sub>4</sub>) 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 contributes only about 1.5% of total global GHG emissions, it is one of the highest per capita emitters, largely as a result of its size, climate (i.e. energy demands) and resource-based economy. In 1990, Canadians released 21.4 t of GHGs per capita. By 2008, this had increased to 22.0 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

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>2</sub> H <sub>3</sub> F <sub>3</sub> (CHF <sub>2</sub> CH <sub>2</sub> F)	300	1.5
HFC-143a	C <sub>2</sub> H <sub>3</sub> F <sub>3</sub> (CF <sub>3</sub> CH <sub>3</sub> )	3 800	3.8
HFC-152a	C <sub>2</sub> H <sub>4</sub> F <sub>2</sub> (CH <sub>3</sub> CHF <sub>2</sub> )	140	48.3
HFC-227ea	C <sub>3</sub> HF <sub>7</sub>	2 900	36.5
HFC-236fa	C <sub>3</sub> H <sub>2</sub> F <sub>6</sub>	6 300	209
HFC-245ca	C <sub>3</sub> H <sub>3</sub> F <sub>5</sub>	560	6.6
Perfluorocarbons (PFCs)			
Perfluoromethane	CF <sub>4</sub>	6 500	50 000
Perfluoroethane	C <sub>2</sub> F <sub>6</sub>	9 200	10 000
Perfluoropropane	C <sub>3</sub> F <sub>8</sub>	7 000	2 600
Perfluorobutane	C <sub>4</sub> F <sub>10</sub>	7 000	2 600
Perfluorocyclobutane	c-C <sub>4</sub> F <sub>8</sub>	8 700	3 200
Perfluoropentane	C <sub>5</sub> F <sub>12</sub>	7 500	4 100
Perfluorohexane	C <sub>6</sub> F <sub>14</sub>	7 400	3 200

Sources:

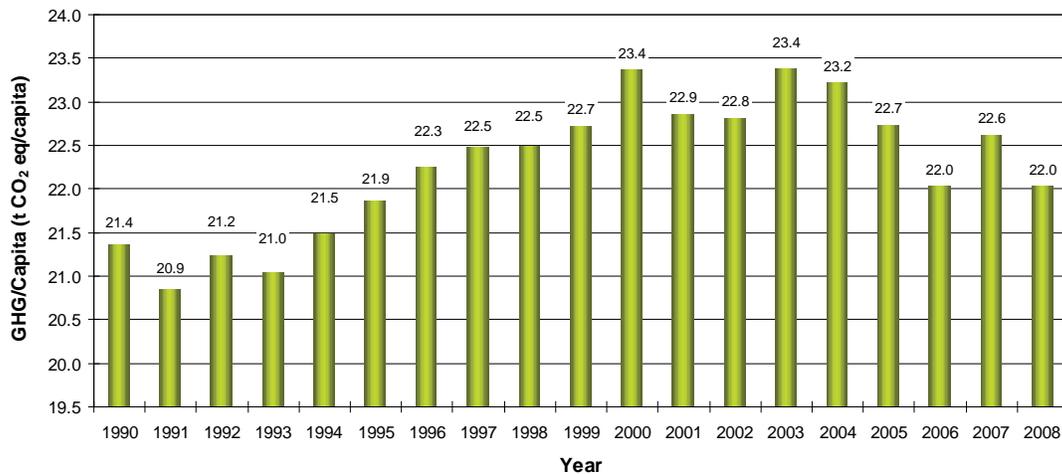
GWP: IPCC (1995), available online at [http://unfccc.int/ghg\\_data/items/3825.php](http://unfccc.int/ghg_data/items/3825.php)

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>.

Figure 1–2 Per Capita GHG Emission Trend for Canada, 1990–2008



(LULUCF), Canada ranks sixth among the Annex I Parties, with an increase in emissions of 26.2% over the 1990–2007 period (Figure 1–3), and ranks first among the G8 countries.

## 1.2. Institutional Arrangements for Inventory Preparation

The following section describes the national system, national registry 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. A new Annex (Annex 11) contains additional details on the specific requirements of Article 7 of the Kyoto Protocol, including additional details on the national registry and supplementary information required under Articles 3.3 and 3.4.

The national entity responsible for Canada's national inventory system is the Greenhouse Gas Division of Environment Canada. The National Inventory Focal Point is:

**Art Jaques**  
 Director, Greenhouse Gas Division  
 Science and Risk Assessment Directorate  
 Science and Technology Branch  
 Environment Canada  
 10th Floor, 200 Sacré-Coeur Boulevard  
 Gatineau (Quebec) K1A 0H3  
 Telephone: +1-819-994-3098  
 Fax: +1-819-953-3006  
 Email: art.jaques@ec.gc.ca

A detailed description of the functions of the Greenhouse

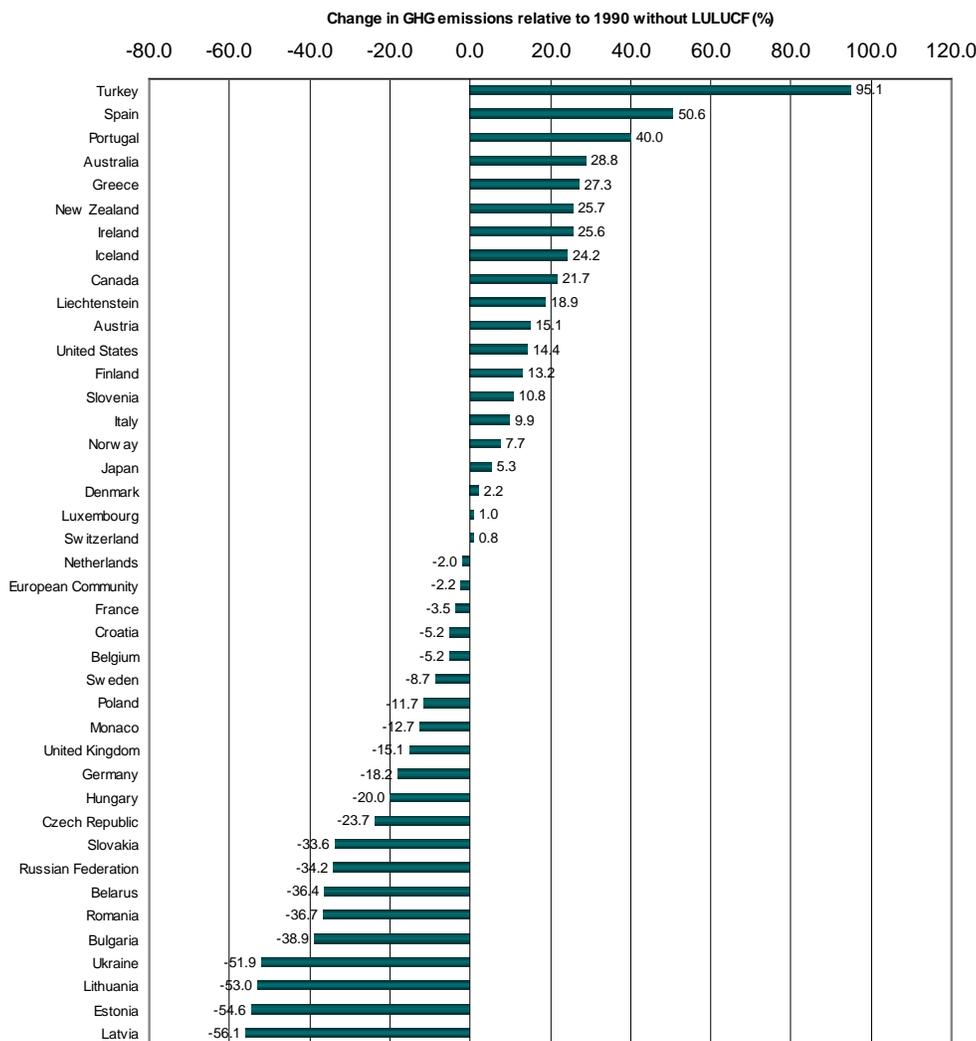
Gas Division is provided in the Institutional Arrangements Section (Section 1.2.3) below.

### 1.2.1. The National System

Under Article 5.1 of the Kyoto Protocol, each Party to the Protocol included in Annex I shall have in place, no later than January 1, 2007, a national system for the estimation of anthropogenic emissions from sources and removals by sinks of all GHGs not controlled by the Montreal Protocol. The national system encompasses the institutional, legal and procedural arrangements necessary to ensure that Parties meet their reporting obligations, that quality inventories are prepared and that proper documentation and archiving occur in order to facilitate third-party review and to assess compliance with targets under the Kyoto Protocol.

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; ability to identify key categories and generate quantitative uncertainty analysis; and a process for performing recalculation for improvement of the inventory (UNFCCC 2008b).

Figure 1–3 Change in Aggregate GHG Emissions for Annex I Parties without LULUCF, 1990–2007



Source: UNFCCC (2009a).

### 1.2.2. Canada’s National Registry

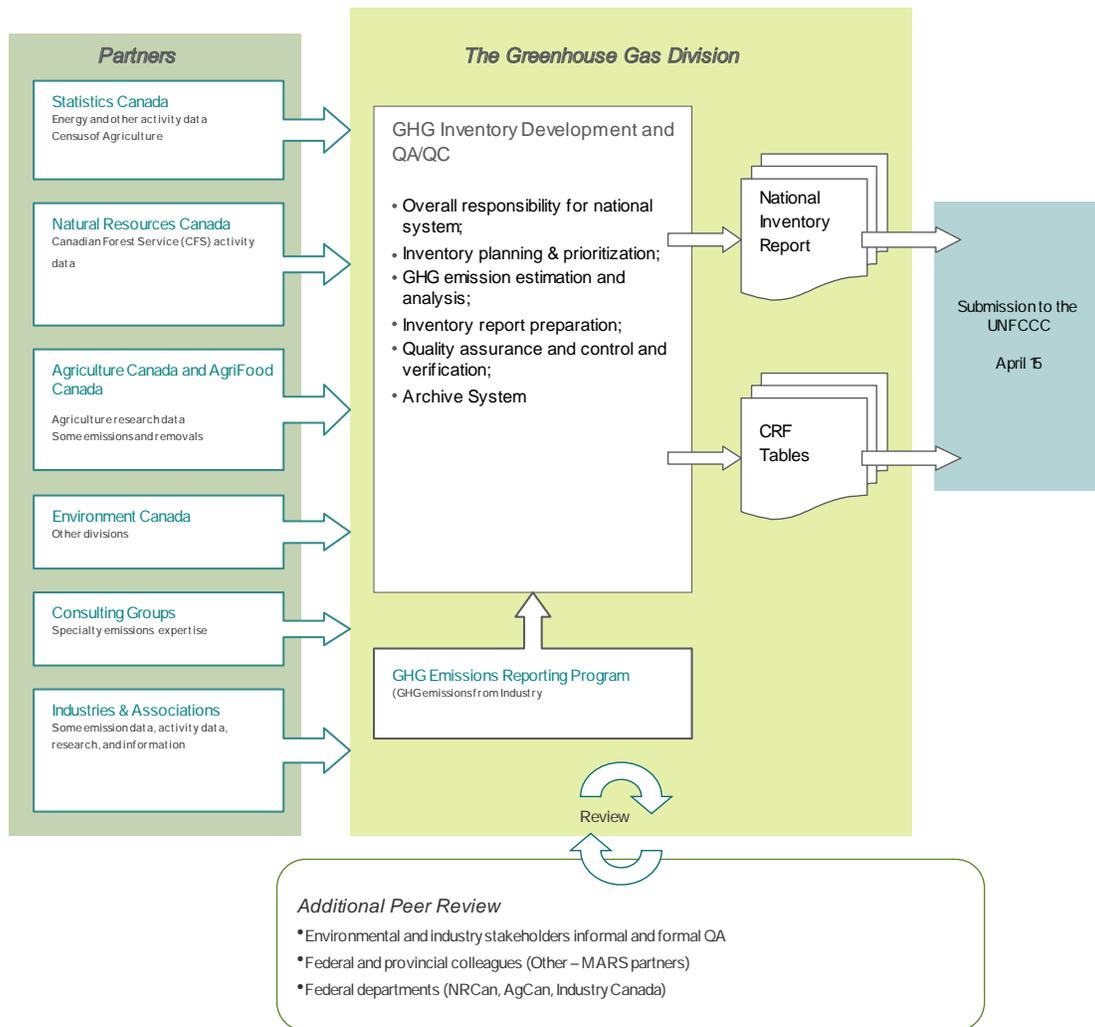
The assessment of compliance with the Kyoto Protocol target is based on a comparison of a country’s inventory of total GHG emissions for the 2008–2012 period with its total holdings of Kyoto accounting units for that same period. In accordance with Article 7.4 of the Kyoto Protocol, Canada has put a national registry in place, which went live on February 12, 2010.

### 1.2.3. Institutional Arrangements

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

Figure 1–4 identifies the different partners of the inventory

Figure 1-4 Partners of the National System



agency and their contribution.

Inventory experts in the Greenhouse Gas Division develop, analyse and verify activity data, methods, emission factors and the emission and removal estimates. The Division develops, reports and publishes the NIR and the Common Reporting Format (CRF) tables. The Greenhouse Gas Division also manages the quality and the archiving systems, performs trend analysis, publishes fact sheets and acts as a clearinghouse for GHG information and technical guidance on GHG quantification. Moreover, the Greenhouse Gas Division manages the Greenhouse Gas Emissions Reporting Program, requiring annual reporting from facilities as described in Section 1.4.1.

Groups at Environment Canada other than the Greenhouse Gas Division also contribute data on waste and waste management, residential fuel use of biomass and emissions of

SF<sub>6</sub>, ozone and aerosol precursors.

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

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

lished between the two departments.

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

Statistics Canada's quality management system for the energy balance includes an internal and external review process. Owing to the complexity of energy data, a Working Group on Energy Statistics consisting of members from Statistics Canada, Environment Canada and Natural Resources Canada (NRCan) was established to provide advice, direction and recommendations on improvements to the energy balance. In addition, a high-level Energy Steering Committee was formed in 2008 to review timing, quality and technical issues related to the RESD 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.

Other groups in Statistics Canada are 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. The statistics agency also collects agricultural activity data (areas under various crops, crop production and management practices) through the *Census of Agriculture* and provides data on other activities such as animal population data.

Natural Resources Canada (NRCan) is a key partner of Environment Canada. It provides energy expertise and analysis, serves as expert reviewer for the Energy Sector and collects and provides activity data on mineral production, ethanol consumption and wood residues. The Analysis and Modelling Division of NRCan is responsible for preparing Canadian energy forecasts. Road vehicle fuel efficiency data are provided by both Transport Canada and Natural Resources Canada.

Since 2004, Environment Canada has had officially designated responsibilities to the Canadian Forest Service (CFS) of NRCan and to Agriculture and Agri-Food Canada (AAFC) for the development of key components of the LULUCF Sector and has established formal and explicit governance

mechanisms to that effect through Memoranda of Understanding. Canada's Monitoring, Accounting and Reporting System (MARS) for LULUCF is managed by an interdepartmental steering committee chaired by Environment Canada, with representatives from the Research Branch of AAFC and from NRCan-CFS. Three technical working groups address the subsectors of Forestry, Agriculture and Land-Use Change, respectively, to ensure that the best available information and data from scientific research are integrated into the LULUCF Sector of the inventory.

NRCan-CFS annually develops and delivers forest-related GHG estimates of the LULUCF Sector (including deforestation and afforestation), while AAFC delivers cropland- and grassland-related GHG estimates. Provided by November 15 annually, estimates must be accompanied by complete and transparent documentation, including uncertainty analysis and QC. NRCan-CFS has developed the National Forest Carbon MARS while AAFC has developed the Canadian Agricultural Greenhouse Gas MARS; both these monitoring systems have contributed major improvements to the LULUCF Sector. Environment Canada develops estimates for other LULUCF categories, undertakes QA, and plays an integrating role, ensuring consistency in the land representation system. In addition to its responsibility in the MARS for LULUCF, AAFC also supports the Agriculture Sector inventory preparation in concert with Environment Canada.

The Earth Science Sector of NRCan contributes earth observation expertise, while the Canadian Space Agency supports the development of Earth Observations products to improve land information reports within LULUCF MARS.

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

When required, and resources permitting, contracts are established with consulting firms and universities to conduct in-depth studies—for example, on updating emission factors. The industrial sector is a key partner in all sectors of the inventory, providing technical hands-on expertise on emission factors, activity data and GHG estimates. A bilateral agreement with the Aluminum Association of Canada (AAC) has been signed, 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, member companies of the Canadian Fertilizer Institute 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).

The inventory schedule is built around a continuous process of methodological improvements, refinements and review, according to the quality management and improvement plans. The Inventory Coordinator is responsible for preparing the inventory schedule based on the results of the lessons-learned review of the previous inventory cycle, QA/QC follow-up, the UNFCCC review report, collaboration with provincial and territorial governments and the improvement plan to identify priorities and areas for improvement. Based on these outcomes, methodologies and emission factors are reviewed, developed and/or refined if necessary during the period from May to September. 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.

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 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 and a national report are prepared by industry experts. Emissions are calculated by designated inventory experts, reviewed internally and then reported according to UNFCCC guidelines in the CRF and the NIR. QC checks and estimates are signed off by sectoral managers before the report and national totals are prepared. The inventory pro-

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

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

Typically, the National Inventory Report is compiled annually by February and its contents are sent for review by a federal/provincial/territorial group of experts (the Emissions and Projections Working Group of the National Air Issues Committee). Once completed, the draft NIR and a summary of the data and trends analysis is prepared for sign-off for submission to the UNFCCC Secretariat. In the process of considering the national inventory and the results, several briefings of senior officials typically take place prior to the report being sent to the Minister. Once 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 Inven-

tories (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; however, these guidelines have not yet been adopted by the UNFCCC.

While not mandatory, the new 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 the Criteria Air Contaminants, or CACs) are inventoried and reported separately. CAC emissions in Canada are reported to the United Nations Economic Commission for the Environment.<sup>4</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 typical sources or sinks diffused over very large areas. Processes that cause emissions and removals display considerable spatial and interannual variability, and they also span several years or decades. The most practical approach to estimating emissions and removals may require a combination of repeated measurements and modelling. The

need, unique to these systems, to separate anthropogenic impacts from large natural fluxes creates an additional challenge.

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 activity data are lacking at the national level, so the more accurate method cannot be used. Some methods have undergone revision and improvement over time, and some new sources have been added to the inventory over time.

Methodology and data improvement activities, which take into account results of QA/QC procedures, reviews and verification, are planned and implemented on a continuous basis by the staff of Environment Canada’s Greenhouse Gas Division. 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 times series, from the 1990 base year to the most recent year available. Further discussion of recalculations and improvements can be found in Chapter 9.

### 1.4.1. Mandatory Reporting System for GHGs

In March 2004, the Government of Canada established the Greenhouse Gas Emissions Reporting Program (GHGRP) under section 46(1) of CEPA 1999. The GHGRP continues to be part of Canada’s ongoing effort to develop, through a collaborative process with the provinces and the territories, a harmonized and efficient GHG reporting system that minimizes duplication and eases the reporting burden for industry and governments alike. The program’s four main objectives are to provide Canadians with timely information on GHG emissions; to enhance the level of detail in the National Greenhouse Gas Inventory; to support provincial and territorial requirements for GHG emissions information; and to support the development of regulations. As published in the *Canada Gazette*, facilities that emit 100 kt CO<sub>2</sub> eq or more annually for the years 2004–2008 had to submit a GHG emission report by June 1 of the following year. As of 2009, the reporting threshold has changed to 50 kt. Voluntary submissions from facilities with GHG emis-

<sup>4</sup> Available online at <http://www.unece.org/>

sions below the reporting threshold are encouraged.

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

Facility-level GHG emission data are used, where appropriate, to confirm emission estimates in the NIR developed from national and provincial statistics. The extent to which the reported GHG emission information can be fully integrated is dependent upon the level of detail and type of data available. Environment Canada will continue to use these data as an important component of the overall inventory development process in comparing and verifying the inventory estimates.

The GHG information dissemination website (available

online at <http://www.ec.gc.ca/pdb/ges-ghg>) provides public access to the reported GHG emission information (GHG totals by gas and by facility).

#### 1.4.1.1. Reported 2008 Facility GHG Emissions

In its fifth year of reporting, the collected GHG data covers the period from 2004 to 2008. A total of 350 facilities reported GHG emissions for the 2008 calendar year, collectively emitting a total of 263 Mt of GHGs.<sup>5</sup> Facilities can voluntarily report their GHG emissions if their emissions are below the reporting threshold, and 53 facilities did so in 2009. Facilities in Alberta accounted for the largest share of reported emissions, with approximately 42% of the total, followed by those in Ontario with 26%. Saskatchewan and Quebec both accounted for 8% of reported emissions (see Table 1–2).

When completing the GHG report, a reporter is required to identify the main activities occurring at its facility by selecting the North American Industry Classification System (NAICS) code that corresponds to these activities. Three industrial sectors accounted for the majority of GHG emissions—Utilities, primarily those generating electricity, representing 43%; Manufacturing, accounting for 32%; and Mining, Quarrying, and Oil and Gas Extraction, accounting for 21% (Figure 1–5)

#### 1.4.1.2. Facility-Reported 2007–2008 Short-term Trend

Over the past year, total reported emissions decreased by 15.7 Mt of CO<sub>2</sub> eq (6%). This decrease occurred across all sectors, with the Utilities and Manufacturing sectors demonstrating the largest decline (8.7 Mt and 3.8 Mt respectively) (see Table 1–3). These changes in reported emissions are likely due to differences in the number of facilities reporting, variability in production volumes or operations (e.g., plant closures, shutdown periods, decreases in demand), economic factors or emission reduction efforts.

Of the reported 6 GHGs, sulphur hexafluoride has seen the largest percentage decline (93%) due to the closure of 2 magnesium facilities over the past year.

Among the provinces and territories, British Columbia and the Northwest Territories had an increase in reported emissions, while other provinces saw a decline in reported

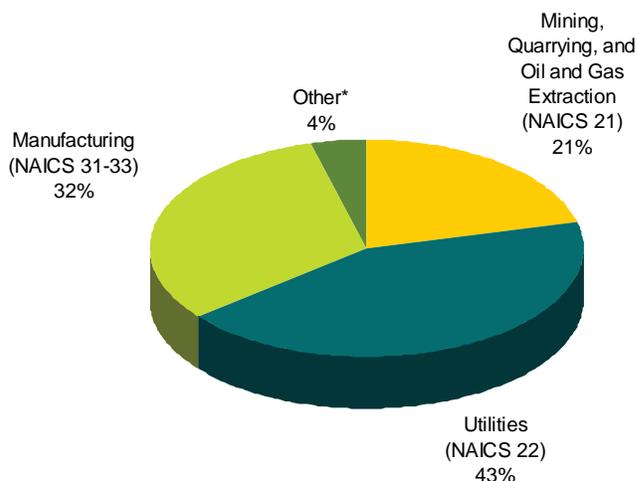
Table 1–2 Facility-Reported 2008 GHG Emissions by Province

Province	Number of Facilities	Total Emissions (kt CO <sub>2</sub> eq)	Percentage of Total Emissions (%)
Newfoundland and Labrador	7	5 273	2
Prince Edward Island	1	99	0
Nova Scotia	9	11 104	4
New Brunswick	12	10 284	3
Quebec	46	20 002	8
Ontario	87	66 911	26
Manitoba	9	2 367	1
Saskatchewan	24	21 885	8
Alberta	109	110 921	42
British Columbia	43	13 186	5
Northwest Territories	3	534	0
Total	350	262 565	100

Note: Totals may not add up due to rounding.

5 Data presented are current as of September 14, 2009.

Figure 1–5 Facility-Reported 2008 GHG Emissions by Industrial Sector



\*“Other” includes Transportation and Warehousing, as well as Administrative and Support, Waste Management and Remediation Services industrial sectors.

Table 1–3 Short-term trend by sector, 2007–2008, all facilities

All Facilities		Number of Facilities		Emissions (kt CO <sub>2</sub> eq)		
NAICS	Sector	2007	2008	2007	2008	Difference
21	Mining, Quarrying, and Oil and Gas Extraction	83	85	57 022	55 568	-1 453
22	Utilities	78	82	121 821	113 110	-8 711
31–33	Manufacturing	160	152	86 703	82 913	-3 790
Other	Other	31	31	12 756	10 972	-1 782
	Totals	352	350	278 301	262 565	-15 736

Notes:

Totals may not add up due to rounding.

1. NAICS = North American Industry Classification System.

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

Figure 1–6 Facility-reported provincial short-term trend, 2007–2008

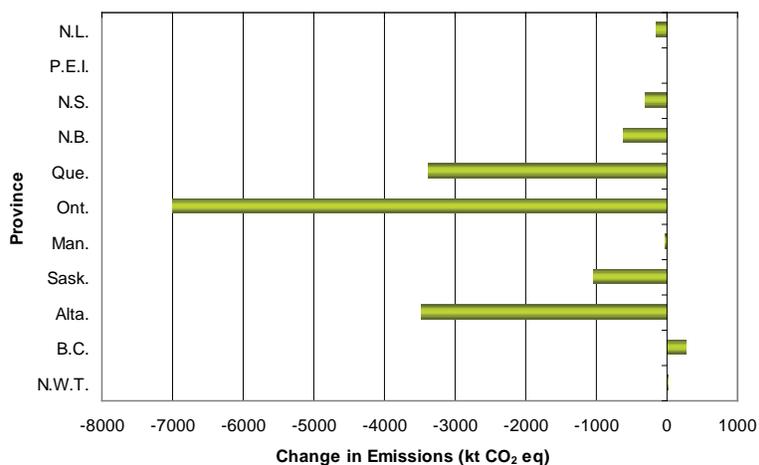
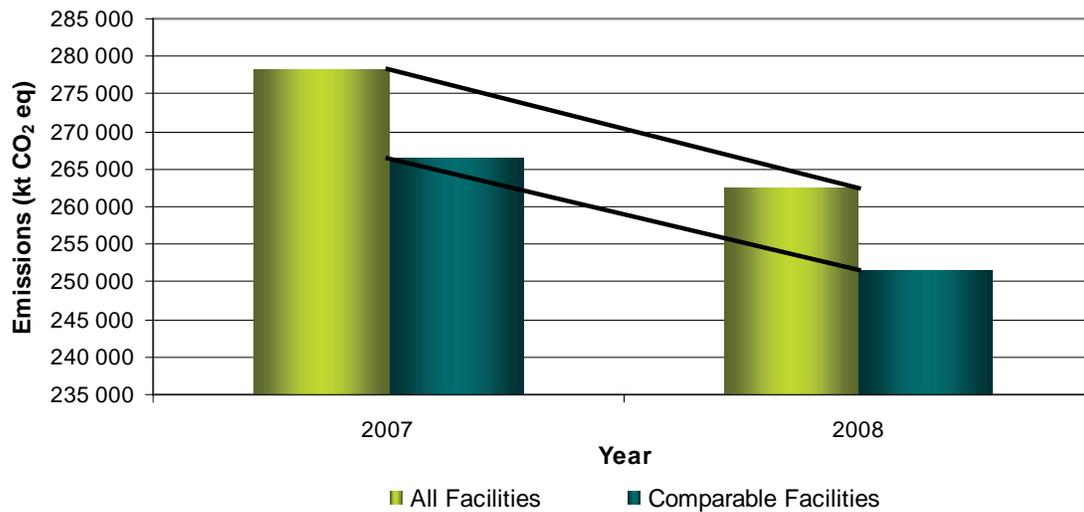


Figure 1-7 Facility-reported comparable facilities versus all facilities, 2007-2008



emissions (see Figure 1-6).

The increase experienced by British Columbia is largely due to an increase in emissions from conventional oil and gas extraction, while the Northwest Territories saw an increase in emissions from diamond mining.

Ontario reported the largest decrease in emission (7.0 Mt), the majority of which occurred within the Utilities Sector, mainly fossil-fuel electric power generation (5.2 Mt), while Manufacturing accounted for a 1.1 Mt drop in reported emissions. The decrease in emissions from the Utilities Sector is a result of the combination of hydraulic conditions, economic activity and increased conservation

efforts. The cool, wet summer led to record hydroelectric production (a low-GHG-emitting source) and lower demand for electricity. Coal-fired electricity generation decreased by 18% from 2007 (Independent Electricity System Operator 2009).

Emissions from Alberta declined by 3.5 Mt. The two largest reductions are linked to oil and gas extraction activities and the Utilities Sector (1.4 Mt each). The decrease in emissions from the Utilities Sector is due to planned and unplanned outages resulting in a 1.3% reduction in coal-fired generation from 2007 (Alberta Electric System Operator 2009).

Figure 1-8 Facility-reported top five short-term changes by industry, 2007-2008, comparable facilities

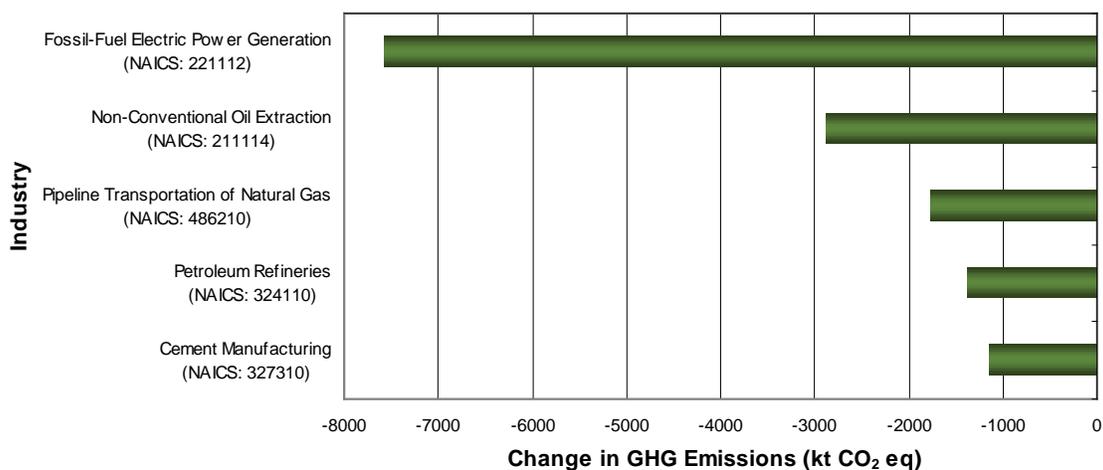




Table 1–4 Facility-reported long-term trend, 2004–2008, all facilities

All facilities	2004	2005	2006	2007	2008
Number of facilities	326	337	345	352	350
Emissions (kt CO <sub>2</sub> eq)	278 315	278 018	271 941	278 301	262 565
Annual change (%)	NA	-0.1	-2.2	2.3	-5.7
Change since 2004 (%)	NA	-0.1	-2.3	-0.0	-5.7

NA=Not applicable

Table 1–5 Facility-reported long-term trend, 2004–2008, comparable facilities

Comparable facilities	2004	2005	2006	2007	2008
Number of facilities	326	337	345	352	350
Emissions (kt CO <sub>2</sub> eq)	278 315	278 018	271 941	278 301	262 565
Annual change (%)	NA	-0.1	-2.2	2.3	-5.7
Change since 2004 (%)	NA	-0.1	-2.3	-0.0	-5.7

NA=Not applicable.

Quebec saw a decline of 3.4 Mt, due largely to a 1.8-Mt decline in Manufacturing, followed by a 1.6-Mt drop in Utilities. The suspension of electricity generation from a natural-gas-powered facility led to the drop in emissions from Utilities (Hydro Quebec 2009).

Comparable facilities are those that reported GHG emissions every year from 2004 to 2008. When comparing emissions between total facilities and comparable facilities, comparable facilities tend to dictate the emission trend (see Figure 1–7). Understanding the trend from comparable facilities provides a more accurate representation of the overall trend as it removes the variability in the number of facilities reporting each year. There are 275

comparable facilities, which generally represent over 95% of the reported emissions from all facilities in any given year. Further facility reported data and analysis presented from this point forward will focus on comparable facilities and their emissions.

When comparing industries and their overall change in emissions, fossil fuel electric power generation led with a decline in emissions of 7.6 Mt, followed by non-conventional oil extraction with a drop of 2.9 Mt. Overall, the industries shown in Figure 1–8 represent a decline of 14.8 Mt (94% of the total short-term decrease). As mentioned above, a number of factors contribute to these changes in emissions.

Figure 1–9 Facility-reported provincial long-term trend, 2004–2008, comparable facilities

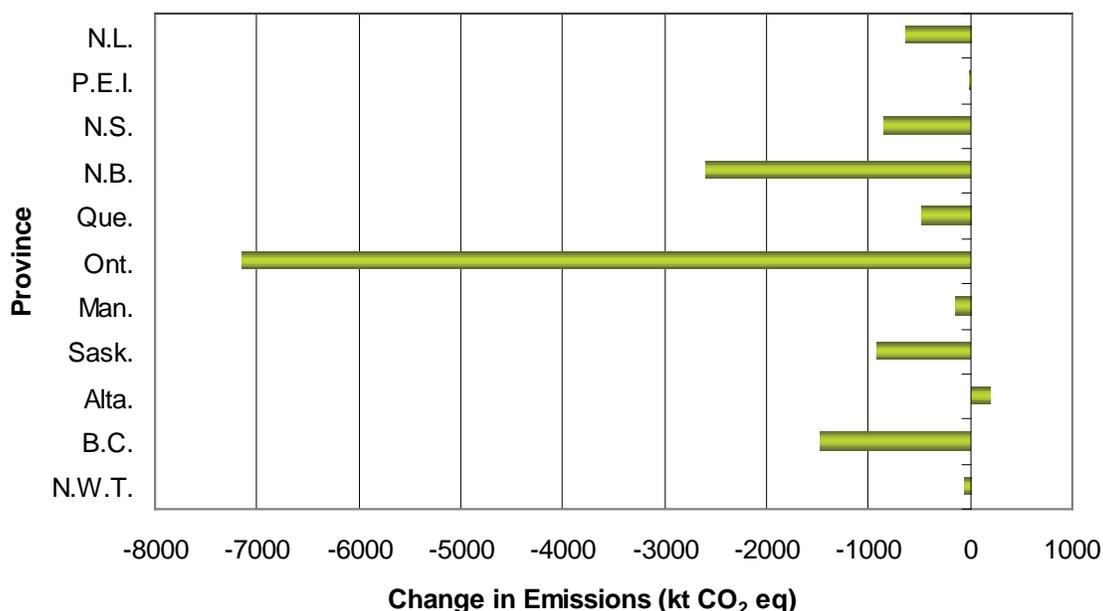
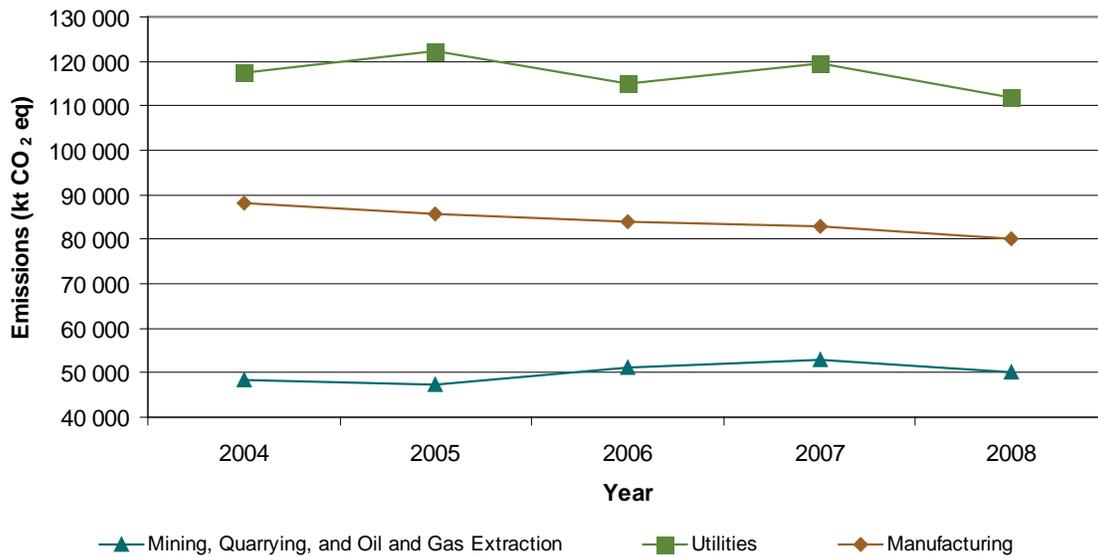


Figure 1–10 Facility-reported long-term sector trend 2004–2008, comparable facilities



### 1.4.1.3. Facility-Reported Long-term Trend: 2004–2008

Over the long term, the total number of facilities reporting increased from 326 in 2004 to 350 in 2008, while total emissions decreased by 16 Mt (6%) in the same time frame (see Table 1–4). If one focuses on comparable facilities over the long term (2004–2008), one sees that emissions declined 14.1 Mt during the period (see Table 1–5). This represents a 5% reduction in reported emissions over the period.

The provincial/territorial long-term trend (Figure 1–9) is similar to the short-term one in that most provinces and territories display a decline in emissions. However, Alberta exhibited a slight increase, largely due to an increase of 3.8 Mt from non-conventional oil extraction. The decline in emissions in Ontario is mostly due to a drop of 5.3 Mt in the Manufacturing Sector, followed by a drop of 1.1 Mt in the Utilities Sector. New Brunswick displayed a 2.6-Mt drop in emissions, attributable to the Utilities Sector, which accounted for 2.2 Mt. Emissions from British Columbia declined by 1.5 Mt, caused by a drop in emissions from conventional oil and gas extraction, the Manufacturing Sector and pipeline transportation.

Of the three largest contributors, emissions from Utilities and Manufacturing have declined, while emissions from Mining, Quarrying, and Oil and Gas Extraction have slightly increased (see Figure 1–10). The Utilities Sector exhibits

significant variability that reflects the many factors that impact this Sector, such as fuel cost (particularly oil and natural gas), weather, generation sources (nuclear, coal, hydro, wind) and demand by the Manufacturing Sector and Residential subsector.

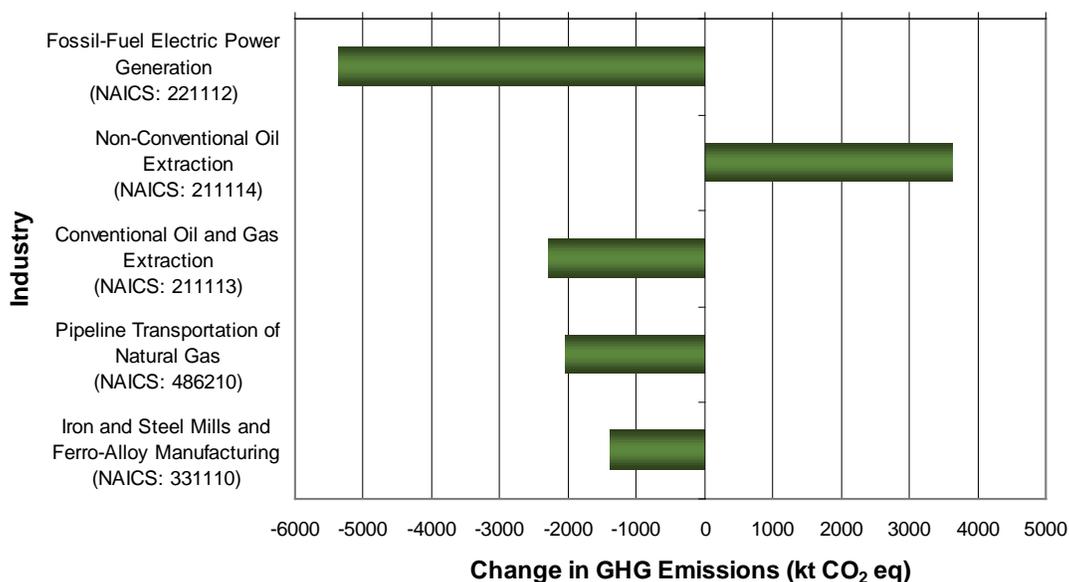
The industries showing the largest change in GHG emissions are different in the short-term (Figure 1–8) versus the long-term (Figure 1–11). Also worth noting is the fact that the top contributors to the short-term emission trend all show a reduction whereas, in the long-term, non-conventional oil extraction increased by 3.6 Mt.

One of the industries showing the largest change in emissions from 2004 to 2008 is iron and steel. The long-term emissions reductions in this industry correspond to the decreases observed in the national production levels for steel (8%). The decrease in steel production is mainly driven by the downturn in the automotive industry, one of the largest consumers of steel. This is reflected in a drop of 53% in the domestic sales (Statistics Canada Monthly).

## 1.5. Key Categories

The IPCC Good Practice Guidance (IPCC 2000, 2003) defines procedures (in the form of decision trees) for the choice of estimation methods recommended in the IPCC Guidelines. The decision trees formalize the choice of estimation method most suited to national circumstances, considering at the same time the need for accuracy and

Figure 1–11 Facility-reported top five long-term changes by industry, 2004–2008, comparable facilities



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

In this context, a *key category* is one that is prioritized within the national inventory system because its estimate has a significant influence on a country's total inventory of direct GHG emissions in terms of the absolute level of emissions (level assessment), 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.

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

For the 1990–2008 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), Adipic Acid Production, and the LULUCF category, Forest Land Remaining Forest Land. Details and results of the assessments are presented in Annex 1.

## 1.6. 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 Greenhouse Gas Division annually conducts QA/QC activities and is committed to improving data and methods in collaboration with industry, the provinces and territories, academia and the international community to ensure that a credible and

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

For 2009, a key focus has been the continued implementation of the QA/QC plan. The implementation has emphasized the transition from an informal approach of QA/QC to an approach that is formally defined and consistent across sectors. Full implementation of the plan is envisaged to span several years.

The reader is referred to Annex 6 of this report for more information on quality assurance/quality control.

## 1.7. Inventory Uncertainty

While national GHG inventories should be accurate, complete, comparable, transparent and verifiable, estimates will always inherently carry some uncertainty. Uncertainties<sup>6</sup> in the inventory estimates may be caused by systematic model uncertainty or (more likely) due to random uncertainties present within the input parameters. While reducing model uncertainty requires in-depth reviews of the estimation models, random uncertainties may be reduced by improvements to the activity data regimes and evaluation of emission factors and other model parameters. 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.

<sup>6</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).

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.

The uncertainty for the national inventory, not including the LULUCF Sector, is  $\pm 3.8\%$ , consistent with the previously reported range of  $-3\%$  to  $+6\%$ . The Energy Sector had the lowest uncertainty at  $\pm 2.2\%$ , while the Agriculture Sector had the highest uncertainty at  $\pm 37\%$ . The Industrial Processes, Solvent and Product Use and Waste Sectors had uncertainties of  $\pm 7.0$ ,  $\pm 19.3$  and  $\pm 34.5\%$ , respectively.

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

- Agriculture – Indirect Agricultural Soils  $N_2O$ , Fuel Combustion;
- Other Transportation (Off-Road)  $N_2O$ , Agriculture – Direct Agricultural Soils  $N_2O$ ;
- Waste – Solid Waste Disposal on Land  $CH_4$ ; and,
- Fuel Combustion – Public Electricity and Heat Combustion  $CO_2$ .

The trend uncertainty, not including LULUCF, was found to be  $0.74\%$ . Therefore, the total increase in emissions since 1990 has a 95% chance of being in the range of  $23.4\%$ – $24.8\%$ .

The uncertainty when the LULUCF emissions and removals are included in the national total was found to be  $8.0\%$ . The top five contributors influencing the national uncertainty when LULUCF is included are

- Forest Land  $CO_2$ , Agriculture – Indirect Agricultural Soils  $N_2O$ ;
- Fuel Combustion – Other Transportation (Off-Road)  $N_2O$ ;
- Agriculture – Direct Agricultural Soils  $N_2O$ ; and,
- Waste – Solid Waste Disposal on Land  $CH_4$ .

## 1.8. Completeness Assessment

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

methodologies has been the reason for exclusion of a minor source.

1 In the Energy Sector, completeness improvements can be further achieved through the study of non-conventional fuels used in the manufacturing industry and non-CO<sub>2</sub> emission factors for waste tires. The Energy Sector has, since the 2007 UNFCCC in-country review, included biodiesel in transport as recommended by the expert review team. In the Industrial Processes Sector, emissions of CH<sub>4</sub> from process sources are being investigated. In the Agriculture Sector, efforts have been made to establish a consistent time series of activity data on crop residue burning in Canada through expert consultations. In the LULUCF Sector, significant improvements have been implemented starting in 2006, but completeness has not yet been fully met as a result of data limitations. As for the Waste Sector, CH<sub>4</sub> emissions from unmanaged landfills, industrial wastewater treatment, and municipal solid waste incineration will be the subjects of further research.

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

# Chapter 2

## Greenhouse Gas Emission Trends, 1990–2008

### A. Trends by IPCC Sector

In this section of the chapter, emission trends are discussed in the standard Intergovernmental Panel on Climate Change (IPCC) sector format. In the following section, the trends will be broken down and reviewed by economic sector.

#### 2.1. Summary of Emission Trends

In 2008, Canada's Greenhouse Gas (GHG) emissions, excluding the Land Use, Land-Use Change and Forestry (LULUCF) Sector, were 734 Mt, which is a 24.1% increase over 1990 emissions. Between 2007 and 2008, emissions decreased by 2.1%.

Since 1990, growth in emissions has resulted primarily from the categories of Electricity and Heat Generation, Fossil Fuel Industries, Mining, Transportation, Consumption

of Halocarbons and SF<sub>6</sub>, Enteric Fermentation and Waste. There have been overall decreases in Manufacturing Industries and Construction, Chemical Industry and Metal Production.

#### 2.2. Emission Trends by Gas

CO<sub>2</sub> is the largest contributor to Canada's GHG emissions. Figure 2–1 shows how the percent contributions of the six GHGs have changed between 1990 and 2008. The proportion of CO<sub>2</sub> has changed only slightly, rising from 77% of emissions in 1990 to 78% in 2008.

#### 2.3. Emission Trends by Category

##### 2.3.1. Energy Sector (2008 GHG emissions, 597 Mt)

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

Overall, fuel combustion and fugitive emissions accounted for 81% of total Canadian GHG emissions in 2008 (534 Mt and 63.8 Mt, respectively). Between 1990 and 2008, fuel combustion-related emissions increased 25%, while

Figure 2–1 Canada's GHG Emissions by Gas, 1990 and 2008 (excluding LULUCF)

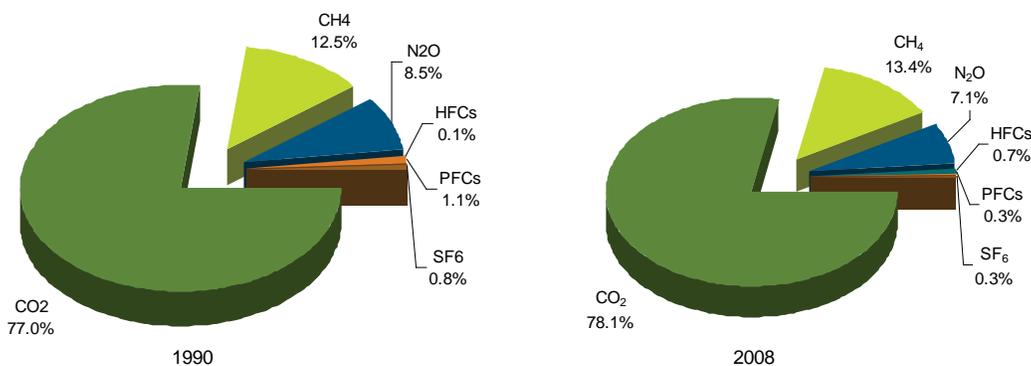


Table 2–1 GHG Emissions from Energy by UNFCCC CRF Sector, Selected Years

GHG Sources/Sinks	GHG Emissions (Mt CO <sub>2</sub> eq)					
	1990	2004	2005	2006	2007	2008
1. Energy	469	603	593	581	614	597
A. Fuel Combustion (Sectoral Approach)	427	537	528	515	549	534
1. Energy Industries	147	199	191	183	195	187
2. Manufacturing Industries and Construction	63.1	67.7	64.6	65.1	73.9	68.5
3. Transport	145	188	192	191	199	198
4. Other Sectors	72	83	80	75	81	80
B. Fugitive Emissions	42.7	65.6	64.7	65.8	64.7	63.8
1. Solid Fuels (Coal)	1.9	0.7	0.7	0.7	0.8	0.8
2. Oil and Natural Gas	40.7	64.9	63.9	65.1	64.0	63.1

Note: Totals may not add up due to rounding.

emissions from fugitive releases rose 50%. Emissions for both fuel combustion and fugitive emissions representing selected years are provided in Table 2–1.

The Energy Industries category, grouped in the Energy Sector, is the largest contributor to Canada's emissions. These industries, consisting of Fossil Fuel Production, Public Electricity and Heat Production, generate both combustion emissions and fugitive emissions and are presented as Fuel Combustion—Energy Industries and Fugitive Emissions in Table 2–1. Altogether, the Energy Industries subsector and the Fugitive Emissions subsector contributed 251Mt or 34% of Canada's total and about 42% of the Energy Sector's emissions in 2008.

Table 2–1 divides energy sources by United Nations Framework Convention on Climate Change (UNFCCC) Common Reporting Format (CRF) category: Fuel Combustion is categorized separately from Fugitive Emissions. By this breakdown, fuel combustion in the Energy Industries accounted for 187 Mt in 2008, while fugitive emissions were responsible for 63.8 Mt. In terms of relative growth, fugitive emissions from Oil and Natural Gas (including production, processing, transmission and distribution activities) have increased more rapidly than any other category (as shown in Table 2–1) in the Energy Sector. Between 1990 and 2008, these emissions rose by 55%.

### 2.3.1.1. Emissions from Fuel Combustion (2008 GHG emissions, 534 Mt)

GHG emissions from fuel combustion rose from 427 Mt in 1990 to 534 Mt in 2008, a 25% increase. Fuel combustion emissions are divided into the following subsectors: Ener-

gy Industries, Manufacturing Industries and Construction, Transport and Other Sectors. The Other Sectors subsector comprises emissions from the Residential and Commercial categories, as well as minor contributions of stationary fuel combustion emissions from the Agriculture and Forestry category.

#### Energy Industries (2008 GHG emissions, 187 Mt)

The Energy Industries subsector accounts for the second-largest portion of Canada's fuel combustion emissions (25% of Canada's total), behind Transport. Emissions included in this subsector are from stationary sources producing, processing and refining energy. This source category includes Public Electricity and Heat Production, Petroleum Refining, and Manufacture of Solid Fuels and Other Energy Industries. In 2008, combustion emissions from the Energy Industries category totalled 187 Mt, an increase of 27% from the 1990 level of 147 Mt.

#### Public Electricity and Heat Production<sup>1</sup> (2008 GHG emissions, 119 Mt)

This category accounted for 16% (119 Mt) of Canada's 2008 GHG emissions (Table 2–2) and was responsible for 16% of the total emission growth between 1990 and 2008. Overall emissions from this category increased 24% (23 Mt) since 1990.

Public Electricity and Heat Production, a constituent of the Energy Industries subsector, has seen a large increase

<sup>1</sup> The Public Electricity and Heat Production category includes emissions from utilities and industrial generation.

Table 2–2 GHG Emissions from Public Electricity and Heat Production, Selected Years

GHG Source Category	GHG Emissions (Mt CO <sub>2</sub> eq)						Change (%)
	1990	2004	2005	2006	2007	2008	1990–2008
Electricity Generation	95	125	123	116	124	118	24
Heat Generation	0.70	2.03	1.40	1.37	1.31	1.12	61
Total	95.5	126.8	124.7	117.0	125.3	118.8	24

Note: Totals may not add up due to rounding.

in emissions since 1990. Rising demand for electricity and the increasing use of fossil fuels in the generation mix drove GHG emissions up 23 Mt between 1990 and 2008. Comparatively, electricity generation was 136 TWh higher in 2008 than in 1990 (Statistics Canada #57-601). Although this long-term increase in demand was supplied in part by greater hydroelectric and nuclear generation, fossil fuel generation has also risen significantly. Record hydro generation and low demand resulted in hydropower's share of the generation mix rising from 63% in 1990 to almost 68% in 2008 (Statistics Canada #57-601). Over the same period, the share of the generation mix from electricity produced through the combustion of fossil fuels rose from 22% to 25%, worsening the average GHG intensity of production. This meant that, from 1990 to 2008, fossil fuel generation rose 45% and GHG emissions increased 24%.

Over the short term, GHG emissions from the Public Electricity and Heat Production categories decreased by more than 6 Mt from 2007, and decreased 8 Mt from 2004. Since electricity is generated to meet an instantaneous demand, decreased GHG emissions are generally a result of lower demand, which can occur via conservation measures, warmer winters and economic factors like plant closures. Emissions can also be reduced through increased nuclear generation, wind energy and higher water levels behind hydroelectric dams, all of which reduce fossil-fuel-based generation requirements. Warmer winters and cooler summers also help to reduce heating and cooling loads.

Of note in these trends is that the GHG emissions associated with coal-fired electricity generation, which had been increasing since the mid-1990s, have fluctuated regularly since peaking in 2001. Fuel costs, economic factors and the regulatory environment continue to play a major role in determining GHG emissions associated with coal-fired generation. Fuel switching, the use of less GHG-intensive coal, increases in other renewables, and interprovincial and international trade have also played a role. The impact of wind power will begin to play a greater role in the coming

years as the installed wind capacity in Canada continues to grow at a rapid rate.

While increasing use of natural gas has helped mitigate the rate of emission growth, the shift away from non-GHG-emitting sources (nuclear and hydro) in the latter part of the 1990s has resulted in large absolute increases. For more information on electricity generation and trends, see Section 2.6 – Trends by Economic Sector, and Annex 13 – Electricity Intensity Tables. Trends and analysis on a provincial/territorial level are discussed in Annex 14 – Provincial/Territorial Analysis.

### **Petroleum Refining and Manufacture of Solid Fuels and Other Energy Industries<sup>2</sup> (2008 GHG emissions, 68 Tableau 2–4Mt)**

The Petroleum Refining category mainly includes emissions from the combustion of fossil fuels during the production of refined petroleum products (RPPs), whereas the Manufacture of Solid Fuels and Other Energy Industries category encompasses fuel combustion emissions associated with the upstream oil and gas (UOG) industry. The majority of combustion emissions from the upgrading of heavy oil and bitumen to produce synthetic crude oil are included in the Manufacture of Solid Fuels and Other Energy Industries category. As shown in Table 2–3, between 1990 and 2008, emissions from these two categories increased by about 17 Mt, or 32%. This growth is due to increases in natural gas and oil production, particularly crude bitumen and heavy crude oil, largely for export.

### **Manufacturing Industries, Construction and Mining (2008 GHG emissions, 68 Mt)**

Emissions from the Manufacturing Industries and Construction subsector include the combustion of fossil fuels by the iron and steel, non-ferrous metals, chemicals,

<sup>2</sup> Fossil Fuel Industries category encompasses both the Petroleum Refining and Upgrading subsector and the Fossil Fuel Production (also known as Manufacture of Solid Fuels and Other Energy Industries) subsector.

Table 2–3 GHG Emissions from Petroleum Refining and Manufacture of Solid Fuels and Other Energy Industries, Selected Years

GHG Source Category	GHG Emissions (Mt CO <sub>2</sub> eq)						Change (%)
	1990	2004	2005	2006	2007	2008	1990–2008
Petroleum Refining	16	18	17	16	18	16	3.9
Manufacture of Solid Fuels and Other Energy Industries	36	53	49	50	52	52	45
Total	52	71	66	66	70	68	32

Note: Totals may not add up due to rounding.

cement, pulp, paper and print, construction, mining, and all other manufacturing industries.<sup>3</sup> In 2008, GHG emissions were 68.5 Mt (Table 2–4). Overall, this subsector was responsible for 9.3% of Canada's total GHG emissions in 2008, up 5.4 Mt from 1990.

Between 1990 and 2008, there were changes in both directions in the emissions produced by the various categories within the Manufacturing Industries and Construction subsector. The majority of the overall increase can be attributed to the Mining category, which has seen a 286% growth since 1990 (mainly as a result of increases in oil sands mining) whereas the largest decrease was in the Pulp, Paper and Print category. Strong demand both domestically and internationally was behind the long-term growth of GHG emission in the Mining, Cement and Non-Ferrous Metals categories. The Mining category includes oil sands mining, as well as mining of metals and minerals. The remaining categories have all shown long-term decreases, from -67% in the Pulp, Paper and Print category to -4.7% in the Iron and Steel category. These decreases can be attributed to decreased demand, fuel switching and changes in manu-

facturing operations.

Between 2004 and 2008, the most notable decrease in GHG emissions (52% or 4.9 Mt) was also observed in the Pulp, Paper and Print category, and reflects the economic difficulties being felt by this sector. Trends and analysis on a provincial/territorial level are discussed in Annex 14 – Provincial/Territorial Analysis.

### Transport (2008 GHG emissions, 198 Mt)

Transport is a large and diverse subsector, accounting for 27% of Canada's GHG emissions in 2008. This subsector includes emissions from fuel combustion for the transport of passengers and freight in five distinct subcategories:

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

From 1990 to 2008, GHG emissions from transport, driven

Table 2–4 GHG Emissions from Manufacturing, Construction, and Mining, Selected Years

GHG Source Category	GHG Emissions (Mt CO <sub>2</sub> eq)						Change (%)
	1990	2004	2005	2006	2007	2008	1990–2008
Iron and Steel	6.48	6.46	6.45	6.22	6.92	6.18	-4.7
Non-Ferrous Metals	3.19	3.23	3.27	3.23	3.49	3.48	9.3
Chemicals	7.14	6.83	6.40	6.82	7.23	6.69	-6.3
Cement	3.83	4.62	4.89	5.07	4.75	4.28	28
Construction	1.87	1.34	1.36	1.30	1.29	1.26	-33
Mining	6.19	14.86	15.63	16.83	23.21	23.87	286
Pulp, Paper and Print	13.73	9.40	7.18	5.86	5.87	4.54	-67
Other Manufacturing	20.6	20.9	19.4	19.8	21.2	18.2	-12
Total	63.1	67.7	64.6	65.1	73.9	68.5	8.6

Note: Totals may not add up due to rounding.

<sup>3</sup> The NIR categories that constitute this UNFCCC sector are Manufacturing Industries, Construction, and Mining (refer to tables S-2 and S-3).

Table 2–5 GHG Emissions from Transport, Selected Years

GHG Source Category	GHG Emissions (Mt CO <sub>2</sub> eq)				
	1990	2005	2006	2007	2008
Transport (Total)	145	192	191	199	198
Civil Aviation (Domestic Aviation)	6.4	7.9	7.7	8.8	8.5
Light-duty Gasoline Vehicles	45.8	39.9	39.9	41.0	40.6
Light-duty Gasoline Trucks	20.7	43.1	43.6	44.8	44.8
Heavy-duty Gasoline Vehicles	7.81	6.30	6.43	6.62	6.66
Motorcycles	0.146	0.252	0.256	0.264	0.264
Light-duty Diesel Vehicles	0.355	0.432	0.435	0.448	0.446
Light-duty Diesel Trucks	0.707	2.13	2.23	2.32	2.37
Heavy-duty Diesel Vehicles	20.7	38.1	38.9	40.0	39.4
Propane & Natural Gas Vehicles	2.2	0.72	0.79	0.83	0.88
Railways	7	6	6	7	7
Navigation (Domestic Marine)	5.0	6.4	5.8	6.1	5.8
Off-road Gasoline	6.7	7.3	6.7	7.1	6.3
Off-road Diesel	15	23	23	25	28
Pipelines	6.85	10.1	9.61	8.94	7.46

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

primarily by energy used for personal transportation, rose 36.4%, or 53 Mt. Overall, transport was the second largest emission-producing category in 2008, contributing 198 Mt and accounting for 37% of Canada's emission growth from 1990 to 2008.

Emissions from light-duty gasoline trucks (LDGTs), the subcategory that includes sport utility vehicles (SUVs), pickups and minivans, increased 116% between 1990 and 2008 (from 20.7 Mt in 1990 to 44.8 Mt in 2008), while emissions from cars (light-duty gasoline vehicles or LDGVs) decreased 11% (from 45.8 Mt in 1990 to 40.6 Mt in 2008) (Table 2–5).

As shown in Table 2–5, the growth in road transport emissions is due not only to the 42% increase in the total vehicle fleet, but also to a shift in light-duty vehicle purchases from cars (LDGVs) to trucks (LDGTs), which, on average, emit 40% more GHGs per kilometre.

Over the 1990–2008 period, the increase of 24 Mt and 19 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 2–6).

In 2008, emissions from HDDVs contributed 39 Mt to Canada's total GHG emissions (an increase of 90% from 1990 emissions). Emissions from heavy-duty gasoline ve-

hicles (HDGVs) were substantially lower at 6.6 Mt for 2008; this figure represents a decrease of 15% over the 1990 level. While there are difficulties in obtaining accurate and complete data for the freight transport mode, the trends in data from major for-hire truck haulers in Canada show conclusively that freight hauling by truck has increased substantially and that this activity is the primary task performed by HDGVs and HDDVs.

Off-road fuel combustion emissions<sup>4</sup> in the Other Transportation subsector increased by 50% between 1990 and 2008, when the contribution from pipelines is not included.

The pipeline emissions included in the Other Transportation subsector are combustion emissions primarily from natural gas transport. Owing to increasing activity in the Energy Sector, these emissions rose 8.9%, from 6.8 Mt in 1990 to 7.5 Mt in 2008.

### Other Sectors (2008 GHG emissions, 80 Mt)

The Other Sectors subsector comprises fuel combustion emissions from the Residential and Commercial categories,

<sup>4</sup> 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.

Table 2–6 Trends in Vehicle Populations for Canada, 1990–2008

Year	Number of Vehicles (000s)							Total
	LDGVs	LDGTs	HDGVs	MCs	LDDVs	LDDTs	HDDVs	
1990	10 646	3 308	518	261	109	112	402	15 356
1991	10 677	3 496	463	255	110	117	394	15 512
1992	10 674	3 712	432	248	109	126	397	15 698
1993	10 761	4 019	425	247	111	145	442	16 149
1994	10 694	4 305	428	234	108	165	487	16 421
1995	10 590	4 395	387	226	104	183	513	16 398
1996	10 273	4 517	383	213	99	174	498	16 157
1997	10 420	4 939	388	225	101	188	537	16 797
1998	10 250	5 347	395	263	107	204	629	17 195
1999	10 696	5 787	349	257	114	205	616	18 024
2000	10 863	6 065	376	288	123	224	649	18 587
2001	10 969	6 266	407	327	131	231	713	19 045
2002	10 929	6 421	394	359	138	234	724	19 200
2003	10 940	6 688	410	390	142	243	742	19 554
2004	10 931	6 959	429	417	153	254	801	19 944
2005	10 961	7 386	435	437	159	277	856	20 510
2006	11 195	7 551	445	446	162	284	876	20 960
2007	11 429	7 715	455	456	166	291	897	21 409
2008	11 663	7 879	465	465	170	298	918	21 858

## 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.

as well as stationary fuel combustion emissions from the Agriculture and Forestry category.<sup>5</sup> Overall, this subsector exhibited increases in GHG emissions of 12% from 1990 to 2008, while individual subcategories within it demonstrated a variety of changes.

### Residential and Commercial

Emissions in these categories arise primarily from the combustion of fuel to heat residential and commercial buildings. Fuel combustion in the Residential and Commercial and Institutional categories<sup>6</sup> accounted for 5.8% (43 Mt) and 4.7% (35 Mt), respectively, of all GHG emissions in 2008.

5 The UNFCCC Other Sectors category comprises the following NIR subsectors: Residential; Commercial and Institutional; and Agriculture and Forestry (listed under Energy, Stationary Combustion Sources in Annex 12).

6 Commercial Sector emissions are based on fuel use as reported in the *Report on Energy Supply and Demand in Canada* (RES-D) (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.

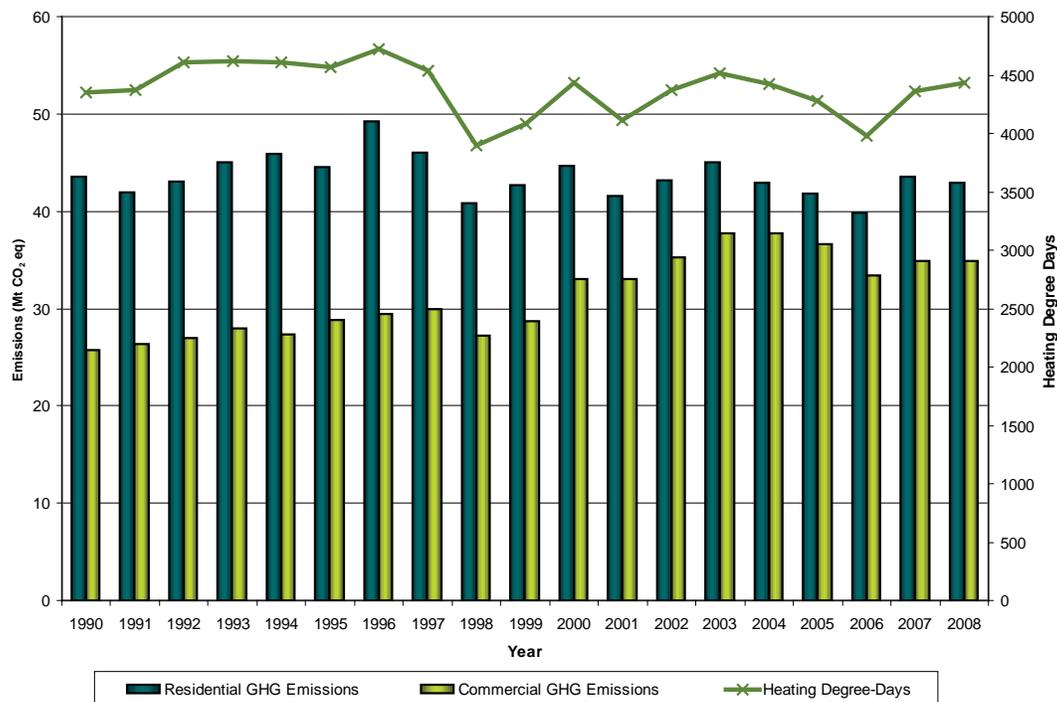
As shown in Figure 2–2, residential emissions fluctuate on an annual basis and, overall, have remained unchanged between 1990 and 2008. Over the short term, emissions decreased by 0.6 Mt from 2007, increased 3.1 Mt from 2006 and 1.1 Mt from 2005. Commercial and Institutional emissions, however, increased 9.2 Mt or 36% between 1990 and 2008 and show a trend similar to that illustrated by the Residential subsector. Combined, the two categories exhibited an overall increase of 8.6 Mt or 12% between 1990 and 2008.

GHG emissions, particularly in the Residential sector, track heating degree-days (HDDs)<sup>7</sup> closely (as shown in Figure 2–2). This close tracking indicates the important influence weather can have on space heating requirements and, therefore, on the demand for natural gas, home heating oil and biomass fuels.

Floor space in both the Residential and Commercial cat-

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

Figure 2–2 GHG Emissions and HDDs from Residential and Commercial Sectors, 1990–2008



egories increased significantly and consistently over the same period. In the Commercial category, there has been a change in the mix of building types, with a reduction in warehouse-type buildings and an increase in office floor space. The increase in office floor space has also led to an increased demand for space cooling and heating and an increase in the number of appliances in homes and auxiliary equipment in offices (NRCAN 2009). This upward trend in floor space and equipment was counteracted by fuel substitution away from petroleum products, improvements in end-use efficiency and improvements in the thermal envelope of houses.

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

### *Agriculture and Forestry*

Stationary fuel combustion related emissions from the Agriculture and Forestry categories amounted to 2.2 Mt in 2008, a decrease of 9% from 1990. Emissions from these categories contributed less than 0.3% of the total for 2008.

#### **2.3.1.2. Fugitive Emissions from Fuels (2008 GHG emissions, 63.8 Mt)**

As stated above, fugitive emissions from fossil fuels are the intentional or unintentional releases of GHGs from the production, processing, transmission, storage and delivery of fossil fuels. Released gases that are combusted before disposal (e.g. flaring of natural gases at oil and gas production and processing facilities) are also considered fugitive emissions. Fugitive emissions have two sources: coal mining and handling, and activities related to the oil and natural gas industry. They constituted 8.7% of Canada's total GHG emissions for 2008 and contributed 15% to the growth in emissions between 1990 and 2008.

Table 2–7 summarizes the changes in fugitive emissions from the Solid Fuels and the Oil and Natural Gas categories. In total, fugitive emissions grew by about 50% between 1990 and 2008, from 42.7 to 63.8 Mt, with emissions from the Oil and Natural Gas category contributing 99% of the total fugitive emissions in 2008, far overshadowing

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

	1990	2004	2005	2006	2007	2008
<b>UPSTREAM PRODUCTION</b>						
Emissions (Mt CO <sub>2</sub> eq) (Total)	39.0	60.7	59.8	61.0	59.7	59.0
Change since 1990 (%)	NA	55	53	56	53	51
Production (PJ)	7 949	12 979	12 937	13 254	13 331	12 916
Change since 1990 (%)	NA	63	63	67	68	62
Intensity (kt CO <sub>2</sub> eq/PJ)	4.91	4.68	4.62	4.60	4.48	4.57
Change since 1990 (%)	NA	-4.8	-5.9	-6.4	-8.8	-6.9
<b>Conventional Oil Production</b>						
Emissions (Mt CO <sub>2</sub> eq)	16.2	24.2	23.2	23.2	22.1	20.8
Change since 1990 (%)	NA	50	43	44	37	29
Production (PJ)	2 978	3 572	3 465	3 441	3 534	3 434
Change since 1990 (%)	NA	20	16	16	19	15
Intensity (kt CO <sub>2</sub> eq/PJ)	5.43	6.77	6.69	6.75	6.27	6.06
Change since 1990 (%)	NA	25	23	24	15	12
<b>Oil Sands Mining, Extraction and Upgrading</b>						
Emissions (Mt CO <sub>2</sub> eq)	2.5	6.3	5.9	6.6	7.1	7.4
Change since 1990 (%)	NA	156	142	171	190	200
Production (PJ)	787	2 288	2 289	2 617	2 804	2 829
Change since 1990 (%)	NA	191	191	233	256	260
Intensity (kt CO <sub>2</sub> eq / PJ)	3.11	2.74	2.59	2.54	2.53	2.60
Change since 1990 (%)	NA	-12	-17	-19	-19%	-16%
<b>Natural Gas Production and Processing</b>						
Emissions (Mt CO <sub>2</sub> eq)	14.2	23.9	24.3	24.6	24.0	24.4
Change since 1990 (%)	NA	68	71	74	69	72
Production (PJ)	4 184	7 118	7 183	7 196	6 994	6 652
Change since 1990 (%)	NA	70	72	72	67	59
Intensity (kt CO <sub>2</sub> eq / PJ)	3.39	3.35	3.38	3.43	3.43	3.66
Change since 1990 (%)	NA	-1.1	-0.3	1.0	1.2	8.1
<b>Oil and Natural Gas Transmission</b>						
Emissions (Mt CO <sub>2</sub> eq)	4.3	5.7	5.7	5.8	5.8	5.8
Change since 1990 (%)	NA	32	32	33	33	33
Pipeline Length (km)	64 222	83 569	83 195	83 814	83 814	83 814
Change since 1990 (%)	NA	30	30	31	31	31
Intensity (kt CO <sub>2</sub> eq / km)	0.067	0.069	0.069	0.069	0.069	0.069
Change since 1990 (%)	NA	1.6	1.6	1.7	1.7	1.7
<b>DOWNSTREAM PRODUCTION</b>						
Emissions (Mt CO <sub>2</sub> eq) (Total)	3.6	4.9	4.8	4.8	5.0	4.8
Change since 1990 (%)	NA	36	34	34	38	33
Production (PJ)	3 907	4 848	4 755	4 710	4 813	4 609
Change since 1990 (%)	NA	24	22	21	23	18
Intensity (kt CO <sub>2</sub> eq / PJ)	0.92	1.01	1.02	1.03	1.04	1.04
Change since 1990 (%)	NA	9.6	10.3	11.1	12.3	12.6
<b>Petroleum Refining</b>						
Emissions (Mt CO <sub>2</sub> eq)	0.9	1.4	1.3	1.3	1.4	1.2
Change since 1990 (%)	NA	64	52	47	65	42
Production (PJ)	3 907	4 848	4 755	4 710	4 813	4 609
Change since 1990 (%)	NA	24	22	21	23	18
Intensity (kt CO <sub>2</sub> eq / PJ)	0.22	0.29	0.27	0.27	0.29	0.26
Change since 1990 (%)	NA	32	25	22	34	20
<b>Natural Gas Distribution</b>						
Emissions (Mt CO <sub>2</sub> eq)	2.8	3.5	3.5	3.6	3.6	3.6
Change since 1990 (%)	NA	27	29	30	30	30
Pipeline Length (km)	168 813	224 223	226 515	228 778	228 778	228 778
Change since 1990 (%)	NA	33	34	36	36	36
Intensity (kt CO <sub>2</sub> eq / km)	0.016	0.016	0.016	0.016	0.016	0.016
Change since 1990 (%)	NA	-4.1	-4.1	-4.1	-4.1%	-4.1%

Notes: NA = Not applicable.

the 1% contribution from Coal Mining. Although fugitive releases from the Solid Fuels category (i.e. coal mining) decreased by 1.2 Mt (61%) between 1990 and 2008 as a result of the closing of many mines in eastern Canada, emissions from oil and natural gas increased 55% during the same period.

This rise in emissions is a result of the increased production of natural gas and heavy oil (including crude bitumen) since 1990, largely for export to the United States. Since 1990, there has been a very large increase in the net energy exported from Canada (refer to section ES.4.1 of the Executive Summary for a discussion of emissions associated with the export of oil and natural gas), accompanied by a 197% increase in GHG emissions associated with those net energy exports.

Although overall fugitive emissions associated with oil and gas production have increased substantially since 1990, the overall emissions intensity (emissions per unit of energy produced) of upstream oil and gas production has decreased by 6.9% (see Table 2-7). This reduction is due to a decrease in oil sands fugitive emissions intensity of 16%, which was somewhat offset by a 12% 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 recovery (EOR) operations.

From 2007 to 2008, the emissions intensity of upstream oil and gas production has increased slightly from 4.48 to 4.57 kt CO<sub>2</sub> eq / PJ (2.0%). During this same time period, the emissions intensity of the oil sands industry has also increased slightly (~2.6%), due to a new upgrader which started operation in 2008. The new upgrader offset the decreases in emissions from the pre-existing oil sands operations that were the result of decreased production.

### 2.3.2. Industrial Processes Sector (2008 GHG emissions, 52.6 Mt)

The Industrial Processes Sector includes GHG emissions that are direct by-products of processes, including Mineral Products, Chemical Industry, Metal Production, Production and Consumption of Halocarbons and SF<sub>6</sub>, and Other and Undifferentiated Production. GHG emissions from the Industrial Processes Sector contributed 52.6 Mt to the 2008 national GHG inventory, compared with 54.8 Mt in 1990. Figure 2-3 illustrates the changes in each of the subsectors over the period 1990–2008, and Table 2-8 provides an emission breakdown by category for selected years.

Figure 2-3 GHG Emissions from Industrial Processes by Category, 1990–2008

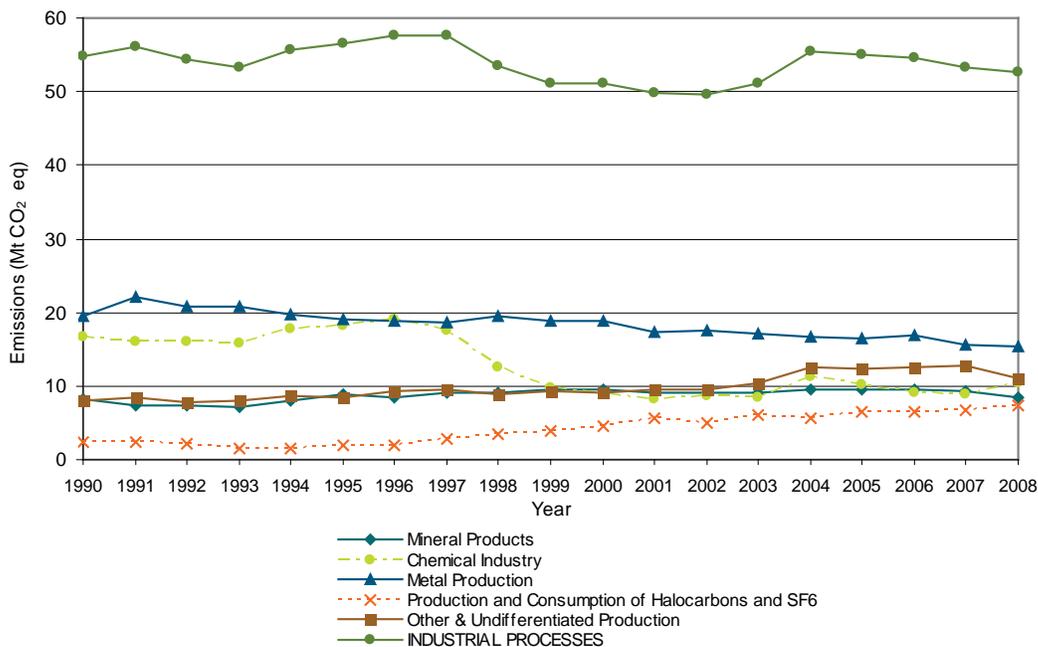


Table 2–8 GHG Emissions from Industrial Processes by Category, Selected Years

GHG Source Category	GHG Emissions (Mt CO <sub>2</sub> eq)				
	1990	2005	2006	2007	2008
Industrial Processes (Total)	54.8	55.1	54.6	53.2	52.6
Mineral Products	8.3	9.5	9.6	9.3	8.5
Cement Production	5.4	7.2	7.3	7.3	6.6
Lime Production	1.8	1.7	1.6	1.6	1.5
Limestone and Dolomite Use	0.73	0.25	0.31	0.16	0.16
Soda Ash Use	0.21	0.16	0.17	0.17	0.14
Magnesite Use	0.147	0.176	0.179	0.067	0.057
Chemical Industry	17	10	9.0	8.9	10
Ammonia Production	5.0	6.3	6.6	6.2	6.7
Nitric Acid Production	1.01	1.25	1.23	1.13	1.23
Adipic Acid Production	11	2.6	1.2	1.5	2.4
Metal Production	19.5	16.5	16.8	15.5	15.3
Iron and Steel Production	7.06	7.02	7.76	7.72	7.44
Aluminium Production	9.3	8.2	7.7	7.3	7.4
Magnesium Production	2.87	1.09	1.20	0.325	0.181
Magnesium Casting	0.236	0.201	0.190	0.198	0.279
Production and Consumption of Halocarbons	0.77	5.2	5.0	5.4	5.5
SF <sub>6</sub> Use in Electric Utilities and Semiconductors	1.5	1.2	1.5	1.3	1.8
Other and Undifferentiated Production	8.0	12	13	13	11

Note: Totals may not add up due to rounding.

Between 1990 and 2008, the overall Sector emissions decreased by approximately 2.2 Mt (4.1%). This change could be explained by significant emission reductions in adipic acid production (N<sub>2</sub>O), aluminium production (PFCs), magnesium production (SF<sub>6</sub>), and mineral product use (CO<sub>2</sub>), which were offset by growths in emissions from consumption of HFCs, other and undifferentiated production (CO<sub>2</sub>)<sup>8</sup>, aluminium production (CO<sub>2</sub>), cement production (CO<sub>2</sub>) and ammonia production (CO<sub>2</sub>).

### 2.3.2.1. Mineral Products

Between 1990 and 2008, the increase in emissions from the category of Cement Production of 22% (1.2 Mt CO<sub>2</sub> eq) could be explained by the growth in clinker production which in turn was associated with the growth in the domestic and foreign demand (mainly American) for clinker and cement. Export of Portland cement has also increased by 52% from 1990 to 2008. However, because of the eco-

nomous downturn and considerable decreases in construction activities in the United States and some provinces in Canada, clinker and cement production dropped by 9.6% and 9.3%, respectively, in 2008 (compared to 2007).

The category of Mineral Product Use (which is made up of uses of limestone and dolomite, soda ash and magnesite) experienced a decrease in emissions of 0.73 Mt CO<sub>2</sub> eq (67%) from 1990 to 2008. Pulp and paper mills, which are consumers of limestone and soda ash, have faced challenges since the mid-1990s. Decline in newsprint demand and foreign competition have caused some plant closures (NRCan 2010). With the decrease in pulp and paper manufacturing came decreases in the use of certain minerals and their resulting emissions. Moreover, limestone and soda ash, along with silica, are raw materials for making glass. The increase in use of recycled glass (cullet) has reduced the need for virgin raw material in the glass batch (NRCan 2007) from which CO<sub>2</sub> emissions could be generated. The closure of Norks Hydro in 2007 accounted for the majority of the decrease in magnesite use and the associated emissions. In 2008, the declines in production for other industry sectors that are users of mineral products

<sup>8</sup> Other and Undifferentiated Production is an emission category composed mainly of petrochemical production that uses hydrocarbons as feedstock. Also, included here is a portion of CO<sub>2</sub> emissions from fuels used as reductants (other than coke) in iron and steel production, and in base-metal smelting.

(e.g. iron and steel production), also indirectly contributed to the decrease of emissions from Mineral Product Use.

### 2.3.2.2. Chemical Industry

Between 1990 and 2008, a significant emission reduction of 8.3 Mt CO<sub>2</sub> eq (78%) was noted in the Adipic Acid Production category. This resulted from the installation of an emission abatement system at Canada's only adipic acid facility in 1997. According to the plant's environmental manager, since the abatement unit had been implemented, emissions were to a large degree dependent on the efficiency of the abatement system and the site's success in maximizing the uptime of the system. The plant has however become indefinitely idled as of the spring of 2009.

### 2.3.2.3. Metal Production

Over the short term (i.e. between 2007 and 2008), emission reductions in the Iron and Steel Production category corresponded to the decreases observed in the national production levels for steel 0.73 Mt (4.7%). In addition to foreign competition, the decrease in steel production was mainly driven by the downturn in the automotive industry, one of the largest consumers of steel. This was reflected in the drop of 29% in the domestic sales of steel products to the sector of motor vehicles and parts (Statistics Canada 2008).

The aluminium industry has succeeded in bringing down its perfluorocarbon (PFC) emissions by 4.3 Mt CO<sub>2</sub> eq (66%), while increasing the production by 100% (1.6 Mt), between 1990 and 2008. The PFC reductions have been achieved through incorporation of computerized sensors and automated alumina feeders, which have helped reduce the occurrence of anode effects. In addition, the provided data showed that the industry continued to increase its production in more modern plants (i.e. with prebaked technology), rather than in older plants (i.e. with Soderberg technology). However, the increase in aluminium production also gave rise to increases in CO<sub>2</sub> emissions of 2.5 Mt CO<sub>2</sub> eq (or 91%), since CO<sub>2</sub> comes from the reduction of alumina with carbon anodes, an essential reaction in the production that cannot be avoided.

Between 1990 and 2005, the category of magnesium production had also shown significant emission diminutions because of progressive replacement of SF<sub>6</sub> with alternatives used as cover gas. For the years 2005–2008, gradual production reductions in anticipation of plant closures in

Norsk Hydro and Timminco brought about considerable decreases in SF<sub>6</sub> emissions. Norsk Hydro was finally shut down in spring of 2007 and Timminco in August 2008.

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

There has been an emission growth of 5.0 Mt CO<sub>2</sub> eq (1000%) for consumption of HFCs since 1995. This could be explained by the fact that more ozone-depleting substances (ODSs) have been replaced by the hydrofluorocarbons (HFCs) within the refrigeration and air conditioning (AC) markets since the Montreal Protocol came into effect in 1996. Although a 1990 value is shown for Production and Consumption of Halocarbons in Table 2–8 this value represents only HFC-23 emissions from the production of HCFC-22, because emissions from the consumption of halocarbons were considered negligible in 1990. The 2005, 2006, 2007 and 2008 values in Table 2–8 account for emissions coming from the consumption of halocarbons (PFCs and HFCs) only, because the last HCFC-22-producing plant was shut down in 1993.

### 2.3.2.5. Other and Undifferentiated Production<sup>9</sup>

The increase in emissions of 3.1 Mt CO<sub>2</sub> eq (39%) as compared to the 1990 level for the category Other and Undifferentiated Production was partly due to the growth in demand of petrochemical products. For example, because of increases in the production of petrochemical products, such as butylene, ethylene and polyethylene, the non-energy use of butane has grown by 220% and that of ethane by 130% since 1990. However, this was only the case until 2007, as high maintenance and feedstock costs as well as increased competition in export markets, and the strength of the Canadian dollar caused production of petrochemicals to drop considerably in 2008 (compared to the 2007 level) (Statistics Canada 1991-2008).

<sup>9</sup> Other and Undifferentiated Production is an emission category composed mainly of petrochemical production activities that use hydrocarbons as feedstock. Also, included here is a portion of CO<sub>2</sub> emissions from fuels used as reductants (other than coke) in base-metal smelting and iron and steel production.

### 2.3.3. Solvent and Other Product Use Sector (2008 GHG emissions, 0.33 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 330 kt CO<sub>2</sub> eq to the 2008 national GHG inventory, compared to 175 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.

### 2.3.4. Agriculture Sector (2008 GHG emissions, 62 Mt)

Canada's Agriculture Sector is composed of approximately 250 000 farms, 98% of which are family-owned. Agricultural emissions accounted for 62 Mt or 8.5% of total 2008 GHG emissions for Canada, an increase of 14 Mt or 29% since 1990. Agriculture accounted for 26% and 71% of the national CH<sub>4</sub> and N<sub>2</sub>O emissions, respectively. All these emissions are from non-energy sources; N<sub>2</sub>O accounts for about 59% of sectoral emissions in 2008 and CH<sub>4</sub> for about 41%.

The processes and activities that produce GHG emissions in the Agriculture Sector are enteric fermentation, which is the process of digestion of ruminant animals; the application of nitrogen fertilizer to agricultural soils; and manure management, storage and application to soils. These

emissions are summarized as coming from either livestock, which includes enteric fermentation (CH<sub>4</sub>) and all manure-related emissions (CH<sub>4</sub> and N<sub>2</sub>O), or crop production, which consists of N<sub>2</sub>O emissions from the application of mineral fertilizers, crop residue decomposition and other management practices (Table 2–9). Emissions from the production of mineral fertilizers and agri-chemicals are also not included in the agricultural section, but are integrated into the Industrial Processes Sector

In 2008, livestock emissions from enteric fermentation are responsible for an average of 56% of animal emissions (22 Mt). Manure management and storage contributed 44% of animal emissions. Emissions of nitrogen oxide (N<sub>2</sub>O) from manure applied to cropland as fertilizer contributed 2.2 Mt. Manure deposited on pastures by grazing animals emitted 3.8 Mt and indirect N<sub>2</sub>O emissions from volatilization of NH<sub>3</sub> and NO<sub>x</sub> and leaching of manure nitrogen contributed an additional 4 Mt.

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.

The significant growth in animal populations largely accounts for the increase from 30 to 40 Mt (30%) in emissions associated with animal production over the 1990–2008 period. Beef production in Canada expanded by 29%, swine by 24% and poultry by 31%.

Specifically, in the period from 1990 to 2008, CH<sub>4</sub> emissions

Table 2–9 GHG Emissions from Agriculture by Production Systems for Selected Years<sup>1</sup>

Production System	GHG Emissions (Mt CO <sub>2</sub> eq)						
	1990	1996	2001	2005	2006	2007	2008
Agriculture (Total)	48	56	58	62	61	61	62
Livestock	30	36	40	42	41	41	40
Dairy Cows	5.2	4.9	4.6	4.5	4.4	4.3	4.5
Beef Cattle	21	27	30	32	31	31	30
Swine	2.4	2.6	3.2	3.5	3.4	3.3	2.9
Other Livestock <sup>2</sup>	1.5	1.7	2.2	2.2	2.2	2.2	2.2
Crop	18	19	18	19	19	21	23
Synthetic Nitrogen Fertilizers	9.2	11	12	11	11	13	13
Crop Residue Decomposition	7.1	6.8	5.6	7.6	7.9	7.6	9.1
Other Management Practices <sup>3</sup>	1.8	1.5	0.86	0.54	0.45	0.35	0.17

<sup>1</sup>Totals may not add up due to rounding.

<sup>2</sup>Other livestock includes sheep, lamb, goat, horse, bison, poultry, llamas and alpacas.

<sup>3</sup>Other management practices includes summer fallow, conservation tillage practices, irrigation and cultivation of organic soils.

from enteric fermentation increased by 29% and emissions from manure management systems by 33%. Furthermore, in the case of beef cattle, herd improvements resulted in an increase in live weight and consequently, an average cow consumes more feed and also emits more GHGs. As a result the relative proportion of greenhouse gases coming from livestock emissions gradually increased through the 1990s from 63 to 67% increasing to a high of 69% during the drought years of 2001 and 2002 (Figure 2-4).

Increases from beef production were partially offset by a 28% reduction of the dairy population. Historically, Ontario and Quebec have been the location of most of Canada's dairy industry. The application of dairy quota systems in these and other provinces has obliged the dairy industry to invest in herd improvement in order to increase industry profitability. As a result, dairy herds have decreased steadily since 1990, resulting in an overall decrease in emissions. Even though the drop in dairy population is driving the emission decline, an average cow produces more milk today than in 1990, consumes more feed and also emits more GHGs.

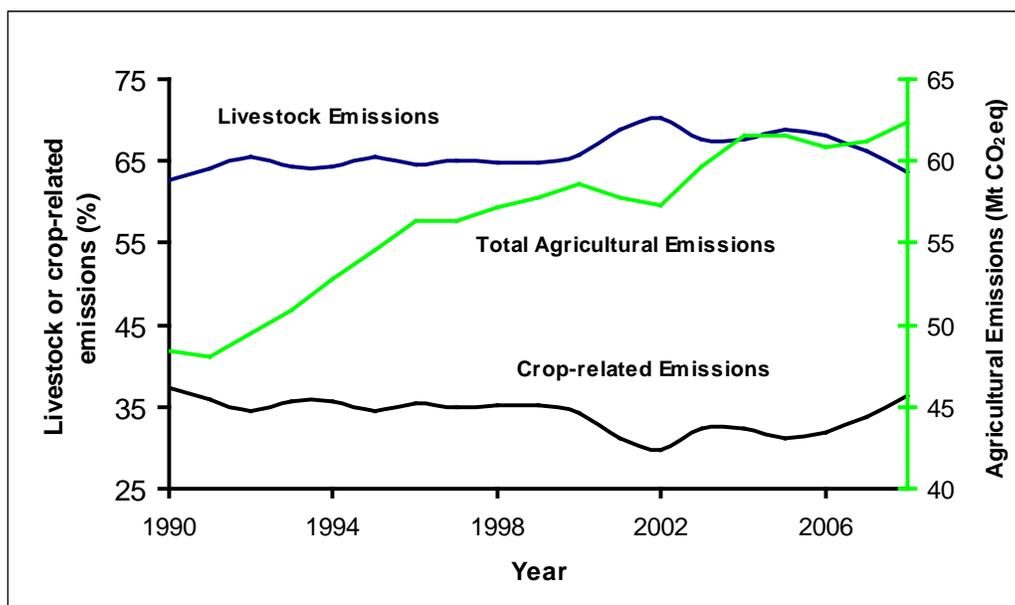
Emissions strictly from crop production are mainly due to either application of synthetic nitrogen fertilizers or crop residue decomposition, which is directly proportional to crop yields. There are about two dozen major crops grown in Canada. Corn, wheat, barley and canola require more fertilizers to sustain high levels of production. Emissions

from synthetic nitrogen fertilizer consumption have increased substantially from 9.2 Mt in 1990 to 13.4 Mt in 2008. The increase in synthetic fertilizer nitrogen use has jumped from 1.2 Mt N to 1.9 Mt N over the same time period due mainly to a reduction in summer fallow and an intensification of cropping systems in western Canada.

Emissions from crop residue decomposition varied greatly from 7.1 Mt in 1990 to 9.1 Mt in 2008, depending on commodity price and weather conditions. For instance, 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 2-4). On the other hand, since 2005 favourable weather conditions along with good commodity price resulted in record production for soybean, corn, pulse and canola and consequently greater emissions of nitrous oxide.

Beef prices continued to be strong until 2003 when the occurrence of bovine spongiform encephalopathy (BSE, or mad cow disease) resulted in a worldwide ban of Canadian beef products. A sudden increase in domestic animal populations occurred (9% increase between January 2003 and January 2004). In September 2003, the United States and other countries agreed to allow imports of Canadian boneless beef from animals younger than 30 months

Figure 2-4 Relative GHG Contribution from Livestock and Crop Production and Total Agricultural Emissions, 1990–2008



under a permit process. Exports of meat began to recover, although populations of older cattle remained high. In July 2005, Canadian live cattle shipments less than 30 months of age were permitted to enter the United States.

Since 2005, emissions from agriculture overall have stabilised and there appears to be some reversal in the trend of the increasing proportion of emissions from livestock production (Figure 2–4). Since the peak of the BSE crisis in 2005, beef populations have decreased by 9%. Furthermore, prices of hogs have been low (Statistics Canada 2009) and populations have also decreased by 16%. These population decreases combined with continued decreasing trends in dairy cattle populations have decreased emissions from livestock by 6%, roughly 2.5 Mt CO<sub>2</sub> eq. At the same time, since 2005, due to improved crop yields and strong grain commodity prices, emissions from crop production have increased by 18% also roughly 2.5 Mt. In 2008, the proportion of emissions coming from livestock production had decreased once again to 63%, the same as in 1990.

Overall, since 2005 decreases in emissions from livestock production have been compensated for by increases in emissions from crop production, resulting in no net changes in agricultural emissions.

### 2.3.5. Land Use, Land-Use Change and Forestry Sector

**(2008 net GHG removals, 13 Mt, not included in national totals)**

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

The net LULUCF flux, calculated as the sum of CO<sub>2</sub> emissions and removals and non-CO<sub>2</sub> emissions, displays high interannual variability over the reporting period. In 2008, this net flux amounted to removals of 13 Mt (Figure 2–5).

All emissions and removals in the LULUCF Sector are excluded from the national totals. In 2008, the estimated 13 Mt would, if included, have decreased the total Canadian GHG emissions by about 2%.

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

The Forest Land category includes GHG emissions from and removals by Canada's managed forests. Managed forests display the highest interannual variability of all categories and exert an overriding influence on the net sectoral GHG balance and trend. The net GHG flux reflects

Figure 2–5 GHG Emissions from LULUCF Relative to Total Canadian Emissions, 1990–2008

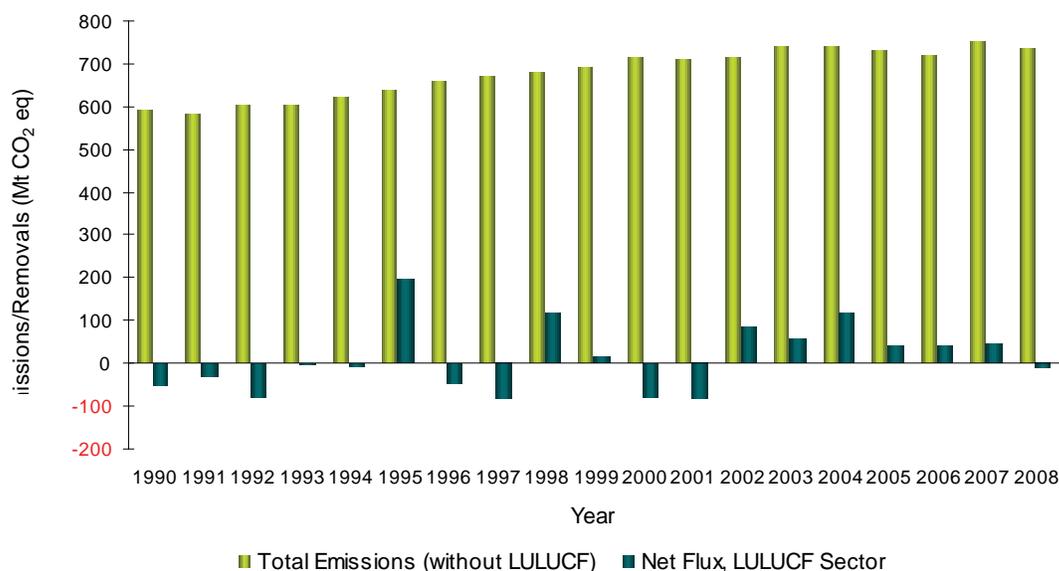
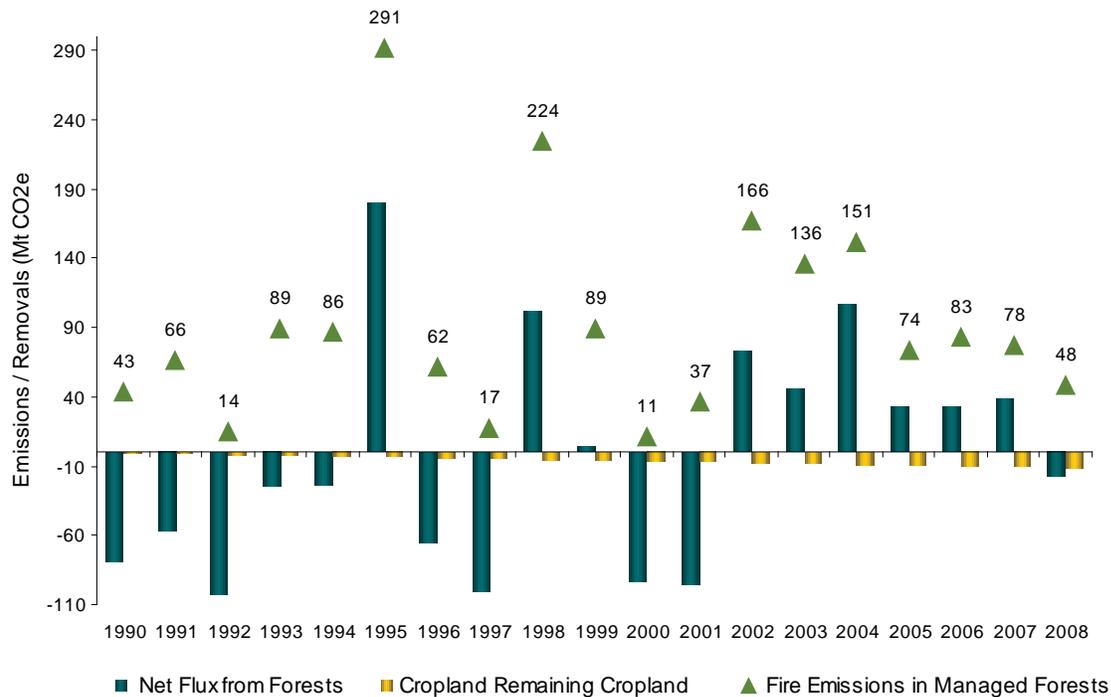


Figure 2-6 Selected GHG Emissions and Removals in LULUCF, 1990–2008



the difference between carbon uptake by tree growth and emissions due to anthropogenic and natural disturbances, specifically forest management activities, wildfires and insect infestations. The high variability in the net flux from managed forests is associated with the immediate impact of wildfires, which alone accounted for annual emissions of between 11 and 291 Mt over the period from 1990 to 2008 (Figure 2-6). Both short- and long-term trends should therefore be interpreted with caution, given that the sector as a whole retains the important interannual variability resulting from large fluctuations in the severity of the fire season, with an additional random effect due to the location of fires with respect to managed forests (as opposed to non-managed). The largest carbon fluxes to and from managed forests consist of carbon uptake by growing trees and its release due to the decay of organic matter (2930 and 2114 Mt in 2008, respectively). Over the last 10 years, forest management activities, namely harvesting, account for annual average emissions of 181 Mt, a 18% increase since 1990 levels. The years 2006 to 2008 have witnessed a consistent decline in harvest levels, reflected in a decreasing trend in the corresponding emissions; harvesting emissions in 2008 alone (136 Mt) dropped 22% from their 2007 levels, reaching their lowest levels in the entire 1990–2008 period.

Note that the current default approach ignores long-term carbon storage in wood products. Taking into account this storage, emission estimates from harvesting in the year 2008 alone could be reduced by 11 to 57 Mt, depending on the approach used to monitor the fate of this carbon.

The Cropland subcategory includes the effect of agricultural practices on CO<sub>2</sub> emissions from, and removals by, arable soils and the short- as well as immediate and long-term impacts of forest and grassland conversion to cropland. In 2008, the net GHG balance of the Cropland category amounted to net removals of 4.4 Mt. The continued adoption of no-till (NT) and reduced tillage (RT) practices and the reduction of summer fallow have resulted in a steady trend of increasing removals in cultivated soils, which, in 2008, more than offset the emissions due to land conversion to agriculture.

The management of mineral soils amounted to net CO<sub>2</sub> removals of about 2 Mt in 1990. This net sink steadily increased to about 14 Mt in 2008, reflecting continuous efforts in reducing summer fallow and increasing conservation tillage. The area of summer fallow declined by more than 61% over the 1990–2008 period, resulting in a net sink that increased from 3.1 Mt in 1990 to 6.6 Mt in 2008. The increase in net sink due to the adoption of conserva-

tion tillage practices from 1.4 Mt in 1990 to 5.7 Mt in 2008 is substantiated by a net total increase of over 11 Mha under NT and RT. The net increase in areas with perennial crops has also had a modest impact on soil C sequestration since 1990 (-4.1 Mt).

CO<sub>2</sub> emissions from peatlands managed for peat extraction and from land flooding are reported under the Wetlands category. Emissions from managed peatlands have increased 46% since 1990, amounting to 1.2 Mt in 2008. Land conversion to flooded lands (reservoirs) accounted for 4 Mt in 1990, decreasing to 1.3 Mt in 2008. Note that reservoirs flooded for more than 10 years are excluded from the accounting (IPCC 2003).

Estimates reported under the Settlements subcategory (7 Mt in 2008) represent primarily the effect of the conversion of forest and other vegetated lands to built-up lands, including urban and recreation, transport infrastructure and resource extraction. The contribution of urban forests is minimal.

Forest losses to cropland, wetlands and settlements amounted to emissions of about 19 Mt in 2008, down from 27 Mt in 1990. This reduction is accounted for by declines of 5 Mt in emissions from forests converted to cropland, 2 Mt in emissions from forests converted to settlements, and nearly 1 Mt in emissions from forest converted to wetlands. The reader is referred to additional information in Chapter 7 and Section A3.4 of the present report.

### 2.3.6. Waste Sector (2008 GHG emissions, 22 Mt)

From 1990 to 2008, GHG emissions from the Waste Sector increased 15%, which is less than the population growth of 20%, while over the same period total national GHG emissions grew by 24%. In 2008, these emissions represented 2.9% of the total national GHG emissions, compared with

a 3.2% contribution in 1990. Of the 22 Mt total emissions from this sector in 2008, solid waste disposal on land, which includes municipal solid waste (MSW) landfills and wood waste landfills, accounted for 20 Mt. CH<sub>4</sub> emissions produced by the decomposition of biomass in MSW landfills were responsible for 83% of the emissions from this Sector. Emissions from municipal wastewater treatment and incineration of waste (excluding emissions from incineration of biomass material) contributed 0.94 Mt and 0.25 Mt, respectively, to the total from the Waste Sector (Table 2–10). Figure 2–7 presents the emission trends for each of the three subsectors compared with the total emissions for the Waste Sector between 1990 and 2008. The tables in Annex 12 summarize this information nationally by CO<sub>2</sub> equivalent and by category (i.e. individual gas and source).

CH<sub>4</sub> emissions from MSW landfills increased by 18% between 1990 and 2008, despite an increase in landfill gas capture and combustion of 71% over the same period. However, it must be noted that the 2007 gas capture data were assumed for the 2008 data year since the data collection is held biennially. Therefore the expected CH<sub>4</sub> emissions could be slightly less if the general increasing trend for landfill gas collection holds constant. This will be confirmed when the landfill gas collection data are revised for the next NIR submission. Approximately 330 kt of CH<sub>4</sub> (or 6 930 kt CO<sub>2</sub> eq) were captured by the 64 landfill gas collection systems operating in Canada (Environment Canada 2009).<sup>10</sup> Of the total amount of CH<sub>4</sub> collected in 2007, 50% (165 kt) was utilized for various energy purposes and the remainder was flared. Based on the information available for 2007, of these 64 sites, 14 sites utilized the

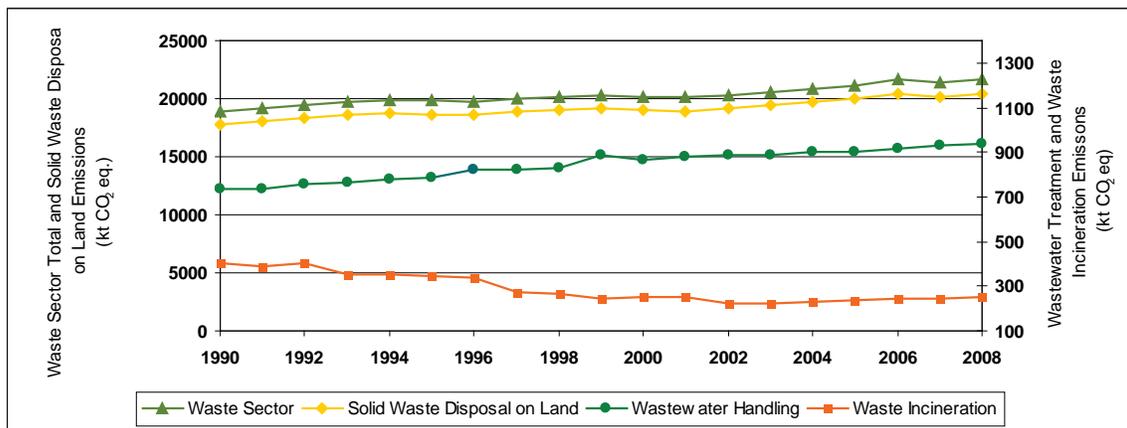
<sup>10</sup> Four landfill gas capture facilities did not provide data for the 2007 landfill gas inventory by December 31, 2008. Thus, for the purposes of the 1990–2007 NIR, these facilities were included in the total number of active facilities collecting landfill gas. Since two of these facilities had provided data for the 2005 landfill gas inventory, it was assumed that the quantities of landfill gas collected were constant for 2005, 2006 and 2007. The other two sites were new installations where gas collection systems were being constructed and for which no landfill gas collection quantity information was available.

Table 2–10 GHG Emissions from Waste, Selected Years

GHG Source Category	GHG Emissions (Mt CO <sub>2</sub> eq)				
	1990	2005	2006	2007	2008
Waste Sector (Total)	19	21	2	21	22
a. Solid Waste Disposal on Land	18	20	20	20	20
b. Wastewater Handling	0.74	0.90	0.91	0.93	0.94
c. Waste Incineration	0.40	0.24	0.24	0.25	0.25

Note: Totals may not add up due to rounding.

Figure 2-7 GHG Emissions from Waste, 1990–2008



captured CH<sub>4</sub>, 36 sites flared the captured CH<sub>4</sub> and 14 sites both utilized and flared the captured CH<sub>4</sub>.

GHG emissions from landfills were estimated for two solid waste types: MSW and wood waste landfills, both of which produce CH<sub>4</sub> anaerobically.<sup>11</sup> The CH<sub>4</sub> production rate at a landfill is a function of several factors, including the mass and composition of biomass being landfilled, the landfill temperature, and the moisture entering the site from rainfall.

CH<sub>4</sub> capture and waste diversion programs at landfills have made significant contributions to reductions in emissions during this period. The quantity of CH<sub>4</sub> captured at MSW landfills for flaring or combustion for energy recovery purposes in 2008 amounted to 28% of the total generated emissions from this source, as compared to 21% in 1990. Per capita emissions from the Waste Sector decreased by 4.6% from 1990 to 2008, owing primarily to the increasing quantities of CH<sub>4</sub> captured at landfill sites (Figure 2-8). The amount of CH<sub>4</sub> captured increased by 71% from 1990 to 2008 and the amount of waste diverted as a percentage of the waste generated has fluctuated from 21% to 25% over the period between 1998 and 2006 (Statistics Canada 2000, 2003, 2004, 2007, 2008). Although the quantity of waste placed in MSW landfills increased by 30% from 1990 to 2008, the landfilled quantity per capita increased by

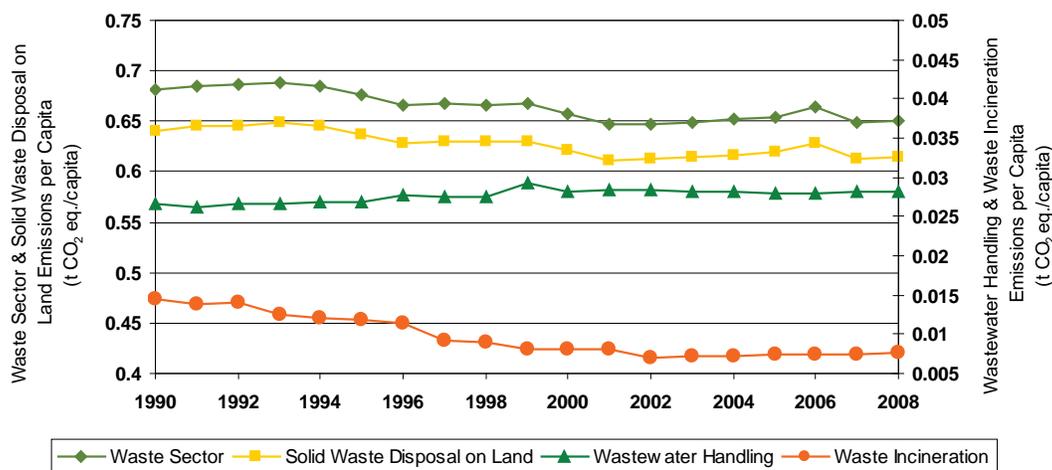
only 8.3%. The amount of waste exported from Canada to the United States for the years 1998 and 2006 were 560 kt and 3660 kt, respectively, giving a 553% increase in the amount of waste exported over this period. However, emissions from MSW landfills are expected to increase in subsequent years as a result of restrictions on the exportation of solid waste from Ontario. An agreement was signed between the state of Michigan and the province of Ontario that calls for a 20% reduction in municipally managed exported waste by the end of 2007, 40% by the end of 2008 and 100% by the end of 2010 (Ontario Ministry of the Environment 2006). This is all based on an estimated figure of 1.34 million tonnes of municipally managed wastes reported for 2005.<sup>12</sup> Municipally managed wastes do not include institutional, commercial or industrial wastes.

From 1990 to 2008, the population growth trend (20%) exceeded that of the sector emissions (15%). The decline in the growth of emissions per capita observed in the mid-1990s, shown in Figure 2-8, is directly attributable to landfill CH<sub>4</sub> capture and waste diversion programs. However, from 1997 to 1999, there was a reduction followed by an increase in the quantities of landfill gas captured. These changes have an inversely proportional influence on the emissions per capita, which is apparent in Figure 2-8. The 2006–2007 drop in emissions from Solid Waste Disposal on Land may be more attributable to the extrapolation method used to derive the waste quantities landfilled for those years rather than a true reflection of the situation. A more accurate determination will be made for 2007 and 2008 in the subsequent NIR submission, when the results

11 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.

12 . Personal communication between Jim Hiraish, Ontario Ministry of the Environment and Craig Palmer, Environment Canada, Nov. 30, 2007.

Figure 2–8 Per Capita GHG Emission Trend for Waste, 1990–2007



from the next biennial MSW waste quantity landfilled data collection survey will be available for the 2009 data year.

In terms of trends in emissions per capita, GHG emissions from wastewater handling remained fairly constant, whereas waste incineration showed a significant decrease in GHG emissions over the 1990–2008 time series (Figure 2–8). Total incineration emissions per capita decreased by 48% over the time series, with the greatest decline in emissions per capita for incineration occurring between 1992 and 1997, due mainly to the closure of aging incinerators.

## 2.4. Emission Trends for Ozone and Aerosol Precursors

Emissions of ozone and aerosol precursors fell over the 1990–2008 period. Sulphur oxides (SO<sub>x</sub>) decreased by 46%, non-methane volatile organic compound (NMVOC) emissions declined 24%, nitrogen oxides (NO<sub>x</sub>) emissions were down by 16%, and carbon monoxide emissions fell by 41%. (See Annex 10 for data tables).

# B Trends By Economic Sector

## Introduction

In 2008, although Canada's Greenhouse Gas (GHG) emissions amounted to 734 Mt CO<sub>2</sub> eq, which is 24% over 1990 levels and 31% above its Kyoto target, the trend since 2004 was one of slight decline: 2008 emissions were 0.9% below 2004 levels. At the same time, Canada's economic GHG intensity—the amount of GHGs emitted per unit of economic activity—was 9% lower in 2008 than in 2004.

After 2004, GHG emission trends first showed a decrease that continued to 2006, followed by rapid rise in 2007 and then another decrease in 2008. The net result was a decrease of a little over 6 Mt between 2004 and 2008. Though there were some significant increases in certain areas (notably road transportation and, to a smaller extent, the fossil fuel industries), these were more than offset by a large decline in emissions from heavy industry and manufacturing and a reduction in emissions from the electricity sector. The drop in emissions from electricity between 2004 and 2008 is a reversal from the long-term trend.

### Economic Sector Breakdown

This section organizes the discussion of trends around more commonly used economic sectors in order to allow a correspondence with normal economic analyses and a breakdown that is more familiar to most people. This organization is not the same as the standard breakdown for national inventories according to the six UNFCCC sectors. Though there is a fair degree of overlap, there are also a number of differences. For a summary of the differences and complete mapping of emissions from one breakdown to the other, see Ancillary 3, at the end of Chapter 2B.

## B1 Emissions by sector

In order to gain a better understanding of the trend in Canada's overall GHG emissions, GHG emission trends need to be evaluated more closely by economic sector. The sectors considered here are the fossil fuel industries (which include both "upstream" (fossil fuel producers) and "downstream" (refiners and distributors of these fuels); electricity

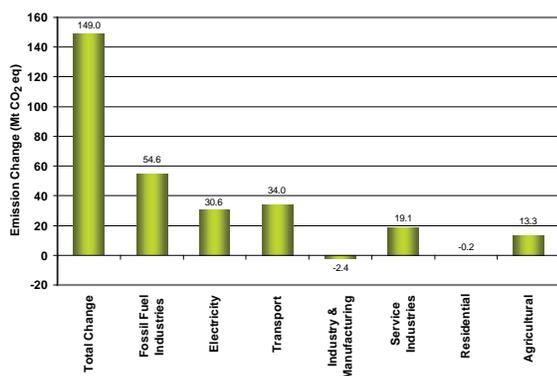
Table 2-11 Summary of emissions and economic activity by sector, 1990 and 2008

Economic Sector	GHG Emissions (Mt CO <sub>2</sub> eq)					GDP (billions) (constant 2002 dollars)				Economic emission intensity (kg GHG/\$ GDP)		
	1990	2008	Change (Mt)	Change (%)	Proportion of total change (%)	1990	2008	Chg (%)	Proportion of total change (%)	1990	2008	Change (%)
Fossil fuel industries	103	160	57	55%	40%	30.4	47.5	56%	3%	3.40	3.40	-1
Electric utilities	97	121	24	24%	17%	23.4	27.6	18%	1%	4.15	4.38	5
Transportation <sup>1</sup>	121	162	40	33%	28%							
Heavy Industry and Manufacturing (includes construction)	123	110	-13	-10%	-9%	201	277	38%	15%	0.61	0.40	-35
Service industries	40	59	19	47%	13%	546	940	72%	79%	0.10	0.10	-14
Residential <sup>2</sup>	52	52	0	1%	0%							
Agriculture	56	71	15	27%	11%	24.5	27.3	12%	1%	2.28	2.60	14
Total	592	734	142.6	24%	100%	825	1 321	60%	100%	0.72	0.56	-22

Notes:

1. Informetrica Inc., Industrial Sector Real Gross Domestic Product (GDP) by North American Industry Classification (NAIC) December 2009. Statistics Canada, CANSIM table 384-0002 - Gross domestic product (GDP) expenditure-based, provincial economic accounts, annual (dollars x 1,000,000)
2. No GDP has been attributed to the residential or transportation sectors. GDP for the entire economy is inclusive of every economic sector, including revenue-generating transport and waste. Therefore, numbers provided in this table will not add exactly to the totals given.

Figure 2–9 Changes in GHG emission levels between 1990 and 2004

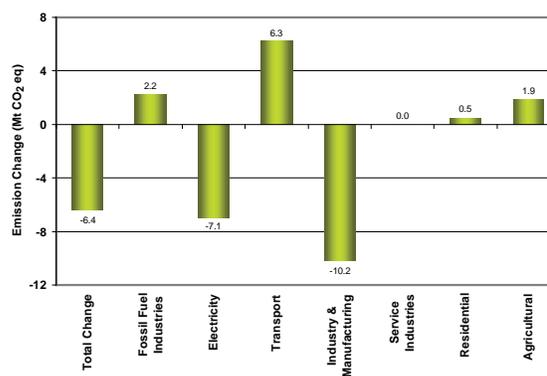


generation (which includes all public utilities as well as electricity generated by private industry); transportation (which includes both passenger and freight transport activity); heavy industry and manufacturing; the service industries (e.g. financial services, hospitality, health, education, etc); the residential sector; and agriculture. Land use, land-use change, and forestry (LULUCF) is also discussed; however, it should be noted that GHG emissions from this sector are not currently included in the national totals.

Table 2–11 provides an overview of changes to these sectors (except LULUCF) from 1990 to 2008 for GHG emissions, GDP and economic emissions intensity. A detailed table of GHG emissions delineating trends by sector and subsector has been included at the end of the chapter (Table 2–16 in Ancillary 1) for 1990, 2000 and 2004 to 2008.

The increase in emissions from the fossil fuel industries has contributed to approximately 40% of Canada's total GHG emission increase, yet this sector only contributed to 3% of the increase in domestic GDP. Similarly disproportionate increases in GHG emissions occurred for electricity generation relative to its contribution to economic growth, with this sector contributing 17% of the increase in domestic GHG emissions since 1990, but only 1% of the growth in GDP. This underscores the importance of the energy production sector to Canada's GHG emission levels. Conversely, the service industries have contributed to 79% of Canada's growth in economic output. The much lower emission intensity of these industries (see the rightmost columns of the table) has meant that they contributed much less to the rise in domestic GHG emissions, about 19 Mt CO<sub>2</sub> eq, or 13% of Canada's total. Meanwhile, improvements in production processes in heavy industry and

Figure 2–10 Changes in GHG emission levels between 2004 and 2008



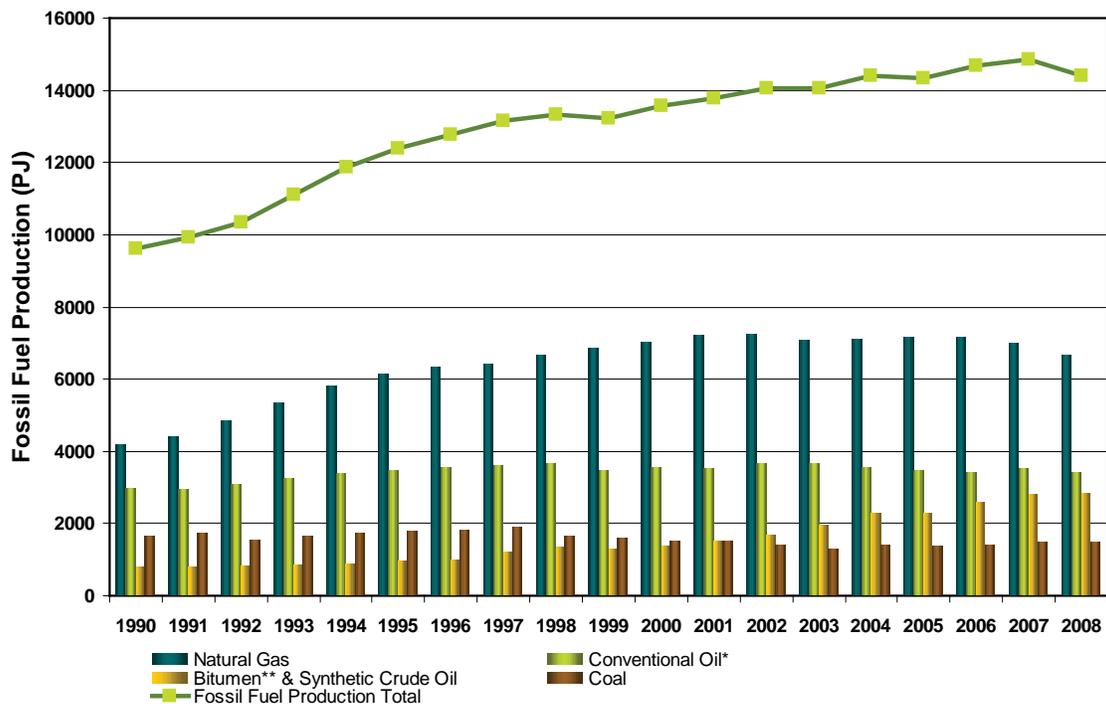
manufacturing, and energy efficiency in the residential sector meant that GHG emissions from these sectors decreased between 1990 and 2008.

In consideration of the divergence in the change in Canada's GHG emissions between 2004 and 2008 and the trend that occurred in years previous, it is appropriate to divide the whole 1990–2008 period into two intervals. Figure 2–9 and Figure 2–10 compare changes in GHG emissions by sector for the periods from 1990 to 2004, and 2004 to 2008.

As illustrated, the period from 1990 to 2004 saw a significant increase in GHG emission levels. In fact, by 2004, GHG emissions were nearly 150 Mt above 1990 levels. However, between 2004 and 2008 GHG emissions decreased by approximately 6.4 Mt.

The graphs clearly demonstrate the considerable changes in sectors affecting the trends. Between 1990 and 2004, the energy-producing industries drove the growth in GHG emissions. From 2004 to 2008, the decline was driven by industry, manufacturing and electricity production. Passenger and freight transportation have consistently contributed to increases in Canada's total GHG emissions, and this has not changed in the inventory over the last five years, where these contributed a GHG emission increase of 6.3 Mt.

Figure 2-11 Canadian production of fossil fuels 1990 to 2008



Notes:

\* Conventional oil includes light, medium and heavy oil production and pentanes plus and condensate

\*\* Bitumen from oilsands operations

## 2.5. Fossil fuel industries

Emissions from the production, transmission and processing of fossil fuels equaled 160 Mt CO<sub>2</sub> eq in 2008, a 55% increase from 1990. In 2008, approximately 87% of the fossil fuel industry's total emissions can be attributed to the upstream fossil fuel industry which includes crude oil production (both conventional,<sup>13</sup> as well as bitumen and synthetic crude oil from oil sands operations), natural gas production and processing, oil and gas transmission and coal mining. The downstream portion includes the refining of crude oil into petroleum products for sale and the distribution of natural gas (via low-pressure pipelines) to industrial, commercial and residential users. Emissions are released during both of these activities, contributing about 13% of the sector's total emissions. The primary drivers on emissions within the fossil fuels industry are production growth and production characteristics (emissions intensity).

### 2.5.1. Production Growth

Production rates of fossil fuels are greatly influenced by both the export and domestic market demands (in 1990 and 2008, net exports<sup>14</sup> of crude oil and natural gas equaled 23 and 43% of total production, respectively). Figure 2-11 illustrates the production of fossil fuels in Canada from 1990 to 2008. During that period, production of crude oil and natural gas increased by 66% and 59% respectively. Conventional crude oil production increased by 15% although, since 1998 production has started to decline (Statistics Canada 2009e). In contrast, bitumen and synthetic crude oil production from Canada's oil sands has increased by 260%, with most of the growth occurring from 1996 onward. (CAPP 2009a).

Natural gas production increased rapidly from 1990 to peak production levels in 2002, a 73% increase over 1990 levels. However, from 2002 onwards production decreased

13 In this discussion, "conventional" oil production includes light, medium and heavy oil as well as pentanes plus and condensate.

14 Although Canada exports significant volumes of oil and natural gas (mainly to the United States), it is also an importer of both crude oil and of refined oil products. This partially reflects historical events that helped ensure significant imports into Montréal and points east of the Ottawa Valley. Nonetheless, as a percentage of total production, the net export of crude oil is increasing.

due to declines in output from the Alberta portion of the Western Sedimentary Basin, the largest gas-producing area in Canada (Nyboer and Tu 2010). Although natural gas production started to decline after 2002, oil production continued to grow rapidly. By 2007, the total production of crude oil and natural gas showed a 68% increase over 1990 levels. Elevated demand, particularly in the United States, drove these trends, with the export market growing by far the most rapidly (exports were up by 153%) (Statistics Canada 2009e). Moreover, new infrastructure requirements, such as natural gas pipelines, have in turn contributed to additional emissions.

Although between 1990 and 2002 GHG emissions from the fossil fuel industries grew by 53%, emissions rose only 1.7 Mt (or 1.1%) between 2002 and 2008. During this recent period, natural gas production decreased by approximately 8.2%, while crude oil production showed an overall growth of about 17%. This growth, which was accompanied by a 156% rise in the price of crude oil,<sup>15</sup> was almost wholly in the export market. While crude oil exports increased by 23%, domestic crude consumption rose by only 0.9%. This negligible change in domestic oil consumption affected not only GHG emissions from the fossil fuel industry, but had a significant impact on the associated emissions of other sectors.

### 2.5.2. 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 high-energy- and GHG-intensive sources, including synthetic 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. Between 1990 and 2000, the energy requirements per barrel of conventional light and medium oil extracted rose by about 60% (Nyboer and Tu 2010). The emission intensity of the average barrel of oil produced in Canada increased by about 6.5% between 1990 and 2008 (Figure 2–12). When natural gas is included, emission intensities for overall upstream oil and gas production industries (not including transmission) increased by 9.5% in the same period.

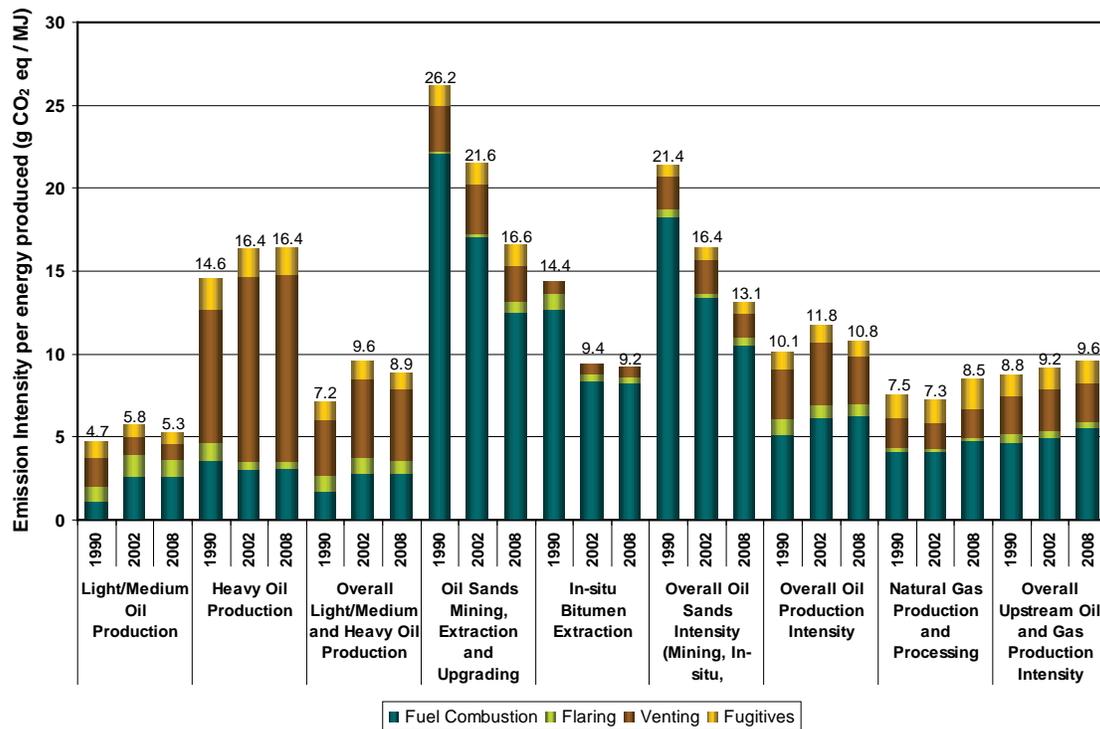
<sup>15</sup> Prices (Canadian dollars) rose from an average of about \$40 a barrel in 2002 to \$102 in 2008 (CAPP 2009b)

Highlights related to the emissions intensity of fossil fuel industries:

- Overall emission intensity from producing oil from oil sands operations declined by 39% between 1990 and 2008. This reduction is due to decreases in emission intensity from both *in-situ* bitumen production and oil sands mining, extraction and upgrading which experienced decreases of 37% and 36%, respectively. The most significant factor contributing to this overall trend has been declining rates of emissions associated with fuel combustion. For each barrel of oil produced from the oil sands, emissions associated with fuel combustion declined by over 42%.
- The 17% increase in the production of oil between 2002 and 2008 was completely driven by oil sands operations, which showed a 67% growth in output while conventional oil production decreased by about 6.2%. Coinciding with the net production increases, emissions from all oil production showed an increase of about 7.3% (4.6 Mt CO<sub>2</sub> eq). In spite of the emissions increase, the emission intensity for overall oil production decreased by 8.2% due to the efficiency gains in oil sands production.
- In particular, *in-situ* bitumen production (where the sand is separated from the bitumen underground while it is being extracted) has recently become responsible for an increasingly large share of oil sands production and in this area a number of technological improvements have been made from cyclic steam stimulation (CSS) to steam-assisted gravity drainage (SAGD) and vapour extraction (VAPEX) where any of these methods can be employed to optimize the bitumen extraction process while reducing energy demand. In addition to selectively choosing the more efficient *in-situ* recovery methods, oil sands producers have been making improvements in the energy efficiency of the bitumen upgrading stage (where the extracted material is converted into synthetic oil).<sup>16</sup>
- Increasingly, bitumen from the oil sands is being shipped to the United States where a much greater upgrading and refining capacity exists for heavier grades of oil (NEB 2006). This is supported by Statistics Canada data, which shows the ratio of bitumen to synthetic crude oil production in Canada rising by 93% between 2002 and 2008 (CAPP 2009a). As a result of this growing quantity of bitumen in the production mix, it appears that emissions associated with the upgrading and refining of bitumen were increasingly avoided in Canada,

<sup>16</sup> Upgrading requires significant amounts of natural gas and process gases in order to provide process fuel, produce electricity and generate hydrogen. Energy efficiencies have been gained in the upgrading process over the last number of years through improvements in technology and changes in processes. In particular, integrated mining, extraction and upgrading projects have been developed that reduce energy requirements per barrel of oil when compared to stand-alone upgraders, while gasification has also been used to develop appropriate fuels needed in the upgrading process.

Figure 2–12 Emission intensity by source type for fossil fuel production (1990, 2002 and 2008)



## Notes:

Intensities are based on total subsector emissions and energy use reported by Statistics Canada. They represent overall averages, not facility intensities.

which also contributed to reductions in overall oil production intensity.

- Though gas production has declined somewhat since its peak in 2002, in 2008 the natural gas production and processing sector contributed 35% to the fossil fuel industries emissions total. Since 1990, emissions have increased 79% with a corresponding increase of 59% in natural gas production. The amount of energy required to extract and process the natural gas also increased by 18% as reflected in the increasing emission intensities.
- Combustion emissions related to petroleum refining and upgrading (a combination of downstream and upstream activities) fell by 2.1 Mt (17%). This was accompanied by a 6.0% reduction in the amount of crude oil refined in Canada. Fuel switching at refineries and upgraders, from petroleum coke to less carbon-intensive natural gas was the largest cause of GHG reductions.

## 2.6. Electricity generation

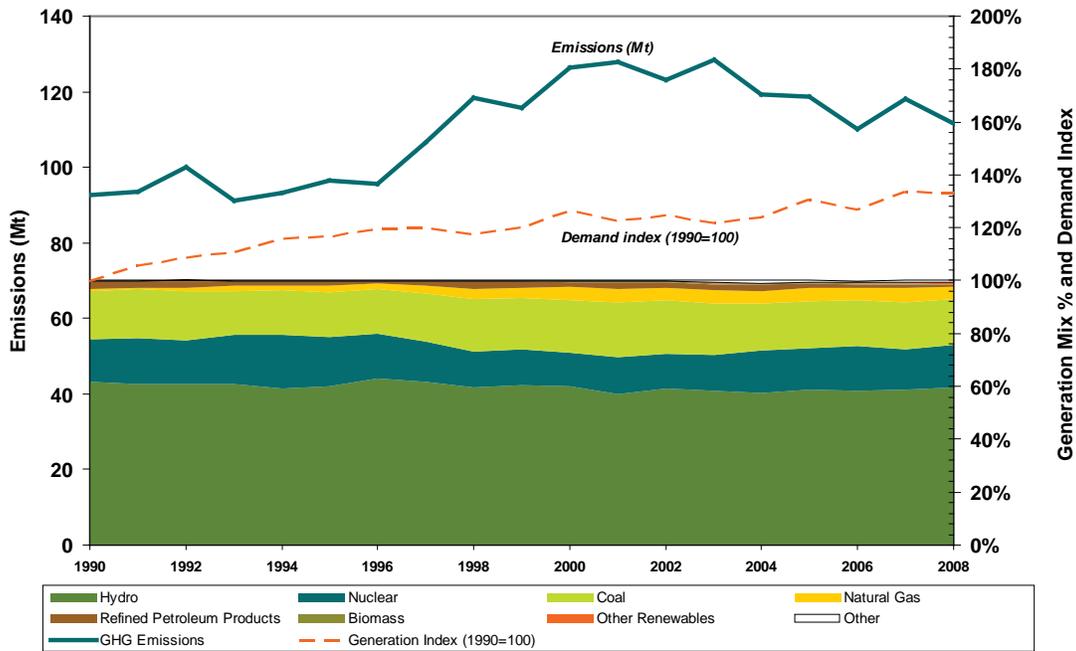
By 2008, emissions from electricity generation and distribution had grown by 24 Mt from the 97.0 Mt emitted in 1990, an increase of 24%. A 27% rise in electricity demand

has played a key role in emission growth due to increasing use of electrically driven manufacturing processes, the rapid penetration of computers, increasing use of electronic equipment and a continued influx of electronic consumer goods (Statistics Canada 2009c, NRCan 2009). Meanwhile, exports of electricity to the United States (mainly from Quebec and Manitoba) have also risen significantly (Statistics Canada 2009c). The increase in domestic demand in conjunction with increasing exports has meant that the amount of electricity generated in Canada has increased by 29% from 1990 to 2008.<sup>17</sup>

Emissions, however, have not always followed the trend in electricity generation. During the early 1990s, even with rising demand, emissions from electricity generation oscillated above and below 1990 levels; then, from 1994 to 2000, emissions rose 37%, though generation increased by only about 5%. After a brief pause, emissions peaked in 2003, following which they decreased by 12% over the

<sup>17</sup> Although a number of provinces import some electricity from the United States, net imports only represent about 5% of the total amount of electricity generated in any given year. In all years since 1990, exports have been larger than imports, almost always by a considerable margin.

Figure 2–13 Utility generated electricity by source and GHG emissions, 1990–2008



Notes:

1. Generation statistics refer to utility based generation only but contribute over 90% of the total supply.
2. Electricity emission include both utility and industrial generation but do not include emissions associated with transmission.

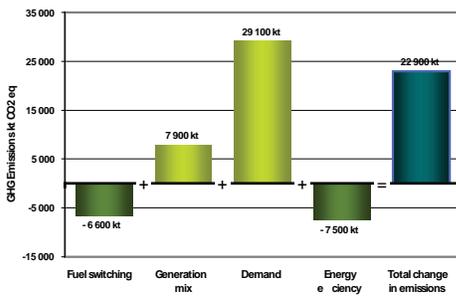
next 5 years—even though generation rose by almost 7%.

Figure 2–13 illustrates the different sources and changes over time of electricity generation between 1990 and 2008.

In terms of electricity supply, the most significant driver relates to changes in the availability of energy sources that

can be used to generate electricity. In 2008, approximately 60% of the electricity generated in Canada was from hydro (down from 62% in 1990), while 16% was generated from nuclear fuel (15% in 1990), 23% was from fossil fuels (about the same as in 1990), and the remainder was generated from renewables such as wind and biomass. Since only fossil-fuel-generated electricity results in direct GHG emis-

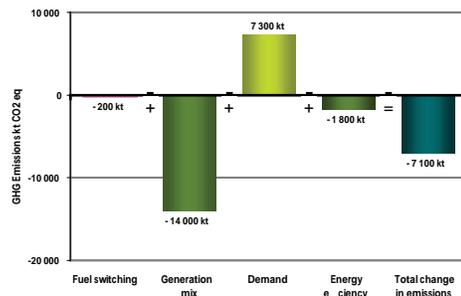
Figure 2–14 Impact of factors on change in electricity emissions, 1990–2008



Notes:

1. Fuel switching, generation mix, demand and efficiency effects illustrate how these drivers have contributed to changes in emissions relative to a base year.
2. Emissions shown in the graph include those from electricity generation, but exclude SF6 emissions from power transmission and distribution.

Figure 2–15 Impact of factors on change in electricity emissions, 2004–2008



sions, switching to this as an energy source for electricity generation will increase emissions, while the opposite holds true if other sources increase in proportion. Similarly, changes in the type of fuel being consumed (e.g. natural gas versus coal-fired generation) can increase or decrease emissions.

The impacts of these different drivers on electricity-related emissions in 2008 (compared to 1990 and 2004 base years) are shown in Figure 2–2 and Figure 2–3.

The trends illustrated by Figure 2–2 and Figure 2–3 can be summarized as follows:

- **Fuel switching (combustion generation)** – between 1990 and 2008 the amount of electricity generated by natural-gas-fired units increased by almost 600% while the amount generated by refined petroleum products (RPPs) decreased by over 60%. The switch from higher GHG intense RPP fuels to natural gas has had the effect of lowering GHG emissions in 2008 as compared to 1990. Over the short term, the amount of fuel switching was less pronounced.
- **Generation mix** – the generation mix refers to the shift between combustion and non-combustion (zero-GHG) sources to meet demand. Although hydro, nuclear and renewable generation increased over time, the proportion of electricity provided by combustion sources also increased compared to 1990. The increased level of non-combustion sources in 2008 is the biggest contributor to lower emissions compared to 2004.
- **Demand** – the amount of electricity generated in 2008 was 33% higher than in 1990. This increase in demand by both the industrial and residential/commercial sectors is the main driver behind the overall net increased in emissions. Continued increases in demand since 2004, especially in Alberta drive the trend towards greater emissions.
- **Energy efficiency** – improvements in energy efficiency, meaning the amount of energy required to generate electricity, helped reduce emissions compared to 1990 and 2004.

The main factor that explains the divergence between electricity demand and emissions from electricity generation is the generation source mix. In particular, in the mid-1990s, increased fossil fuel generation (mainly from coal plants) was used to support the growing demand for electricity, while nuclear and hydro-powered generation lagged. This consequently led to disproportionately higher increases in emissions relative to the early 1990s, when more nuclear generation capacity was available in Ontario. Since around 2003, although coal continued to be the fuel of choice in Alberta and Saskatchewan, Ontario

initiated a program to shut down its coal-fired generators, while bringing a number of nuclear units back into service. In addition, precipitation since about 2004 was greater than the 30-year average throughout many areas of the country and led to higher water levels and significantly greater hydro generation, while high oil prices also caused a significant shift from RPP fuels. In recent years, wind-generated electricity has begun also to have some impact on lowering emissions.<sup>18</sup> These events have all contributed to the decline in electricity sector emissions between 2003 and 2008. For that period, GHG emissions from electricity generation decreased by about 16 Mt.

The decrease in GHG emissions resulting from less electricity being generated from coal was further enhanced by continued fuel switching from higher- to lower-carbon fossil fuels and efficiency gains in fossil fuel-fired generators. In particular, the use of natural gas for electricity generation has increased significantly since 1990, and it now surpasses refined petroleum products (RPPs) in its contribution to total supply (natural gas is about half as carbon-intensive as coal, and approximately 25% lower than most RPPs). By 2008, natural gas's share of the generation mix was 5%—more than 5 times that of 1990. Aside from its environmental benefits, natural gas has also been price-competitive with oil prices. Natural gas electricity plants are now operating in most regions of the country, with Ontario and Alberta leading in gas-fired generation, followed by British Columbia and Saskatchewan. In Quebec and the Atlantic provinces, gas has been available only since 2000, but it is already being used in several new plants and a few retrofitted oil plants.

Emissions from electricity increased significantly between 2007 and 2008 (Figure 2–14). The majority of the decrease between 2007 and 2008 was observed in Ontario (4.5 Mt), followed by Quebec (1.7 Mt). The overall decrease in emissions is mainly due to record hydroelectric generation and lower peak demand for electricity in Ontario due to milder weather, economic conditions and increased conservation efforts. The natural gas cogeneration plant in Becancour, Quebec ceased operations at the request of Hydro-Québec

18 By 2008, new large-scale wind farm installations had helped increase wind power generation by 44% from 2007 and 179% from 2005. Wind and tidal generation has nearly equaled RPP fired generation and provincial programs for increased renewable content (from wind and other sources) in the electrical supply grid will continue to play a role in 2009 and beyond as more projects come on line. The Canadian Wind Energy Association (CanWEA) reports that Canada's installed capacity grew to 2 369 MW in 2008, an increase of 523 MW from 2007. For comparison purposes, Canada's 18 nuclear reactors (operating in 2008) have a gross total capacity of 13 400 MW. ([http://www.cna.ca/english/pdf/nuclear-facts/2009/CNA\\_Booklet\\_09.pdf](http://www.cna.ca/english/pdf/nuclear-facts/2009/CNA_Booklet_09.pdf))

in 2008. This was the main reason for the decrease in emissions from that province.

## 2.7. Passenger and freight transportation

The transportation sector's emissions rose 40 Mt (23 Mt Passenger, 17 Mt freight) between 1990 and 2008, a 34% increase from 1990, and representing 26% of the rise in Canada's total emissions. Since 1990, there has been a steady increase in the requirement for passenger and freight travel. These trends can be partially explained by a rising population, Canada's continued urbanization, rising income and spending, and increasing domestic and international trade.

### 2.7.1. Trends in Canada's passenger transportation sector

Activity is measured by vehicle kilometres travelled (VKT) and passenger kilometres travelled (PKT), whereas freight transportation activity is measured by tonne-kilometres

travelled (TKT).

As indicated in Table 2–12, Canadians are travelling 30% more on a PKT-per-capita basis, reflected by the increase in VKT (45%) and PKT (56%). Canadians travel predominantly via personal passenger vehicles (representing approximately 85% of all ground-based passenger transport in 2008). Meanwhile, since 1990, there has been a significant shift in the vehicle types used for passenger transport: VKT by light trucks has risen by 141%, whereas VKT by cars has risen by only 11%.

Increases in population will result in proportional increases in passenger transportation requirements unless changes occur in per capita travel. Canada's population grew by 20.3% between 1990 and 2008, while the actual "driving population" (i.e., the population 16 years of age or older) had increased by 21% as of 2008 (Statistics Canada 2009a, 2010f).

Vehicle population has also grown since 1990 but at a higher rate than the population. Overall, Canada's on-road fleet has ballooned to over 21 million from around 15 mil-

Table 2–12 Emissions and Activity Drivers in the Passenger Transport Sector 1990 and 2008

	Vehicle activity (billions VKT) <sup>1</sup>			Passenger activity (billions PKT) <sup>1</sup>			Activity intensity (1000's PKT/capita)			GHG emissions (Mt CO <sub>2</sub> eq)			GHG intensity (kg CO <sub>2</sub> eq/PKT)		
	1990	2008	% change	1990	2008	% change	1990	2008	% change	1990	2008	% change	1990	2008	% change
Car	174	193	11%	271	301	11%	9.77	9.04	-7%	46.2	41.1	-11%	0.17	0.14	-20%
Light truck	63	152	141%	95	264	179%	3.42	7.92	132%	21.4	47.2	120%	0.23	0.18	-21%
Bus <sup>2,3</sup>	2.3	3.2	39%	32	52	61%	1.17	1.56	34%	1.90	2.46	30%	-	0.05	-
Natural gas and propane cars <sup>4</sup>	-	-	-	-	-	-	-	-	-	2.21	0.88	-60%	-	-	-
Motorcycles <sup>4</sup>	-	-	-	-	-	-	-	-	-	0.15	0.26	80%	-	-	-
Rail	-	-	-	1.33	1.44	8%	0.048	0.043	-10%	0.23	0.21	-11%	0.17	0.14	-17%
Aviation	-	-	-	24.6	43.5	77%	0.89	1.31	47%	5.22	7.48	43%	0.21	0.17	-19%
Total passenger	239	348	45%	424	663	56%	15.29	19.88	30%	77	100	29%	0.18	0.15	-18%
Recreational and residential <sup>5</sup>	-	-	-	-	-	-	-	-	-	4.60	4.69	2%	-	-	-
Total (with recreational)	-	-	-	-	-	-	-	-	-	82	104	0	-	-	-

Notes:

- "VKTs" and "PKTs" refer to vehicle kilometres travelled and passenger kilometres travelled. These are frequently used metrics for transportation analysis and represent the total distance that vehicles and passengers travel, respectively.
- Vehicle occupancies are drawn from data published by the Office of Energy Efficiency of Natural Resources Canada.
- Estimates of bus passenger kilometres are based upon the total number of buses in the Canadian vehicle registry and assumptions on bus occupancy. This therefore includes all types of buses, including urban, intercity, school, and private buses. Owing to uncertainties with vehicle population, GHG intensities per PKT have not been shown.
- Vehicle distances are not available for natural gas cars, propane cars, or motorcycles.
- "Recreational and residential" refers to recreational vehicles (e.g., snowmobiles, dirt bikes) and equipment such as lawnmowers and residential snow removal equipment. Since these vehicles and equipment are not commonly used to transport people or goods but are more closely related to Canadian households, these emissions are briefly mentioned in the residential section of Chapter 2B.

lion in 1990, a 42% increase.

### 2.7.1.1. The increasing dominance of the personal passenger vehicle

The increasing contribution of emissions from personal vehicles for passenger transport has been driven by economics and market demand. Fuel prices throughout the 1990s were relatively low compared with the 1980s. Numerous studies have also suggested a close relationship among income, spending levels and vehicle ownership (NRCan 2009). Canadians are buying larger SUVs and vans at the expense of smaller-sized cars; in 1990, 24% of light-duty vehicles were trucks, vans or SUVs but, by 2008, this percentage had increased to 41%.

### 2.7.1.2. Stagnation in the fuel consumption ratio's (FCR) of vehicles

The GHG emission impacts of increasing vehicle travel can be further reduced by increases in fuel-efficient or switches to lower-carbon fuels (i.e. to natural gas or biofuels). The resulting "on-road" fuel consumption rates are shown in Table 2-13 for gas and diesel cars and trucks as well as for the "fleet average" for both 1990 and 2008.

Since 1990, Canadians have bought smaller, more fuel efficient cars compared with the large town cars of the 1970s and 1980s, furthering technical gains in fuel efficiency for gas and diesel cars. On the other hand, data from the United States indicate that decreases in FCRs for light trucks and SUVs have been limited significantly due to the increasing demand for horsepower (NHTSA 2007). The increasing power to weight ratios have severely limited the gains in vehicle fuel efficiency.

Table 2-13 FCRs for Light Duty Vehicles in Canada 1990 and 2008

	1990	2008	% change
Gasoline cars	11.2	9.4	-16
Diesel cars	7.2	6.1	-15
Gasoline trucks	14.3	13.3	-7
Diesel trucks	11.1	13.8	24
Fleet average	11.9	11.0	-8

### 2.7.1.3. Changes in fuel mix

Ethanol and biodiesel were introduced into the fuel stream for Canada's road transportation fleet during the 1990s. As these fuels contain carbon from renewable sources, they have the potential to reduce total GHG emissions. In 2008, biofuel use equalled approximately 1 100 ML of ethanol and 45 ML of biodiesel (B<sub>100</sub>) (TFIS 2008). This represents 2.7% of total gasoline and 0.2% of total diesel consumed.

### 2.7.1.4. Domestic aviation transport

Domestic air travel has grown significantly in the past decade due to increasing passenger demand as the incomes of Canadians have risen and as expenditures on travel have increased. Domestic air travel was not affected as significantly as international transport by the events of September 11, 2001 and by 2008, the PKTs were 77% above 1990 levels (Statistics Canada 2009b). By international agreement, only emissions associated with domestic air travel are accounted for in the inventory.

Between 1990 and 1995, the load factor, which is a measure of the "fullness" of an airplane, ranged between 62% and 64% for Canadian carriers. By 2008, average load factors were approximately 80%, leading to reductions in the GHG intensity of air travel.

## 2.7.2. Trends in Canada's freight transportation sector

"Freight" can be defined as goods moved by truck, rail, marine, or aviation, or any combination through inter-modal operations. The activity, related activity metrics and GHG emissions associated with the Canadian freight sector are summarized in Table 2-14 for 1990 and 2008.

The 64% rise in freight transport (as measured by TKTs) and the rising freight intensity of the economy (as measured by TKTs per unit of GDP) comes about from rising trade within and between provinces and increasing international trade.

Since 1990, there has been a significant rise in the use of heavier freight trucks for freight transport relative to rail, marine, and air. Alongside rapid increases in freight transport (as measured by TKTs), this trend has been one of the most significant factors increasing emissions and the emission intensity of freight transport, as moving freight by truck is one of the most emission-intensive ways of moving freight.

Table 2–14 Emissions and Activity Drivers in the Freight Transport Sector 1990–2008

	Freight activity (billions TKT) <sup>1</sup>			GHG emissions (Mt CO <sub>2</sub> eq)			GHG intensity (kg CO <sub>2</sub> eq/TKT)		
	1990	2008	% change	1990	2008	% change	1990	2008	% change
Truck (Heavy-duty) <sup>2</sup>	103	276	168%	26.6	43.6	64%	-	160	-
Rail	248	357	44%	6.73	6.90	3%	-	20	-
Marine	190	253	33%	5.04	5.83	16%	-	-	-
Aviation	0.54	0.62	15%	1.14	1.06	-7%	-	2000	-
Total	542	886	64%	40	57	45%	-	-	-

Notes:

1. TKT refers to tonne-kilometres travelled, which is a frequently used metric for freight truck transportation analysis. It is a measure of the distance and weight of goods moved.
2. TKT for trucks include estimates of both “for-hire” and “private” trucking.

The drivers underlying freight transportation are closely tied to economic activity and trade, particularly Canada’s increasing integration with the United States and global economies. Increasing requirements for “just-in-time” delivery since 1990 have necessitated a flexible transportation system (such as could be delivered by truck), while the trucking industry was also able to take advantage of the reduction in trade barriers seen after the Free Trade Agreement in 1989. Canada’s railways did not establish north–south routes until the late 1990s, when Canadian National purchased Illinois Central Railway.

### 2.7.2.1. Freight trucking

For survey purposes, the freight trucking industry is commonly broken down into the for-hire and not-for-hire trucking carriers. A “for-hire carrier” is defined as any carrier that undertakes the transport of goods for compensation. “Not-for-hire trucking” involves the transportation fleet of companies whose main business is anything other than transportation. The for-hire component of the trucking industry is by far the largest when measured by both TKTs and tonnes moved.

Average heavy-duty diesel vehicle fleet FCRs have decreased 12% since 1990, thereby decreasing total fuel consumption and emissions from what they would have been without efficiency improvements.

### 2.7.2.2. The rail freight sector

As shown in Table 2–14, rail freight activity has increased 44% since 1990 when measured by TKT, while emissions decreased by 3%. Similar to the freight trucking sector,

this divergence can be explained by both increasing load factors on trains and technical gains in efficiency (Statistics Canada, CANSIM Table 404-0016). Between 1990 and 2008, fuel consumption rates of rail freight transport decreased by approximately 29% when measured by TKT.

### 2.7.2.3. The marine freight sector

Similar to other modes of transporting freight, the 33% increase in marine freight activity shown in Table 2–14 is mainly related to increases in international trade. Also, since capital turnover is slow in this sector, it is assumed that there were only minor improvements in fuel efficiency.

### 2.7.2.4. The aviation freight sector

The aviation freight sector in Canada includes activity on board both passenger aircraft (carried in the bellyhold of the plane) and activity associated with the several operators that provide dedicated all-cargo service. Freight travel associated with the domestic market increased about 15% from 1990 to 2008, while emissions decreased by approximately 7%. It is assumed that emissions have decreased due to both increased load factors on aircraft and decreases in fuel consumption rates.

## 2.8. Heavy Industry and Manufacturing

Overall, GHG emissions from Canada’s industrial sector, which include the energy- and emission-intensive heavy

Table 2–15 Changes in emissions, GDP and economic emission intensity by industrial subsector, 1990 and 2008

	GHG Emissions (Mt CO <sub>2</sub> eq)				GDP (millions) (constant 2002 dollars)			Economic emission intensity (kg GHG/\$ GDP)		
	1990	2008	Change	Change (%)	1990	2008	Change (%)	1990	2008	Change (%)
Other Manufacturing	28.0	33.0	4.99	18	90 000	131 100	46	0.31	0.25	-19
Industrial Chemicals	29.0	23.0	-6.50	-22	13 100	19 000	45	2.20	1.20	-46
Iron and Steel	13.6	13.7	0.04	0	5 200	6 000	15	2.61	2.27	-13
Forestry, Pulp and Paper	17.3	8.46	-8.89	-51	19 600	17 900	-9	0.89	0.47	-46
Smelting and Refining	15.6	11.4	-4.27	-27	3 900	8 300	112	3.99	1.37	-66
Cement	9.3	11	1.60	17	2 300	3 300	44	4.10	3.30	-19
Mining	6.05	6.69	0.64	11	12 900	19 700	53	0.47	0.34	-28
Construction	3.77	3.57	-0.20	-5	52 300	70 200	34	0.07	0.05	-29
<b>Total</b>	<b>123</b>	<b>110</b>	<b>-12.6</b>	<b>-10</b>	<b>201 100</b>	<b>277 400</b>	<b>38</b>	<b>0.61</b>	<b>0.4</b>	<b>-35</b>

industry subsectors<sup>19</sup> such as iron and steel, aluminium, chemicals, pulp and paper and cement, and the less emission-intensive (mainly secondary) manufacturing subsectors, fell by about 13 Mt between 1990 and 2008, a decrease of approximately 10%. This significant decline in GHG emissions came about as the result of technological and process changes, increases in productivity, and some of the most emission-intensive subsectors of heavy industry have not grown substantially in terms of economic or physical output (i.e. the restructuring effect). These longer-term trends contrasted with those of the fossil fuel production, transportation and electricity generation sectors, all of which experienced strong growth in activity and GHG emissions.

Growth and the rate of change in GHG emissions, economic output and emissions intensity are different across industrial subsectors when considering the period from 1990 to 2008 (Table 2–15). In the early 1990s, the Canadian economy was in the midst of a recession, which reduced GHG emissions from the manufacturing and industrial sectors. With the rise of the knowledge economy, and high levels of construction and personal consumption during the 1990s, manufacturing output rose. In recent years, however, the softening of exports to the United States, the appreciation of the Canadian dollar in comparison with the American dollar, rising oil costs and the beginning of the new global recession in 2008 all played a role in lowering GHG emissions from particular subsectors. Table 2–15 includes seven distinct subsectors, as well as manufacturing

which includes GHG emissions from all other manufacturing activities.

Highlights of industrial subsectors:

**Manufacturing**<sup>20</sup>: As mentioned above, this subsector includes a variety of industrial GHG emission sources, such as, vehicle manufacturing, food and beverages, textile, mineral products (mainly lime production), consumption of halocarbons, and the use of certain refined petroleum products. Due to the strong growth in output (especially in the latter half of the 1990s), this subsector has been the most important one in contributing to GHG emission increases. Also important in relation to the growth in GHG emissions, has been the gradual replacement of ozone-depleting substances (ODSs) by hydrofluorocarbons (HFCs) within the refrigeration and air conditioning (AC) markets since the Montreal Protocol came into effect in 1996. However, although GHG emissions have risen over the long term, the manufacturing subsector has reduced its economic emission intensity by increasing energy efficiency and making productivity improvements.

**Industrial Chemicals**: Chemical manufacturing is an energy-intensive process, and one that results in process emissions through the many chemical reactions involved. However, even with an increase in production since 1990, GHG emissions from this sector have declined by 6.5 Mt. This has meant a decrease in absolute GHG emissions of 2% and a decline in economic emission intensity of ap-

19 I.e., primary industries and construction

20 Manufacturing, or Other Manufacturing as it is often known, consists largely of secondary and light manufacturing industries.

proximately 46%. This longer-term trend reflects both a general reduction in the energy requirements for chemical production and the reduction of industrial process emissions through use of emission abatement technologies. For example, Invista (formerly Dupont) Canada installed a nitrous oxide emission abatement system at its adipic acid<sup>21</sup> manufacturing facility in 1997, which reduced N<sub>2</sub>O emissions by about 8 Mt between 1990 and 2008. However, the plant has become indefinitely idled as of the spring of 2009.

**Iron and Steel:** Emissions from iron and steel production increased by only 0.04Mt between 1990 and 2008, although 1990 was anomalous due to a protracted strike at one of Canada's largest steel producers. The 5-month-long strike meant that steel production was about 20% lower than in 1989 (CIEEDAC 2008). Steel producers, like chemical producers, have been able to achieve significant improvements in energy efficiency. In fact, steelmakers saw reductions in energy intensity of almost 12% between 1990 and 2008 based on adjusted fossil fuel and electricity consumption to take into consideration the impact of the 1990 strike (CIEEDAC 2010). Another process that has lowered emissions has been an increase in the proportion of steel produced using electric arc furnaces (EAFs). This production method uses recycled steel scrap and avoids the emissions resulting from the reduction of iron ore into pig iron, and consequently results in about half the emissions released when producing steel from virgin material.

**Forestry, Pulp and Paper:** GHG emissions from this sector decreased 51% (8.9 Mt) between 1990 and 2008. Sector restructuring due to globalization, increases in oil prices and the appreciation of the Canadian dollar has resulted in reduced demand for Canadian products. Technological and process improvements have included the use of wood waste as an energy source, cogeneration and switching from heavy fuel oil to natural gas.

**Smelting and Refining:** Decreases in GHG emissions were observed in the smelting and refining of non-ferrous metals, in particular in the aluminium industry, where GHG emissions decreased from 15.6 Mt to 11.4 Mt. This was influenced by changes in technology that helped reduce PFCs substantially from 1990 levels. Progressive and voluntary objectives by the aluminium industry have helped to reduce GHG emissions and average energy consumption over the long term, even though production has increased

by around 100% (1.6 million tonnes) since 1990. Between 1990 and 2005, the magnesium industry had also shown significant emission diminutions because of progressive replacement of SF<sub>6</sub> with alternative cover gases<sup>22</sup>. For the years 2005–2008, gradual production reductions in anticipation of plant closures in Norsk Hydro and Timminco brought about considerable decreases in SF<sub>6</sub> emissions. Norsk Hydro was finally shut down in spring of 2007 and Timminco in August 2008.

**Cement:** Emissions from cement production have increased by over 17% from 1990 to 2008, rising from 9.3 Mt to 10.9 Mt. The rise in emissions closely follows the increase in clinker<sup>23</sup> production, which grew by 22% between 1990 and 2008. A drop in domestic and foreign (mainly U.S.) demand for cement saw a decrease in production from the peak year of 2007 (Statistics Canada 2010), accompanied by a 10% fall in emissions between 2007 and 2008.

**Mining:** In the mining subsector<sup>24</sup>, emissions increased from 6.1 Mt to 6.7 Mt. Between 1990 and 2008, sector GDP increased by nearly 54%. The increase in GDP has been largely due to the start of large-scale production from Canada's diamond mines and a general increase in commodity prices for minerals, such as, uranium and potash (Sask. Bureau of Statistics 2009). The extensive use of heavy vehicles in modern mining has resulted in an increase in transport emissions from mining of 1 Mt from 1990 to 2008.

**Construction:** Emissions from construction activities declined by about 17%, even as economic activity associated with construction activity nearly doubled. Although part of this decline can be attributed to lower fuel consumption of more GHG-intense fuels like kerosene and fuel oil, data limitations reduce the opportunity for further scrutiny.

## 2.9. The service industries

Since 1990, Canadian industry has achieved significant increases in productivity and technical efficiency and has experienced a shift towards a service-oriented economy.<sup>25</sup>

22 Cover gases are used in the magnesium manufacturing industries to prevent combustion of magnesium during high temperature processing.

23 Clinker is the primary component of cement (making up the vast bulk of it).

24 "Mining" in this report only includes minerals, metals and gems, etc. and does not include the extraction of energy products such as bitumen or coal.

25 Examples of "services" in this report include retail trade, maintenance, financial services, government, social and other public services.

21 Adipic acid is used in the manufacture of nylon. The presently idled plant is in Maitland, Ontario.

These factors have accelerated during the current decade due both to the increase in relative productivity in the raw material, processing and manufacturing sectors and changes in Canada's economic position within the global economy.<sup>26</sup> Economic restructuring, technological advances and automation in primary and secondary sectors have consequently meant that by 2008, approximately 93% of the additional 4.0 million jobs added to the country's goods and services producing industries have been in the service sectors of the economy (Statistics Canada, *Table 282-0008*). Overall, this restructuring has had the effect of reducing greenhouse gas emissions.

Over 30% of the decline in Canada's economic emission intensity can be attributed to this structural shift in the economy towards these lower carbon-intensive economic sectors. In that period, various high-tech and service-based sectors of Canada's economy grew faster than more energy- and emission-intensive manufacturing and industrial activities.

Energy use by the service industries is largely related to heating and cooling buildings and powering the lights, computers and other auxiliary equipment required during operations. Emissions attributed to this sector in the National Inventory Report include only direct fuel use and not the electricity consumed.<sup>27</sup> Between 1990 and 2008, emissions directly associated with the service industries increased by over 19 Mt, an increase of about 47%. The majority of this increase, however, occurred between 1990 and 2003, as in the last five years emissions have stayed roughly the same.

Two important drivers that have helped to increase emissions over the longer term have been the more than 172 million square metres of additional office floor space for commercial establishments (an increase of almost 34% between 1990 and 2007) and the increasing use of office equipment, heating and cooling systems and other energy-intensive equipment. Natural Resources Canada estimates that energy intensity per unit of floor space peaked in 2003 (at 10% higher than 1990) but has been decreasing since then to a value in 2007 of 1% lower than

in 1990 (NRCan 2009)<sup>28</sup>.

If emissions from electricity were included in these calculations, emissions attributed to the service industries would be substantially higher, since electricity use has increased by almost 27% between 1990 and 2007, with the majority of the increase attributable to auxiliary equipment such as computers and other electronic equipment and space cooling (NRCan 2009). This evolution has come about as global business has been transformed by the personal computer and, in the most recent years, by the Internet, while increasing office floor area has meant increased requirements for air conditioning (since most offices are occupied during the warmest parts of the day).

Nonetheless, since 2004, the direct emissions associated with the sector have remained unchanged with small annual fluctuations. The most important factor that has influenced this trend has been a decrease in the energy required for heating and cooling; a trend driven in part by programs initiated to help consumers reduce energy demand, and by warmer winters.

## 2.10. Residential Sector

GHG emissions in the residential sector (comprising houses, apartments and other dwellings) increased by 0.3 Mt between 1990 and 2008 (an increase of 0.6%), even as the combined floor area of these buildings increased by at least 44%. A typical Canadian housing unit has increased by about 11 m<sup>2</sup> (NRCan 2009). The relatively constant GHG emissions since 1990 are a result of efforts by both industry and consumers, encouraged by a number of government programs to increase efficiency (e.g. ENERGY STAR<sup>®</sup>) and to reduce GHG emissions (e.g. EnerGuide), but the effects of warmer winter weather and rising fuel costs made significant contributions. (See box, *Reducing heating requirements in residential buildings*) for links between temperature and energy demand).

There have been a number of important technological developments that have been particularly relevant for the residential sector. First, home heating systems have become more efficient and homeowners have increasingly used natural gas as a fuel source, replacing oil and electricity. This is important as residential space heating requires the most energy of any end-use in Canadian homes, meaning that these changes led to a direct reduction in GHG

26 As restructuring toward a service-oriented economy has occurred, domestic manufacturing has moved to other countries with more economical means of production. Thus, another part of the trend involves a shifting of emissions to those other countries.

27 Emissions also occur due to vehicles and private trucking operated by retailers, etc., but the majority of this is captured in the transportation sector since these vehicles buy fuel from retail fuelling stations.

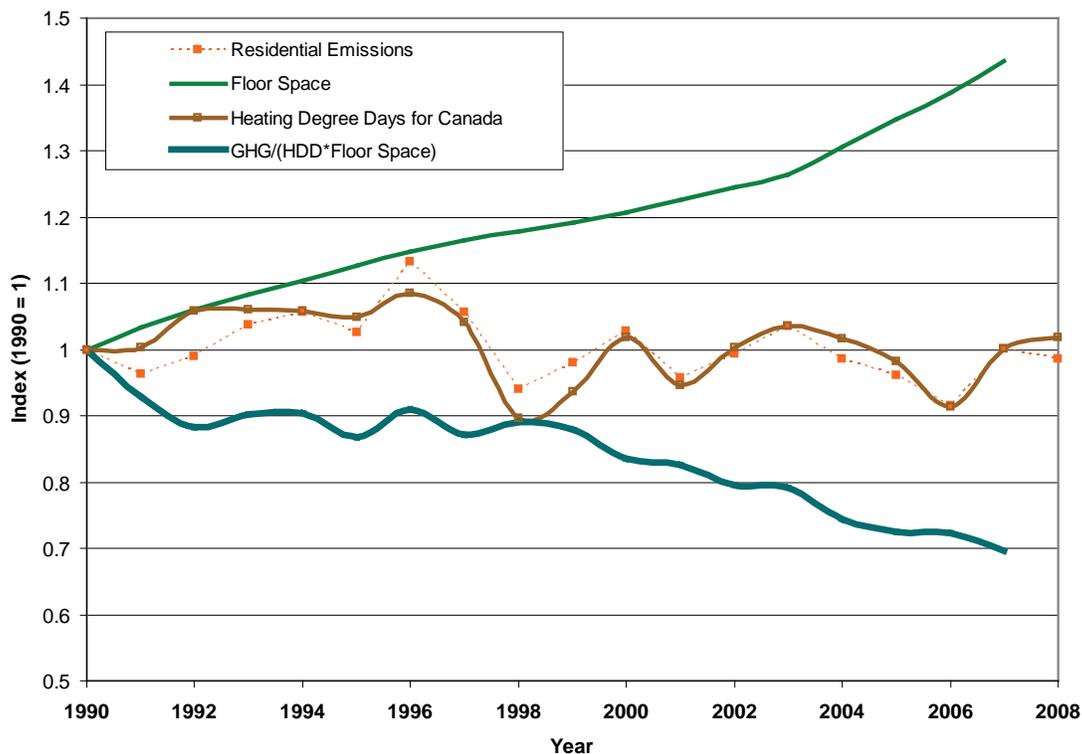
28 Data on floor space is available to 2007 at the time of publishing.

## 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.

Between 1990 and 2007, there was a strong correlation between HDDs in Canada and the energy-related GHG emissions originating from the residential sector (see Figure 2–16). This indicates the close relationship between outside air temperatures and how much energy is required to heat the home. Another important relationship that can be seen is the decrease in GHG emissions per amount of floor space requiring heating (as indicated by the product of floor space and HDDs). This decoupling has been the result of increases in the efficiency of heating and the thermal envelope of buildings, as well as some changes in the mix of heating fuels.

Figure 2–16 Relationship between HDDs and residential GHG emissions, 1990–2007



Notes:

- To remove the effect of climatic and population variables, the trend is measured in terms of GHG emissions divided by the product of floor space and HDDs over the period. The curve is shown indexed to 1990. If efficiency or fuel use patterns had not changed, the graph would likely have shown a horizontal line. However, the resultant GHG emission rate shows a declining trend between 1990 and 2007. This illustrates how building efficiency improvements and fuel switching produced GHG emission reductions.
- Residential floor space estimated based upon dwelling counts available from Statistics Canada.

emissions. In recent years, there also have been a number of home retrofit benefit programs to help Canadians improve the energy efficiency of their homes, and energy-efficient new homes have been encouraged through programs such as the R-2000 initiative.

The residential sector is also a large consumer of electricity and, 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, thanks to programs like ENERGY STAR®, the energy efficiency of refrigerators has improved by up to 40% since 1990 (NRCan 2009).

## 2.11. Agriculture

The agriculture sector also contributed to Canada's growth in emissions since 1990. Emissions were about 71 Mt in 2008, representing an increase of 15 Mt (27%) from 1990 levels (Figure 2-17).

Emission-generating activities in Canada's agricultural sector are animal production, crop production and on-farm fuel use, which in 2008 respectively accounted for 56%, 32% and 12% of agricultural emissions. Approximately 62% of the increase in agricultural emissions between 1990 and 2008 is associated with animal production.

Animal emissions are driven primarily by enteric fermentation, i.e. food digestion, which is responsible for an average of 56% of animal emissions (2 Mt in 2008). The remaining emissions relate to manure management (19% of animal emissions) and the emissions of nitrous oxide from manure disposal (25% of animal emissions).

The significant growth in animal populations largely accounts for the 30% increase from 30 to 40 Mt in emissions associated with animal production over the 1990–2008 period. Notably, the beef industry expanded by 29% in Canada (most of it in Alberta), the Canadian swine industry by 24% (particularly in Manitoba, Quebec, Ontario, Saskatchewan and New Brunswick) and the poultry industry by 31%.

Among all important Canadian livestock categories, the non-dairy cattle herd has had the largest impact on the trends in agricultural GHG emissions in Canada. Overall, non-dairy cattle are responsible for 80% to 84% of all enteric fermentation emissions and 25 to 30% of emissions

from manure management. Emission trends due to population increases are augmented by an average weight increase in non-dairy cattle of 26% since 1990 and as a result each individual beef cattle produces a greater quantity of GHGs from both enteric fermentation and manure production. Even if the animal population had remained the same as in 1990, the weight increase would still have resulted in an emission increase.

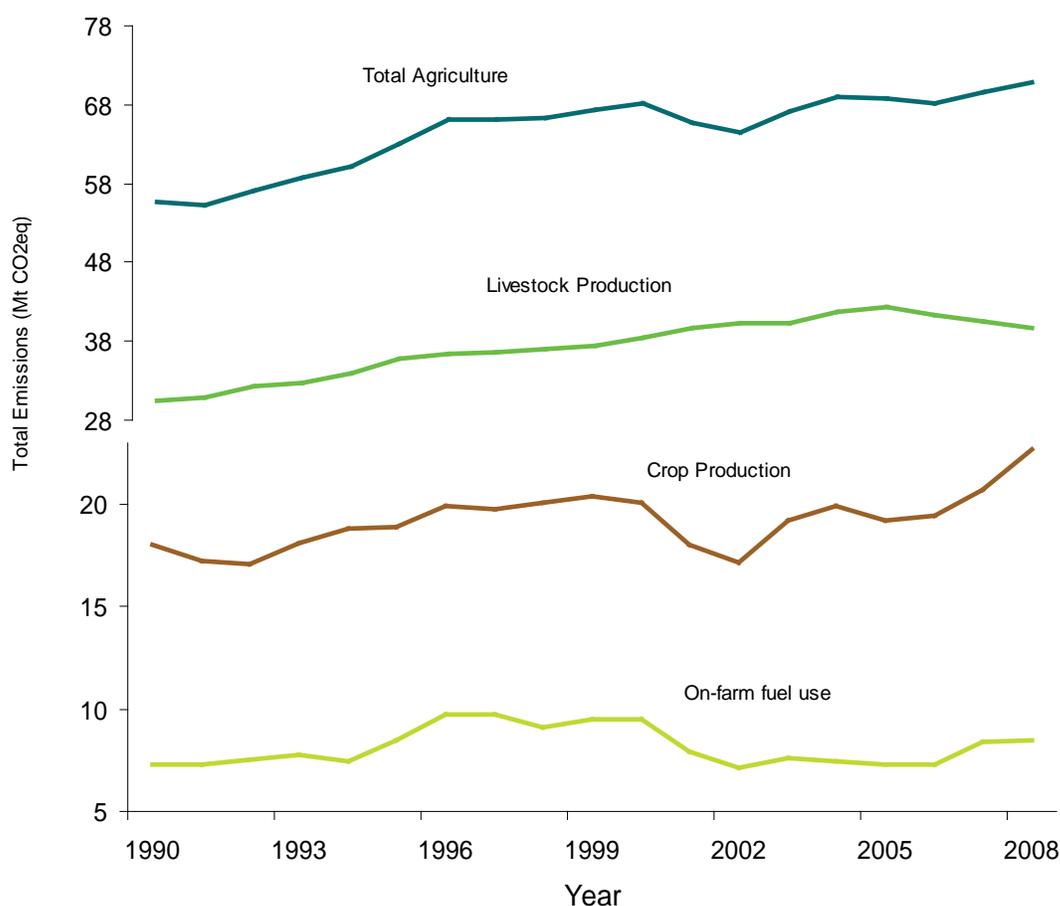
In contrast, emissions associated with dairy cows have fallen by approximately 14% since 1990, while their population has decreased by 28%. The decline in the dairy herd has been partly offset by a 26% increase in average milk productivity, due to improved genetics and changes in feeding and/or management practices. Therefore, even though the drop 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.

Strong regional trends should also be noted. Historically, Ontario and Quebec have been the location of most of Canada's dairy industry, while Alberta is home to the majority of Canada's beef production. Based on the beef cattle population, Alberta counts for about 40% to 45% of the national total of non-dairy cattle in Canada. This has meant that agricultural emissions have increased, particularly in Alberta, thereby contributing along with other sectors of its economy to its strong growth in emissions.

Emissions from crop production are due mainly to applications of synthetic nitrogen fertilizers and the decomposition of crop residues. The use of synthetic fertilizer nitrogen has jumped from 1.2 million tonnes to 1.9 million tonnes of nitrogen between 1990 and 2008, mainly because of the intensification of cropping systems in the Canadian prairies. Emissions from synthetic nitrogen fertilizer consumption have increased substantially from 9.2 Mt to 13.4 Mt over the same time period. This trend was partly offset by the mitigation effects of a 55% reduction in summer fallow area and a 104% increase in conservation tillage, mainly on the Prairies. Summer fallow is known to increase emissions of nitrous oxide because of its impact on nitrate leaching and denitrification. Conservation tillage directly reduces fuel use for field operations, and is also encouraged as a best management practice for erosion control and carbon sequestration.

Crop residue decomposition is directly proportional to the amount of crop produced. There are about two dozen

Figure 2–17 Trends in the Agriculture Sector, 1990–2008



major crops grown in Canada including wheat, canola, barley, corn, soybean, lentil, etc. Emissions from crop residue decomposition varied greatly between 7.1 Mt in 1990 to 9.1 Mt in 2008, depending on commodity price and weather conditions. For instance, 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 2–17). 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.

Since 1990, emissions from on-farm fuel use have increased by 16% from 7.3 Mt to 8.5 Mt. On-farm fuel use for off-road vehicles increased by 30% but this was partially offset by a 13% decrease in emissions from stationary combustion (for agricultural installations such as farm buildings). Overall, increases in emissions from off-road vehicle

fuel use are proportional to increased agricultural production during the 1990 to 2008 period. Emissions from stationary combustion peaked in 1993 and have steadily declined since, indicating that there have been reductions in energy consumption by farm infrastructure, even with the large increases in production that were observed during this period.

The general economic drivers in agriculture are similar to those of other sectors. In the case of beef cattle and swine, increasing production has largely served the export market. From 1990 to 1998, both beef and swine commodity prices were strong and stable, encouraging farmers in western Canada to invest in these industries (Statistics Canada 2001), spurring increases in beef and swine populations. The occurrence of bovine spongiform encephalopathy (BSE or mad cow disease) had an important influence on the export markets and the Canadian cattle population: in May 2003, a worldwide ban of Canadian beef products was declared. Prior to the ban, almost half of the cattle sold in Canada were exported, either as live animals or meat;

in 2002, about 90% of Canadian beef exports went to the United States, totalling \$3.7 billion. Beef prices plummeted due to the drastic drop in all beef exports (live and meat), inducing a sudden increase in domestic animal populations (9% increase between January 2003 and January 2004). In September 2003, the United States and other countries agreed to allow imports of Canadian boneless beef from animals younger than 30 months under a permit process. Exports of meat began to recover, although populations of older cattle remained high. In July 2005, Canadian live cattle shipments less than 30 months of age were permitted to enter the United States. Export markets have recovered but beef cattle populations do not appear to have stabilized since the BSE crisis.

Canadian swine production is mostly exported: exports of pork meat are 44% higher than the domestic consumption and represented \$2,740 M in 2008. The United States and Japan account for 37% and 26% respectively of Canadian exports of swine products.

Since 2004, emissions from agriculture overall have stabilized. Since the BSE crisis in 2004, beef populations have decreased by 9%. Furthermore, prices of hogs have been low (Statistics Canada 2009) and populations have also decreased by 16%. These population reductions combined with continued decreasing trends in dairy cattle populations have lowered emissions from livestock by roughly 2.5 Mt (6%). At the same time, due to improved crop yields and strong grain commodity prices, emissions from crop production has increased, also roughly by 2.5 Mt (18% in this case), and emissions from on-farm fuel use have increased by about 1 Mt.

Overall, between 2004 and 2008 decreases in emissions from livestock production have been compensated for by increases in emissions from crop production, resulting in no net changes to agricultural emissions. The large increase in emissions from crop production in recent years combined with a decreasing trend for beef cattle and swine populations may be indicative of a new decreasing trend. High demand for land and biofuel may become important drivers in agriculture in the future.

## 2.12. Land Use, Land-Use Change, and Forestry Sector

Trends in the LULUCF sector are primarily driven by those in forest land, cropland and forest conversion. 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 forests includes a 21% increase in the carbon removed in harvested wood biomass between 1990 and 1999, which had since then stabilized at around a 50-Mt annual average of carbon transfers off-site. Significant reductions in forest management activities have occurred since 2006, with harvest levels in 2008 (36 Mt C) being at their lowest for the entire time period covered by this report. This trend reflects a deep restructuring of the Canadian forest sector, aggravated by the consequences of the economic recession in the United States, Canada's main export market. The other trend of interest consists of a steady decline in emissions from cropland, from 13 Mt CO<sub>2</sub> eq in 1990 to a net removal of 4.4 Mt in 2008. This pattern largely results from changing agricultural land management practices in western Canada, such as the extensive adoption of conservative tillage practices and reduction in summer fallow. Lastly, greenhouse gas emissions from the conversion of forests to other land use have dropped from 27 Mt CO<sub>2</sub> in 1990 to 19 Mt in 2008. These figures reflect a reduction of over 20 kha in the annual rate of forest clearing for agriculture, from 67 kha in 1990 to 46 kha in 2008; most of these reductions took place in the Boreal Plains, Sub-humid Prairies, and Montane Cordillera of western Canada, following a period of active agricultural expansion in the previous decades. Other patterns of forest conversion have steadily increased, notably forest clearing for oil and gas extraction (from 2.4 to 3.8 kha of forests converted in 1990 and 2008 respectively). Nevertheless, the immediate and long-term effect of major natural disturbances in managed forests, notably the Mountain Pine Beetle infestation in western Canada, will undoubtedly continue to dominate the apparent LULUCF trend. Again, the LULUCF sector is not counted toward the estimate of Canada's national greenhouse gas total.

## B2 Placing Canada's current GHG emission trends in a longer-term perspective

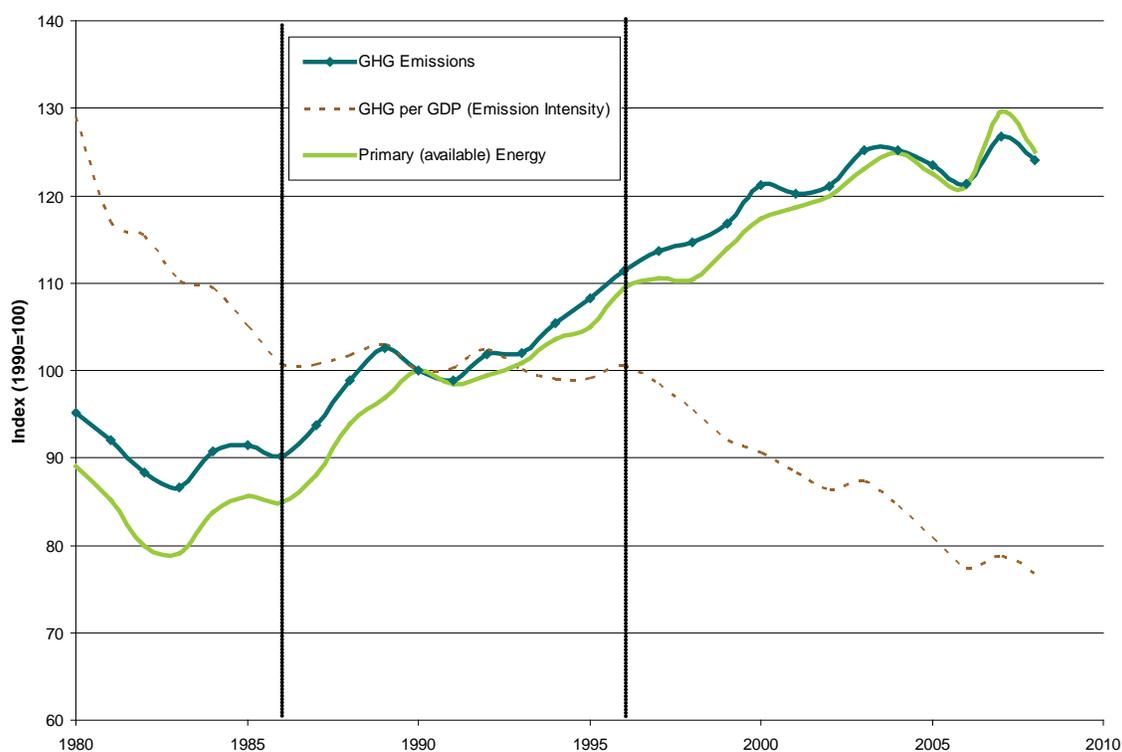
Emission reduction initiatives are one of the key components of the global response to climate change. To help place into historical perspective the challenges currently facing Canada, Figure 2–18 illustrates a longer-term trend of emissions from 1980 to 2008, along with two metrics: the emission intensity of the economy when measured by GDP (constant dollars) and the total amount of energy used in Canada. The stretch of history from 1980 to 2008 can be divided into three distinct periods: 1980 through 1986 (when the emission intensity of the economy fell by approximately 30%), the 10 years from 1986 through to 1996 (when the emission intensity of the economy remained relatively constant), and the most recent 10 years (when again this metric fell) (see Figure 2–18).

The early 1980s were a turbulent period in world history

with respect to energy supply and demand. The large efficiency gains seen during the 1980s were primarily due to price shocks, government regulations and policies to increase energy security and industrial innovation. Industry took measures to reduce energy requirements, and energy consumption in the residential sector dropped in response to the increase in the price of home heating oil, in line with the price of other petroleum products. Consequently, even though the economy grew by over 17% between 1980 and 1986, emissions fell significantly. This meant that the emission intensity of the economy dropped by about 4% per year over this period.

In the second phase, beginning in 1986 and continuing until about 1996, the GHG intensity of the economy remained relatively flat. Two macroeconomic events were of particular importance. First, the price of crude oil fell significantly throughout the latter part of the 1980s with the convergence of a marked slowdown in energy demand and a surge in fuel production (EIA 2004). This significantly limited the economic incentives to improve energy ef-

Figure 2–18 Longer-term trend in GHG emissions along with key metrics, 1980–2008



Note:

The 1980–1986, 1986–1996, and 1996–2008 periods have been separated to highlight the fact that these were periods that saw significant changes in economy, energy, and emissions.

efficiency. Second, Canada went through a deep recession starting in 1990, with GDP recovering only in 1993. The end result over this period was stabilization in emissions and a slight upward trend in emission intensity. When Canada's economy came out of this recession in 1993, emissions rose nearly in step with the stronger economic growth. Compared with the less than 1% annual growth in emissions during the period from 1990 to 1993, emissions grew by over 3% per year in the years that followed.

Beginning in 1997, there was again a decoupling of GDP and emissions, with the emission intensity of the Canadian economy decreasing on average by 2.2% per year. This decrease can be explained by structural changes in the composition of the economy, as well as by increases in efficiency, fuel mix changes and changing industrial processes. The structural changes are those discussed in Section B2, 2.6, involving a commencement of the ongoing shift from a manufacturing- to a more service-oriented economy, along with the attendant growth of manufacturing in other countries. Although the economic emission intensity reduction that occurred was an improvement over the 1986–1996 period, this trend was only about half what was achieved between 1980 and 1986 and was not enough to attain absolute emission reductions, since the rate of Canada's economic growth was even higher (the annual GDP increase averaged 3.5% over this period).

Since 2004 emissions have, as stated earlier, not grown but declined slightly, though the trend has been unsteady with positive and negative swings of up to 4%. Overall, however, a number of positive signs are in evidence. The continuation of the structural shift to a more service-based economy is in strong evidence. For instance, GDP for the service industries (e.g. trade, finances, professional services, maintenance, public administration, etc.) rose by 8%,<sup>29</sup> while that for all of heavy industry and manufacturing minus construction fell by almost 7%. As the economic greenhouse gas intensity of service industries is about one quarter that of heavy industry and manufacturing and falling, this shift towards services has resulted in significant emission reductions. In fact, in spite of the growth in economic output, emissions from the service industries remained unchanged, while that from heavy industry and manufacturing fell by 10 Mt between 2004 and 2008. Though this trend was intensified by the commencement of the global recession in 2008, the structural shift is expected to continue into the future, which will tend to help

drive emissions down.

Another positive note in the trends is the fact that GHG emissions associated with coal-fired electricity generation, which had been increasing since the mid-1990s, have begun to decrease since peaking in 2001. Part of the decrease is due to fuel switching and targeted measures (notably in Ontario) to reduce the use of coal generation. Renewables such as wind energy will begin to play a greater role in the coming years as power from these sources is growing rapidly. In 2008, wind and other renewables for the first time contributed more than 1% of Canadian electrical energy generation, twice their contribution in 2006. However, the impacts of weather, fuel costs, economic factors and the regulatory environment continue to play a major role in determining whether coal-fired generation and the associated GHG emissions will be reduced further in the future.

Canada currently has more than 40 programs in place that encourage or target measures to make emission reductions. There are also a number of additional provincial programs, including forms of carbon-based taxation in both British Columbia and Quebec. Although tracking systems have not been put in place to comprehensively determine the total effect of these programs, they, in conjunction with the current public awareness of climate change, are likely to have had some impacts on emission reductions and will contribute yet more in the future.

Recently, one of the most prevalent emission trends in Canada (and all of North America) has been the continuous increase in GHG emissions from personal vehicles. Since the 1990s, this trend has largely been driven by the rapidly growing preference by consumers for light-duty trucks (pickups, sport utility vehicles and vans) as opposed to lower fuel-consuming automobiles. Exemplifying this trend, between 2004 and 2007, an average of about 252 000 light gasoline trucks and 166 000 automobiles<sup>30</sup> were added to the vehicle fleet annually. However, in 2008, a year when oil prices reached a record high and then fell again dramatically a few months later, vehicle statistics showed a remarkable reversal. That year, 234 000 additional automobiles were added to the fleet, but only 164 000 light trucks. As a result road transport emissions, which had grown by close to 5% between 2004 and 2007, showed a small decline between 2007 and 2008. This is the first decrease observed since 1996 in a category that

29 Statistics Canada, October 2009

30 Federal government statistics (Environment Canada, NRCan).

contributes close to 20% of Canada's total greenhouses. Although this represents only a one-year change so far, should the trend continue, it will hold significant potential for future emission reductions.

Nevertheless, it is not clear that the decrease in emissions growth seen since 2004 will continue into the future. Petroleum extraction from the oil sands is expected to steadily increase, with 2015 production projected to be almost double that of 2008 (Nyober and Tu 2010). This will put a strong upward pressure on emissions, particularly considering that the oil and gas industry contributed almost 40% of Canada's total emission increase between 1990 and 2008. On the other hand, natural gas production appears to have levelled off and is not projected to grow in the future (Nyober and Tu 2010). Impressed upon these trends, globalization issues affecting Canadian exports not only in energy, but in agriculture and other sectors as well, are expected to continue to be a driver on emissions.

Weather variability, too, will continue to be a major driver. As has been discussed elsewhere, colder winters create significant additional energy requirements throughout the economy, but particularly in the residential and commercial sectors, influencing the demand for natural gas and other fuels. Climate effects can impact emissions in a variety of ways, particularly in Canada, a country renowned for its ever-changing weather. Hydro-electric generation is one activity highly affected by weather, there being a close relationship between lower water levels and the need for supplementary combustion generation along with its concomitant greenhouse gas emissions.

The federal government has set targets for emission reductions in Canada. After agreeing to the Copenhagen Accord in December 2009, Canada pledged to reduce its emissions to 17% below 2005 levels by 2020. In commencement of achieving this goal, it has developed the Action Plan on Climate Change. Through this program, Canada has set the following objectives: a target of having 90% of its electricity provided by non-emitting sources such as hydro, nuclear or wind power by 2020; introducing new regulations to limit greenhouse gas emissions from the automotive sector; continuing to advance discussions with the United States administration on a coordinated North American reduction program (the Clean Energy Dialogue); and investing additional funds to support technologies and actions to further reduce emissions.

Evidence indicates that in order to achieve success with a

program of emission reductions the continued reduction in the emission intensity of Canada's economy over time will be required and it must occur at a pace that counteracts the country's continued population and economic growth. In addition, until large emission trading, carbon storage or sequestration programs begin to affect Canada's total emissions, further significant reductions in fossil fuel energy consumption will have to take place. A variety of climate change-related measures at both the federal and provincial/territorial levels will affect Canada's national emissions total. Furthermore, it is possible that awareness of climate change and the volatility of oil prices will continue to push industry, consumers and government towards strategies that minimize energy consumption and, in turn, emissions. It may be that recent events such as steep oil price increases and heightened public awareness of climate change issues are beginning to have some effect, but more significant actions must be in place before the historical record will show the steep and continued emission reductions required to achieve Canada's current target.

## Ancillary 1

Table 2-16 Details of trends in GHG emissions by sector

	1990	2000	2004	2005	2006	2007	2008
	Mt CO <sub>2</sub> equivalent						
<b>NATIONAL GHG TOTAL</b>	<b>592</b>	<b>717</b>	<b>741</b>	<b>731</b>	<b>718</b>	<b>750</b>	<b>734</b>
<b>Fossil Fuel Production</b>	<b>103</b>	<b>149</b>	<b>158</b>	<b>154</b>	<b>155</b>	<b>164</b>	<b>160</b>
Upstream Fossil Fuel Production	83.6	131	134	132	134	140	139
Conventional Oil Production	21.3	33.6	32.6	32.0	32.3	31.9	30.4
Conventional Light Oil Production	10.5	12.2	11.9	11.9	12.5	12.5	12.2
Conventional Heavy Oil Production	10.8	21.5	20.7	20.1	19.8	19.4	18.2
Oil Sands (Mining, In-situ, Upgrading)	16.8	26.8	31.6	29.6	32.2	37.1	37.2
Oil Sands Mining, Extraction and Upgrading	12.2	19.7	23.0	20.7	22.7	25.9	24.9
In-situ Bitumen	4.6	7.1	8.6	8.8	9.5	11.2	12.2
Natural Gas Production and Processing	31.5	51.6	53.8	52.7	53.1	55.6	56.4
Natural Gas Production	16.8	27.7	29.8	29.5	29.7	30.8	30.7
Natural Gas Processing	14.7	23.9	24.0	23.1	23.3	24.8	25.7
Coal Production	2.8	2.2	2.1	1.5	0.9	1.3	1.4
Oil and Natural Gas Transmission	11.2	16.8	14.2	15.8	15.4	14.7	13.2
Oil Transmission	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Natural Gas Transmission	11.1	16.7	14.1	15.7	15.3	14.6	13.1
Downstream Fossil Fuel Production	19.3	18.3	23.3	22.1	20.9	23.4	21.1
Petroleum Refining	16.6	15.0	19.8	18.6	17.3	19.8	17.5
Natural Gas Distribution	2.8	3.3	3.5	3.5	3.6	3.6	3.6
<b>Electricity</b>	<b>97.0</b>	<b>134</b>	<b>128</b>	<b>126</b>	<b>118</b>	<b>127</b>	<b>121</b>
Utility Generation	92.5	126	119	119	110	118	112
Industry Generation	2.2	4.7	5.4	4.5	5.4	5.9	6.0
Heat and Steam Generation	0.7	1.5	2.0	1.4	1.4	1.3	1.1
Transmission	1.5	1.5	0.8	1.2	1.5	1.3	1.8
<b>Transportation</b>	<b>121</b>	<b>142</b>	<b>155</b>	<b>157</b>	<b>157</b>	<b>163</b>	<b>162</b>
Passenger Transport	77.3	89.9	95.7	95.9	96.0	100	99.5
Cars	46.2	42.4	41.6	40.3	40.4	41.4	41.1
Light Trucks	21.4	38.5	44.0	45.2	45.8	47.1	47.2
Propane and Natural Gas Vehicles	2.2	1.1	0.9	0.7	0.8	0.8	0.9
Motorcycles	0.1	0.2	0.2	0.3	0.3	0.3	0.3
Bus	1.9	2.0	2.3	2.4	2.5	2.5	2.5
Rail	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Domestic Aviation	5.2	5.5	6.6	6.7	6.1	7.7	7.5
Freight Transport	39.5	47.1	54.1	55.6	56.4	57.9	57.4
Heavy Duty Trucks	26.6	34.6	40.5	42.0	42.9	44.1	43.6
Rail	6.7	6.3	5.7	6.0	6.2	6.6	6.9
Domestic Aviation	1.1	1.1	1.3	1.1	1.6	1.1	1.1
Domestic Marine	5.0	5.1	6.6	6.4	5.8	6.1	5.8
Other: Recreational and Residential	4.6	5.3	5.6	5.4	5.0	5.3	4.8
<b>Heavy Industry and Manufacturing</b>	<b>123</b>	<b>118</b>	<b>120</b>	<b>116</b>	<b>115</b>	<b>117</b>	<b>110</b>
Mining	6.1	6.6	5.6	5.7	6.3	6.2	6.7
Smelting and Refining (Non Ferrous Metals)	15.6	14.2	12.7	12.7	12.3	11.3	11.4
Forestry, Pulp and Paper	17.3	15.3	13.7	11.3	9.8	9.8	8.5
Forestry	0.5	1.0	1.2	1.1	1.1	1.1	1.2
Pulp and Paper	14.3	11.4	9.6	7.4	6.1	6.0	4.7
Iron and Steel	13.6	15.1	13.7	13.5	14.0	14.7	13.7
Cement	9.3	10.9	11.7	12.1	12.4	12.1	10.9
Industrial Chemicals	29.1	21.8	24.3	22.4	22.1	22.8	22.6
Other Manufacturing	28.0	31.2	35.4	35.0	34.7	36.3	33.0
Construction	3.8	2.9	3.2	3.4	3.2	3.5	3.6
<b>Service Industries</b>	<b>40.3</b>	<b>52.5</b>	<b>59.4</b>	<b>59.3</b>	<b>55.9</b>	<b>58.0</b>	<b>59.4</b>
Commercial and Institutional	36.6	48.8	55.8	55.6	52.6	54.6	56.0
Public Administration	3.7	3.8	3.6	3.7	3.3	3.4	3.4
<b>Residential</b>	<b>51.5</b>	<b>52.8</b>	<b>51.3</b>	<b>50.4</b>	<b>48.7</b>	<b>52.3</b>	<b>51.9</b>
<b>Agriculture Production</b>	<b>55.7</b>	<b>68.1</b>	<b>69.0</b>	<b>68.9</b>	<b>68.1</b>	<b>69.6</b>	<b>70.9</b>
On Farm Fuel Use	7.3	9.5	7.5	7.3	7.3	8.4	8.5
Crop Production	18.0	20.1	19.9	19.2	19.5	20.7	22.7
Animal Production	30.4	38.5	41.6	42.4	41.4	40.5	39.8
<b>Land Use, Land Use Change and Forestry<sup>a</sup></b>	<b>-51.6</b>	<b>-80.3</b>	<b>117</b>	<b>41.4</b>	<b>41.4</b>	<b>45.5</b>	<b>-12.8</b>
Forest Land - Management Practices <sup>b</sup>	153	193	199	196	180	174	136
Forest Land - Other	-231	-286	-92.5	-163	-147	-136	-154
Cropland - Management Practices	-1.5	-8.0	-10.8	-11.5	-12.2	-12.8	-13.5
Wetlands - Management Practices	1.5	0.4	0.3	0.1	0.2	0.2	0.2
Settlements	0.0	0.0	-0.0	-0.0	-0.0	-0.0	-0.0
Forest Conversion	27.2	20.8	20.8	20.5	20.4	19.7	18.7

a. National GHG totals excludes all emissions/sinks from the Land Use, Land Use Change and Forestry sector.

b. Management Practices in Forests refer to the harvest of merchantable wood. The estimates reflect the assumption that the carbon contained in harvested wood is immediately emitted to the atmosphere. In reality, wood products can store carbon for extended time periods. Taking into account this carbon storage, emission estimates from harvesting in the year 2008 alone could be reduced by 11 to 57 Mt CO<sub>2</sub>, depending on the approach used to monitor the fate of this carbon.

Note: Totals may not add up due to rounding.

## Ancillary 2

## Canada's emissions in an international context

Table 2–17 below summarizes changes in economic growth as measured by GDP, population, and total and per capita GHG emissions for selected Annex I nations for 1990 and 2007. Canada is ranked among the highest of all countries in the world in terms of per-capita GHG emissions.

Table 2–17 Changes in emissions and activity drivers by country, 1990–2007<sup>1</sup>

	GHG Emissions					Change in Activity drivers (%)		Population Intensity (CO <sub>2</sub> /capita) <sup>6</sup>	Intensity of the Economy (kg CO <sub>2</sub> eq per \$ GDP) <sup>5</sup>		
	(Mt CO <sub>2</sub> eq)	1990	2007	% Change from 1990	Kyoto Target (% of 1990)	Kyoto Gap <sup>4</sup> (%)	GDPe	Pop	2007	Change since 1990	2007
United States <sup>2</sup>	6 084	7 107	16.8%			146.7%	20.7%	23.6	-3.2%	0.05	-52.7%
European Community <sup>3</sup>	4 233	4 052	-4.3%	-8.0%	3.3%	140.0%	7.4%	10.4	-10.8%	0.02	-60.1%
Japan	1 208	1 374	13.8%	-6.0%	15.9%	62.7%	3.4%	10.8	10.0%	0.03	-30.0%
Germany	1 215	956	-21.3%	-21.0%	-1.8%	113.1%	3.6%	11.6	-24.0%	0.03	-63.1%
Canada	592	747	26.2%	-6.0%	33.8%	140.3%	18.7%	22.7	6.4%	0.05	-47.5%
Italy	516	553	7.1%	-6.5%	14.4%	102.3%	4.7%	9.3	2.3%	0.02	-47.1%
Australia	416	541	30.0%	8.0%	-8.5%	232.3%	23.1%	25.8	5.6%	0.05	-60.9%
France	565	536	-5.3%	0.0%	-5.0%	129.3%	8.8%	8.7	-12.9%	0.02	-58.7%
Spain	288	442	53.5%	15.0%	32.7%	207.9%	15.6%	9.9	32.8%	0.03	-50.1%
United Kingdom	926	436	-52.9%	0.0%	-52.7%	121.4%	-10.4%	9.4	-47.5%	0.24	-78.7%
Netherlands	212	208	-2.1%	-6.0%	3.6%	191.8%	9.6%	12.7	-10.7%	0.02	-66.5%
Czech Republic	195	151	-22.5%	-8.0%	-15.6%	520.7%	-0.3%	14.6	-22.3%	0.07	-87.5%
Austria	79	88	11.3%	-13.0%	27.9%	152.4%	7.8%	10.6	3.2%	0.02	-55.9%
Denmark	70	68	-3.3%	-21.0%	23.2%	152.3%	6.3%	12.5	-9.0%	0.02	-61.7%
Sweden	72	65	-9.1%	4.0%	-12.8%	96.2%	6.9%	7.2	-14.9%	0.01	-53.6%
Norway	50	55	10.8%	1.0%	9.8%	282.6%	11.0%	11.7	-0.2%	0.01	-71.0%

## Notes:

1. Since all source data are from the UNFCCC, the latest year available (at the time of writing) is 2007. This differs from the main report, which presents analysis up to the year 2008. The UNFCCC will publish data for 2008 after information has been submitted by all Parties and after the data are compiled and summarized.
2. The United States has not ratified the Kyoto Protocol and thus has no Kyoto target to reference.
3. The European Community includes the original "EU-15": Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, and United Kingdom. Only selected EU countries have been shown to illustrate those of interest.
4. A positive "Kyoto gap" indicates how far (in percentage) a country is above its emission reduction target as stipulated under the Kyoto Protocol.
5. For comparative purposes, here (only) Canada's GDP (and all others in this table) is based on the World Bank's metric, which utilizes 2000 U.S. constant dollars.
6. Population.

Sources: Population and GDP are from the World Bank Group's World Development Indicators database (<http://go.worldbank.org/1SF48T40L0>). GHG emissions are from the UNFCCC GHG emissions database ([http://unfccc.int/ghg\\_data/ghg\\_data\\_unfccc/items/4146.php](http://unfccc.int/ghg_data/ghg_data_unfccc/items/4146.php)) except for Canada, for which information is taken from Environment Canada, Canada's Greenhouse Gas Inventory, 1990–2006.

### Ancillary 3:

#### **Relationship between economic sectors and the Intergovernmental Panel on Climate Change category emissions**

In other sections of the National Inventory Report (NIR) the estimated quantities of all greenhouse gas emissions and removals are reported according to internationally accepted categories, divided among six UNFCCC sectors (Energy; Industrial Processes; Solvent and Other Product Use; Agriculture; Land Use, Land-Use Change and Forestry; and Waste).

This categorization, originally established by the Intergovernmental Panel on Climate Change (IPCC), has been used by the UNFCCC to group certain standardized estimation approaches together. It does not, however, match with the more typical economic grouping of Canadian activities, which is the approach taken to categorize the emissions for this section (Chapter 2, section B). However, the totals of GHG emissions reported elsewhere in the NIR are identical to those reported here (for each and every year from 1990 to 2008).

The following Table 2–18 demonstrates (for 2008) how emissions given by economic categories in this section match the IPCC sector and category emissions shown elsewhere in the NIR.

Table 2–18 2008 Greenhouse Gas Emissions by *National Inventory Report* category and economic category

		National Inventory Category <sup>a</sup>											
		Economic Category Total <sup>b</sup>	Energy: Fuel Combustion			Energy: Fugitive			Total	Mineral Products <sup>d</sup>	Chemical Industry <sup>e</sup>	Metal Production <sup>f</sup>	Consumption of Halocarbon and SF <sub>6</sub>
			Stationary <sup>c</sup>	Transport	Fugitive (Unintentional)	Flaring	Venting (Production and Process)						
		Mt CO <sub>2</sub> equivalent											
<b>National Inventory Total<sup>a,b</sup></b>		<b>734</b>	<b>335</b>	<b>198</b>	<b>27.6</b>	<b>5.5</b>	<b>30.8</b>	<b>597</b>	<b>8.5</b>	<b>10.7</b>	<b>15.3</b>	<b>7.3</b>	
<b>Fossil Fuel Production</b>		<b>160</b>	<b>87.5</b>	<b>8.5</b>	<b>27.6</b>	<b>5.5</b>	<b>30.8</b>	<b>160</b>					
Upstream Fossil Fuel Production <sup>c</sup>		139	71.2	8.5	23.9	5.3	29.8	139					
Conventional Oil Production		30.4	9.6		3.4	2.8	14.6	30.4					
Conventional Light Oil Production		12.2	6.2		1.5	2.3	2.2	12.2					
Conventional Heavy Oil Production		18.2	3.4		1.8	0.5	12.4	18.2					
Oil Sands (Mining, In-situ, Upgrading)		37.2	29.2	0.6	2.0	1.4	4.0	37.2					
Oil Sands Mining, Extraction and Upgrading		24.9	18.2	0.6	2.0	1.0	3.2	24.9					
In-situ Bitumen		12.2	11.0		0.0	0.5	0.8	12.2					
Natural Gas Production and Processing		56.4	32.1		12.1	1.1	11.2	56.4					
Natural Gas Production		30.7	14.7		10.9	0.7	4.4	30.7					
Natural Gas Processing		25.7	17.4		1.2	0.4	6.8	25.7					
Coal Production		1.4	0.3	0.4	0.8	0.0	0.0	1.4					
Oil and Natural Gas Transmission		13.2		7.5	5.7	0.0	0.0	13.2					
Oil Transmission		0.1		0.1	0.0	0.0	0.0	0.1					
Natural Gas Transmission		13.1		7.4	5.7	0.0	0.0	13.1					
Downstream Fossil Fuel Production		21.1	16.3		3.7	0.2	0.9	21.1					
Petroleum Refining		17.5	16.3		0.1	0.2	0.9	17.5					
Natural Gas Distribution		3.6			3.6	0.0	0.0	3.6					
<b>Electricity</b>		<b>121</b>	<b>119</b>	<b>0.0</b>				<b>119</b>				<b>1.8</b>	
Utility Generation		112	112					112					
Industry Generation		6.0	6.0					6.0					
Heat and Steam Generation		1.1	1.1					1.1					
Transmission		1.8						0.0				1.8	
<b>Transportation</b>		<b>162</b>		<b>162</b>				<b>162</b>					
Passenger Transport		99.5		99.5				99.5					
Cars		41.1		41.1				41.1					
Light Trucks		47.2		47.2				47.2					
Propane and Natural Gas Vehicles		0.9		0.9				0.9					
Motorcycles		0.3		0.3				0.3					
Bus		2.5		2.5				2.5					
Rail		0.2		0.2				0.2					
Domestic Aviation		7.5		7.5				7.5					
Freight Transport		57.4		57.4				57.4					
Heavy Duty Trucks		43.6		43.6				43.6					
Rail		6.9		6.9				6.9					
Domestic Aviation		1.1		1.1				1.1					
Domestic Marine		5.8		5.8				5.8					
Other: Recreational and Residential		4.8		4.8				4.8					
<b>Heavy Industry and Manufacturing</b>		<b>110</b>	<b>49.1</b>	<b>7.5</b>				<b>56.6</b>	<b>8.5</b>	<b>10.3</b>	<b>15.3</b>	<b>5.5</b>	
Mining		6.7	4.4	2.3				6.7					
Smelting and Refining (Non Ferrous Metals)		11.4	3.5	0.0				3.5			7.9		
Forestry, Pulp and Paper		8.5	4.6	1.2				5.9					
Forestry		1.2	0.1	1.1				1.2					
Pulp and Paper		4.7	4.5	0.2				4.7					
Iron and Steel		13.7	6.2	0.0				6.2			7.4		
Cement		10.9	4.3	0.0				4.3	6.6				
Industrial Chemicals		22.6	6.7	0.1				6.8		10.3			
Other Manufacturing		33.0	18.2	1.6				19.8	1.9			5.5	
Construction		3.6	1.3	2.3				3.6					
<b>Service Industries</b>		<b>59.4</b>	<b>34.9</b>	<b>14.2</b>				<b>49.1</b>		<b>0.3</b>			
Commercial and Institutional		56.0	33.0	12.8				45.7		0.3			
Public Administration		3.4	1.9	1.5				3.4					
<b>Residential</b>		<b>51.9</b>	<b>42.9</b>	<b>0.0</b>				<b>42.9</b>					
<b>Agriculture Production</b>		<b>70.9</b>	<b>2.1</b>	<b>6.4</b>				<b>8.5</b>					
On Farm Fuel Use		8.5	2.1	6.4				8.5					
Crop Production		22.7											
Animal Production		39.8											
<b>Land Use, Land Use Change and Forestry<sup>b</sup></b>		<b>-12.8</b>											
Forest Land - Management Practices		136											
Forest Land - Other		-154											
Cropland - Management Practices		-13.5											
Wetlands - Management Practices		0.2											
Settlements		-0.0											
Forest Conversion		18.7											

Notes: Totals may not add up due to rounding

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

b. National inventory and economic category total excludes all emissions/sinks from Land Use, Land-Use Change and Forestry sector.

c. Emissions resulting from the use of gasoline and diesel fuel in the conventional oil production and natural gas production and processing have been included in the stationary combustion column.

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

e. Chemical industry includes ammonia production, nitric acid production and adipic acid production.

f. Metal production includes iron and steel production, aluminum production, and SF<sub>6</sub> used in magnesium smelters and casters.

## National Inventory Category

Other & Undifferentiated Production	Agriculture					Waste				LULUCF <sup>b</sup>	National Inventory Total <sup>a, b</sup>	
	Total	Manure Management	Enteric Fermentation	Agriculture Soils	Total	Solid Waste Disposal on Land	Waste Water Handling	Waste Incineration	Wastewater Treatment Sludge Incineration			Total
11.1	52.9	7.5	22.5	32.4	62.4	20.5	0.9	0.2	0.0	21.7	-12.8	<b>National Inventory Total<sup>a, b</sup></b>
												<b>Fossil Fuel Production</b>
												Upstream Fossil Fuel Production <sup>c</sup>
												Conventional Oil Production
												Conventional Light Oil Production
												Conventional Heavy Oil Production
												Oil Sands (Mining, In-situ, Upgrading)
												Oil Sands Mining, Extraction and Upgrading
												In-situ Bitumen
												Natural Gas Production and Processing
												Natural Gas Production
												Natural Gas Processing
												Coal Production
												Oil and Natural Gas Transmission
												Oil Transmission
												Natural Gas Transmission
												Downstream Fossil Fuel Production
												Petroleum Refining
												Natural Gas Distribution
	1.8											<b>Electricity</b>
												Utility Generation
												Industry Generation
												Heat and Steam Generation
	1.8											Transmission
												<b>Transportation</b>
												Passenger Transport
												Cars
												Light Trucks
												Propane and Natural Gas Vehicles
												Motorcycles
												Bus
												Rail
												Domestic Aviation
												Freight Transport
												Heavy Duty Trucks
												Rail
												Domestic Aviation
												Domestic Marine
												Other: Recreational and Residential
11.1	50.8					2.6	0.1				2.7	<b>Heavy Industry and Manufacturing</b>
												Mining
	7.9					2.6					2.6	Smelting and Refining (Non Ferrous Metals)
												Forestry, Pulp and Paper
												Forestry
												Pulp and Paper
												Iron and Steel
												Cement
												Industrial Chemicals
5.5	15.8						0.1				0.1	Other Manufacturing
5.7	13.1											Construction
	0.3					9.7	0.2	0.1			10.0	<b>Service Industries</b>
	0.3					9.7	0.2	0.1			10.0	Commercial and Institutional
												Public Administration
	0					8.2	0.6	0.1	0.0	9.0		<b>Residential</b>
		7.5	22.5	32.4	62.4							<b>Agriculture Production</b>
					0.0							On Farm Fuel Use
					22.7							Crop Production
		7.5	22.5	9.8	39.8							Animal Production
												<b>Land Use, Land Use Change and Forestry<sup>b</sup></b>
											-12.8	Forest Land - Management Practices
											136	Forest Land - Other
											-154	Cropland - Management Practices
											-13.5	Wetlands - Management Practices
											0.2	Settlements
											-0.0	Forest Conversion
											18.7	

ECONOMIC CATEGORY

# Chapter 3

## Energy (CRF Sector 1)

### 3.1. Overview

Overall, the Energy Sector contributed about 81% (or 597 Mt) of Canada's total Greenhouse gas (GHG emissions in 2008 (Table 3–1). The Energy Sector accounts for all GHG (CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O) emissions from stationary and transport fuel combustion activities as well as fugitive emissions from the fossil fuel industry. Fugitive emissions associated with the fossil fuel industry are the intentional or unintentional (e.g. leaks, accidents) releases of GHGs that may result from production, processing, transmission and storage activities. Emissions from flaring activities by the oil and gas industry are reported in the Fugitive category, since their purpose is not to produce heat or to generate mechanical work (IPCC/OECD/IEA 1997).

Emissions resulting from stationary fuel combustion include, for example, the use of fossil fuels by the electricity generating industry, the oil and gas industry, the manufacturing and construction industry, and the residential and commercial sector. Only CH<sub>4</sub> and N<sub>2</sub>O emissions resulting from the combustion of biomass fuels by the pulp and paper industry and by the residential sector are accounted

for in the Energy Sector, whereas CO<sub>2</sub> emissions resulting from the use of biomass are reported as a memo item in the Common Reporting Format (CRF) tables.

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

### 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 2008, about 534 Mt (or 73%) of Canada's GHG emissions were from the combustion of fossil fuels (Table 3–1). The overall GHG emissions from fuel combustion activities

Table 3–1 GHG Emissions from Energy, Selected Years

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)				
	1990	2005	2006	2007	2008
<b>Energy Sector</b>	<b>469 000</b>	<b>593 000</b>	<b>581 000</b>	<b>614 000</b>	<b>597 000</b>
<b>Fuel Combustion (1.A)</b>	<b>427 000</b>	<b>528 000</b>	<b>515 000</b>	<b>549 000</b>	<b>534 000</b>
Energy Industries (1.A.1)	147 000	191 000	183 000	195 000	187 000
Manufacturing Industries and Construction (1.A.2)	63 100	64 600	65 100	73 900	68 500
Transport (1.A.3)	145 000	192 000	191 000	199 000	198 000
Other Sectors (1.A.4)	71 600	80 400	75 100	80 700	79 900
<b>Fugitive Emissions from Fuels (1.B)</b>	<b>42 700</b>	<b>64 700</b>	<b>65 800</b>	<b>64 700</b>	<b>63 800</b>

Note: Totals may not add up due to rounding.

have increased by 25% since 1990 and have decreased by 3% since 2007. Between 1990 and 2008, combustion-related emissions from the Energy Industries and from the Transport category increased by about 27% and 36%, respectively (Figure 3–1).

## 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 2008, the Energy Industries subsector accounted for 187 Mt (or about 25%) of Canada's total GHG emissions, an increase of about 27% since 1990. The Public Electricity and Heat Production subsector accounted for 64% (or 119 Mt) of the Energy Industries' GHG emissions, while Petroleum Refining and the Manufacture of Solid Fuels and Other Energy Industries contributed 8.7% (16 Mt) and 28% (52 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 in the electricity generation industry and the production, processing and refining of fossil fuels. All of the emissions associated with the fossil fuel industry are estimated, although a portion of emissions from coal mining and from oil and gas extraction associated with the Petroleum Refining and the Manufacture of Solid Fuels and Other Energy Industries categories have been allocated to the Manufacturing Industries and Construction—Mining and the Transport—Other subsectors, because fuel consumption data at a lower level of disaggregation are not available. Combustion emissions associated with the pipeline transmission of oil and natural gas are included under Other Transportation according to the revised 1996 IPCC guidelines (IPCC/OECD/IEA 1997).

Although actually associated with the Energy Industries, emissions from venting and flaring activities related to the production, processing and refining of fossil fuels are reported as fugitive emissions (refer to Section 3.2).

Figure 3–1 GHG Emissions from Fuel Combustion, 1990–2008

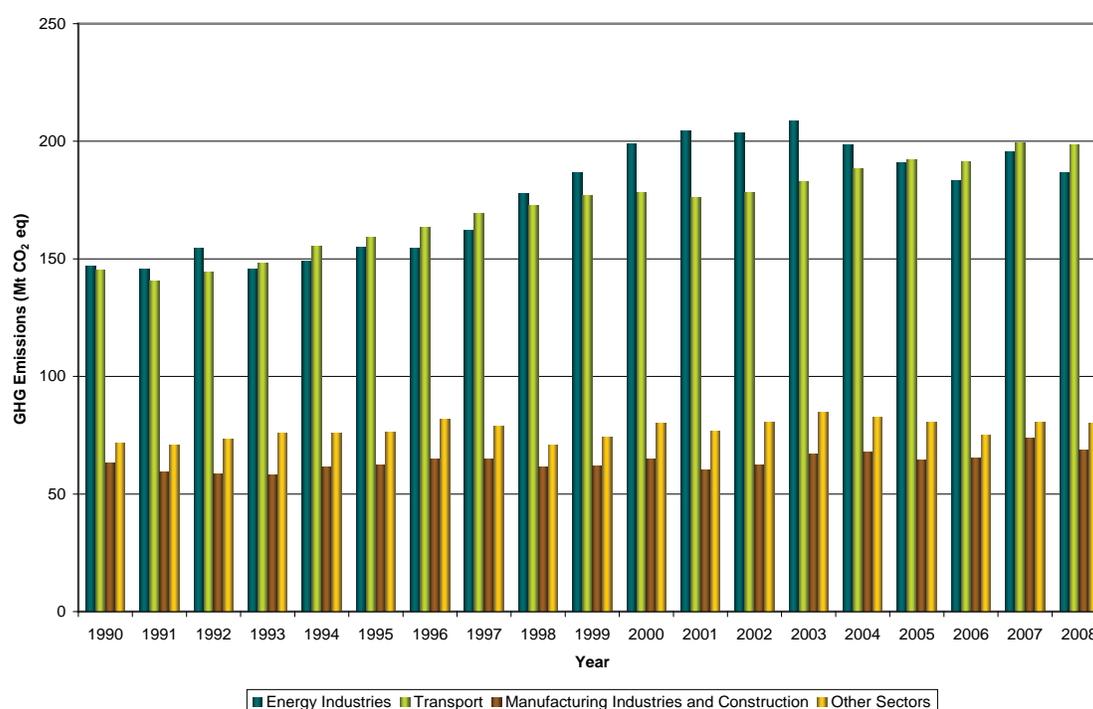


Table 3–2 Energy Industries GHG Contribution

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)				
	1990	2005	2006	2007	2008
<b>Energy Industries TOTAL (1.A.1)</b>	<b>147 000</b>	<b>191 000</b>	<b>183 000</b>	<b>195 000</b>	<b>187 000</b>
<b>Public Electricity and Heat Production</b>	<b>95 500</b>	<b>125 000</b>	<b>117 000</b>	<b>125 000</b>	<b>119 000</b>
Electricity Generation—Utilities	92 500	118 800	110 200	118 000	111 600
Electricity Generation—Industry	2 200	4 500	5 400	5 900	6 000
Heat/Steam Generation	700	1 400	1 400	1 300	1 100
<b>Petroleum Refining</b>	<b>16 000</b>	<b>17 000</b>	<b>16 000</b>	<b>18 000</b>	<b>16 000</b>
<b>Manufacture of Solid Fuels and Other Energy Industries</b>	<b>36 000</b>	<b>49 000</b>	<b>50 000</b>	<b>52 000</b>	<b>52 000</b>

Note: Totals may not add up due to rounding.

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

The Public Electricity and Heat Production category includes emissions associated with the production of electricity and heat from the combustion of fuel in thermal power plants in both the public and private sectors. The estimated GHG emissions from this sector also include emissions from industrial generation, as fuel consumption data are not available at the appropriate level of disaggregation to support further division and reallocation to the specific industrial sectors.

The electric 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.

Two systems are used to generate electricity using thermal combustion:

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

Steam turbine boilers are fired with coal, petroleum coke, heavy fuel oil, natural gas or biomass. For turbine engines, the initial heat may be generated from natural gas and refined petroleum products (RPPs—e.g. light fuel oil or diesel fuel). Reciprocating engines can use natural gas and/or

a combination of RPPs, whereas gas turbines are also fired with natural gas or RPPs.

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

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

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

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

versa for a portion of the emissions associated with bitumen upgrading in the oil sands industry). Refer to Annex 2 for additional details on the method used to disaggregate the activity data.

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

The Manufacture of Solid Fuels and Other Energy Industries category comprises fuel combustion emissions associated with the crude oil, natural gas, oil sands mining, bitumen extraction and upgrading, and coal mining industries. A portion of emissions associated with coal mining and with the oil and gas mining and extraction component of the fossil fuel industry are reported in the Manufacturing Industries and Construction–Mining category, whereas emissions associated with pipeline transmission and with the use of transport fuels (such as gasoline and diesel oil) in the mining and the oil & 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 (i.e. thermal extraction). The synthetic (or upgraded) crude oil has a hydrocarbon composition similar to that of conventional crude oil, which can be refined to produce RPPs such as gasoline and diesel oil. Upgrading facilities also rely on internally generated fuels such as process gas and natural gas for their operation, which result in both combustion- and fugitive-related emissions.

#### **3.2.1.2. Methodological Issues**

Emissions for all source categories are calculated following the methodology described in Annex 2 and are primarily based on fuel consumption statistics reported in the *Report on Energy Supply–Demand in Canada* (RES—Statistics Canada #57-003), with additional information from the *Electric Power Generation, Transmission and Distribution* (EPGTD) publication (Statistics Canada #57-202). LFG utilization estimates are provided by the Waste Sector. The method is consistent with the IPCC Tier 2 approach, with country-specific emission factors.

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

The revised 1996 IPCC guidelines (IPCC/OECD/IEA 1997)

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

Overall, emissions associated with electricity generated by industry made up 2.3% of the Public Electricity and Heat Production category's emissions in 1990 and 5.1% in 2008.

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

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

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

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

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

The estimated uncertainty for the Energy Industries sub-sector ranges from -4% to +6% for all gases and from -6%

to +2% for CO<sub>2</sub> alone (ICF Consulting 2004).

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

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

Approximately 83% of the 2008 emissions from the Manufacture of Solid Fuels and Other Energy Industries category are associated with natural gas production and processing. The uncertainty for this category is influenced by the CO<sub>2</sub> emission factors (±6%) and CH<sub>4</sub> emission factors (0% to +240%) for the consumption of unprocessed natural gas. A national weighted emission factor was used to estimate emissions for the natural gas industry due to a lack of plant-level information, such as the physical composition of unprocessed natural gas (which will vary from plant to plant). Thus, the overall uncertainty estimate is based on a rather broad assumption as well.

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

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

#### 3.2.1.4. QA/QC and Verification

Quality control (QC) checks were done in a form consistent with IPCC 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.

Activity data revisions primarily affecting historical data were identified during the review and corrected. The level of trend analysis and assessment has been improved through the use of additional sources of data for comparison purposes, such as facility-level GHG emissions reporting via Environment Canada's mandatory reporting program for major emitters. No 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.

#### 3.2.1.5. Recalculations

The 2007 fuel-use data were revised by Statistics Canada and estimates were recalculated accordingly.

Refer to Chapter 9 for additional discussions on sectoral recalculations.

#### 3.2.1.6. Planned Improvements

A review of coal emission factors continues, based on detailed data analysis for coal mined in Canada. This multi-year review is being conducted with support from the Geological Survey of Canada, an agency of Natural Resources Canada, and may result in revised and updated emission factors for all years and provinces. The energy industries are the major consumers of coal, and any revisions will have the greatest impact in these categories.

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

#### 3.2.2.1. Source Category Description

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

In 2008, the Manufacturing Industries and Construction subsector accounted for 68.5 Mt (or 9.3%) of Canada's total GHG emissions, with a 9% (5.4 Mt) increase in overall emissions since 1990 (refer to Table 3–3 for more details). Within the Manufacturing Industries and Construction subsector, more than 47 Mt (or 69%) of the GHG emissions are from the Others category. This category is followed by (in order of decreasing contributions) the Chemical Industries; Iron and Steel; Pulp, Paper, and Print; and Non-Ferrous Metals categories, at 6.7 Mt (or 9.8%), 6.2 Mt (or 9.0%), 4.5 Mt (or 6.6%) and 3.5 Mt (or 5.1%), respectively. Emissions from Food Processing, Beverages and Tobacco are included in the Other Manufacturing subcategory due to fuel-use data not being available at the appropriate level of disaggregation.

The Others category is made up of cement, mining, construction and other manufacturing activities.

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

use data at the appropriate level of disaggregation are not available (see Section 3.2.1).

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

### 3.2.2.2. Methodological Issues

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

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

Canada has 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, blast furnace, coke oven). As such, emissions from coke production are included in the

Table 3–3 Manufacturing Industries and Construction GHG Contribution

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)				
	1990	2005	2006	2007	2008
Manufacturing Industries and Construction TOTAL (1.A.2)	63 100	64 600	65 100	73 900	68 500
Iron and Steel	6 480	6 450	6 220	6 920	6 170
Non-Ferrous Metals	3 190	3 270	3 230	3 490	3 480
Chemicals	7 100	6 400	6 820	7 230	6 690
Pulp, Paper and Print	13 700	7 180	5 860	5 870	4 540
Food Processing, Beverages and Tobacco <sup>1</sup>	IE	IE	IE	IE	IE
Others	32 500	41 300	43 000	50 400	47 600
Cement	3 830	4 890	5 070	4 750	4 280
Mining	6 190	15 600	16 800	23 200	23 900
Construction	1 870	1 360	1 300	1 290	1 260
Other Manufacturing	20 700	19 400	19 800	21 200	18 200

Notes:

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

IE = included elsewhere.

Totals may not add up due to rounding.

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 (Statistics Canada #57-003). 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 construction, cement, vehicle manufacturing, textiles, mining, food, beverage and tobacco sectors. Consumption of diesel fuels associated with on-site off-road vehicles in mining (which also includes oil and gas mining and extraction use of diesel) have been allocated to the Other Transportation category.

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

The estimated uncertainty for the Manufacturing Industries and Construction subsector ranges from -3% to +6% for all gases and from -3% to +2% for CO<sub>2</sub> (ICF Consulting 2004).

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.

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, since these assumptions were not reviewed by industry experts, owing to a lack of available time in the study's preparation.

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

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

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**

The 2007 fuel-use data were revised by Statistics Canada and estimates were recalculated accordingly.

Refer to Chapter 9 for additional discussions on sectoral recalculations.

#### **3.2.2.6. Planned Improvements**

As a continuous improvement activity, 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 27% of Canada's total GHG emissions (198 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 116% (24.1 Mt) for LDGTs and 90% (18.7 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 and heavy-duty gasoline vehicles (HDGVs), for a combined decrease of 7.7 Mt since 1990. Generally, emissions from the Transport subsector have increased 36% and have contributed the equivalent of 37% 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 A2-1 in Annex 2. However, because of the many different types of vehicles, activities and fuels, the emission factors are numerous and complex. In order to cope with the complexity, transport emissions are calculated using Canada's Mobile Greenhouse Gas Emission Model (MGEM). This model incorporates a version of the IPCC-recommended methodology for vehicle modelling (IPCC/OECD/IEA 1997) and is used to calculate all transport emissions with the exception of those associated with pipelines (energy necessary to propel oil or natural gas).

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

This category includes all GHG emissions from domestic air

Table 3–4 Transport GHG Contribution

GHG Source Categories	1990	2005	2006	2007	2008
			<i>kt CO<sub>2</sub> eq</i>		
Transport TOTAL (1.A.3.)	145 000	192 000	191 000	199 000	198 000
Civil Aviation (Domestic Aviation)	6 400	7 900	7 700	8 800	8 500
Road Transport	98 400	131 000	133 000	136 000	135 000
Light-duty Gasoline Vehicles	45 800	39 900	39 900	41 000	40 600
Light-duty Gasoline Trucks	20 700	43 100	43 600	44 800	44 800
Heavy-duty Gasoline Vehicles	7 810	6 300	6 430	6 620	6 660
Motorcycles	146	252	256	264	264
Light-duty Diesel Vehicles	355	432	435	448	446
Light-duty Diesel Trucks	707	2 130	2 230	2 320	2 370
Heavy-duty Diesel Vehicles	20 700	38 100	38 900	40 000	39 400
Propane & Natural Gas Vehicles	2 200	720	790	830	880
Railways	7 000	6 000	6 000	7 000	7 000
Navigation (Domestic Marine)	5 000	6 400	5 800	6 100	5 800
Other Transport	29 000	41 000	39 000	41 000	41 000
Off-road Gasoline	6 700	7 300	6 700	7 100	6 300
Off-road Diesel	15 000	23 000	23 000	25 000	28 000
Pipelines	6 850	10 100	9 610	8 940	7 460

Note: Totals may not add up due to rounding.

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

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

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

The methodology used to estimate road transportation GHG emissions follows 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). The MGEM disaggregates vehicle data and calculates emissions of CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O from all mobile sources except pipelines (refer to Annex 2 for a description of the methodology).

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

The methodology used to estimate GHG emissions from railways is considered to be an IPCC Tier 1 (IPCC/OECD/IEA 1997) methodology. Emission estimates are performed within MGEM. Fuel consumption data from the RESD (Statistics Canada #57-003), reported under railways, are multiplied by 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 domes-

tic 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 allow accurate disaggregation of domestic and international marine emissions are being investigated (refer to Section 3.2.3.6 Planned Improvements).

The emission estimation methodology is considered to be an IPCC Tier 1 approach (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>1</sup> (ground, non-rail vehicles and equipment) includes GHG emissions resulting from both gasoline and diesel fuel 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 fuel in non-road vehicles. The mining and construction industries (including coal, oil and natural gas mining and extraction activities) both operate significant numbers of heavy non-road vehicles and are the largest diesel fuel users in the group.

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

#### *Pipeline Transport*

<sup>1</sup> Referred to as non-road or off-road vehicles. The terms “non-road” and “off-road” are used interchangeably.

Pipelines<sup>2</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 fuel, is also used 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 (Statistics Canada #57-003), 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 to more accurately reflect uncertainties in the latest Transport subsector emissions estimates. Modifications to the 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. 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 Subsector Fossil Fuel Combustion

The Transport subsector comprises 1) the mobile sources of transport, including on-road and off-road vehicles, railways, civil aviation and navigation; and 2) pipeline transport. The overall uncertainty of the 2008 estimates for the mobile Transport subsector (not including pipelines) was estimated to be between -2.4% and +5.4%.

The uncertainty for Transport fuel combustion CO<sub>2</sub> emissions was ±1%. In contrast, and similar to the stationary fuel combustion sources, CH<sub>4</sub> and N<sub>2</sub>O emission uncer-

tainty ranges were one to two 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 the 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 -3% to +16%. This implied the source category was more likely underestimated than overestimated. The high uncertainties associated with jet kerosene CH<sub>4</sub> and N<sub>2</sub>O emissions factor (-90% to +900%) 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 subsector only contributed approximately 4% 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 ±2%, 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 71% of the Transport subsector's GHG emissions were attributable to road transportation. Accordingly, the Transport subsector's relatively low inventory uncertainty is justified through the results of the Road Transportation subsector uncertainty analysis.

### Emissions from Railways

The uncertainty associated with emissions from rail transport was estimated to be between -11% and +31%, indicating that this subsector 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.

<sup>2</sup> Consisting of both oil and gas types.

### Emissions from Navigation (Domestic Marine)

The uncertainty associated with emissions from the domestic marine source category ranged from -6% to +16%, suggesting that GHGs were underestimated. The greatest influence was exerted by the high N<sub>2</sub>O emission factor uncertainty (-90% to +900), 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 Transport subcategory includes both off-road gasoline and off-road diesel consumption. The uncertainty associated with the off-road mobile transport sources ranged from -9% to +26%, indicating that the 2010 submission likely underestimates total emissions from this subsector. Consistent with the inventory estimation methodology for this source category, off-road diesel fuel consumption is calculated from the on-road diesel fuel 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 fuels (-90% to +900%) which indicated a downward bias in the GHG estimate. Approximately 18% of the Transport subsector's GHG emissions were attributable to off-road transportation and therefore 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 the 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.

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, there are indications that the underlying data may be compiled incorrectly. 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. Recently, 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 publishes the *Canadian Vehicle Survey (CVS)*, a quarterly report that provides both vehicle population and VKTs in aggregated regional classes. It provides alternative interpretation of provincial registration files and can therefore corroborate the commercially available data sets mentioned above. Unfortunately, the resolution necessary for emission modelling is unavailable from the CVS, and therefore it cannot replace the annually purchased data sets.

### 3.2.3.5. Recalculations

Transportation estimates were revised for the year 2007 due to the following factors:

*Statistics Canada fuel consumption data:* A revised data set

for 2007 was received. Minor adjustments resulted for that year.

*Statistics Canada taxed fuel sales data:* Revised data set for 2007 was received. Minor adjustments resulted for those years.

*Statistics Canada air carrier traffic at Canadian airports and Canadian civil aviation data:* Revised data set for 2007 was received. Minor reallocations between domestic (civil) and international (bunker) aviation are observed for those years.

### 3.2.3.6. Planned Improvements

The transportation model (MGEM) was upgraded in 2009–2010 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 following:

- The development of better on-road activity data. Interdepartmental partnerships have been established among Environment Canada, Transport Canada and Natural Resources Canada to develop common and better on-road activity data. Some work is now being done on decoding the vehicle identification numbers (VINs). This work will hopefully allow us to use provincial registration files and obtain a better representation of the Canadian fleet.kilometre accumulation rates (KARs). Fuel consumption ratios (FCRs) are also being evaluated to make sure that what we use represents the Canadian situation accurately.
- The development of a Tier 3a model to estimate aircraft emissions based on origin-destination data and aircraft-specific emission factors. Modellers now have aircraft movement data for the entire time series and are working on the introduction of the data into the model. Once completed the emission estimates generated will be compared against other known models and sources of data to ensure consistency. The T3a model will allow a more accurate disaggregation of emissions between civil aviation (domestic aviation) and aviation bunkers (international aviation).
- The development of an improved model to estimate marine emissions. Recently, interdepartmental partnerships have been established among Environment Canada, Transport Canada and the marine industry to develop a bottom-up marine model. Environment Canada's focus for this model is to better represent the disaggregation between domestic and international marine traffic.

## 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>3</sup> combustion is a significant source of emissions in the residential sector, and CH<sub>4</sub> and N<sub>2</sub>O emissions are included in the subsector estimates. However, CO<sub>2</sub> emissions from biomass combustion are reported separately in the CRF tables as memo items and are not included in Energy Sector totals. This method is consistent with the treatment of biomass in the Pulp, Paper and Print subsector.

In 2008, the Other Sectors subsector contributed 79.9 Mt (or 13%) of Canada's total GHG emissions, with an overall growth of about 12% (8.4 Mt) since 1990. Within the Other Sectors subsector, residential emissions contributed about 42.9 Mt (or 54%), followed by a 34.9 Mt (or 44%) contribution from the Commercial/Institutional category, which also includes emissions from the public administration sector (i.e. federal, provincial and municipal establishments). Since 1990, GHG emissions have grown by about 36% in the Commercial/Institutional category, while GHG emissions in the Residential category have remained almost constant, decreasing by about 1.4%. 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.

<sup>3</sup> Typically firewood.

Table 3–5 Other Sectors GHG Contribution

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)				
	1990	2005	2006	2007	2008
Other Sectors TOTAL (1.A.4)	71 600	80 400	75 100	80 700	79 900
Commercial/Institutional	25 700	36 700	33 400	34 900	34 900
<i>Commercial and Other Institutional</i>	23 700	34 600	31 600	32 900	33 000
<i>Public Administration</i>	1 980	2 050	1 820	2 010	1 920
Residential	43 500	41 800	39 800	43 500	42 900
Agriculture/Forestry/Fisheries	2 400	2 000	1 900	2 200	2 200
<i>Forestry</i>	50	100	100	100	100
<i>Agriculture</i>	2 300	1 800	1 800	2 100	2 100

Note: Totals may not add up due to rounding.

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

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

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

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

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

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

tor ranges from -4% to +41% for all gases and from -3% to +2% for CO<sub>2</sub> (ICF Consulting 2004).

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

These estimates are consistent over the time series.

#### 3.2.4.4. QA/QC and Verification

The Other Sectors subsector 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. 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 2007 fuel-use data were revised by Statistics Canada and estimates were recalculated accordingly.

### 3.2.4.6. Planned Improvements

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

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

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

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

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

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

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

In 2008, the Fugitives category accounted for about 63.8 Mt (or 8.7%) of Canada's total GHG emissions, with about a 50% growth in emissions since 1990. Between 1990 and 2008, fugitive emissions from oil and natural gas increased 55% to 63.1 Mt, and those from coal decreased by about 1.2 Mt from 2 Mt in 1990. The oil and gas production, processing, transmission and distribution activities contributed 99% of the fugitive emissions. Refer to Table 3–6 for more 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 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.

Table 3–6 Fugitive GHG Contribution

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)				
	1990	2005	2006	2007	2008
Fugitive Emissions from Fuels (1.B)	42 700	64 700	65 800	64 700	63 800
Solid Fuels—Coal Mining (1.B.1)	2 000	700	700	800	800
Oil and Natural Gas (1.B.2)	40 700	64 000	65 100	64 000	63 100
a. Oil <sup>1</sup>	4 200	5 700	5 700	5 800	5 500
b. Natural Gas <sup>1</sup>	12 900	20 800	21 400	21 300	21 300
c. Venting and Flaring <sup>2</sup>	23 700	37 400	38 000	36 900	36 200
Venting	19 300	32 000	32 000	31 600	30 800
Flaring	4 400	5 500	6 000	5 300	5 500

Notes:

1. All other fugitives except venting and flaring.

2. Both oil and gas activities.

Totals may not add up due to rounding.

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

There were no recalculations required for fugitive emissions from coal mining.

### 3.3.1.6. Planned Improvements

In the long-term, a comprehensive study of coal mining in Canada is planned, with the goal of improving aspects of the model, such as new emission factors.

## 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, heavy oil/bitumen upgrading, natural gas transmission and natural gas distribution. Fuel combustion emissions from facilities in the oil and gas industry (when used for energy) are included under the Petroleum Refining and the Manufacture of Solid Fuels and Other Energy Industries categories (Section 3.2.1).

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

### Conventional Oil and Gas Production

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

duce hydrogen, and accidents, spills and deliberate vents.

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

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

*Oil and Gas Well Servicing and Associated Testing:* Well servicing is also a minor emission source. The emissions are mainly from venting, flaring and fuel combustion, which are included in the Stationary Combustion 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.

*Crude Bitumen Production:* Crude bitumen is a highly viscous, dense liquid that cannot be removed from a well using primary production means. Enhanced heavy oil recovery is required to recover the hydrocarbons from the

formation. The sources of emissions are wells, flow lines, satellite batteries and cleaning plants. The main source of emissions is the venting of casing gas.

*Gas Processing:* Natural gas is processed before entering transmission pipelines to remove water vapour, contaminants and condensable hydrocarbons. There are four different types of plants: sweet plants, sour plants that flare waste gas, sour plants that extract elemental sulphur, and straddle plants. Straddle plants are located on transmission lines and recover residual hydrocarbons. They have a similar structure and function and so are considered in conjunction with gas processing. The largest source of emissions is equipment leaks.

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

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

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

*Surface Casing Vent Blows and Gas Migration:* At some wells, fluids will flow into the surface casing from the surrounding formation. Depending on the well, the fluids will be collected, sealed in the casing, flared or vented. The vented emissions are estimated in this section. At some wells, particularly in the Lloydminster (Alberta) region, gas may migrate outside of the well, either from a leak in the production string or from a gas-bearing zone that was

penetrated but not produced. The emissions from the gas flowing to the surface through the surrounding strata have been estimated.

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

### Unconventional Oil Production

This category includes emissions from oil sand open pit mining operations, *in situ* bitumen extraction, and heavy oil/bitumen upgrading to produce bitumen, synthetic crude oil and other derived products for sale. Fugitive emissions are primarily from hydrogen production, flue gas 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.

### 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

### Conventional Oil and Gas Production

#### *Upstream Oil and Gas Production*

Fugitive emission estimates from the conventional upstream oil and gas (UOG) industry are based on the

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

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

A multitude of data were collected and used in the study. These included activity data from the facilities, such as process and equipment data. Emission factors were obtained from a variety of sources: published reports, such as 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 2001–2008 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 by Clearstone Engineering Ltd. 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).

#### *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.

### 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, whereas the emissions for 2003–2007 were estimated using the respective data in the report and the petroleum refinery energy consumption data from the RESD as published by Statistics Canada (#57-003). A detailed description of the methodology used to estimate emissions from 1991 to 1993 and from 2003 onward can be found in Annex 3.

### Unconventional Oil Production

Sources of GHG emissions from unconventional oil production include oil sands mining, heavy oil/bitumen extraction and heavy oil upgraders, and integrated cogeneration facilities. Fugitive emissions for the oil sands mining and heavy oil upgrading industries are from the bitumen study, *An Inventory of GHGs, CACs, and H<sub>2</sub>S Emissions by the Canadian Bitumen Industry: 1990 to 2003* (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* oil sands extraction to produce heavy oil/bitumen for sale and for upgrading to synthetic oil and other products are from CAPP's UOG study (CAPP 2005a).

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

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: *Mineable Alberta Oil Sands Annual Statistics ST43* from the Energy Resources Conservation Board (previously known as the Alberta Energy and Utilities Board) (ERCB 2009) and the National Energy Board's (1998–2008) 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.

Emissions for new oil sands facilities such as CNRL and Petro-Canada Fort Hills have been estimated using activity data from the ERCB (2009) and emission factors from similar facilities.

### 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.

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

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

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

## Conventional Oil and Gas Production

### Upstream Oil and Gas Production

The UOG fugitive emissions for 2000 are taken directly from CAPP's UOG study (CAPP 2005a). The emissions from 1990–1999 and from 2001–2008 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 IPCC (2000), there are three sources of uncertainties: definitions, natural variability of the process that produces the emissions and the assessment of the process or quantity. Only the last two sources of uncertainty were considered in the analysis: it was assumed that the uncertainties from the definitions were negligible, as they were adequately controlled through QA/QC procedures. The uncertainty 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.

The emission data used in the inventory for fugitive emissions from refineries for 1990 and for 1994–2002 are directly from the CPPI (2004) study. The uncertainty for the 1991–1993 and the 2003–2008 is greater 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  $\pm 8.3\%$ . The Tier 2 analysis determined that the overall uncertainty was  $\pm 14\%$ . The difference between the Tier 1 and Tier 2 uncertainties may be due to the high level of variability in some of the emission factors. The uncertainty results can be found in Table 3–9.

### Unconventional Oil Production

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

## Downstream Oil and Gas Production

Table 3–7 Uncertainty in Oil Production Industry Fugitive Emissions

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

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

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

Source: CAPP (2005b).

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

### 3.3.2.4. QA/QC and Verification

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

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

- Oil and Natural Gas Industries
- 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 year 2007 were recalculated using updated refinery total energy use data from Statistics Canada. This resulted in an approximately 0.1 Mt increase in CO<sub>2</sub> emissions.

*Upstream Oil and Gas:* Updated 2007 activity data from various sources, including Statistics Canada and several provincial and industry reports, were utilized in the Upstream Oil and Gas (UOG) extrapolation model. These updates were implemented in order to improve accuracy and ensure consistency with the most up-to-date data available. The adjustments resulted in a decrease in UOG emission estimates of approximately 0.3 Mt CO<sub>2</sub> eq (less

than 1%) for 2007.

### 3.3.2.6. Planned Improvements

*Petroleum Refining:* There are planned changes in the methodology of the model for future reporting years. The current model calculates fugitive emissions using total refinery energy use; future improvements to the model will estimate emissions based on quantity of refinery output.

*Upstream Oil and Gas:* A study is being commissioned to update the UOG study (CAPP 2005a).

*Bitumen/Oil Sands:* 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, extraction 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.C1)

According to the revised 1996 IPCC guidelines (IPCC/OECD/IEA 1997), emissions resulting from fuels sold for international marine and aviation transportation should

Table 3–10 GHG Emissions from Domestic and International Aviation, 1990, 2005–2008

	GHG Emissions (kt CO <sub>2</sub> eq)				
	1990	2005	2006	2007	2008
Aviation Bunkers (International)	7 100	10 200	10 100	9 300	9 200
Civil Aviation (Domestic)	6 400	7 900	7 700	8 800	8 500
<b>Total</b>	<b>13 400</b>	<b>18 100</b>	<b>17 800</b>	<b>18 100</b>	<b>17 800</b>

Note: Totals may not add up due to rounding.

not be included in national inventory totals, but should be reported separately as emissions from “bunkers” or “international bunkers.” Historically, in the Canadian inventory, any fuel reported by Statistics Canada as having been sold to foreign-registered marine or aviation carriers was excluded from national inventory emission totals.

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

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

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

represents the total fuel allocated to international aviation.

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

The development of a Tier 3a model, as mentioned in Section 3.2.3.6., will allow a more accurate disaggregation of emissions between civil aviation (domestic aviation) and aviation bunkers (international aviation).

#### 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

Table 3–11 GHG Emissions from Domestic and International Navigation, 1990, 2005–2008

	GHG Emissions (kt CO <sub>2</sub> eq)				
	1990	2005	2006	2007	2008
Marine Bunkers (International)	3 100	2 000	1 800	2 100	1 800
Navigation (Domestic)	5 000	6 400	5 800	6 100	5 800
<b>Total</b>	<b>8 200</b>	<b>8 400</b>	<b>7 600</b>	<b>8 300</b>	<b>7 600</b>

Note: Totals may not add up due to rounding.

## from Biomass

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

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

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

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

1. Conventional stoves
  - non-airtight
  - airtight, non-advanced technology
  - masonry heaters
2. Stove/fireplace inserts with advanced technology or catalyst control
  - advanced-technology fireplaces
  - advanced-technology stoves
  - catalytic fireplaces
  - catalytic stoves
3. Conventional fireplaces
  - without glass doors
  - with non-airtight glass doors
  - with airtight glass doors

4. Furnaces
  - wood-burning fireplaces
5. Other equipment
  - other wood-burning equipment

The firewood consumption data for the other years were extrapolated based on the number of houses in each province using wood as a principal or supplementary heat source (from Statistics Canada 1995) in relation to 1995. The emission factors for CO<sub>2</sub> are from an Environment Canada study (ORTECH Corporation 1994) and assume a moisture content of 50%. The N<sub>2</sub>O and CH<sub>4</sub> emission factors for different wood-burning appliances are from the U.S. Environmental Protection Agency's *AP 42, Supplement B* (U.S. EPA 1996). These emissions are included in the fuel combustion sector of the inventory.

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

### 3.4.2.2. Industrial Wood Wastes

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

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

Industrial firewood N<sub>2</sub>O emission factors are those assigned to wood fuel and to wood waste (Rosland and Steen 1990; Radke et al. 1991) (see Annex 8).

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

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

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

$$EF = 0.41 \times 0.95 \times \left( \frac{44 \text{ g/mol}}{12 \text{ g/mol}} \right)$$

$$EF = \frac{1.428 \text{ t CO}_2}{\text{t spentpulpingliquor}}$$

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

### 3.4.2.3. Fuel Ethanol

Amounts of fuel ethanol used in transportation (TFIS Inc. 2008) 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.

Fuel ethanol was introduced and modelled as if it were

Table 3–12 Ethanol Used for Transport in Canada, 2005–2008

Year	1990	2005	2006	2007	2008
Ethanol Consumed (ML)	7	462	482	1 110	1 110

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 (TFIS Inc. 2008) are presented 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 petrodiesel for the region(s). Total fuel avail-

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

Year	1990	2005	2006	2007	2008
Biodiesel Consumed (ML)	0	2	29	43	43

able 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 petrodiesel 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 petrodiesel 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, anthropogenic CO<sub>2</sub> is used as a flooding agent in enhanced oil recovery (EOR) operations to increase crude oil production volume at 2 depleting oil reservoirs. CO<sub>2</sub> flooding started in 2000 at the Encana Weyburn site and in 2005 at the Apache Midale site in order to extend the life of these mature reservoirs by another 30 years (Mourits 2008). CO<sub>2</sub> is purchased from the Dakota Gasification Company located in North Dakota (US), transported via pipeline to the field and 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 (Mourits 2010). The Weyburn site has, from 2000 to 2009, been injecting about 15 Mt of fresh CO<sub>2</sub> as purchased from the Dakota gasification plant with a current injection rate of 6500 t of CO<sub>2</sub> per day. From 2005 to 2009, the Midale site has been injecting about 1.91 Mt of fresh CO<sub>2</sub> with an injection rate of 1165 t of CO<sub>2</sub> per day.

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 which were previously occupied by hydrocarbon molecules and 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 lead 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's 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 will focus 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>.

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

Canada exports a great deal of its produced fossil fuel resources, mostly to the United States. In 2008, Canada exported approximately 58% (energy equivalent) of its gross (or 40% of its net) natural gas and crude oil production. Emissions associated with the import/export of crude oil and natural gas are estimated using the updated "Fossil Fuel Import and Export" models (Smyth 2010; Environment Canada 2008). The methodology used in the updated models is based on McCann (1997) which, prior to the 2009 submission, had been used to estimate these emissions. The new methodology uses pre-existing models currently used in assembling the national emission estimates as well as annually updated activity data from a variety of sources. (See also Executive Summary).

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

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are allocated to this category. Any gas equipment that is dedicated to servicing on-site fuel needs is part of the oil system. Gas conservation systems that collect emissions in a gas-gathering system are allocated to the natural gas system.

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

# 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 greenhouse gases, including CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, and PFCs, can be released (IPCC/OECD/IEA 1997). Certain halocarbons (HFCs and PFCs) and SF<sub>6</sub> are also consumed in industrial processes or used as alternatives to ozone-depleting substances (ODS) in various applications; these emissions are also included in the Industrial Processes Sector.

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

The processes addressed in the Industrial Processes Sector include production and use of mineral products, metal production, chemical production, consumption of SF<sub>6</sub>, halocarbon production and use as alternatives to ozone-depleting substances, and other and undifferentiated production using fossil fuels for non-energy purposes.

CO<sub>2</sub> emissions resulting from the use of fossil fuels as feedstock for the production of chemical products other than ammonia, nitric acid, adipic acid and fuels used as reductants in the mining and processing of non-ferrous metals

are reported in the Other and Undifferentiated Production subsector (Section 4.16).

Indirect GHG (such as CO, NMVOC and SO<sub>2</sub>) emissions from industrial process activities including asphalt roofing, road paving with asphalt, pulp and paper production, and production of food and drink have not been estimated. These emissions, along with the indirect GHG emissions associated with energy activities, are reported under Annex 10 of this National Inventory Report.

As shown in Table 4–1, GHG emissions from the Industrial Processes Sector contributed 52.6 Mt to the 2008 national GHG inventory, compared with 54.8 Mt in 1990. These emissions represented 7.2% of the total Canadian GHG emissions in 2008. The contributing factors of the long-term and short-term trends in this sector are discussed in Chapter 2, and highlights of these are provided below.

Between 1990 and 2008, N<sub>2</sub>O emissions from the adipic acid industry had been considerably reduced (-76% or -8.3 Mt CO<sub>2</sub> eq) due to the use of an emission abatement system at Invista's plant in Maitland, Ontario, since 1997. It should be noted that the plant has, however, been indefinitely idled as of spring 2009. Aluminium producers have also decreased their PFC emissions (-66% or -4.3 Mt CO<sub>2</sub> eq) by means of emission control technologies, while doubling their production volume. In addition, the industry has tried to gradually reduce its use of the old Soderberg production technology. For the category of Magnesium Production, the replacement of SF<sub>6</sub> with alternatives could explain the drop in emissions for one of the major plants between 1990 and 2005. For more recent years (i.e. 2006 onwards), the emission decrease was mainly due to a decrease in production and, hence, a decrease in SF<sub>6</sub> use, in anticipation of plant closures (one at the beginning of 2007 and another in August 2008). Also worth mentioning is that the 1990 estimate for the Iron and Steel industry was lower than it would normally be due to a strike. The decrease (over the long term) has been, in fact, greater since 1991.

The emission decreases mentioned above were partly offset by significant increases in emissions from other sources between 1990 and 2008. For instance, emissions from consumption of halocarbons have grown by 1050% or 5.0 Mt CO<sub>2</sub> eq (since 1995) because of the progressive replacement of ODS, such as chlorofluorocarbons (CFCs), by HFCs.

In this submission, in order to provide updates to the uncertainty values, a Tier 1 uncertainty assessment has

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

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)				
	1990	2005	2006	2007	2008
Industrial Processes TOTAL	54 800	55 100	54 600	53 200	52 600
a. Mineral Products	8 300	9 500	9 600	9 300	8 500
Cement Production	5 400	7 200	7 300	7 300	6 600
Lime Production	1 800	1 700	1 600	1 600	1 500
Limestone and Dolomite Use	730	250	310	160	160
Soda Ash Use	210	160	170	170	140
Magnesite Use	147	176	179	67.5	56.7
b. Chemical Industry	17 000	10 000	9 000	8 900	10 000
Ammonia Production	5 000	6 300	6 600	6 200	6 700
Nitric Acid Production	1 010	1 250	1 230	1 130	1 230
Adipic Acid Production	11 000	2 600	1 200	1 500	2 400
c. Metal Production	19 500	16 500	16 800	15 500	15 300
Iron and Steel Production	7 060	7 020	7 760	7 720	7 440
Aluminium Production	9 300	8 200	7 700	7 300	7 400
Magnesium Production	2 870	1 090	1 200	325	181
Magnesium Casting	236	201	190	198	279
d. Production and Consumption of Halocarbons (HFCs & PFCs)	770	5 200	5 000	5 400	5 500
e. SF <sub>6</sub> Use in Electric Utilities and Semiconductors	1 500	1 200	1 500	1 300	1 800
f. Other and Undifferentiated Production	8 000	12 000	13 000	13 000	11 000

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.

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.

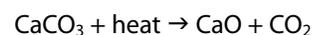
To ensure that the inventory was correctly prepared, the key, new, and updated categories of this sector have all undergone Tier 1 level quality control checks.

To keep up with the principle of continuous improvement and to address a comment made by the Inventory Expert Review Team, a study covering emission categories (e.g. caprolactum and carbide production) that have been reported as “NE” (not estimated) in the CRF reporter and improvements for other existing categories are underway. It is expected that the findings and results of the study would become available in fall 2010.

## 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 table 303-0060), 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 national CO<sub>2</sub> emissions from cement production, the equation recommended in the IPCC Good Practice Guidance (IPCC 2000), as shown below, was used:

Equation 4–1:

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

where:

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

The IPCC default EF<sub>clinker</sub> of 0.5071 kt CO<sub>2</sub>/kt clinker produced was applied. This factor was developed based on an average 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 2004* (CIEEDAC 2007). Clinker production data for 1997–2004 were obtained from Statistics Canada (#44-001) and for 2005–2008 from CANSIM table 303-0060 (Statistics Canada

2009). 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 2007–2008 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.

## 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 cement production was ±28%. The main contributor to the uncertainty was the use of the IPCC default correction factor related to cement kiln dust. 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.

To improve the quality of this category with country-specific values of CaO content in clinker and CKD correction factor, a quality assurance (QA) package was sent to the Cement Association of Canada (CAC) in mid-2009. How-

<sup>1</sup> Panagapko D. 2008–2009. Personal communications (emails from Panagapko D. to A. Shen, GHGD, on December 12, 2008, and to A. Au, GHGD, on November 13, 2009). Natural Resources Canada.

ever, at the request of CAC, the project was deferred until January 2010. Results of this QA project will be applied in the inventory as they become available.

### 4.2.5. Category-Specific Recalculations

The 2007 emission estimate was recalculated for the category of cement production because of the update in clinker production data. The estimate (compared to that of the previous submission) was increased by 0.96% (or 0.07 Mt CO<sub>2</sub> eq).

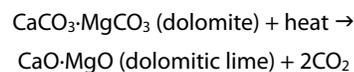
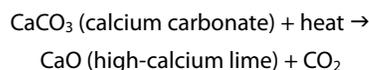
### 4.2.6. Category-Specific Planned Improvements

As mentioned above, to improve on methodology, emission factors and uncertainty of this category, a QA package was sent to the CAC. Results of this project will be applied in the inventory as they become available.

## 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 Limestone 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 2007–2008). 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 water content of 28.25%<sup>3</sup>. Furthermore, the corrected lime production data were divided

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

<sup>3</sup> Kenefick W. Personal communication (email from Wayne Kenefick to Amy Shen, GHGD, dated October 22, 2008). Canadian Lime Institute.

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  $\pm 8.0\%$ , 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 4.2.2.

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

The 2007 emission estimate was recalculated as a result of an update in the lime production data. The estimate (compared to that shown in the previous submission) was slightly changed by  $-0.17\%$  (or  $-0.0028$  Mt CO<sub>2</sub> eq).

### 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 desulphurisation (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 from 38% to 41% MgCO<sub>3</sub>. An overall emission factor of 468 g CO<sub>2</sub>/kg of dolomite used was derived based on the emission factors for pure limestone (440 kg CO<sub>2</sub>/tonne) and magnesite (522 kg CO<sub>2</sub>/tonne), and the assumption that dolomite is composed of 58% CaCO<sub>3</sub> and 41% MgCO<sub>3</sub> (AMEC 2006).

Data on raw stone use in iron and steel furnaces, non-ferrous smelters, glass factories, pulp and paper mills, and other chemical uses were obtained from the *Canadian Minerals Yearbook* (NRCan 1990–2006) or from the author of the stone section of the Yearbook (for 2007–2008). Although a national consumption value of stone was available for 2008, the most recent stone use data for each of the sectors that could be provided by NRCan were only for 2007. To estimate the stone use by sector for 2008, the ratio of national stone consumption in 2008 to that in 2007 was calculated. The ratio was then applied to the stone use in each sector in 2007, assuming that the change of stone use by sector from 2007 to 2008 was proportional to that of the national total. Moreover, data for stone use as flux in iron and steel furnaces were disaggregated into limestone and dolomite based on a 70/30 split (AMEC 2006). National CO<sub>2</sub> emissions were estimated by multiplying the quantities of limestone and dolomite consumed by the corresponding emission factors.

Provincial emission estimates were obtained by apportioning the national emissions according to the sum of the provincial gross domestic product values for the major sectors in which limestone and 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 ±17% to ±19%, 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 4.2.2.

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

#### 4.4.5. Category-Specific Recalculations

The update in the 2007 activity data caused a recalculation of the 2007 estimate. Compared to the previous submission's value, the 2007 estimate has decreased by 46% (or -0.14 Mt CO<sub>2</sub> eq).

#### 4.4.6. Category-Specific Planned Improvements

The emissive portion of the subcategory Other chemical uses published in the *Canadian Minerals Yearbook* (NRCan 1990–2006) or obtained from the author of the stone section of the Yearbook, was estimated based on U.S. activity data. There is a plan to improve or refine this estimate by using Canadian activity data.

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

#### 4.5.1. Source Category Description

Soda ash (sodium carbonate, Na<sub>2</sub>CO<sub>3</sub>) is a white crystalline

solid that is used as a raw material in a large number of industries, including glass manufacture, chemical production, soap and detergents, pulp and paper manufacture, flue gas desulphurisation, 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. CO<sub>2</sub> is emitted as the soda ash decomposes at high temperatures in a glass manufacturing furnace.

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

### 4.5.2. Methodological Issues

Based on the carbon mass balance, there is one mole CO<sub>2</sub> emitted for each mole of soda ash used. The emission factor (EF) for the mass of CO<sub>2</sub> emitted is estimated based on the stoichiometry of the chemical process as follows:

Equation 4–2:

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

National CO<sub>2</sub> emissions were calculated by applying the emission factor of 415 g CO<sub>2</sub>/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, 2007–2008). 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. In the emission estimation, uses of soda ash in soaps and detergents manufactur-

ing, and in water treatment were excluded because these were considered as non-emissive (AMEC 2006).

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 CO<sub>2</sub> 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 domestic product 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 CO<sub>2</sub> emitted from this facility was recovered for reuse (as mentioned in Section 4.5.1), some CO<sub>2</sub> may have been released from vents on absorbers, scrubbers, and distillation units. However, the amount of net CO<sub>2</sub> emissions from soda ash production in Canada is assumed to be 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 ±10.2% to ±13.8%.

The same emission factor was consistently applied over the time series. The activity data source is provided in Section 4.2.2.

### 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

The 2007 emission estimate was slightly recalculated due to a minute update in the activity data. The estimate was decreased by 0.000 22% (-0.000 38 kt CO<sub>2</sub> eq).

### 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)

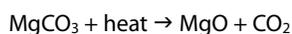
### 4.6.1. Source Category Description

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 period 1990–2008. 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.

The 1990–2005 facility-specific magnesite use data came from British Columbia's Ministry of Energy, Mines and Petroleum Resources (2006) and Environment Canada, Quebec Region, Environmental Protection Branch (2006 email from J. Banville).<sup>4</sup> For 2006 and 2007, to estimate the use of magnesite at two of the plants for which data could not be obtained, some assumptions were made. For the first plant for which data could not be obtained, the ratio of magnesite use to magnesium production was first calculated for each year of the 1990–2005 period (2007 email from J. Banville).<sup>5</sup> The average of the calculated (magnesite use / magnesium production) ratios was then taken. Finally, the average was multiplied by the plant's 2006 and 2007 production to yield the 2006 and 2007 magnesite use respectively. For the other plant for which 2006 data was again not available, it was assumed that the 2006 use of magnesite stayed at the 2005 level. The 2007–2008 use data for the latter plant (the only operating one in 2008) came from British Columbia's Ministry of Energy, Mines and Petroleum Resources<sup>6</sup>. 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 associat-

4 Banville J. 2006. Personal communication (email from Banville J to Renata Zaremba, GHGD, dated March 3, 2006). Environment Canada, Environmental Protection Branch, Quebec Region.

5 Banville J. 2007. Personal communication (email from Banville J. to Maryse Pagé, GHGD, dated October 4, 2007). Environment Canada, Environmental Protection Branch, Quebec Region.

6 Meredith-Jones S. 2009. Personal communication (email from Meredith-Jones S. to Maryse Pagé, GHGD, dated July 2, 2009). B.C. Ministry of Energy, Mines and Petroleum Resources.

ed with the category as a whole for the time series ranging from  $\pm 5.0\%$  to  $\pm 9.0\%$ , 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 4.2.2.

#### 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

The 2007 estimate was recalculated as a result of an activity data update. The estimate was decreased by 38% (-0.041 Mt CO<sub>2</sub> eq).

#### 4.6.6. Category-Specific Planned Improvements

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

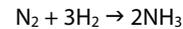
### 4.7. Ammonia Production (CRF Category 2.B.1)

#### 4.7.1. Source Category Description

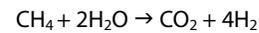
Ammonia (NH<sub>3</sub>) is gaseous at standard temperature and pressure. It is toxic and corrosive, and has a pungent odour. Commercially used ammonia is referred to as “anhydrous ammonia,” which must be stored under pressure or at low temperature to remain a liquid. It is used mainly in the production 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:

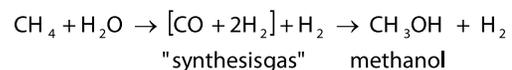


The nitrogen required is obtained from air. The typical source of hydrogen for ammonia plants is the catalytic steam reforming of CH<sub>4</sub> (and minor amounts of other hydrocarbons) contained in natural gas. CO<sub>2</sub> is also generated, as a by-product gas, during the steam methane reforming (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

Emissions from ammonia production were estimated by multiplying CO<sub>2</sub>-related ammonia production by an emission factor of 1.56 t CO<sub>2</sub>/t NH<sub>3</sub> produced. The emission factor was developed based on typical energy and material requirements for ammonia production in Canada (Jaques 1992). Data on CO<sub>2</sub>-related production used in the calculation were either directly collected from ammonia plants or estimated. For plants that had used SMR (i.e. releasing CO<sub>2</sub>), but whose data were not available, estimation of production was done based on the reported production and capacity data of other plants and national ammonia production statistics. Data on production and production capacity for 1990–2004, where available, were gathered in a study conducted by Cheminfo Services (2006); those for 2005–2008 were collected by Environment Canada's GHG Division through a voluntary data submission process. Data on national ammonia production were found in Statistics Canada's publication #46-002.

The estimation technique (emissions = production of ammonia × emission factor) is one of the default methods suggested in the revised 1996 IPCC guidelines (IPCC/OECD/IEA 1997). However, it should be noted that the emission factor of 1.56 t CO<sub>2</sub>/t NH<sub>3</sub> produced is a national average value and that plant-specific production data were used whenever possible. Methodological issues for calculating CO<sub>2</sub> emissions from ammonia production are not addressed specifically in the IPCC Good Practice Guidance (IPCC 2000).

Finally, the quantity of natural gas used to produce hydrogen for ammonia production was also recorded by Statistics Canada with all other non-energy uses of natural gas. Therefore, to avoid double counting, the CO<sub>2</sub> emissions from ammonia production were subtracted from the total non-energy fossil fuel use CO<sub>2</sub> emissions reported under the Other and Undifferentiated Production category at the national level. At the provincial and territorial levels, CO<sub>2</sub> emissions from ammonia production are reported together with emissions from Other and Undifferentiated Production under the Other and Undifferentiated Category.

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 and the emission factor. The uncertainty associated with the category as a whole was evaluated at ±7% and is applicable to all years of the time series.

The same emission factor was consistently applied over the time series. The activity data sources are described in Section 4.2.2.

## 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

There has been no recalculation for this category.

## 4.7.6. Category-Specific Planned Improvements

Efforts will be made to determine the amounts of natural gas used as feedstock and as fuel during ammonia production over the years and to update the emission factor to better reflect the process-related emissions.

## 4.8. Nitric Acid Production (CRF Category 2.B.2)

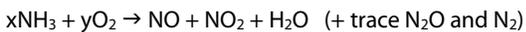
### 4.8.1. Source Category Description

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 ( $\text{NH}_3$ ) to nitrogen dioxide ( $\text{NO}_2$ ) and then subsequent formation of nitric acid by addition of water ( $\text{H}_2\text{O}$ ) to  $\text{NO}_2$ . As shown below, the first stage is the reaction of ammonia gas with oxygen ( $\text{O}_2$ ) (from air) at high temperatures:

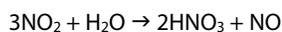
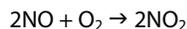
Stage 1 (Reaction):



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 ( $\text{NO}$ ),  $\text{NO}_2$ , and water vapour, with trace amounts of  $\text{N}_2\text{O}$  and nitrogen ( $\text{N}_2$ ) (Cheminfo Services 2006). An excess of oxygen may drive the  $\text{NO}$  to be converted to  $\text{NO}_2$ . Nitrogen oxidation steps under reducing conditions are sources of  $\text{N}_2\text{O}$ . More specifically,  $\text{NO}$ , an intermediate in the production of nitric acid, can readily decompose to  $\text{N}_2\text{O}$  and  $\text{NO}_2$  at high pressures and at a temperature range of 30–50°C (IPCC/OECD/IEA 1997).

During the second stage of the production process, water is added at the top of an absorber tower to hydrate the  $\text{NO}_2$  and to scrub the gases. As shown below, hydration of cooled  $\text{NO}_2$  with water forms a 60–65% solution of nitric acid, leaving the bottom of the tower. To complete the conversion of  $\text{NO}$  to  $\text{NO}_2$ , excess air (oxygen) is introduced at the bottom tray of the absorber tower. The  $\text{NO}_2$  formed is also absorbed.

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  $\text{N}_2\text{O}$ ,  $\text{NO}$ ,  $\text{NO}_2$ , and other  $\text{NO}_x$ . The concentration of  $\text{N}_2\text{O}$  in the exhaust gases depends on the

type of plant and its emission controls (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  $\text{NO}_x$ . In contrast, a “selective” catalytic reduction (SCR) uses ammonia, which selectively reacts only with  $\text{NO}$  and  $\text{NO}_2$  gases, and not with  $\text{N}_2\text{O}$  (hence a higher  $\text{N}_2\text{O}$  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 4–2 as “absorption Type 1.” Alternatively, plants can have in place a second tower to allow “double absorption.” This is referred to in Table 4–2 as “absorption Type 2” (Cheminfo Services 2006).

## 4.8.2. Methodological Issues

Data supporting the estimation of  $\text{N}_2\text{O}$  emissions from nitric acid production for 1990–2004 were gathered through a study conducted for Environment Canada (Cheminfo Services 2006), and those for 2005–2008 were obtained by the Department’s GHG Division from industry through a voluntary data submission process. The collected data were used in the country-specific hybrid emission estimation methodology, which could be described as three categories:

Plant-specific production data and plant-specific emission factors (i.e. Tier 3 type method) when these were available from companies; or

1. 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
2. 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.

3. In all three scenarios, the equation applied was as follows:

Equation 4–3:

$$\text{N}_2\text{O Emission (t)} = \text{Production-Based Emission Factor (kg N}_2\text{O/t HNO}_3\text{)} \times \text{Production (kt HNO}_3\text{)}$$

To estimate emissions in scenarios 2 and 3, the types of production process and emission control technology of a plant were first determined. The reported or estimated production was then multiplied by the corresponding emission factor. The industry-typical emission factors used had been obtained from the Canadian Fertilizer Institute in the early 1990s (G. Collis 1992).<sup>7</sup> 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 same study (Cheminfo Services 2006). Table 4–2 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 national production data from Statistics Canada (# 46-002), and the reported production data and the production capacity data of other plants. More specifically, the sum of all production reported by companies was deducted from the national total production (Statistics Canada # 46-002) to give the national unreported nitric acid production. The latter was then allocated based on the capacities of the non-reporting plants to give the estimated production values for the non-reporting plants. The estimated production was multiplied by what was believed to be the most

7 Collis G. 1992. Personal communication (letter from Collis G. to Director, GHGD, dated March 23, 1992). Canadian Fertilizer Institute.

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 2005–2008, the data used were reported by companies to Environment Canada’s Greenhouse Gas Division on a voluntary basis.

Finally, the estimates of N<sub>2</sub>O emissions (by plant) were summed either all together to yield the national emission estimate or by province to give the provincial emission estimate.

### 4.8.3. Uncertainties and Time-Series Consistency

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 4.2.2.

### 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.

Table 4–2 Nitric Acid Industry–Typical Emission Factors

Type of Production Process Technology	Type of Emission Control Technology	Emission Factor (kg N <sub>2</sub> O/t HNO <sub>3</sub> )	Data Source
Dual Pressure	Extended Absorption “Type 1”	9.4	1992 letter from G. Collis <sup>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)

### 4.8.5. Category-Specific Recalculations

A minor correction in the calculation model has triggered a recalculation of the 2007 estimate. The 2007 estimate was decreased by 0.24% (or -0.002 7 Mt CO<sub>2</sub> eq).

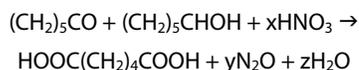
### 4.8.6. Category-Specific Planned Improvements

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.

### 4.9.2. Methodological Issues

The 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:

$$\text{Total Emissions (t)} = \text{N}_2\text{O Emissions (t) with abator} + \text{N}_2\text{O Emissions (t) without abator}$$

The first term accounts for emissions that occur when the abator is operating, and the second for emissions that occur when the abator is not operating because of maintenance or technical problems.

N<sub>2</sub>O Emissions with Abator:

Equation 4–5:

$$\text{N}_2\text{O Emissions (t) with Abator} = (\text{Production (t)}) \times \left( \frac{0.3 \text{ t N}_2\text{O}}{\text{t adipic acid}} \right) \times (1 - \text{Destruction Efficiency}) \times (\text{Abatement Utilization Ratio})$$

where:

Destruction Efficiency is determined based on the difference between the amount of N<sub>2</sub>O entering the abatement unit and that leaving the unit. It is a monthly average calculated using values recorded by analyzers, which are located at the inlet and outlet of the abator. The targeted instantaneous destruction efficiency is 97.

Abatement Utilization Ratio is the number of hours during which N<sub>2</sub>O goes through the abator divided by the total operating time.

N<sub>2</sub>O Emissions without Abator:

Equation 4–6:

$$\text{N}_2\text{O Emissions (t) without Abator} = (\text{Production (t)}) \times \left( \frac{0.3 \text{ t N}_2\text{O}}{\text{t adipic acid}} \right) \times (1 - \text{Abatement Utilization Ratio})$$

It is important to note that the in-line continuous emission monitor has never been used to directly monitor net N<sub>2</sub>O emissions. This is because the analyzer is limited to accurately measuring relatively low concentrations of N<sub>2</sub>O only when the reactor is online and abating N<sub>2</sub>O gas. The analyzer is not capable of measuring the full range of N<sub>2</sub>O concentrations that could potentially exist in the stack. The N<sub>2</sub>O concentration can vary from a low nominal level of 0.3% when the stream leaves the abator to a high nominal level of 35–39% N<sub>2</sub>O in the unabated stream. When the abatement reactor is bypassed, there is no N<sub>2</sub>O abatement occurring, and the analyzer will not record N<sub>2</sub>O stack emissions (Cheminfo Services 2006).

The calculation techniques used to estimate emissions for the periods 1990–1997 and 1998–2008 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 4.2.2, 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

There were no recalculations of N<sub>2</sub>O emissions related to adipic acid production.

### 4.9.6. Category-Specific Planned Improvements

There are currently no improvements planned specifically for this category.

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

### 4.10.1. Source Category Description

Crude (pig) iron is produced in a blast furnace through the reduction of iron oxide (ore), with the carbon in coke or other carbonaceous material as the reducing agent. In most iron furnaces, the process is aided by the use of limestone fluxes (IPCC 2000). Steel can be made in electric arc furnaces (EAFs), basic oxygen furnaces, or cupola furnaces. Low-carbon steel is produced in basic oxygen furnaces, where a mixture of pig iron and iron scrap is remelted in the presence of pure oxygen, which oxidizes the dissolved carbon to CO or CO<sub>2</sub>. Carbon and alloy steels are produced in EAFs, refractory-lined pots that utilize electric heating through graphite electrodes, which are consumed in the process (IPCC/OECD/IEA 1997).

In the production of pig iron, carbon plays the dual role of fuel and reductant. Emissions from the combustion of fuels such as coke oven gas are not reported in this category, but rather under the appropriate industrial category in the

Energy Sector. CO<sub>2</sub> emissions from carbon oxidation, which occurs when iron ore is reduced to pig iron, are included in this category. Also accounted for in this category are emissions during steel production, which occur to a much lesser extent. These come from the oxidation of carbon in crude iron and electrode consumption. Additional CO<sub>2</sub> given off by limestone flux in the blast furnace is covered under the Limestone and Dolomite Use category (Section 4.4.1).

## 4.10.2. Methodological Issues

To estimate CO<sub>2</sub> emissions from iron and steel production at a national level, the Tier 2 method, as described in the IPCC Good Practice Guidance (IPCC 2000), was used. With this methodology, the fate of carbon was tracked throughout the production process, and emissions from iron production and steel production were calculated separately. The following equation was used to estimate emissions from pig iron production:

### Equation 4–7:

$$\text{Emissions}_{\text{pig iron}} = (\text{Emission Factor}_{\text{reductant}} \times \text{mass of reductant}) + (\text{mass of carbon in ore} - \text{mass of carbon in pig iron}) \times \left(\frac{44}{12}\right)$$

where:

Emissions <sub>pig iron</sub>	= emissions from pig iron production, kt
Emission factor <sub>reductant</sub>	= 2.479 kt CO <sub>2</sub> /kt of coke used (Jaques 1992)
mass of reductant	= mass of metallurgical coke used in the process, kt
mass of carbon in the ore	= zero; according to 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

Reducing agents used to produce crude iron from iron ore can be coke, coal, charcoal, heavy fuel oil, or petroleum coke. However, for the purposes of this category's emission estimates, it was assumed that the reductant used in the Canadian industry is 100% metallurgical coke. The carbon content in ore is almost zero (IPCC 2000). The GHG emissions associated with the use of reductants other than metallurgical coke are estimated in the Other and Undif-

ferentiated Production source category and under the appropriate industrial category in the Energy Sector.

The data source for the use of metallurgical coke was the *Report on Energy Supply-Demand in Canada* (RES-D – Statistics Canada #57-003). Data on total pig iron production in Canada came from Statistics Canada (for 1990–2003: #41-001; and for 2004–2008: #41-019).

Emissions from steel production were estimated using the following equation:

### Equation 4–8:

$$\text{Emissions}_{\text{crude steel}} = \left[ (\text{mass of carbon in pig iron used for crude steel} - \text{mass of carbon in crude steel}) \times \frac{44}{12} \right] + [\text{Emission Factor}_{\text{EAF}} \times \text{steel produced in EAFs}]$$

where:

Emissions <sub>crude steel</sub>	= emissions from crude steel production, kt
mass of carbon in pig iron used for crude steel	= total pig iron charged to steel furnaces, kt × carbon content of pig iron
mass of carbon in crude steel	= total steel production, kt × carbon content in crude steel, 1.25%
44/12	= ratio of the molecular weight of CO <sub>2</sub> to the molecular weight of carbon
Emission Factor <sub>EAF</sub>	= emission factor for steel produced in EAFs, 0.005 kt CO <sub>2</sub> /kt steel
steel produced in EAFs	= the amount of steel produced in EAFs, kt

According to Equation 4–8, the amount of CO<sub>2</sub> emitted from steel production is estimated based on the difference between the amount of carbon in the iron used to make steel and that in the steel produced. It should be noted that the amount of pig iron fed to steel furnaces (used in Equation 4–8) does not equal the amount of total pig iron production (used in Equation 4–7).

Data on the total pig iron charged to steel furnaces, on total steel production, and on the amount of steel produced in EAFs were obtained from Statistics Canada (for 1990–2003: #41-001 and for 2004–2008: #41-019). The value of the carbon content in crude steel applied in the equation was 1.25%, which is the midpoint of the IPCC default range (0.5–2%). The emission factor for steel produced in EAFs of 5 kg CO<sub>2</sub>/t steel (or 0.005 kt CO<sub>2</sub>/kt steel) was the default value shown in the IPCC Good Practice Guidance (IPCC

2000).

The total emission from the sector of iron and steel production is the sum of Equation 4–7 and Equation 4–8 above.

Data on metallurgical coke use at provincial/territorial levels from the RESD (Statistics Canada #57-003) were used to derive the percentage of total reductant consumption attributed to each province and territory. CO<sub>2</sub> emissions at provincial/territorial levels were then estimated by multiplying the percentage derived by the national emission estimate.

It should be noted that RESD data (Statistics Canada #57-003) published for any given year are preliminary and subject to revision in subsequent publications.

The method described above does not account for additional CO<sub>2</sub> given off by the use of limestone as flux in blast furnaces, since the limestone consumption-related emissions are included in the subsector of Limestone and Dolomite Use.

The use of petroleum coke in EAF electrodes is reported by Statistics Canada with all other non-energy uses of petroleum coke. To avoid double counting, the CO<sub>2</sub> emissions from the consumption of electrodes in the steel production process in EAFs are therefore subtracted from the total non-energy emissions. It is assumed that there are no imported electrodes used for steel production in EAFs in Canada. If electrodes are imported, then the portion of CO<sub>2</sub> generated by the imported electrodes will need to be subtracted from the emissions from electrode consumption before being subtracted from the total non-energy emissions.

### 4.10.3. Uncertainties and Time-Series Consistency

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 ranged from  $\pm 5.8\%$  to  $\pm 6.4\%$ .

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

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

Iron and steel production is a key category that has undergone Tier 1 QC checks as developed in the QA/QC plan (see Annex 6). The checks performed are consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC 2000). No issues of importance were detected from the Tier 1 QC process.

### 4.10.5. Category-Specific Recalculations

As a result of an activity data update, the 2007 estimate was recalculated. It was, compared to the value of the previous submission, increased by 25% (or 0.68 Mt CO<sub>2</sub> eq).

### 4.10.6. Category-Specific Planned Improvements

Efforts will be made to rectify the assumption made regarding the agents used to reduce iron ore. In the current estimation methodology, it is assumed that the reductant used by industry is 100% metallurgical coke. However, it is known that there are other reductants, such as natural gas, heavy fuel oil and coal, that have been used by the iron and steel industry over the years. Hence, part of the CO<sub>2</sub> emissions coming from non-energy use of fossil fuels, currently reported under the category of Other and Undifferentiated Production and also reported under the Energy Sector, may be reallocated to the category of Iron and Steel Production.

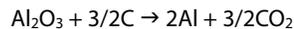
The country-specific carbon contents of pig iron and steel are also planned to be used in the next inventory submission.

## 4.11. Aluminium Production (CRF Category 2.C.3)

### 4.11.1. Source Category Description

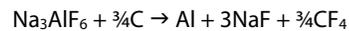
Primary aluminium is produced in two steps. In the first stage, bauxite ore is ground, purified, and calcined to produce alumina (Al<sub>2</sub>O<sub>3</sub>). The latter is then, in the second stage, electrically reduced to aluminium in large pots with carbon-based anodes. The pot itself (a shallow steel container) forms the cathode, whereas the anode consists of one or more carbon blocks suspended within it. Inside the pot, alumina is dissolved in a cryolite (Na<sub>3</sub>AlF<sub>6</sub>) bath. Passing a current through the resistance of the cell causes the heating effect, which maintains the contents in a liquid state. The aluminium forms at the cathode and gathers on the bottom of the pot.

As the anode is consumed, CO<sub>2</sub> is formed in the following reaction, provided that enough alumina is present at the anode surface:



Although most of the CO<sub>2</sub> forms from the electrolysis reaction of the carbon anode with alumina as shown above, other sources, namely the baking of prebaked anodes, can contribute to some (usually less than 10%) of the total non-energy-related CO<sub>2</sub> emissions. Emissions from the combustion of fossil fuels used in the production of baked anodes are covered in the Energy 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 (2007 email from P. Chaput).<sup>8</sup>

Aluminium plants are characterized by the type of anode technology employed. In general, older plants with Søderberg technology have higher emissions than newer plants, which usually use pre-baked anodes. The trend in the Canadian aluminium industry has been towards modernizing facilities, since production efficiency has improved. In some cases, this has meant taking old lines out of production as new ones are installed to meet increasing demand.

Finally, even though aluminium production consumes extremely large quantities of electrical energy, currently estimated to be 13.5 kWh/kg of aluminium (AIA 1993), GHG emissions associated with its electricity consumption are not necessarily high in a Canadian context. All of Canada’s primary aluminium smelters are located in Quebec and British Columbia, where almost all (95%) of the electricity generated is produced by hydraulic generators; these are believed to emit a negligible amount of GHGs compared with conventional fossil fuel-based electricity generators.

### 4.11.2. Methodological Issues

Process-related emission estimates for aluminium production were directly obtained from companies via the Aluminum Association of Canada (AAC). In addition to the smelter-specific emission estimates, information on the methodologies used by the aluminium producers to calculate CO<sub>2</sub>, PFC, and SF<sub>6</sub> emissions was obtained from the AAC. The estimation techniques applied may be Tier 3, Tier 2, or Tier 1 type, as described below, depending on

<sup>8</sup> Chaput P. 2007. Personal communication (email from Chaput P. to A. Au, GHGD, dated Oct 12, 2007). Aluminum Association of Canada.

data availability; a Tier 3 type technique has mostly been applied for estimating emissions for recent years.

#### Calculating CO<sub>2</sub> emissions:

Typically, the equations used by smelters to estimate CO<sub>2</sub> emissions from the reaction of the carbon anode with alumina are (AAC 2002b) as follows:

#### Equation 4–9: for pre-baked anode consumption

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

#### 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 4–10: for Söderberg anode consumption:

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

#### 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 4–3 are Tier 2 industry-typical values that can be applied by facilities.

When no process data other than aluminium production are available, emission factors for a Tier 1 method (as shown below) can be used. These factors depart slightly from the IPCC default factors, because the IPCC Tier 1 default factors reflect 1990 emissions and would produce considerable errors if applied to current production. The factors below reflect the considerable progress that has been made over the period from 1990 to 2001 (AAC 2002b and IAI 2006):

Söderberg: EF = 1.7 t CO<sub>2</sub>/t Al produced; and

Pre-baked: EF = 1.6 t CO<sub>2</sub>/t Al produced.

To calculate CO<sub>2</sub> emissions resulting from anode baking (i.e. pitch volatiles combustion and combustion of baking furnace packing material), the following equations are used (AAC 2002a):

#### Equation 4–11: for Pitch Volatiles Combustion:

$$\text{CO}_2 \text{ Emissions (t)} = (\text{GAW} - \text{BAP} - \text{HW} - \text{RT}) \times \left( \frac{44}{12} \right)$$

#### 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

Table 4–3 Default Tier 2 Parameter Values for the Estimation of CO<sub>2</sub> Emissions from Anode Consumption

Parameter	Industry-Typical Value	Source
<b>For Prebaked Anode Consumption:</b>		
sulphur content in baked anodes (wt %) - S <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.

Equation 4–12: for Packing Coke:

$$\text{CO}_2 \text{ Emissions (t)} = \left[ \text{PCC} \times \text{BAP} \times \frac{(100 S_{pc} \text{ Ash}_{pc})}{100} \right] \times \left[ \frac{44}{12} \right]$$

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 4–11 and Equation 4–12 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 4–4 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 recent communication with representatives of the Canadian aluminium industry (2007 emails from

P. Chaput and C. Dubois),<sup>9</sup> one of the three aluminium companies has only relied on plant-specific values to develop its process CO<sub>2</sub> estimates (Tier 3), whereas the other two companies have used default parameter values shown in Table 4–3 and Table 4–4 above for estimates of some years.

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):

9 Chaput P. and Dubois C. 2007. Personal communications (emails from Chaput P. and Dubois C. to A. Au, GHGD, dated October 12, 2007). Aluminium Association of Canada and Alcoa.

Table 4–4 Default Tier 2 Parameter Values for the Estimation of CO<sub>2</sub> Emissions from Anode Baking

Parameter	Industry-Typical Value	Source
<b>For Pitch Volatiles Combustion:</b>		
hydrogen content in pitch (wt%) - %H <sub>2</sub>	0.5%	IAI 2006
waste tar collected (t) – RT	For Riedhammer furnaces only; all others are insignificant	IAI 2006
<b>For Packing Coke:</b>		
packing coke consumed (t coke/ t of baked anode) – PCC	0.015 t/ t	IAI 2006
sulphur content in packing coke (wt%) - S <sub>pc</sub>	2%	IAI 2006
ash content in packing coke (wt%) - Ash <sub>pc</sub>	2.5%	IAI 2006

Equation 4–13: for Slope Method:

$$\text{PFC Emissions (t CO}_2\text{ e)} = \frac{\text{slope} \times \text{AEF} \times \text{AED} \times \text{MP} \times \text{GWP}}{1000}$$

**where:**

Slope	=	slope (for CF <sub>4</sub> or C <sub>2</sub> F <sub>6</sub> ) of the emission relationship ((kg PFC/t Al)/[AE-minutes/cell-day])
AEF	=	number of anode effects per pot per day (AE/cell-day)
AED	=	anode effect duration (minutes)
MP	=	total aluminium production (t)
GWP	=	global warming potential for CF <sub>4</sub> or C <sub>2</sub> F <sub>6</sub>

Equation 4–14:

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

**where:**

overvoltage coefficient	=	((kg PFC/t Al)/[mV/cell-day])
AEO	=	anode effect overvoltage (mV/cell-day)
CE	=	aluminium production process current efficiency expressed as a fraction
GWP	=	global warming potential for CF <sub>4</sub> or C <sub>2</sub> F <sub>6</sub>
MP	=	total aluminium production (t)

The use of the above equations with actual process data to estimate PFC emissions is considered a Tier 3 type methodology. The estimation technique is considered as Tier 2 type when the default coefficients shown in Table 4–5 (IAI 2006) are used together with smelter-specific operating parameters. In a Tier 2 approach, one would first estimate emissions of CF<sub>4</sub> using the slope or overvoltage coefficients as per Equation 4–13 and Equation 4–14. Emissions of C<sub>2</sub>F<sub>6</sub> are then calculated by multiplying the CF<sub>4</sub> estimates by the CF<sub>4</sub>/C<sub>2</sub>F<sub>6</sub> weight fraction.

If only production statistics are available (i.e. no data on anode effect frequency, anode effect duration, or anode effect overvoltage), the Tier 1 emission factors shown in Table 4–6 can be used by smelters (IAI 2006).

Based on recent information provided by the Canadian aluminium industry (2007 email from P. Chaput),<sup>10</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 4–4 and Table 4–5 above for estimates of some years.

Calculating SF<sub>6</sub> emissions:

According to the methodology documents supplied by the AAC, SF<sub>6</sub> emissions are equal to consumption in the aluminium industry. This method is consistent with the revised 1996 IPCC guidelines (IPCC/OECD/IEA 1997).

### 4.11.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has been performed for the subsector 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 International Aluminium Institute (IAI) (2006) was the main source of the parameters' uncertainty values. The uncertainties of 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).

10 Chaput P. 2007. Personal communication (email from Chaput P. to A. Au, GHGD, dated October 12, 2007). Aluminum Association of Canada.

Table 4–5 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

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.

Table 4–6 PFC Emission Factors

Type of Cell	Emission Factors (kg PFC/t Al)	
	CF <sub>4</sub>	C <sub>2</sub> F <sub>6</sub>
Centre Worked Pre-Baked	0.4	0.04
Side Worked Pre-Baked	1.6	0.4
Vertical Stud Søderberg	0.8	0.04
Horizontal Stud Søderberg	0.4	0.03

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.

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

CO<sub>2</sub> and PFC emissions from aluminium production were key categories that have undergone Tier 1 QC checks as elaborated in the QA/QC plan (see Annex 6). The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC 2000). No issues of importance were detected from the Tier 1 QC process.

#### 4.11.5. Category-Specific Recalculations

There was no recalculation for the subsector of Aluminium Production.

#### 4.11.6. Category-Specific Planned Improvements

Efforts will also be made to acquire more information on the QC procedures followed by member companies during the emission estimation.

## 4.12. Magnesium Metal Production and Casting (CRF Categories 2.C.5.1 & 2.C.4.2)

### 4.12.1. Source Category Description

SF<sub>6</sub> is emitted during magnesium production and casting, where it is used as a cover gas to prevent oxidation of the molten metals. Although emitted in relatively small quantities, SF<sub>6</sub> is an extremely potent GHG, with a 100-year GWP of 23 900. SF<sub>6</sub> is not manufactured in Canada. All SF<sub>6</sub> is imported.

During the 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 (2004 email from J. Laperrière).<sup>11</sup> This research and 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 2005–2007 period, only seven facilities were in operation and still used SF<sub>6</sub>.

### 4.12.2. 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/web-sol/querysite/query\\_e.cfm](http://www.ec.gc.ca/pdb/web-sol/querysite/query_e.cfm)). For previous years (i.e. 1990–1998), the data were provided voluntarily by the producers to the GHG Division over the telephone. 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).

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 (2006 email from J. Laperrière).<sup>12</sup> This method is based on measuring the weight of gas cylinders used at the facility at the time when these were purchased and when these were returned to suppliers at the end of the usage. The accounting method was reported as being used by Timminco for estimating its SF<sub>6</sub> use (2006 email from R. Katan).<sup>13</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,

11 Laperrière J. 2004. Personal communication (email from Laperrière J. to A. Au, GHGD, dated October 27, 2004). Norsk Hydro.

12 Laperrière J. 2006. Personal communication (email from Laperrière J. to A. Au, GHGD, dated October 4, 2006). Norsk Hydro.

13 Katan R. 2006. Personal communication (emails from Katan R. to A. Au, GHGD, dated March 16–22, 2006). Timminco.

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 in a voluntary data submission process. They were used for the calculation of emissions. For 2008, data were made available by five out of the seven casting facilities in the voluntary data submission process. For the remaining two facilities, it was assumed that their 2008 SF<sub>6</sub> use stayed at 2007 level.

The technique applied to estimate emissions from magnesium casting for 1990–2004 and 2008 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.

### 4.12.3. 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 ±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 (±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.

### 4.12.4. 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 Practice Guidance (IPCC 2000). No issues of importance were detected from the Tier 1 QC process.

### 4.12.5. Category-Specific Recalculations

There was no recalculation for the categories of Magnesium Production and Magnesium Casting.

### 4.12.6. Category-Specific Planned Improvements

There is currently no improvement planned specifically for the estimation of SF<sub>6</sub> emissions from magnesium production and casting in Canada.

## 4.13. Production of Halocarbons (CRF Category 2.E)

### 4.13.1. Source Category Description

Chlorodifluoromethane (HCFC-22 or CHClF<sub>2</sub>) is produced when reacting chloroform (CHCl<sub>3</sub>) with hydrogen fluoride (HF), in the presence of antimony pentachloride (SbCl<sub>5</sub>) as catalyst. During the manufacture of HCFC-22, trifluoromethane (HFC-23 or CHF<sub>3</sub>) is generated as a by-product (IPCC 2002).

The reaction is carried out in a continuous flow reactor, usually under high pressure (up to 500 psig) and tempera-

tures 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, but none in the years 1990 and after. Allied-Signal only submitted its 1990–1992 production data to UPCIS because it stopped its operation in 1993 (2007 email from Y. Bovet).<sup>14</sup>

HCFC-22 can be used as refrigerant, as a blend component in foam blowing and as a chemical feedstock for manufacturing synthetic polymers (IPCC 2002). However, due to its ozone-depleting properties, developed countries have scheduled the phase-out of HCFC-22 for the coming years. In Canada, there should be no more manufacturing or import of equipment containing HCFC-22 as of Jan. 1, 2010 (HRAI 2008).

### 4.13.2. Methodological Issues

To estimate HFC-23 emissions from HCFC-22 production, the total HCFC-22 production was multiplied by the IPCC Tier 1 default emission factor of 0.04 t HFC-23 / t HCFC-22 produced (IPCC/OECD/IEA 1997). It was assumed that destruction (through thermal oxidation) or transformation of HFC-23 was not practiced in Canada. The 1990–1992 production data were collected by the UPCIS from HCFC producers (2007 email from Y. Bovet).<sup>16</sup>

### 4.13.3. Uncertainties and Time-Series Consistency

Uncertainty in the HFC-23 emission estimates has not been assessed. However, it was believed that the production data reported by HCFC-22 producers were reasonably accurate. The major source of uncertainty could be the Tier 1 default emission factor, because the correlation between the quantity of HFC-23 emitted and the HCFC-22 production rate can vary with plant infrastructure and operating conditions (IPCC 2002).

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

Informal checks (such as data transcription checks, calculation checks, and unit conversion checks) were done on the category of HCFC-22 production. No issues of importance were detected.

### 4.13.5. Category-Specific Recalculations

There were no recalculations for this category.

### 4.13.6. Category-Specific Planned Improvements

There are currently no improvements planned for this category.

## 4.14. Consumption of Halocarbons (CRF Category 2.F)

Hydrofluorocarbons (HFCs) and, to a very limited extent, perfluorocarbons (PFCs) are serving as alternatives to ozone-depleting substances being phased out under the Montreal Protocol. Application areas of HFCs and PFCs include refrigeration and air conditioning; fire suppression; aerosols; solvent cleaning; foam blowing; and other applications (such as semiconductor manufacturing in the case of PFCs).

Before the ban on the production and use of CFCs came into effect in 1996, as a result of the Montreal Protocol, very few HFCs were produced and used. The only HFCs produced were HFC-152a, a component of the refrigerant blend R-500, and HFC-23, a by-product of HCFC-22 production (discussed in the previous section). As such, emissions from HFC consumption were considered negligible

<sup>14</sup> Bovet Y. 2007. Personal communication (email from Bovet Y. to A. Au, GHGD, dated November 8, 2007). Environment Canada, UPCIS.

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.

### 4.14.1. 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>15</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 2005–2008 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. Over 80% of the companies to which a request was sent were able to provide their data. In the cases where data on import/export HFC-containing products 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. Since the 2007 and 2008 data were not provided by one of the major importers of bulk HFCs, 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. In addition, for the

years 1995 and 1999–2003, data on the quantities of HFCs contained in imported and exported products, except imported and exported vehicles, were not available. The 1999 and 2000 amounts of HFCs found in imported and exported vehicles were provided by the UPCIS. For 1995, HFC quantities in imported and exported products were assumed to be zero. For 1999–2003, these quantities were assumed to stay at 1998 levels and at the 2000 level for imported/exported vehicles.

Since detailed 1995 HFC data were not available, the IPCC Tier 2 method could not be applied. Instead, a modified Tier 1 methodology was used to obtain a representative estimate of the actual 1995 HFC emissions for the following groups: aerosols; foams; air conditioning original equipment manufacture (AC OEM); AC service; refrigeration; and total flooding systems. To estimate 1996–2008 HFC emissions at 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 GDP 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 1995–2008. 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 2005–2007 PFC use data from major consumers of PFCs. Over 50% of the companies to which a request was sent reported their data to the Division. The collected data were used in the emission estimation. For the companies for which data were not available, it was assumed that PFC use stayed constant at the 2000 levels. Moreover, as companies that have been closed or that stopped using PFCs were identified throughout the process, the corresponding activity data used to develop estimates were adjusted accordingly. For 2008 PFC use data, it was assumed that the quantities stayed at the lev-

<sup>15</sup> Bovet Y. and Y. Guilbault. 2004–2006. Personal communications (emails received from Bovet Y. and Guilbault Y. to A. Au, GHGD, during the years 2004–2006). UPCIS.

els of the most recent years for which data were available.

#### 4.14.1.1. 1995 HFC Emission Estimates

The following subsections provide explanations on the emission factors used and the assumptions made to develop 1995 HFC emission estimates for AC OEM; AC service; refrigeration; foam blowing; aerosol products; and total flooding systems.

##### Air Conditioning Original Equipment Manufacture (AC OEM)

To estimate emissions from AC OEM, the revised 1996 IPCC guidelines (IPCC/OECD/IEA 1997) suggest a 2–5% loss rate. For Canada, a rate of 4% was assumed.

##### AC Service

Since it was assumed that 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 4–15:

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

The IPCC considers that operating loss is approximately 0.17(charge) (IPCC/OECD/IEA 1997). Therefore, assuming the total charge remains constant for the short term,

$$\text{HFC (refrig)} = \text{Charge} + 0.17(\text{Charge}) = 1.17(\text{Charge})$$

or

$$\text{Charge} = \frac{\text{HFC (refrig)}}{1.17}$$

Assuming assembly leakage was minimal,

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

Thus,

Equation 4–16:

$$\text{Emissions} = 0.17 \times \left( \frac{\text{HFC (refrig)}}{1.17} \right)$$

##### 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.

#### 4.14.1.2. 1996–2008 HFC and 1995–2008 PFC Emission Estimates

The following subsections provide explanations on the emission factors used and the assumptions made to develop 1996–2008 HFC and 1995–2008 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 4–17:

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

where:

$E_{\text{assembly}, t}$	=	emissions during system manufacture and assembly in year $t$
$\text{Charge}_t$	=	quantity of refrigerant charged into new systems in year $t$
$k$	=	assembly losses in percentage of the quantity charged

The  $k$  value was chosen from a range of values that were provided for each equipment category in the revised 1996 IPCC guidelines (IPCC/OECD/IEA 1997) (see Table 4–7).

## Annual Leakage

The equation below, given in the revised 1996 IPCC guidelines (IPCC/OECD/IEA 1997), was used to calculate HFC and PFC emissions from leakage:

Equation 4–18:

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

where:

$E_{\text{operation}, t}$	=	quantity of HFCs/PFCs emitted during system operations in year $t$
$\text{Stock}_t$	=	quantity of HFCs/PFCs stocked in existing systems in year $t$
$x$	=	annual leakage rate in percentage of total HFC/PFC charge in the stock

The term “ $\text{Stock}_t$ ” 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 equip-

ment. 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 4–8.

## System Disposal

It was assumed that there were no HFC/PFC emissions from the disposal of refrigeration and stationary AC systems during 1995–2008, 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.

## Foam Blowing

The IPCC Tier 2 methodology presented in the revised 1996 IPCC guidelines (IPCC/OECD/IEA 1997) was used to estimate HFC (1996–2008) and PFC (1995–2008) 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.

Table 4–7 Percentage of Losses during Assembly ( $k$ ) for Various Applicatio

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 4–8 Annual Leakage Rates (x) for Various Applications

For HFC estimates:		For PFC estimates:	
Application Type	x Values (%)	Application Type	x Values (%)
Residential Refrigeration	1.0	Refrigeration (including ultra low temperature refrigeration)	17.0
Commercial Refrigeration	17.0	Stationary AC	17.0
Stationary AC	17.0	Mobile AC	30.0
Mobile AC	15.0		

### Closed Cell Foam Blowing

During the production of closed cell foam, approximately 10% of the HFCs/PFCs used are emitted (IPCC/OECD/IEA 1997). The remaining quantity of HFCs/PFCs is trapped in the foam and is emitted slowly over a period of approximately 20 years. The IPCC Tier 2 equation (as shown below) was used to calculate emissions from closed cell foam:

Equation 4–19:

$$E_{\text{foam},t} = 10\% \times Q_{\text{ty}_{\text{manufacturing},t}} + 4.5\% \times \text{Orig. Charge}$$

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 its use in aerosols were negligible.

### Solvents

The IPCC Tier 2 methodology presented in the revised 1996 IPCC guidelines (IPCC/OECD/IEA 1997) was used to estimate HFC and PFC emissions from solvents. The emission estimate for the current year is equal to half of the HFCs/PFCs used as solvents in the current year plus half of the HFCs/PFCs used as solvents in the previous year. The amount of HFCs/PFCs used each year is equal to the amount of HFCs/PFCs produced and imported as solvents and excludes the amount of HFCs/PFCs exported as solvents. HFCs/PFCs used as solvents include the following categories:

- electronics industries;
- laboratory solvents; and
- general cleaning.

### Semiconductor Manufacture

There are two main uses of PFCs in the semiconductor manufacturing industry: plasma etching of silicon wafers and plasma cleaning of chemical vapour deposition chambers.

IPCC Tier 2b methodology, as shown below, was used to estimate PFC emissions from the semiconductor manufacturing industry:

Equation 4–20:

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

where:

- $E_{SC}$  = total PFC emissions from semiconductor
- $E_{FC}$  = emissions resulting from the use of PFCs (see Equation 4–21 below)
- $E_{CF_4}$  =  $CF_4$  emitted as a by-product during the use of PFCs (see Equation 4–22 below)

Equation 4–21:

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

where:

- $h$  = fraction of fluorocarbon remaining in shipping container (heel) after use
- $p$  = process type (plasma etching or chemical vapour deposition chamber cleaning)
- $FC_{i,p}$  = quantity of fluorocarbon  $i$  fed into the process type  $p$
- $C_{i,p}$  = use rate (fraction destroyed or transformed) for each fluorocarbon  $i$  and process type  $p$
- $a_{i,p}$  = fraction of gas volume  $i$  fed into the process  $p$  with emission control technologies
- $d_{i,p}$  = fraction of fluorocarbon  $i$  destroyed in the process  $p$  by the emission control technologies

Equation 4–22:

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

where:

- $B_{i,p}$  = fraction of gas  $i$  transformed into  $CF_4$  for each process type  $p$

and other terms are as defined above.

Default values for variables used in the above equations are shown in Table 4–9 (IPCC 2000).

As no information on emission control technologies for these processes was available,  $a_{i,p}$  was assumed to equal 0 and  $d_{i,p}$  to 1. Also,  $h$  was assumed to equal 0.1, as suggested in IPCC (2000).

Table 4–9 PFC Emission Rates<sup>1</sup>

Process	IPCC Default Emission Fractions			
	$CF_4$	$C_2F_6$	$C_3F_8$	$c-C_4F_8$
(1-C) Plasma Etching	0.7	0.4	0.4	0.3
(1-C) Chemical Vapour Deposition Chamber	0.8	0.7	0.4	ND
B Plasma Etching	NA	0.1	ND	NA
B Chemical Vapour Deposition Chamber	NA	0.1	0.2	NA

Notes:

1. Tier 2b, from IPCC (2000)

N/A = not available

## 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 PFC use as an electronic insulator and a dielectric coolant for heat transfer in the electronics industry. The IPCC Tier 2 emission factors (IPCC 2000) are applied to the PFC use data obtained from the PFC survey to estimate PFC emissions from contained sources, as follows:

Equation 4–23:

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

where:

$E_{\text{contained}, t}$	=	emissions from contained sources
$Qty_t$	=	quantity of PFC sale for use or manufacturing of contained sources in year $t$
$Stock_t$	=	quantity of PFCs in stock in year $t$
$k$	=	manufacturing emission rate (1% of annual sales)
$x$	=	leakage rate (2% of stock)
$d$	=	disposal emission factor (5% of annual sales)

## 4.14.2. Uncertainties and Time-Series Consistency

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  $\pm 50\%$ .

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  $\pm 24\%$ .

## 4.14.3. 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). No issues of importance were detected from the Tier 1 QC process.

Informal checks (such as data transcription checks, calculation checks, and unit conversion checks) were done on the category of PFC Consumption. No issues of importance were detected.

## 4.14.4. Category-Specific Recalculations

The 2007 HFC emission estimate was recalculated as a result of data revisions, the correction of an error in the calculation file and acquisition of new data. The difference between the last submission's and this submission's 2007

estimates was around +10.0% (or +0.49 Mt CO<sub>2</sub> eq). There was no recalculation for the category of PFC Consumption.

#### 4.14.5. Category-Specific Planned Improvements

Although some information on emission factors related to the use of HFCs has been obtained throughout the preparation of this inventory, a follow-up with companies will be needed to acquire more details, such that well-founded country-specific HFC emission factors can be developed. The inventory agency is also looking into the development of a regulatory collection tool, in future, for gathering of HFC and PFC use data. This, it is hoped, will improve the response rates and decrease the uncertainty in emissions. Finally, efforts will be made to acquire more information on the recovery and recycling technologies in place for the disposal of equipment using HFCs.

### 4.15. Production and Consumption of SF<sub>6</sub> (CRF Categories 2.E & 2.F)

#### 4.15.1. Source Category Description

In addition to magnesium production and casting, electrical equipment in electric utilities and semiconductor manufacturing are known sources of SF<sub>6</sub> emissions. In electric utilities, SF<sub>6</sub> is used as an insulating and arc-quenching medium in high-tension electrical equipment, such as electrical switchgear, stand-alone circuit breakers, and gas-insulated substations.

There is currently no production of SF<sub>6</sub> in Canada; therefore, all Canadian supply of SF<sub>6</sub> is obtained through imports. From 1990 to 1996, more than 95% of total SF<sub>6</sub> imports came from the United States; however, in recent years, this percentage has declined, with an increase in SF<sub>6</sub> imports from Germany (Cheminfo Services 2002).

#### 4.15.2. Methodological Issues

For SF<sub>6</sub> emissions from electrical equipment:

The method used for estimating SF<sub>6</sub> emissions from electrical equipment in utilities was a top-down approach, assuming that all SF<sub>6</sub> purchased from gas distributors

replaces SF<sub>6</sub> lost through leakage.

In a study conducted by Cheminfo Services (2002) to review and assess potential SF<sub>6</sub> emission sources in Canada, several Canadian utilities reported that new equipment is typically delivered with a few cylinders of SF<sub>6</sub> supplied for charging by the original equipment manufacturer (OEM). This implies that the amount of SF<sub>6</sub> purchased from OEMs can be small compared with the quantity bought from gas distributors. Hence, it is assumed that 100% of the SF<sub>6</sub> sales from gas distributors to utilities are used to refill leaking equipment, and that SF<sub>6</sub> supplied by OEMs is added to new stock and not emitted.

This method is considered as modified Tier 1 type because it follows the Tier 1 logic in assuming that all of the SF<sub>6</sub> purchased from gas distributors goes to replace SF<sub>6</sub> lost through leakage. It is considered as “modified” because it focuses only on gas distributor SF<sub>6</sub> sales (Cheminfo Services 2005a).

Gas distributors have been requested by the Greenhouse Gas Division to submit their annual SF<sub>6</sub> sales data by market segment, so that this modified Tier 1 method can be applied. However, comprehensive sets of sales data were collected from major gas distributors only for 1995–2000 inclusively. For the other years of the time series during which data were not provided by one of the major distributors, alternative approaches were employed to approximately calculate SF<sub>6</sub> sales. For example, 1990–1994 sales estimates were assumed to be the same as in 1995, as recommended by the Expert Review Team during the 2007 in-country review. The 2001–2008 sales were estimated by taking the difference between SF<sub>6</sub> imports<sup>16</sup> and the use of SF<sub>6</sub> in other sectors, such as primary magnesium production, magnesium product casting, laboratories, and aluminium production.

The 2004–2008 sales data from some major gas distributors were collected by the GHG Division and were used to determine the SF<sub>6</sub> sales distribution (in %) by market segment. The distribution percentages were then multiplied by the total import values to estimate the sales to smaller SF<sub>6</sub> users from which data could not be collected.

For SF<sub>6</sub> emissions from semiconductor manufacturing:

The method applied to estimate SF<sub>6</sub> emissions from

<sup>16</sup> Data obtained from Statistics Canada's International Merchandise Trade database [http://cansim2.statcan.gc.ca/cgi-win/CNSMCGI.PGM?Lang=E&CIMT\\_Action=Sections&ResultTemplate=CII\\_CIMT5](http://cansim2.statcan.gc.ca/cgi-win/CNSMCGI.PGM?Lang=E&CIMT_Action=Sections&ResultTemplate=CII_CIMT5)

semiconductor manufacturing was similar to the one used for calculating PFC emissions. However, as there is no by-product CF<sub>4</sub> created during the use of SF<sub>6</sub> in the process, Equation 4–22 is not needed. Hence,

Equation 4–24:

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

where:

h	=	fraction of SF <sub>6</sub> remaining in shipping container (heel) after use (%)
FC	=	quantity of SF <sub>6</sub> fed into the process (or sales) (t)
C	=	use rate (fraction destroyed or transformed) (%)
a	=	fraction of gas volume fed into the process with emission control technologies
d	=	fraction of SF <sub>6</sub> destroyed in the process by the emission control technologies

The value of h provided and confirmed by two major SF<sub>6</sub> gas distributors, Air Liquide and Praxair, was 12% (2006 emails from H. Rahal and A. Tardif).<sup>17</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. However, 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 2004–2008 were estimated by multiplying the SF<sub>6</sub> import (data purchased from Statistics Canada’s international merchandise trade database: [www.statcan.ca/trade/scripts/trade\\_search.cgi](http://www.statcan.ca/trade/scripts/trade_search.cgi)) by the sales distribution (in %) to 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

<sup>17</sup> Rahal H. and Tardif A. 2006. Personal communications (emails from Rahal H. and Tardif A. to A. Au, GHGD, dated November 22, 2006, and November 13, 2006, respectively). Praxair and Air Liquide.

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.

### 4.15.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has been performed for the category of Electrical Equipment. It should be noted, though, that the uncertainty assessment was done for only one year of the time series (2007). Therefore, it is expected that emission estimates of more recent years would have a similar uncertainty value, while older estimates would have a different uncertainty value. The uncertainty for the category as a whole was estimated at ±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 4–1, 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 ±45%. The uncertainty value is applicable to all years of the time series.

The data source and methodology used (for both electrical equipment and semiconductor manufacturing) were generally consistent throughout the time series.

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

SF<sub>6</sub> consumption in electrical equipment was a key category that has undergone Tier 1 QC checks as developed in the QA/QC plan (see Annex 6). The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC 2000). No issues of importance were detected.

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.

### 4.15.5. Category-Specific Recalculations

The 2007 estimate of SF<sub>6</sub> emissions from electrical equipment was recalculated due to an activity data revision. The difference between the last submission's and this submission's 2007 estimates was around +5.8% (or +0.07 Mt CO<sub>2</sub> eq).

The 2007 estimate of SF<sub>6</sub> emissions from semiconductor manufacturing was recalculated because of a major correction in the SF<sub>6</sub> sales data reported by a SF<sub>6</sub> distributor. The difference between the last submission's and this submission's 2007 estimates was around -95.3% (or -0.031 Mt CO<sub>2</sub> eq).

### 4.15.6. Category-Specific Planned Improvements

Collection of SF<sub>6</sub> emission estimates directly from utilities for inclusion in future GHG inventories is a planned improvement for the category of SF<sub>6</sub> emissions from electrical equipment. The estimates will be prepared and reported by utilities to the GHG Division according to the SF<sub>6</sub> emission estimation and reporting protocol recently developed by the GHG Division and the Canadian Electricity Association. These will be included in a future submission. Also to be performed, in collaboration with the Canadian electric utility companies, is the assessment of the uncertainty associated with the new emission data.

## 4.16. Other and Undifferentiated Production (CRF Category 2.G)

### 4.16.1. Source Category Description

Emissions from this subsector are from the non-energy use of fossil fuels and are not accounted for under any of the other subsectors of Industrial Processes. Examples of fuels in non-energy applications are the use of natural gas liquids (NGLs) and feedstocks in the chemical industry and the use of lubricants. All of them result in varying degrees of oxidation of the fuel, producing CO<sub>2</sub> emissions.

The use of fossil fuels as feedstock or for other non-energy uses is reported in an aggregated manner by Statistics Canada (#57-003) under "Non-Energy Use" for each individual fuel. In the event that CO<sub>2</sub> emissions resulting from non-energy fuel use are allocated to another category of the Industrial Processes Sector (as is the case for ammonia production, iron and steel production, and aluminium production), those emissions are subtracted from the total non-energy emissions to avoid double counting.

### 4.16.2. Methodological Issues

Emission rates for non-energy use of fuels were developed based on the total potential CO<sub>2</sub> emission rates and the IPCC default percentages of carbon stored in products. The total potential CO<sub>2</sub> emission rates were derived from the carbon emission factors shown in Jaques (1992), McCann (2000) and CIEEDAC (2006).

Fuel quantity data for non-energy fuel usage were reported by the *Report on Energy Supply-Demand in Canada* (RES-D – Statistics Canada #57-003). It should be noted that the RES-D data for any given year are preliminary and subject to revisions in subsequent publications. These data were multiplied by the emission rates shown in Annex 3 to estimate CO<sub>2</sub> emissions for this subsector.

This technique is considered to be a Tier 1 type method, as it is based on the use of national consumption data and average national emission factors. Methodological issues for calculating CO<sub>2</sub> emissions from the non-energy use of fossil fuels are not addressed specifically in the IPCC Good Practice Guidance (IPCC 2000).

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

### 4.16.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has also been performed for the category 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 data sources and methodology used are consistent

over the time series.

#### **4.16.4. Category-Specific QA/QC and Verification**

Other and Undifferentiated Production was a key category that has undergone Tier 1 QC checks as developed in the QA/QC plan (see Annex 6). The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC 2000). No issues of importance were detected.

#### **4.16.5. Category-Specific Recalculations**

The 2007 emission estimate was recalculated due to an update in the activity data. It is slightly different (-2.3% or -0.30 Mt CO<sub>2</sub> eq) than the one shown in the previous inventory.

#### **4.16.6. Category-Specific Planned Improvements**

It is planned to allocate emissions from petroleum products used as feedstock in the petrochemical industry into a new category, petrochemical production, which will be included under the Chemical subsector.

# 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) mention 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 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 0.33 Mt CO<sub>2</sub> eq to the 2008 national GHG inventory, compared with 0.18 Mt CO<sub>2</sub> eq in 1990. These emissions represented

0.05% of the total Canadian GHG emissions in 2008. 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 this food product has been relatively stable since 1995 (Cheminfo Services 2006).

To ensure the correctness of the estimates, this Sector has undergone Tier 1 quality control checks. 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 the steam is condensed out, the “crude” N<sub>2</sub>O is further purified, compressed, dried and liquefied for storage and distribution. Nitrous Oxide of Canada in Maitland, Ontario, is the only known producer of compressed N<sub>2</sub>O for commercial 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 9 000 to 12 000 final end-use customers for N<sub>2</sub>O in Canada, including dental offices, clinics, hospitals and laboratories (Cheminfo Services 2006).

N<sub>2</sub>O is used in a limited number of applications, with anaesthetic use representing the vast majority of consump-

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

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)				
	1990	2005	2006	2007	2008
Solvent and Other Product Use TOTAL	170	180	320	320	330
Use of N <sub>2</sub> O as an anaesthetic	150	150	270	270	280
Use of N <sub>2</sub> O as a propellant	28	28	51	51	52

tion 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 was used to inflate automobile airbags), atomic absorption spectrometry and semiconductor manufacturing. According to the distributors that were surveyed during the recent study, approximately 82% of their N<sub>2</sub>O sales volume 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 used as an anaesthetic, approximately 97.5% of the N<sub>2</sub>O is not metabolized and quickly leaves the body in exhaled breath (i.e. is emitted) as a result of its poor solubility 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). Nitrous Oxide of Canada (NOC) was contacted to obtain its annual production and domestic sales data, but it was able to provide only rough estimates of historical data. Also, a questionnaire requesting sales volumes by market segment was sent to each of the N<sub>2</sub>O distributors. However, these companies did not provide the full set of historical data that was requested. For the 2006–2008

data, requests for data were sent to NOC and the gas distributors directly by the GHG Division.

As a complete set of sales data covering 1990–2008 could not be gathered, the domestic sales of Canadian production data provided by NOC and N<sub>2</sub>O import data purchased from Statistics Canada's merchandise trade database<sup>2</sup> (Statistics Canada 2009) were used to estimate the total domestic sales volumes (or consumption) of N<sub>2</sub>O for 1990–2008. 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 2006–2008 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, the amount of N<sub>2</sub>O sold for anaesthetic purposes was multiplied by a factor of 97.5%. The latter factor was used for the reason mentioned in the source category description, which is that approximately 97.5% of the N<sub>2</sub>O is not metabolized and is emitted in exhaled breath. The same factor was also applied by the U.S. EPA.

To estimate emissions coming from N<sub>2</sub>O use in food products (i.e. whipped cream cans) at the national level, it was assumed that 100% of the quantity used in the whipped cream manufacturing was emitted, as explained previously in the source category description section. The same assumption was also made by the U.S. EPA.

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

The national emission estimates were divided by the national total population to yield an emissions per capita factor. This factor was then multiplied by the population in each province and territory to estimate emissions at provincial/territorial levels. The 1990–2000 annual population statistics were obtained from Statistics Canada (#91-213) and 2001–2008 data from Statistics Canada (#91-215).

The IPCC *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000)

<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.

<sup>2</sup> Available at [http://www.statcan.ca/trade/scripts/trade\\_search.cgi](http://www.statcan.ca/trade/scripts/trade_search.cgi)

does not provide any recommendations on the estimation of N<sub>2</sub>O emissions.

### 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 was expected that the uncertainty for this Sector would not vary considerably from year to year, especially for more recent years, as the data sources and methodology applied were the same.

### 5.1.4. Quality Assurance, Quality Control and Verification

This Sector was a key category which 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

There was no recalculation for this Sector.

### 5.1.6. Planned Improvements

First, the recently obtained historical N<sub>2</sub>O production data will be used to improve the N<sub>2</sub>O emission estimates in a future inventory. Another improvement would be the application of the default emission rate of 100% for the use of N<sub>2</sub>O as anaesthetic, as recommended by the 2006 IPCC guidelines (IPCC 2006). Finally, the use patterns of N<sub>2</sub>O will be reviewed based on data and inputs to be supplied by gas distributors.

# Chapter 6

## Agriculture (CRF Sector 4)

### 6.1. Overview

Emission sources from agriculture include animal production—namely, enteric fermentation (CH<sub>4</sub>) and manure management (N<sub>2</sub>O and CH<sub>4</sub>)—and agricultural soils (N<sub>2</sub>O). CO<sub>2</sub> emissions from and removals by agricultural lands are reported under the Land Use, Land-Use Change and Forestry (LULUCF) Sector under the Cropland category (see Chapter 7).

Total greenhouse gas (GHG) emissions from the Canadian Agriculture Sector were 48 Mt CO<sub>2</sub> eq in 1990 and 62 Mt CO<sub>2</sub> eq in 2008 (Table 6–1). This represents an increase of 29% between 1990 and 2008, mainly resulting from the expansion of the beef cattle and swine populations since 1990 (29% and 25%, respectively), as well as an increase in the consumption of synthetic nitrogen fertilizers (60%).

Since 2005, there have been no significant increases or decreases in total emissions, as increases in emissions due to nitrogen fertilizer use and crop residue decomposition are offset by reductions in emissions from animal production (Enteric Fermentation and Manure Management, Table 6-1).

In this submission, changes in the Agriculture Sector consist of updates in synthetic nitrogen fertilizer consumption for 2007. This resulted in an overall upward recalculation of emissions by about 1.6 Mt CO<sub>2</sub> eq or 2.6% for 2007 for the Agriculture Sector.

Biological nitrogen fixation by the legume-rhizobium association is reported as not occurring. This decision is supported by Rochette and Janzen (2005) (and reflected in the IPCC 2006 Guidelines), who concluded that there is no evidence that measurable amounts of N<sub>2</sub>O are produced during the nitrogen fixation process. Methane emissions

from rice production in Canada do not occur. Field burning of agricultural residues has not yet been estimated for this submission, but will be included in the next annual submission. Prescribed 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 Section A3.3.

The expert review committee (ERT) raised certain issues during the review of Canada's 2009 submission. Table 6–2 provides details of actions taken to address reviewers' concerns.

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

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)				
	1990	2005	2006	2007	2008
<b>Agriculture TOTAL</b>	<b>48 000</b>	<b>62 000</b>	<b>61 000</b>	<b>61 000</b>	<b>62 000</b>
Enteric Fermentation	17 000	24 000	23 000	23 000	22 000
—CH <sub>4</sub>					
Dairy Cattle	2 700	2 500	2 500	2 400	2 600
Beef Cattle <sup>2</sup>	14 000	20 000	20 000	19 000	19 000
Others <sup>3</sup>	610	1 100	1 100	1 000	1 000
Manure Management	6 000	8 100	8 000	7 800	7 500
—CH <sub>4</sub>					
Dairy Cattle	570	530	520	510	550
Beef Cattle <sup>2</sup>	700	890	860	840	830
Swine	1 100	1 600	1 600	1 500	1 300
Poultry	72	92	92	92	92
Others <sup>4</sup>	23	37	37	37	37
—N <sub>2</sub> O					
All Animal Types	3 500	5 000	4 900	4 800	4 700
<i>Agricultural Soils (N<sub>2</sub>O)</i>	26 000	30 000	30 000	31 000	32 000
Direct Sources	14 000	15 000	15 000	16 000	17 000
Synthetic Nitrogen Fertilizers	5 900	7 000	7 100	8 100	8 500
Manure Applied as Fertilizers	1 900	2 300	2 300	2 200	2 200
Crop Residue Decomposition	4 800	5 200	5 400	5 200	6 200
Cultivation of Organic Soils	63	63	63	63	63
Conservation Tillage <sup>5</sup>	-300	-900	-860	-950	-1 200
Summerfallow	1 300	800	700	690	740
Irrigation	280	350	340	350	390
Pasture, Range, and Paddock Manure	2 600	4 100	4 000	3 900	3 800
Indirect Sources	9 100	11 000	11 000	11 000	12 000

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.

Table 6-2 Proposals for Improvement by the ERT for Canada's 2009 Submission and Actions Taken in the 2010 Submission.

ERT proposal for revision in 2009 submission	Actions taken in 2010 submission.
Report emissions of CH <sub>4</sub> from mules and asses.	Canada reports mules, asses and camels as not occurring after confirming that mules and asses are not raised for commercial purposes in Canada.
Review and explain the reason for the low average gross energy intake values for non-dairy cattle estimated by Canada	The calculation procedure used to input gross energy in the CRF was reviewed and corrections to calculations were integrated in the database. Gross energy values are reported accurately this year
Provide a detailed description of how animal waste management systems (AWMSs) are broken down by regions	A more detailed description of regional differences in AWMSs is presented in Annex 3.3 in Table A3-23.
Update uncertainty analysis using the most recent inventory data	Updated uncertainty analysis has been integrated into Canada's planned improvement process, to be reported in 2011.

## 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. Most dairy production occurs in eastern Canada in high-production, high-density production 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, 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 emit-

ted by eructation and exhalation. Some CH<sub>4</sub> is released later in the digestive process by flatulation, but this accounts for less than 5% of total emissions. Ruminant animals, such as cattle, generate the most CH<sub>4</sub>.

### 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. A national study by Boadi et al. (2004) characterized cattle populations across Canada by animal type, physiological status, age, sex, weight, growth rate, activity level and production environment. Data were obtained by surveying beef and dairy cattle specialists across the country. Herd improvements that have produced increases in milk production and fat content from dairy cattle over the 1990–2008 time period are reflected in Tier 2 estimates of gross energy consumption (GE) and result in gradual increases in CH<sub>4</sub> emission factors from this

Table 6–3 Animal Categories and Sources of Population Data

Category	Sources/Notes
Cattle	Data downloaded from CANSIM <sup>1</sup> in October 2009, Table 003-0032
—Dairy Cattle	Dairy cows
—Non-Dairy Cattle	All other cattle
Buffaloes	Statistics Canada (2008), Alternative Livestock on Canadian Farms: Census years 1981, 1986, 1991, 1996, 2001 and 2006 (Catalogue # 23-502-X)
Sheep and Lambs	Data downloaded from CANSIM in October 2009, Table 003-0031
Goats and Horses	Statistics Canada (2008), Alternative Livestock on Canadian Farms: Census years 1981, 1986, 1991, 1996, 2001 and 2006 (Catalogue # 23-502-X)
Llamas and Alpacas	Statistics Canada (2008), Alternative Livestock on Canadian Farms: Census years 1981, 1986, 1991, 1996, 2001 and 2006 (Catalogue # 23-502-X)
Mules and Asses	Not raised for commercial purposes in Canada
Swine	All pigs Data downloaded from CANSIM in October 2009, Table 003-0004
Poultry	Farm data and farm operator data tables (section 6.5 of publication #95-629) (Statistics Canada 2007a) Selected historical data from the Census of Agriculture, Canada and provinces: census years 1976 to 2006 (Table 2.16 and section 4.6 of Statistics Canada catalogue #95-632) (Statistics Canada 2007b)

<sup>1</sup> CANSIM is Statistics Canada's online database that stores the most up-to-date statistics available in Canada.

animal category. In beef cattle, herd improvements have led to increases in mature body weight, also reflected in GE, and have resulted in an increase in emission factors over the 1990 to 2008 time-series (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 (Table 6–3). The data is based on the *Census of Agriculture*, conducted every 5 years and updated annually by semi-annual or quarterly surveys for important animal categories.

### 6.2.3. Uncertainties and Time-Series Consistency

The uncertainty associated with CH<sub>4</sub> emissions from enteric fermentation was determined using the Monte Carlo technique based on the IPCC Tier 2 methodology (Hutchinson et al. 2007). Uncertainties associated with animal populations are deemed to be relatively low, ranging from ±1% for poultry, ±2% for sheep and lambs, ±3% for dairy cattle, ±5% for non-dairy cattle, ±10% for swine, and ±15% for horses, goats, and llamas. Uncertainties associated with the IPCC Tier 2 emission factors for cattle vary from ±5% for dairy cows to ±17% for steers (Boadi et al. 2004). Uncertainties associated with emission factors taken from the IPCC Tier 1 defaults for non-cattle categories were estimated to be ±20% (IPCC/OECD/IEA 1997).

Two issues that effect the time-series calculation were identified in the Agricultural database but were not corrected in time to be incorporated in the 2010 submission.

First, in the time-series data for milk fat for the province of Quebec, the percentage (%) of fat was used as input into Equation 4.5a of the *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, whereas the unit for this calculation should be kg day<sup>-1</sup>. This error results in an underestimation of the emissions from the province of Quebec of approximately 10 to 15% for the period of 1990 to 1998 and 2 to 3% on the national emissions. This error modifies the data trend, by decreasing the 1990 to 1998 emissions from agriculture relative to

emissions from 2008.

Second, inconsistencies were identified in the implementation of equations 4.3a, and 4.4b of the *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* used to calculate net energy mobilization (NE<sub>mob</sub>, see Equation A3-9 in Annex 3.3) due to weight loss during lactation. The result was an approximate decrease in estimated GE of 5 to 15 % for the 1990 to 2007 time-series (see equations A3-9 and A3-10 in Annex 3.3) and therefore a reduction of emission factors for lactating cattle. Preliminary investigations suggest that emissions from enteric fermentation and manure management may be underestimated by 1 to 4% from 1990 to 2007, but the trend does not change. These inconsistencies were corrected for the calculation of emission estimates for 2008, but were not corrected for the 1990 to 2007 time-series.

### 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 5) 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 emission factors for cattle, derived from Boadi et al. (2004), have been reviewed by independent experts (McAllister and Basarab 2004).

Research involving direct on-farm measurements of CH<sub>4</sub> emissions from enteric fermentation is ongoing in Canada. Canadian researchers have adopted a tracer technique for measuring CH<sub>4</sub> emissions from grazing cattle using SF<sub>6</sub> (McCaughy et al. 1997, 1999; Boadi and Wittenberg 2002; Boadi et al. 2002a, 2002b; McGinn et al. 2004, 2006; Beauchemin and McGinn 2005). These studies will be compiled and compared to current Tier 2 country-specific emission factors.

### 6.2.5. Recalculations

All data sources were consistent with the 2009 submission. No recalculations were done to the 1990–2007 time-series.

### 6.2.6. Planned Improvements

Calculations of net energy (NE) contributions to gross energy (GE) balance due to weight loss during lactation in beef and dairy cattle will be corrected for the 1990 to 2007 time-series. Consultations are ongoing with national

experts to review the data currently used in the Canadian Tier 2 model for live body weight, weight loss and weight gain that must be considered when calculating  $NE_{mob}$  due to weight loss. Once this consultation is complete, the time-series will be corrected using appropriate data and methods.

Tier 2 uncertainty analyses will be updated considering improved methods and new data sources.

As noted in the 2009 submission, in the current methodology, digestible energy by animal category is static over time based on the 2001 feed rations. Consultations are ongoing with national animal production experts to evaluate the possibility of developing a time-series that accounts for changes in feed ration digestibility. If possible, this will be incorporated over the medium to long term.

## 6.3. Manure Management (CRF Category 4.B)

In Canada, the animal waste management systems (AWMSs) typically used in animal production include 1) liquid, 2) solid storage and drylot, and 3) pasture and paddock, but include some 4) other systems such as composters and biodigestors. No manure is burned as fuel.

As animal production varies from region to region, so do manure management practices. Dairy, poultry and swine production occur in modern high-density production facilities. Dairy and swine produce large volumes of liquid manure while poultry production 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 medium-density production facilities producing mainly solid manure.

Both  $CH_4$  and  $N_2O$  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  $CH_4$  emissions but relatively low  $N_2O$  emissions, whereas well-aerated systems generate high  $N_2O$  emissions but relatively low  $CH_4$  emissions.

## 6.3.1. $CH_4$ 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  $CO_2$ ; however, if little oxygen is present, carbon is reduced, resulting in the production of  $CH_4$ . The quantity of  $CH_4$  produced depends on manure characteristics and on the type of manure management systems. Manure characteristics are in turn linked to animal types and diets.

### 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). A national average was used to quantify the distribution of different types of manure management systems for each animal category, taken from Marinier et al. (2004) for all provinces with the exception of British Columbia. The distribution of manure management systems are taken from Marinier et al. (2005) as provincial experts considered that they better reflect their production systems and climate. A more complete description of the derivation of the distribution factor for manure management systems is contained in Appendix A3.3, Section A.3.3.4.4.

Methane emission factors for manure management are estimated using the IPCC Tier 2 methodology. Emission factors were derived from a study conducted by Marinier et al. (2004), with updates of  $CH_4$  producing potential ( $B_0$ ) and  $CH_4$  conversion factors (MCF) according to the IPCC 2006 Guidelines. For dairy and beef cattle, volatile solids (VS) were estimated using Equation 4.16 of the Good Practice Guidance. The same cattle characterization as in the enteric fermentation Tier 2 method developed by Boadi et al. (2004) was used to derive gross energy of consumption (GE). The digestible energy (DE) and ash content were taken from Marinier et al. (2004), who compiled data from expert consultations. The increase in emission factors over time reflects higher gross energy intake for dairy cattle due to increased milk productivity and for beef cattle due

to increased live body weights. For non-cattle categories, VS was derived from expert consultations (Marinier et al. 2004).

### 6.3.1.3. Uncertainties and Time-Series Consistency

The uncertainty associated with CH<sub>4</sub> emissions from manure management was determined using a Monte Carlo technique based on the IPCC Tier 2 methodology (Hutchinson et al. 2007).

Animal population uncertainties were identical to the Enteric Fermentation category input, ranging from  $\pm 1\%$  for poultry,  $\pm 2\%$  for sheep and lambs,  $\pm 3\%$  for dairy cattle,  $\pm 5\%$  for non-dairy cattle,  $\pm 10\%$  for swine, and  $\pm 15\%$  for horses, goats, and llamas. Uncertainties associated with the gross energy intake for cattle vary from  $\pm 5\%$  for dairy cows to  $\pm 17\%$  for steers (Boadi et al. 2004). Uncertainty associated with the MCF and B<sub>0</sub> for various animal categories were taken from the IPCC 2006 defaults. Marinier et al. (2004) calculated uncertainties related to animal manure distribution systems. The uncertainties associated with the IPCC Tier 2 emission factors varied from  $\pm 26\%$  for beef cows to  $\pm 50\%$  for poultry (Marinier et al. 2004). The overall level and trend uncertainties for emission estimates from 1990 to 2007 were estimated to be  $\pm 29\%$  and  $\pm 23\%$ , respectively (Hutchinson et al. 2007).

As noted in the Enteric Fermentation category section 6.2.3, issues were identified in the implementation of equations 4.3a and 4.4b of *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*. The calculation of GE directly modifies the calculation of volatile solids, which in turn influences the CH<sub>4</sub> emission factor for manure management for certain cattle subcategories. As such, it is estimated that emissions from 1990 to 2007 are underestimated by approximately 0.5 to 2%. As was the case with the Enteric Fermentation category, these inconsistencies were corrected for the calculation of estimates for 2008, but were not corrected for the 1990 to 2007 time-series.

### 6.3.1.4. QA/QC and Verification

CH<sub>4</sub> emissions from manure management have undergone Tier 1-level QC checks as elaborated in the QA/QC plan (Annex 5) in a manner consistent with IPCC good practice guidance. 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 forms.

### 6.3.1.5. Recalculations

All data sources were consistent with the 2009 submission. No recalculations were done to the 1990–2007 time-series.

### 6.3.1.6. Planned Improvements

As noted in Section 6.2.6, inconsistencies identified in the equations to calculate GE will be corrected in the 1990–2007 time-series.

A weighted Canadian average is currently used for the distribution of manure management systems (by each animal type or category). Marinier et al. (2005) supplied estimates of the distribution of manure management systems for Canadian regions. To improve the description of regional manure management systems, this information will be integrated into the agricultural database.

Tier 2 uncertainty analyses will be updated considering improved methods and new data sources.

As noted in Section 1.2.6, the possibility of incorporating a time-series for digestible energy used in the calculation of volatile solids is being considered for the medium to long 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>. In general, the amount of N<sub>2</sub>O produced increases with greater aeration of the manure. Manure from beef cattle, sheep, lamb, goats, and horses are mainly handled with a solid and drylot system, which is the manure management system that emits the most N<sub>2</sub>O. Nitrous oxide emissions from manure on pasture, range, and paddock by grazing animals

are reported separately (refer to Manure on Pasture, Range, and Paddock, Section 6.4.2).

### 6.3.2.2. Methodological Issues

There have been very little published data on N<sub>2</sub>O emissions from manure management systems in Canada. 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 population 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 IPCC 2006 Guidelines. The amount of manure nitrogen subject to losses because of leaching and volatilization of NH<sub>3</sub> and NO<sub>x</sub> is adjusted by animal type and manure management system according to the default values provided in the IPCC 2006 Guidelines.

The fraction of nitrogen available for conversion into N<sub>2</sub>O is estimated by applying system-specific emission factors to the manure nitrogen handled by each management system. The IPCC 2006 default emission factors for a developed country with a cool climate are used to estimate manure nitrogen emitted as N<sub>2</sub>O for each type of AWMS.

### 6.3.2.3. Uncertainties and Time-Series Consistency

Uncertainties associated with N<sub>2</sub>O emission estimates from manure management result from uncertainties associated with estimates of animal populations from the *Census of Agriculture* and range from ±1% to ±15%, as noted in Sections 6.2.3 and 6.3.1.3. Uncertainties associated with rates of nitrogen excretion are ±20% (IPCC 2006), with types of AWMS are ±20% (Marinier et al. 2004), and with the emission factors are ±20% (IPCC 2006). The overall level and trend uncertainties associated with this source of emission estimates from 1990 to 2008 were estimated to be ±25% and ±21%, respectively (Hutchinson et al. 2007).

The same methodology, emission factors, and data sources are used for the entire time-series (1990–2008).

### 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 5) in a manner consistent with IPCC good practice guidance. The activity data, methodology, and changes to methodologies are documented and archived in both paper and electronic form.

### 6.3.2.5. Recalculations

All data sources were consistent with the 2009 submission. No recalculations were done to the 1990–2007 time-series.

### 6.3.2.6. Planned Improvements

Data from direct measurements of N<sub>2</sub>O emissions from manure management in Canada are scarce. Recent scientific advances in analytical techniques allow direct measurements of N<sub>2</sub>O emissions from point sources. However, it will likely take several years before N<sub>2</sub>O emissions can be reliably measured and verified for various manure management systems in Canada.

## 6.4. N<sub>2</sub>O Emissions from Agricultural Soils (CRF Category 4.D)

Emissions of N<sub>2</sub>O from agricultural soils consist of direct and indirect emissions as well as emissions from animal manure 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 organic matter decomposition and the subsequent mineralization of organic nitrogen which becomes available for 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 synthetic nitrogen fertilizers, animal manure applied as fertilizers, crop

residue decomposition, and soil organic matter decay as affected by tillage practices, summerfallow, irrigation, and cultivation of histosols.

#### 6.4.1.1. Synthetic Nitrogen Fertilizers

##### Source Category Description

Synthetic fertilizers add large quantities of nitrogen to agricultural soils. This added nitrogen undergoes transformations, such as nitrification and denitrification, which release  $N_2O$ . 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).

##### Methodological Issues

As elaborated in detail in Section A3.3, Canada has developed a country-specific, Tier 2 methodology to estimate  $N_2O$  emissions from synthetic nitrogen fertilizer application on agricultural soils, which takes into account moisture regimes and topographic conditions. Emissions of  $N_2O$  are estimated by ecodistrict, then summed 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. Since 2007, fertilizer nitrogen data have been compiled and published by Statistics Canada. 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.

##### Uncertainties and Time-Series Consistency

Uncertainties associated with  $N_2O$  emission estimates from synthetic nitrogen fertilizer applications result from the uncertainty in estimates of nitrogen fertilizer sales ( $\pm 20\%$ ), estimates of  $EF_{BASE}$  ( $\pm 25\%$ ), an ecodistrict-based  $N_2O$  emission factor and estimates of  $RF_{TEXTURE}$ , a ratio factor adjusting  $EF_{BASE}$  for soil texture ( $\pm 30\%$ ). These terms and emission calculations are explained in the methodological Section A3.3. The overall level and trend uncertainties associated with this source of emissions from 1990 to 2008 were estimated to be  $\pm 21\%$  and  $\pm 19\%$ , respectively (Hutchinson et al. 2007).

The same methodology and emission factors are used for the entire time-series (1990–2008).

##### QA/QC and Verification

This category has undergone Tier 1-level QC checks as elaborated in the QA/QC plan (Annex 5) 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 Greenhouse Gas Division of Environment Canada carries out its own Tier 2 QC checks through historical records and consultations with regional and provincial agricultural industries.

$N_2O$  emissions 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).

##### Recalculations

In this submission, synthetic nitrogen fertilizer consumption for 2007 has been updated based on the most recent release of data from Statistics Canada. This resulted in an overall upward adjustment of emissions by 1 Mt  $CO_2$  eq or 14% for 2007, and had a significant impact for the long-term trend.

##### Planned Improvements

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

#### 6.4.1.2. Manure Applied as Fertilizer

##### Source Category Description

The application of animal manure as fertilizer to agricultural soils can increase the rate of nitrification and denitrification and result in enhanced  $N_2O$  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, Manure on Pasture, Range, and Paddock

## Methodological Issues

Similar to the methodology used to estimate emissions from synthetic nitrogen fertilizers, the methodology used to estimate N<sub>2</sub>O emissions from animal manure applied to agricultural soils is a country-specific IPCC Tier 2 method that takes into account moisture regimes (long-term monthly precipitation and potential evapotranspiration) and topographic conditions. Emissions are calculated by multiplying the amount of manure nitrogen applied to agricultural soils by 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).

## Uncertainties and Times Consistency

Uncertainties associated with N<sub>2</sub>O emission estimates from animal manure applied as fertilizers result from uncertainties associated with estimates of manure nitrogen based on types of animal population ( $\pm 1\% \sim \pm 15\%$ ), average animal manure nitrogen excretion rate ( $\pm 20\%$ ), manure nitrogen loss ( $\pm 20\%$ ), RF<sub>TEXTURE</sub> ( $\pm 30\%$ ), and EF<sub>BASE</sub> ( $\pm 25\%$ ). The overall level and trend uncertainties associated with this source of emission estimates from 1990 to 2008 were estimated to be  $\pm 32\%$  and  $\pm 28\%$ , respectively (Hutchinson et al. 2007).

The same methodology and emission factors are used for the entire time-series (1990–2008).

## QA/QC and Verification

This category has undergone Tier 1-level QC checks as elaborated in the QA/QC plan (Annex 5) in a manner consistent with IPCC good practice guidance. The activity data, methodologies, and changes to methodologies are documented and archived in both paper and electronic form.

## Recalculations

There has been no recalculation in this source of emission estimates.

## Planned Improvements

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

## 6.4.1.3. Biological Nitrogen Fixation

### Source Category Description

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)

### 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.

## 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, using moisture regimes and topographic conditions.

## Uncertainties and Time-Series Consistency

Uncertainties associated with N<sub>2</sub>O emission estimates from crop residue decomposition result from uncertainties associated with estimates of crop residue nitrogen returned to the soil based on crop production data ( $\pm 15\%$ ), above- and below-ground crop residue nitrogen concentration ( $\pm 15\%$ ), RF<sub>TEXTURE</sub> ( $\pm 30\%$ ), and EF<sub>BASE</sub> ( $\pm 25\%$ ). The overall level and trend uncertainties associated with this source of emission estimates from 1990 to 2008 were estimated to be  $\pm 23\%$  and  $\pm 20\%$ , respectively (Hutchinson et al. 2007).

The same methodology and emission factors are used for the entire time-series (1990–2008).

## QA/QC and Verification

This category has undergone Tier 1-level QC checks as elaborated in the QA/QC plan (Annex 5) in a manner consistent with IPCC good practice guidance. The activity data, methodologies, and changes to methodologies are documented and archived in both paper and electronic form.

## Recalculations

There has been no recalculation in this source of emission estimates over the last two years.

## Planned Improvements

Activity data on the area of crop residue burning are only available from the Farm Environmental Management Survey by Statistics Canada in 2001 and 2006. Efforts have been made to fill in the data gap since 1990 through expert consultations. Emissions of non-CO<sub>2</sub> gases (N<sub>2</sub>O and CH<sub>4</sub>) from crop residue burning using the IPCC default emission factors are estimated at 0.2 Mt in 1990 and 0.03 Mt in 2007, and these emissions will be reported separately in the next annual submission, while the amount of nitrogen lost from burning will be subtracted from crop residue decomposition.

### 6.4.1.5. Cultivation of Organic Soils (Histosols)

#### Source Category Description

Cultivation of organic soils (histosols) for crop production usually involves drainage, lowering the 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).

#### Methodological Issues

The IPCC Tier 1 methodology is used to estimate N<sub>2</sub>O emissions from cultivated organic soils. N<sub>2</sub>O emissions are calculated by multiplying the area of cultivated histosols by the IPCC default emission factor.

Areas of cultivated histosols at a provincial level are not covered in the *Census of Agriculture*. Consultations with numerous soil and crop specialists across Canada have resulted in an estimate of cultivated organic soils in Canada to be 16 kha, a constant level for the period 1990–2008 (Liang et al. 2004a).

## Uncertainties and Time Series Consistency

Uncertainties associated with N<sub>2</sub>O emission estimates from the cultivation of histosols result from uncertainties associated with area estimates of cultivated histosols ( $\pm 50\%$ ) and emission factors ( $\pm 50\%$ ). The overall level and trend uncertainties associated with this source of emission estimates from 1990 to 2008 were estimated to be  $\pm 67\%$  and  $\pm 65\%$ , respectively (Hutchinson et al. 2007).

The same methodology and emission factors are used for the entire time-series (1990–2008).

## QA/QC and Verification

This category has undergone Tier 1-level QC checks as elaborated in the QA/QC plan (Annex 5) in a manner consistent with IPCC good practice guidance. The activity data, methodologies, and changes to methodologies are documented and archived in both paper and electronic form.

## Recalculations

There has been no recalculation in this source of emission estimates over the last two years.

## Planned Improvements

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

### 6.4.1.6. Changes in N<sub>2</sub>O Emissions from Adoption of No-Till and Reduced Tillage

#### Source Category Description

This category is not derived from additional nitrogen inputs (i.e. fertilizer, manure, or crop residue) but 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).

#### 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 (hence the negative sign in Table 6–1).

Changes in N<sub>2</sub>O emissions resulting from the adoption of NT and RT are estimated through modifications of emission factors for synthetic fertilizers, manure nitrogen applied to cropland, and crop residue nitrogen decomposition. This subcategory is kept separate from the fertilizer and crop residue decomposition source categories to preserve the transparency in reporting; however, this separation causes negative emissions to be reported (Table 6–1). An empirically derived 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 A3.3).

### Uncertainties and Time-Series Consistency

Uncertainties associated with changes in N<sub>2</sub>O emission estimates from adoption of NT and RT result from uncertainties associated with area estimates of NT and RT from the *Census of Agriculture* ( $\pm 15\%$ ),  $F_{TILL}$  ( $\pm 20\%$ ), and  $EF_{BASE}$  ( $\pm 25\%$ ). The overall level and trend uncertainties associated with this source of emission/removal estimates from 1990 to 2008 have not been assessed.

The same methodology and emission factors are used for the entire time-series (1990–2008).

### QA/QC and Verification

This category has undergone Tier 1-level QC checks as elaborated in the QA/QC plan (Annex 5) in a manner consistent with IPCC good practice guidance. The activity data, methodologies, and changes to methodologies are documented and archived in both paper and electronic form.

### Recalculations

There is no change in the area of tillage practices, but recalculations have occurred in this category as a result of update for synthetic nitrogen fertilizer consumption for 2007 as noted in Section 6.3.2. These recalculations increased removals by 0.07 Mt CO<sub>2</sub> eq or 8% for 2007 and had a modest impact on the long-term trend.

### Planned Improvements

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

## 6.4.1.7. N<sub>2</sub>O Emissions Resulting from Summerfallowing

### Source Category Description

This category is not derived from additional nitrogen input but reflects changes in soil conditions that affect N<sub>2</sub>O emissions. Summerfallow (SF) is a farming practice typically used in the Prairie region to conserve soil moisture by leaving the soil unseeded for an entire growing season in a crop rotation. During the fallow year, several soil factors may stimulate N<sub>2</sub>O emissions relative to a cropped situation, such as higher water content, higher temperature, and greater availability of carbon and nitrogen (Campbell et al. 1990, 2005).

### 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 A3.3. 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.

Following the Expert Review Team's recommendations in 2007, Canada has expanded explanations for the estimation method in Annex A3.3.

### Uncertainties and Time-Series Consistency

Uncertainties associated with N<sub>2</sub>O emission estimates from summerfallow result from uncertainties associated with area estimates of summerfallow from the *Census of Agriculture* (cropland area: 1.25% ~10%; the fraction of cropland that is under summerfallow ( $FRAC_{FALLOW}$ ): 1.25% ~10%) and  $EF_{BASE}$ :  $\pm 25\%$ . The overall level and trend uncertainties associated with this source of emission estimates from 1990 to 2008 were estimated to be  $\pm 24\%$  and  $\pm 21\%$ , respectively (Hutchinson et al. 2007).

The same methodology and emission factors are used for the entire time-series (1990–2008).

### QA/QC and Verification

This category has undergone Tier 1-level QC checks as elaborated in the QA/QC plan (Annex 5) in a manner consistent with IPCC good practice guidance. The activity data, methodologies, and changes to methodologies are documented and archived in both paper and electronic form.

### Recalculations

There is no change in the area of summerfallow, but recalculations have occurred in this category as a result of the update for synthetic nitrogen fertilizer consumption for 2007 as noted in Section 6.3.2. These recalculations increased emissions by 0.05 Mt CO<sub>2</sub> eq or 7% for 2007 and had a modest impact on the long-term trend.

### Planned Improvements

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

## 6.4.1.8. N<sub>2</sub>O Emissions from Irrigation

### Source Category Description

Similar to tillage practices and summerfallow, the effect of irrigation on N<sub>2</sub>O emissions is not derived from additional nitrogen input but reflects changes in soil conditions that affect N<sub>2</sub>O emissions. Higher soil water content under irrigation increases the potential for N<sub>2</sub>O emissions through increased biological activity, reducing soil aeration (Jambert et al. 1997), thus enhancing denitrification.

### 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 (or EF<sub>BASE</sub> = 0.017 N<sub>2</sub>O-N/kg N) for the irrigated areas of a given ecodistrict.

### Uncertainties and Time-Series Consistency

Uncertainties associated with N<sub>2</sub>O emission estimates from irrigation result from uncertainties associated with syn-

thetic nitrogen ( $\pm 20\%$ ) and animal manure nitrogen inputs ( $\pm 20\%$ ), crop residue nitrogen ( $\pm 15\%$ ), area estimates of irrigated cropland from the *Census of Agriculture* (1.25% to 10%), as well as EF<sub>BASE</sub> ( $\pm 25\%$ ). The overall level and trend uncertainties associated with this source of emission estimates have not been assessed at this time.

The same methodology and emission factors are used for the entire time-series (1990–2008).

### QA/QC and Verification

This category has undergone Tier 1-level QC checks as elaborated in the QA/QC plan (Annex 5) in a manner consistent with IPCC good practice guidance. The activity data and methodology are documented and archived in both paper and electronic form.

### Recalculations

There is no change in the area of irrigation, but recalculations have occurred in this category as a result of the update for synthetic nitrogen fertilizer consumption for 2007 as noted in Section 6.3.2. These recalculations increased emissions by 0.02 Mt CO<sub>2</sub> eq or 6% for 2007 and had a modest impact on the long-term trend.

### Planned Improvements

The level and trend uncertainties associated with this source of estimates are planned to be assessed in future submissions.

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

### 6.4.2.1. Source Category Description

When manure is excreted on pasture, range, and paddock from grazing animals, nitrogen in the manure undergoes transformations, such as ammonification, nitrification, and denitrification. During these transformation processes, 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 animal population 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, section 6.2. 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 poultry, and 0.01 kg N<sub>2</sub>O-N/kg N for sheep/lamb, goat, and horse, which represents the fraction of excreted manure nitrogen converted to N<sub>2</sub>O-N.

### 6.4.2.3. Uncertainties and Time-Series Consistency

Uncertainties associated with N<sub>2</sub>O emission estimates from animal manure on pasture, range, and paddock result from uncertainty in animal populations and categories ( $\pm 1\%$  to  $\pm 15\%$ ), manure nitrogen excretion rate ( $\pm 20\%$ ), fraction of manure nitrogen on pasture, range, and paddock ( $\pm 20\%$ ), as well as emission factors ( $-25\% \sim +150\%$ ). The overall level and trend uncertainties associated with these estimates from 1990 to 2008 were estimated to be  $\pm 19\%$  and  $\pm 21\%$ , respectively (Hutchinson et al. 2007).

The same methodology and emission factors are used for the entire time-series (1990–2008).

### 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

There has been no recalculation associated with the estimate of this source of 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 is 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 the country-specific emission factors.

## 6.4.3. Indirect Emissions of N<sub>2</sub>O from Soils (CRF Category 4.D.3)

A fraction of the nitrogen from both synthetic fertilizer and manure that is applied to agricultural fields is transported off-site through volatilization and subsequent redeposition or leaching, erosion, and runoff. The nitrogen that is transported from the agricultural field in this manner provides additional nitrogen for subsequent nitrification and denitrification to produce N<sub>2</sub>O. The nitrogen leaving an agricultural field may not be available for the process of nitrification and denitrification for many years, particularly in the case of nitrogen leaching into groundwater.

### 6.4.3.1. Volatilization and Redeposition of Nitrogen

#### Source Category Description

When synthetic fertilizer or manure is applied 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.

#### Methodological Issues

There are few published scientific data that actually

determine N<sub>2</sub>O emissions from volatilization and redeposition of ammonia and NO<sub>x</sub> in Canada. 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 fertilizer and manure. The amount of synthetic fertilizer and manure nitrogen is multiplied by the fraction of nitrogen that is volatilized as NH<sub>3</sub>-N and NO<sub>x</sub>-N and then by an emission factor. The amount of nitrogen applied is obtained from yearly fertilizer sales data, which are available from Statistics Canada, and from the amounts of manure nitrogen excreted by animals (see Annex A3.3). The amount of nitrogen that volatilizes is assumed to be 10% of the total amount of synthetic fertilizer applied and 20% of the applied manure nitrogen to cropland (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).

### Uncertainties and Time-Series Consistency

Uncertainties associated with N<sub>2</sub>O emission estimates from volatilization of NH<sub>3</sub> and NO<sub>x</sub> due to applications of synthetic and manure nitrogen result from uncertainty in estimates of synthetic fertilizer nitrogen consumption ( $\pm 20\%$ ), fraction of volatilized NH<sub>3</sub> and NO<sub>x</sub> from synthetic nitrogen fertilizers ( $\pm 20\%$ ), animal populations and categories ( $\pm 1\%$  to  $\pm 15\%$ ), manure nitrogen excretion rate ( $\pm 20\%$ ), fraction of volatilized NH<sub>3</sub> + NO<sub>x</sub> from animal manure ( $\pm 20\%$ ), as well as emission factors ( $-50\%$  to  $+300\%$ ). The overall level and trend uncertainties associated with this source of emission estimates from 1990 to 2008 were estimated at  $\pm 40\%$  and  $\pm 34\%$ , respectively (Hutchinson et al. 2007).

The same methodology and emission factors are used for the entire time-series (1990–2008).

### 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 5) in a manner consistent with IPCC good practice guidance. The activity data, methodologies, and changes to methodologies are documented and archived in both paper and electronic form.

### Recalculations

Recalculations have occurred in this category as a result of the update for synthetic nitrogen fertilizer consumption for 2007 as noted in Section 6.3.2. These recalculations increased emissions by 0.1 Mt CO<sub>2</sub> eq or 3% for 2007 and had a modest impact on the long-term trend.

### Planned Improvements

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

#### 6.4.3.2. Leaching, Erosion, and Runoff

##### Source Category Description

When synthetic fertilizer or manure nitrogen is applied to cropland, a portion of the nitrogen is lost through leaching, erosion, and runoff. The magnitude of this loss depends on a number of factors, such as application rate and method, crop type, soil texture, rainfall 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.

##### 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 ammonia 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  $\text{FRAC}_{\text{LEACH}}$  value of 0.3 recommended by the IPCC 2006 Guidelines is assigned. The minimum  $\text{FRAC}_{\text{LEACH}}$  value of 0.05 is assigned to ecodistricts with the greatest moisture deficit. For the remaining ecodistricts,  $\text{FRAC}_{\text{LEACH}}$  is estimated by the linear extrapolation of the two endpoints described above.

### Uncertainties and Time-Series Consistency

Uncertainties associated with  $\text{N}_2\text{O}$  emission estimates from leaching, runoff, and erosion of nitrogen from synthetic, manure, and crop residue nitrogen result from uncertainties associated with estimates of synthetic fertilizer nitrogen consumption ( $\pm 20\%$ ), manure nitrogen excretion rate ( $\pm 20\%$ ), animal populations ( $\pm 1\% \sim \pm 15\%$ ), crop residue nitrogen ( $\pm 15\%$ ),  $\text{FRAC}_{\text{LEACH}}$  ( $\pm 50\%$ ), as well as the leaching/runoff emission factor  $\text{EF}_{\text{LEACH}}$  ( $-48\% \sim +200\%$ ). The overall level and trend uncertainties associated with this source of emission estimates from 1990 to 2008 were estimated to be  $\pm 32\%$  and  $\pm 29\%$ , respectively (Hutchinson et al. 2007).

The same methodology and emission factors are used for the entire time-series (1990–2008).

### 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 5) in a manner consistent with IPCC good practice guidance. The activity data, methodologies, and changes to methodologies are documented and archived in both paper and electronic form.

### Recalculations

Recalculations have occurred in this category as a result of the update for synthetic nitrogen fertilizer consumption for 2007 as noted in Section 6.3.2. These recalculations increased emissions by 0.5 Mt  $\text{CO}_2$  eq or 6% for 2007 and had a significant impact on the long-term trend.

### Planned Improvements

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

# 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 changes. The assessment includes emissions and removals of CO<sub>2</sub>, additional emissions of CH<sub>4</sub>, N<sub>2</sub>O and CO due to wildfires and controlled burning, and N<sub>2</sub>O released following land conversion to cropland. All emissions from and removals by the LULUCF Sector are excluded from the national totals.

In 2008, 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 removals of 13 Mt. If these were included in the national totals, they would decrease the total Canadian GHG emissions by about 2%. 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 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 10 of the 19 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.

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 -100 Mt (1992) and 180 Mt (1995). These fluctuations are carried over to the LULUCF Sector totals, which vary between net emissions and net removals, depending on the net flux from managed forests.

Over the entire period, the Cropland category displays a steady trend towards decreasing emissions, and since 2003 removals up to 4.4 Mt in 2008. The 50% decline of emissions from land converted to cropland and growing removals by cropland remaining cropland equally contribute to the 17 Mt reduction in net emissions over the 1990-2008 period.

Over the 1990-2008 period, net fluxes in the Wetlands category (managed peatlands and flooded lands) fluctuate between 2.0 Mt and 5.0 Mt. Emissions from land converted to wetlands declined from a little less than 4 Mt to 0.6 Mt during the period. Current emissions from flooded lands account for 50% of all emissions in the Wetlands category compared to a share of 83% in 1990.

With this submission, Canada continues the implementation of a multi-year effort to substantially improve its estimates in the LULUCF Sector.<sup>2</sup> The contribution of the best Canadian expertise to this effort occurred 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 provides a means for coordinating, planning and integrating the activities of many groups of scientists and experts across several government levels and research institutions.

Work within MARS for LULUCF is expected to continue. In addition to enhanced collaboration within the framework, planned improvements include the completion of formal and documented uncertainty estimates in all LULUCF categories and quantification of missing land use and land-use change categories.

This marks the first year that LULUCF estimates are reported under both the Convention and the Kyoto Protocol. The same definition and approaches apply to all LULUCF estimates, hence there is no separate section in this chapter

1 Unless otherwise indicated, all emissions and removals are in CO<sub>2</sub> equivalents.

2 First described in the NIR of the 2004 submission and implemented in the 2006 submission.

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

Sectoral Category	Net GHG Flux (kt CO <sub>2</sub> eq) <sup>4</sup>				
	1990	2005	2006	2007	2008
<b>Land Use, Land-Use Change and Forestry TOTAL<sup>1</sup></b>	<b>-52 000</b>	<b>41 000</b>	<b>41 000</b>	<b>45 000</b>	<b>-13 000</b>
<b>a. Forest Land</b>	<b>-79 000</b>	<b>32 000</b>	<b>33 000</b>	<b>38 000</b>	<b>-18 000</b>
Forest Land Remaining Forest Land	-78 000	33 000	34 000	39 000	-17 000
Land Converted to Forest Land	-1 000	-1 000	-1 000	-1 000	-1 000
<b>b. Cropland</b>	<b>13 000</b>	<b>-2 100</b>	<b>-2 300</b>	<b>-3 400</b>	<b>-4 400</b>
Cropland Remaining Cropland	-1 400	-9 700	-10 000	-11 000	-12 000
Land Converted to Cropland	14 000	7 700	8 000	7 500	7 200
<b>c. Grassland</b>	<b>NE</b>	<b>NE</b>	<b>NE</b>	<b>NE</b>	<b>NE</b>
Grassland Remaining Grassland	NE	NE	NE	NE	NE
Land Converted to Grassland	NE	NE	NE	NE	NE
<b>d. Wetlands</b>	<b>5 000</b>	<b>3 000</b>	<b>3 000</b>	<b>3 000</b>	<b>2 000</b>
Wetlands Remaining Wetlands	1 000	2 000	2 000	2 000	2 000
Land Converted to Wetlands	4 000	1 000	900	800	600
<b>e. Settlements</b>	<b>10 000</b>	<b>8 000</b>	<b>8 000</b>	<b>8 000</b>	<b>7 000</b>
Settlements Remaining Settlements	-100	-200	-200	-200	-200
Land Converted to Settlements	10 000	8 000	8 000	8 000	8 000
Forest conversion (memo item) <sup>2</sup>	27 000	21 000	20 000	20 000	19 000
Grassland conversion (memo item) <sup>2,3</sup>	300	200	200	200	200

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 removal of CO<sub>2</sub> from the atmosphere.

NE = Not estimated.

devoted to estimates reported under the Kyoto Protocol. Discrepancies between estimates reported under the Convention and the Kyoto Protocol are discussed in Annex 11.

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). A special section (Section 7.8) is devoted to the cross-category estimates of forest conversion to other lands.

The expert review team that examined Canada's 2009 inventory submission recommended that additional information be provided in this report. Table 7–2 lists those recommendations and where such information can be found in the present report.

## 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 and the Kyoto Protocol.

Forest land includes all areas of 1 ha or more where tree formations can reach 25% crown cover and 5 m in height *in situ*. Not all Canadian forests are under the direct influence of human activities, prompting the non-trivial ques-

Table 7–2 External Review Team Recommendations and Action Taken by Canada

External Review Team Recommendation	Location
Provide better explanation for the high inter-annual variability in removals from the LULUCF Sector	Chapter 7, Section 7.3.1.1 Methodological Issues
Provide a more transparent explanation of NIR 2009 recalculations in forest land due to the change in harvest data from area to volume data	Chapter 7, Section 7.3.1.4 Recalculations
Further development of uncertainty estimates for forest land	Chapter 7, Section 7.3.1.2 Uncertainty and Time-Series Consistency
Improve transparency in documentation in the explanation of soil organic carbon accounting for land conversion in western Canada	Annex 3.4, Section A3.1.3.3 Western Canada

tion 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, summer fallow, 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 grasslands.

Wetlands are areas where permanent or recurrent saturated conditions allow the establishment of vegetation and soil development typical of these conditions and that are not already in forest land, cropland or agricultural grasslands. A national wetland inventory is under preparation (Fournier et al. 2007). 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 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 7–3 illustrates the land-use areas (diagonal cells) and cumulative land-use change areas (non-diagonal cells) in 2008. Cumulative land-use change areas are the total land areas converted over the past 20 years (10 years for reservoirs). The grassland diagonal cell refers to the total area of agricultural grasslands, whereas grassland converted to settlements refers to land conversion of un-managed tundra to settlements in northern Canada. If columns are totalled, this would indicate the total land area as reported in the CRF for each category.

The MARS land monitoring system includes the conver-

Table 7-3 Managed Land Areas (kha) in the 2008 LULUCF Accounting System<sup>1</sup>

Initial Land Use	Final Land Use					
	Forest	Cropland	Grassland	Wetlands	Settlements	Other
Forest	229 400	574	NO	65	415	NO
Cropland	107	47 100	NO	NE	NE	NO
Grassland	NO	3	NE	NE	1	NO
Wetlands	NO	NE	NO	402 <sup>2</sup>	NE	NE
Settlements	NO	NE	NO	NO	NE	NO
Other	NO	NO	NO	38	NE	NE

Notes:

1. Non-diagonal cells refer to cumulative areas, i.e., total land converted over the last 20 years (10 years for reservoirs).

2. Only includes wetland areas for which emissions are reported in the CRF.

NE = Not estimated.

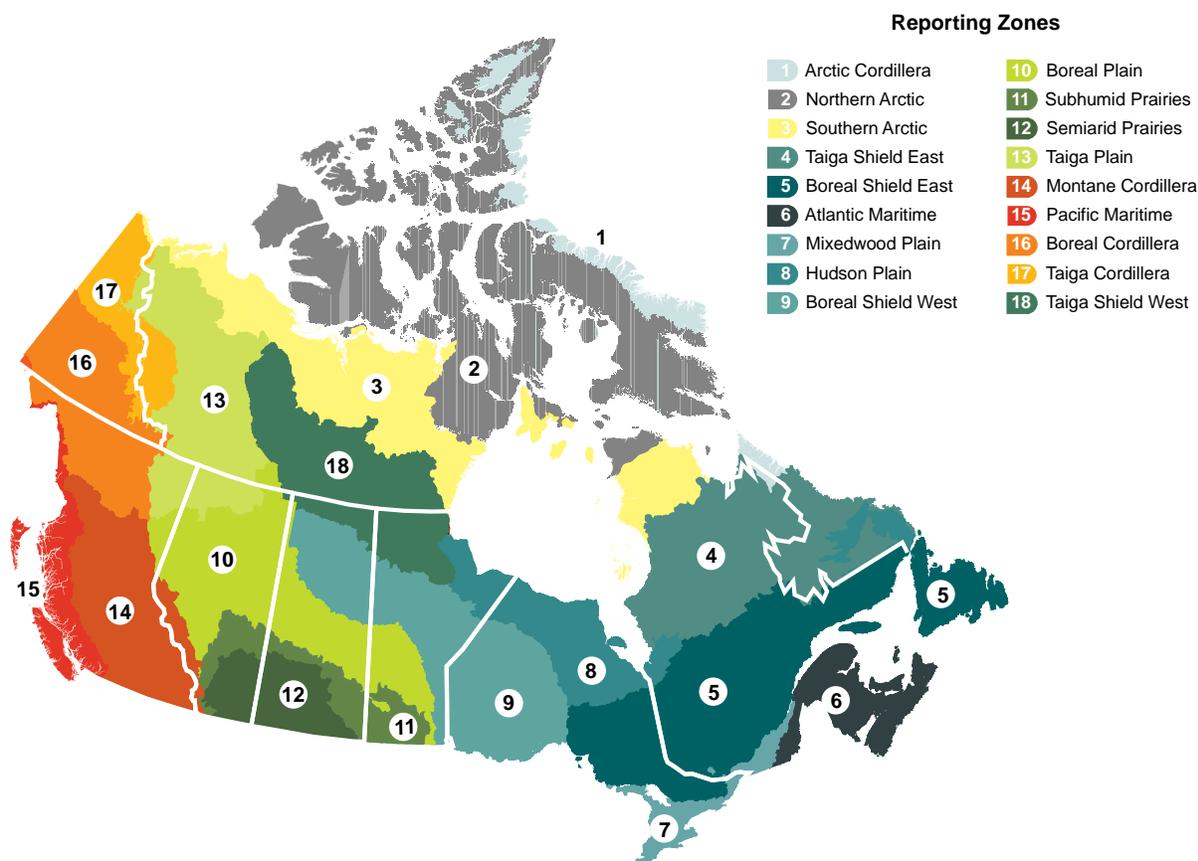
NO = Not occurring.

sion of un-managed forests and grassland to other land categories. Un-managed land converted to any use always becomes “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

Figure 7-1 Reporting Zones for LULUCF Estimates



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 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.

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 402 million hectares (Mha) of Canadian territory; forest lands alone occupy 310 Mha (NRCan 2007). Managed forests, those under direct human influence, extend over 229 Mha, or 74% of all forests. Four reporting zones (Boreal Shield East, Montane Cordillera, Boreal Plains and Boreal Shield West) account for 68% of managed forests (Table 7-4).

In 2008, the net GHG balance of managed forest land amounted to removals of 18 Mt (Table 7-1 above and CRF Table 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 (229 Mha, net removals of 17 Mt) and land converted to forest land (0.11 Mha, net removals of 1.0 Mt) in 2008.

GHG fluxes from and to managed forests are not spatially homogeneous. In 2008, managed forests in the Montane Cordillera and Pacific Maritime reporting zones are two large net sources of GHG, while those in the Taiga Plains, Boreal Shield East and Boreal Cordillera are three net sinks (Table 7-4). 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 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.

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 applies a Tier 3 methodology for estimating GHG

Table 7–4 GHG Balance of Managed Forests by Reporting Zone, 2008<sup>1</sup>

Reporting Zone Number	Reporting Zone Name	Managed Forest Area (kha)	Net GHG Balance (Mt CO <sub>2</sub> eq)
1	Arctic Cordillera	–	NA
2	Northern Arctic	–	NA
3	Southern Arctic	–	NA
4	Taiga Shield East	1 100	1.3
5	Boreal Shield East	55 600	-32
6	Atlantic Maritime	15 500	-0.7
7	Mixedwood Plains	2 700	-7.8
8	Hudson Plains	302	-0.5
9	Boreal Shield West	28 800	0.6
10	Boreal Plains	36 100	-5.2
11	Subhumid Prairies	1 820	-1.9
12	Semiarid Prairies	18	~0
13	Taiga Plains	20 000	-24
14	Montane Cordillera	35 400	65
15	Pacific Maritime	13 200	16
16	Boreal Cordillera	16 600	-29
17	Taiga Cordillera	412	-0.1
18	Taiga Shield West	1 830	-1.2

Notes:

1. Negative sign indicates removal of CO<sub>2</sub> from the atmosphere.

NA = Not applicable.

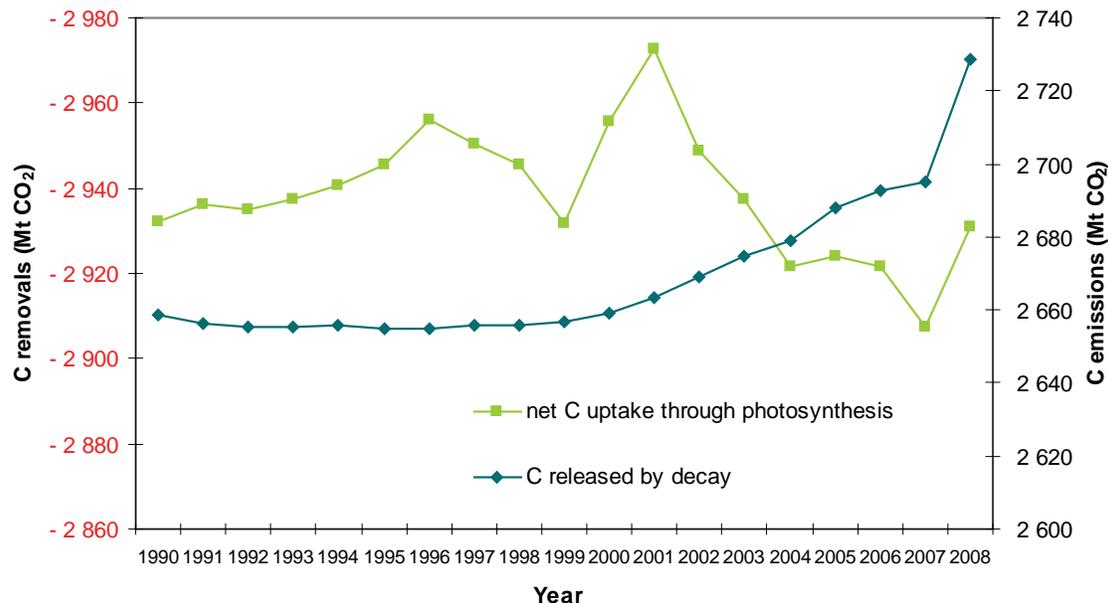
emissions and removals in managed forests. Canada's National Forest Carbon Monitoring, Accounting and Reporting System (NFCMARS – Kurz and Apps 2006) includes a model-based approach (Carbon Budget Model of the Canadian Forest Sector, CBM-CFS3 – Kull et al. 2006; Kurz et al. 2009). This model integrates 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) 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. These net carbon stock changes include not only exchanges of GHG with

the atmosphere, but also the carbon transfers between pools, for example its transfer from living biomass to dead organic matter upon stand mortality. Therefore 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 (–2900 and 2700 Mt, respectively, in 2008; see Figure 7–2). The upward trend in dead organic matter (DOM) decay reflects the long-term, growing effect of past disturbances, especially insect epidemics that have left substantial quantities of decaying DOM. Over the last three years, insect epidemics have affected a total of over 19<sup>3</sup> Mha of managed forests, with 96% 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 and severity of fires. During the 1990–2008 period, annual wildfire emissions fluctuated between

<sup>3</sup> May include areas repeatedly infested, e.g. a hectare infested in three subsequent years is counted as three hectares towards the 19 Mha.

Figure 7–2 Large Annual Carbon Fluxes to and from the Atmosphere in Managed Forests, 1990–2008: Net Carbon Uptake (or Net Primary Production) and Release Due to Decay (From Heterotrophic Respiration)



11 and 291 Mt. The consumption of dead organic matter by fires accounts for 79% of immediate emissions; much biomass is killed by forest fires and is thus transferred to the dead organic matter 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 as CO<sub>2</sub>, CH<sub>4</sub> and CO due to biomass burning, which are reported in Table 5(V). Emissions and removals are automatically tallied in CRF Table 5.

In keeping with the current IPCC default methodology, CO<sub>2</sub> emissions from forest management activities comprise all the carbon contained in harvested roundwood and harvest residues. All carbon transferred out of managed forests as wood products is deemed an immediate emission. Under this approach, in 2008 the transfer of carbon from forests to harvested wood products (HWPs) from forest management activities accounts for emissions of 128 Mt, a decrease of 13% compared to 1990 values. Three alternative approaches—atmospheric flow, production and stock change—have been preliminarily evaluated in Canada to attempt to correctly account for delayed emissions due to long-term carbon storage in HWPs. These approaches account for the carbon stored in HWPs and emissions from

the eventual decay of products derived from domestically harvested, imported (stock change, atmospheric flow) or exported (production) wood in the current and previous years; they are therefore more spatially and temporally realistic than the current default, which does not account for emissions from HWPs where or when they actually occur. They differ with respect to their allocation of emissions and removals. A breakdown and brief discussion of each of the accounting approaches, along with implications for Canada, are contained in Annex 3.4.

### 7.3.1.2. Uncertainties and TimeSeries Consistency

#### Uncertainty Estimates

Performing an 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.

A Monte-Carlo approach was used to quantify uncertainties about the outputs of the CBM-CFS3 (Metsaranta et al. 2009). Careful consideration was given to the identification and representation of uncertainty sources in the analysis (see Annex A3.4.2.4 for additional information).

Table 7–5 Estimates of the net Annual CO<sub>2</sub> Fluxes for Forest Land Remaining Forest land, 1990–2007, 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	-83 000	-160 000	-67 000
1991	-65 000	-140 000	-32 000
1992	-100 000	-180 000	-82 000
1993	-35 000	-110 000	-2 800
1994	-33 000	-100 000	-6 600
1995	150 000	98 000	200 000
1996	-72 000	-120 000	-8 800
1997	-100 000	-170 000	-49 000
1998	78 000	25 000	120 000
1999	-6 200	-71 000	29 000
2000	-95 000	-150 000	-33 000
2001	-99 000	-141 000	-28 000
2002	55 000	1 000	106 000
2003	31 000	-31 000	68 000
2004	90 000	36 000	128 000
2005	24 000	-14 000	75 000
2006	24 000	-720	76 000
2007	30 000	-14 000	69 000

Table 7–7 Estimates of the Annual N<sub>2</sub>O Emissions from Forest Land Remaining Forest land, 1990–2007, with 2.5<sup>th</sup> and 97.5<sup>th</sup> 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	2 100	1 600	2 300
1991	3 300	2 700	4 100
1992	1 000	750	1 100
1993	4 200	3 000	5 000
1994	4 100	3 000	4 700
1995	13 000	10 000	15 000
1996	3 000	2 400	3 600
1997	1 000	800	1 200
1998	9 800	8 300	12 000
1999	4 200	3 600	5 100
2000	840	690	1 000
2001	1 900	1 500	2 300
2002	7 400	6 000	9 300
2003	6 100	5 000	7 000
2004	6 800	5 100	8 000
2005	3 600	2 900	4 100
2006	3 900	3 200	4 800
2007	3 700	3 000	4 100

Table 7–6 Estimates of the Annual CH<sub>4</sub> Emissions from Forest Land Remaining Forest Land, 1990–2007, 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	3 400	2 500	3 700
1991	5 300	4 300	6 700
1992	1 700	1 200	1 900
1993	6 800	4 900	8 100
1994	6 500	4 900	7 500
1995	21 000	17 000	24 000
1996	4 800	3 900	5 800
1997	1 700	1 300	2 000
1998	16 000	13 000	19 000
1999	6 700	5 700	8 100
2000	1 400	1 100	1 500
2001	3 100	2 400	3 700
2002	12 000	9 600	15 000
2003	9 800	8 100	11 000
2004	11 000	8 300	13 000
2005	5 700	4 600	6 600
2006	6 300	5 100	7 700
2007	5 900	4 800	6 600

One hundred Monte-Carlo runs were conducted using the base input data for the 2009 submission (1990–2007 time series) for all of Canada, requiring approximately one month of run time on 10 desktop computers, and generating circa one terabyte of output data. Separate uncertainty estimates were produced for each gas.

The uncertainties about annual estimates are expressed as a 95% confidence interval, bound by 2.5<sup>th</sup> and 97.5<sup>th</sup> percentiles of the Monte Carlo run outputs (Table 7–5, Table 7–6 and Table 7–7 for CO<sub>2</sub> fluxes and 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 50 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 potential improvements in the estimation of anthropogenic emissions and removals in this category.

### Time Series Consistency

All estimates up to inventory year 2007 have been developed in a consistent manner. 2008 estimates incorporated improvements that could not be implemented to the remainder of the time series (see Section 7.3.1.5 Planned Improvements).

Estimates for wildfire areas in 2004–2008 were derived from real-time, remotely sensed imagery by the Canadian Wildland Fire Information System.<sup>4</sup> Estimates for 1990–2003 were derived from the Canadian Forest Service (CFS) large fire database which comprises information from provincial resource management agencies.

The forest inventory data incorporated in the analyses were not 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, implemented and documented by the CFS (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 T2 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

There were no recalculations to the 1990–2007 time series of estimates.

Very significant recalculations had occurred in this category in the 2008 submission, primarily as a result of changes in the modelling of forest management activities. While the data source has always remained the same, in the 2008 submission, harvest statistics were incorporated in the modelling environment as “volume” targets as opposed to “area” targets. In previous submissions, annual statistics on harvested areas were directly input into the model, which would then calculate the volume of wood harvested based on the forest inventory information already in the model; this volume was then converted into carbon. In other words, in the modelling framework, forest stands were subject to a harvesting disturbance according to “areas” instructions entered in the model (hence the “area targets”). However, the volume output from the model did not reconcile well with independent volume statistics. The alternative was to use volume data directly: enter “volume” instructions in the model, and have the model generate harvested areas based on the same forest inventory information.

As a result of a quality assessment of the available data on harvested areas and volumes, it was decided to modify the input algorithm and subsequent processing to allow the direct use of the more reliable volume data. Conversion of area to volume is a step that adds much uncertainty, whereas the conversion of volume directly into carbon provides more consistent results in terms of the quantity of carbon affected by forest management.

This correction caused major recalculations both in areas harvested and in carbon transferred to the forest product sector. Carbon emissions associated with the removal of harvested wood were recalculated upwards in the early years of the time series, by as much as 43% in 1990 (over 12 Mt carbon). Areas harvested were recalculated downwards in the early 1990s, and upwards after 1999. Overall,

<sup>4</sup> [http://cwfis.cfs.nrcan.gc.ca/en\\_CA/index](http://cwfis.cfs.nrcan.gc.ca/en_CA/index)

the amount of carbon transferred from forests to the forest product sector (treated as immediate harvest emissions in the inventory) has increased significantly, primarily because of recalculations of the carbon harvested. The apparent trend in harvesting activities has also been altered.

Over the decade of 1998–2007, harvesting activities accounted for annual average emissions of 184 Mt, a 21% increase since 1990 levels; this contrasted with the estimated 54% increase reported in the 2008 submission.

The recalculations arising from the change in harvest methods produced the estimates reported in Canada's 2009 submission. These methodological changes therefore have no impact on the 2010 estimates; in fact, the volume-target approach is consistently applied throughout the 1990–2008 time series reported in the 2010 submission.

### 7.3.1.5. Planned Improvements

Short-term planned improvements include methodological changes and updated activity data. The following changes have been implemented in the 2008 estimates only, resulting in an inconsistency in the time series (see Section 7.3.1.2 Uncertainties and Time-Series Consistency). In the next annual submission these changes will be applied to the whole time series since 1990.

Carbon transfer parameters for fires will be modified due to ongoing improvements in fuel consumption equations. Additional fieldwork generated new data on forest fuel consumption during both experimental burns and wildfires (de Groot et al. 2009). Data analyses resulted in modifications of equation parameters for the estimation of wildfire emissions, which were previously based on slash burning data alone (McRae 1980), or on expert judgement. Preliminary findings suggest that wildfires burn a smaller proportion of pre-fire fuel load than controlled burns, leaving more dead organic matter to decay in the post-burn years. Once implemented, these improvements will decrease immediate emissions from wildfire, from an average of 0.14 kt CO<sub>2</sub> eq ha<sup>-1</sup> to 0.13 kt CO<sub>2</sub> eq ha<sup>-1</sup>. The almost 10% difference in immediate GHG emissions per ha burned amounts to a large difference in immediate wildfire emissions, up to 28 Mt in 1995 (a bad fire year). This improvement, once implemented, will dampen inter-annual variability due to the immediate emissions from wildfires (the most important cause of this variability).

For the 2009 submission, the algorithm used to simulate the growth of very young stands was modified to reduce

discontinuities as these stands grew to merchantable volume and were assigned standard growth curves. Further refinement of this algorithm is planned, including the use of linear and non-linear smoothing techniques.

Substantial updates to forest management information is now available for the years 2005 to 2007, including the latest official harvest statistics from provinces and territories, updated maps of area burned by wildfires, and the collection of additional insect monitoring data.

Long-term planned improvements include enhancing the quality of forest inventory data, refining model parameters and expanding its scope. A more systematic approach is considered for implementing improvements, to reduce the frequency of recalculations.

## 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 plantations where the previous land use was not forest (typically, abandoned farmland).

The total cumulative area of land converted to forest land declined from 220 kha in 1990 to 107 kha in 2008. The trend reflects decreasing rates of forest planting in eastern Canada and the gradual transfer of lands afforested more than 20 years ago to the forest land remaining forest land category. Only 6% of all farmland converted to forest land over the last 20 years is located in the Prairies (Boreal Shield West, Boreal Plains and Subhumid Prairies reporting zones); 89% is in Eastern Canada (Atlantic Maritime, Mixed-wood Plains and Boreal Shield East reporting zones).

Net removals consequently declined throughout the period, from 1.2 Mt in 1990 to 1.0 Mt in 2008. Net carbon accumulation largely occurs in biomass (203 Gg C in 2008 – 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

Up to a few years ago, national compilations of afforestation records in Canada were not available. The Feasibility Assessment of Afforestation for Carbon Sequestration (FAACS) initiative collected and compiled afforestation records for 1990–2002 (NRCan 2005a). 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).

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

It was not possible, owing to resource limitations, to develop formal uncertainty estimates for this submission.

All estimates up to inventory year 2007 have been developed in a consistent manner. 2008 estimates incorporated improvements that could not be implemented to the remainder of the time series (see Section 7.3.2.5 Planned Improvements).

### 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. Planned Improvements

The following planned improvements were implemented for the 2008 estimates only and include both updated activity data and methodological changes. They will be implemented to the entire time series in the next submission, thereby correcting the current inconsistency in the time series (see Section 7.3.2.3 Uncertainties and Time-Series Consistency).

Area estimates of land converted to forest land were reviewed, including a reanalysis and error correction of pre-2002 activity data, and the deletion of unsupported post-2002 afforestation activity derived from the Feasibility Assessment of Afforestation for Carbon Sequestration (FAACS). Additional activity data from lumber companies and provincial governments for the 2003–2008 period will also be included in the next inventory submission. The lower CO<sub>2</sub> removals due to the smaller areas of land converted to forest land will be partly offset by changes within the CBM-CFS3 (see Section 7.3.1.5 Planned Improvements), which will result in higher per hectare carbon removals.

## 7.4. Cropland

Cropland covers approximately 48 Mha of the Canadian territory. In 2008, the net GHG balance in the Cropland category amounted to removals of 4.4 Mt (Table 7–1 and CRF Table 5). For the purpose of reporting under the Convention (UNFCCC), Cropland is divided into cropland remaining cropland (net removals of about 12 Mt in 2008) and land converted to cropland, due to either forest or grassland conversion (net emissions of about 7.2 Mt and 0.009 Mt respectively in 2008). The estimates in land “converted to cropland” include net emissions and removals of CO<sub>2</sub>, as well as N<sub>2</sub>O, CO and CH<sub>4</sub> emissions.

### 7.4.1. Cropland Remaining Cropland

Cultivated agricultural land in Canada includes areas of field crops, summerfallow, hayland and tame or seeded pasture. Cropland is found only in the nine southernmost reporting zones. About 83% of Canada’s cropland is in the interior plains of western Canada, made up of the Semi-Arid Prairies, the Subhumid 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

Table 7–8 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	2005	2006	2007	2008
<b>Total Cropland Remaining Cropland</b>		<b>-1 400</b>	<b>-9 700</b>	<b>-10 000</b>	<b>-11 000</b>	<b>-12 000</b>
<i>Cultivation of Histosols</i>		300	300	300	300	300
<i>Liming</i>		200	290	290	290	290
<i>Perennial Woody Crops</i>		50	30	20	20	10
<i>Total Mineral Soils</i>		-2 000	-10 000	-11 000	-12 000	-12 000
Change in Crop Mixture	Increase in Perennial	-1 200	-4 500	-4 800	-5 100	-5 500
	Increase in Annual	3 500	3 800	3 800	3 800	3 700
Change in Tillage	Conventional to Reduced Tillage	-850	-870	-840	-820	-790
	Conventional to No-till	-520	-3 600	-3 800	-3 900	-4 100
	Other	NO	-570	-640	-710	-780
Change in Summer Fallow (SF)	Increase in SF	1 700	1 300	1 200	1 200	1 200
	Decrease in SF	-4 800	-7 600	-7 700	-7 800	-7 800
Land Conversion—Residual Emissions <sup>2</sup>		150	1 700	1 800	1 800	1 800

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.

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 7–8 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, the management of mineral soils amounted to a net CO<sub>2</sub> removal of about 2 Mt (Table 7–8). This net sink steadily increased to about 12 Mt in 2008, reflecting continuous efforts in reducing summer fallow and increasing conservation tillage (Campbell et al. 1996; Janzen et al. 1998; McConkey et al. 2003). The area of summer fallow

declined by more than 50% over the 1990–2008 period, resulting in a net sink that increased from 3.1 Mt in 1990 to 6.6 Mt in 2008. The increase in net sink due to the adoption of conservation tillage practices (from 1.4 Mt in 1990 to 5.7 Mt in 2008) is substantiated by a net total increase of over 10 Mha in areas under no-till and reduced tillage over the 1990–2008 period. The net increase in areas with perennial crops has had a much more modest impact (-4.1 Mt).

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 an accounting 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 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 summer fallow.

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 annual change in SOC subject to LMC (Mg C/ha) |
| A          | = | area of LMC (ha)                                      |

In theory, a more accurate estimate of soil carbon stock change could be derived by individually considering the cumulative effects of the long-term management history of each piece of land or farm field. However, limits are imposed by the availability of activity data. At this point of development, the inventory relies extensively on the *Census of Agriculture* for estimates of areas of LMC (i.e. changes in tillage, types of crop and fallow). The area of LMC was determined individually for 3264 SLC polygons having agricultural activities, each one having an area in the order of 1000–100 000 ha. This is the finest possible resolution of activity data, given the limitations imposed by confidentiality requirements of census data. 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.

Table 7–9 Level and Trend Uncertainty Estimates (kt CO<sub>2</sub> eq) for Land Management Changes in Mineral Soils of Cropland Remaining Cropland. Negative sign indicates removals of CO<sub>2</sub> from the atmosphere

Land Management Practice	Change in Land Management	Level (2007)		Trend (1990–2007)	
		Mean Estimate	Uncertainty	Mean Estimate	Uncertainty
Change in Crop Mixture	Increase in Perennial	-5 100	±1 100	-3 900	±1 600
	Increase in Annual	3 800	±1 500	220	±1 700
	Conventional to Reduced Tillage	-820	±190	30	±290
Change in Tillage	Conventional to No-till	-3 900	±870	-3 400	±890
	Other Tillage Change	-710	±240	-710	±270
Change in Summer Fallow	Increase in Summer Fallow	1 200	±240	-440	±460
	Decrease in Summer Fallow	-7 800	±1 200	-3 000	±1 520
Residual Emissions <sup>1</sup>		130	±200	90	±200
<b>Total Mineral Soils</b>		<b>-13 000</b>	<b>±2 500</b>	<b>11 000</b>	<b>±3 000</b>

Notes:

1. Net residual CO<sub>2</sub> emissions from the conversion of forest land and grassland to cropland that occurred more than 20 years prior to the inventory year, excluding emissions from the decay of woody biomass and DOM.

## 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% of the area to 1.25% of the area as the relative area of that practice increased.<sup>5</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. The overall level and trend uncertainty estimates as-

sociated with various LMCs were developed by McConkey et al. (2007), and updated in 2009 (Table 7–9).

Consistency in the CO<sub>2</sub> estimates is ensured through the use of the same methodology for the entire time series of estimates (1990–2008). However, temporary updates of forest land converted to cropland and cropland converted to forest land were only applied for 2008. These changes will slightly affect cropland emissions/removals indirectly through altering the spatial distribution of tillage practices, summer fallow and annual/perennial crops from 1990 to 2007.

## 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 Vanden-Bygaart et al. (2008). The comparison showed that empirical data on changes in SOC change in response to no till-

<sup>5</sup> T. Huffman, Agriculture and Agri-Food Canada, personal communication to Brian McConkey, 2007.

age 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 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

There were no recalculations to the 1990–2007 time series of estimates.

### Planned Improvements

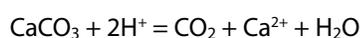
A comprehensive review of cropland converted to forest land data revealed that the total cumulative area may be considerably lower (by 11%–99%) than previously estimated. Work is ongoing to update all pre-1990 and post-2000 activity data on forest conversion (see Section 7.8.5). Temporary updates of forest land converted to cropland and cropland converted to forest land were only applied for 2008. Canada plans to update the entire time series of forest land converted to cropland and cropland converted to forest land in the next annual submission. These changes will result in recalculations of cropland emissions and removals indirectly through altering the

spatial distribution of tillage practices, summerfallow and annual/perennial crops.

Longer-term work is ongoing to reduce uncertainties associated with the modelled carbon factors, through general improvements to factor methodologies, validation, and review of assumptions, where possible. Publication of scientific, peer-reviewed material is also under way. Improvements to the CENTURY model and the use of alternative models are also being explored, to improve the simulation of Canadian agricultural conditions. The quality of area statistics collected through the *Census of Agriculture* will be improved using land cover maps.

#### 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 for the level uncertainty and  $0.09 \pm 0.30$  Mt for the trend uncertainty (McConkey et al. 2007).

The same methodology is used for the entire time series of emission estimates (1990–2008).

### 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 agriculture 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 1990–2008) was estimated to be 16 kha.

### Uncertainties and Time-Series Consistency

The uncertainty associated with emissions from this source is due to the uncertainties associated with the area estimates for the cultivated histosols and with the emission factor. The 95% confidence limits associated with the area estimate of cultivated histosols are assessed to be  $\pm 50\%$  (Hutchinson et al. 2007). The 95% confidence limits of the default emission factor are  $\pm 90\%$  (IPCC 2006). The overall mean and uncertainties associated with this source of emissions were estimated to be  $0.3 \pm 0.09$  Mt for the level uncertainty and  $0 \pm 0.13$  Mt for the trend uncertainty (McConkey et al. 2007).

The same methodology and emission factors are used for the entire time series of emission estimates (1990–2008).

### 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, and 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 area of 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 carbon from woody specialty crops were estimated to be  $0.02 \pm 0.02$  Mt for 2007 and  $-0.03 \pm 0.04$  Mt for the trend uncertainty (1990–2007) (McConkey et al. 2007).

The same methodology was used for the entire time series of emission estimates (1990–2008).

## 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 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 14 Mt CO<sub>2</sub> eq in 1990 to 7.2 Mt CO<sub>2</sub> eq in 2008. 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 the single most important cause of forest conversion (accounting for 54% of forest area conversion in 2008). The cumulative area of forest land converted to cropland since 1971 was 1310 kha in 1990; in 2008, the cumulative area converted since 1989 was 574 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 2008, immediate emissions from this year’s forest conversion accounted for 4.4 Mt, or 61% of all forest land converted to cropland emissions, while residual emissions from events that occurred in the last 20 years accounted for the remainder. 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. The residual emissions from the decay of dead organic matter and soil organic matter will last for decades. This long-term effect is unique to the LULUCF Sector.

## 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> sink 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

Generally, all 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 compared 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 characteristics (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); (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

Table 7–10 Uncertainty about Components of the Total CO<sub>2</sub> Fluxes from Forest Land Converted to Cropland for the 2007 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	4 300	± 850
Residual emissions from the DOM pool	2 800	± 540
Residual emissions from the soil pool	270	± 160

Table 7–11 Uncertainty about Non-CO<sub>2</sub> Emissions from Forest Land Converted to Cropland for the 2007 Inventory Year

Flux Component	Emissions (kt CO <sub>2</sub> eq)	Uncertainty (kt CO <sub>2</sub> eq)
CH <sub>4</sub> emissions	280	± 66
N <sub>2</sub> O emissions	90	± 20

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 7–10 and Table 7–11). 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.

### Biomass and Dead Organic Matter Pools

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. Given its heavy computational requirements, the analysis was conducted with the time series 1990–2007 of the 2009 submission, which was readily available. 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.

## Soil Pool

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 A3.4.2.4 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

There were no changes in methodologies or factors associated with emission estimates related to forest conversion to cropland.

## 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. It is assumed that carbon losses from the above-ground or below-ground biomass or dead organic matter upon conversion are insignificant. This assumption largely results from the definitional framework of land categories (see Section 7.2). Total emissions in 2008 from soils amounted to 9 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 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 0.008 ± 0.01 Mt in 2007. The uncertainty associated with the trend between 1990 and 2007 was estimated to be -0.06 ± 0.04 Mt.

The same methodology and emission factors are used for the entire time series of emission estimates (1990–2008).

### 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

Canada plans to validate the modelled soil carbon change factors with the measured and published soil carbon change factors from grassland conversion.

## 7.5. Grassland

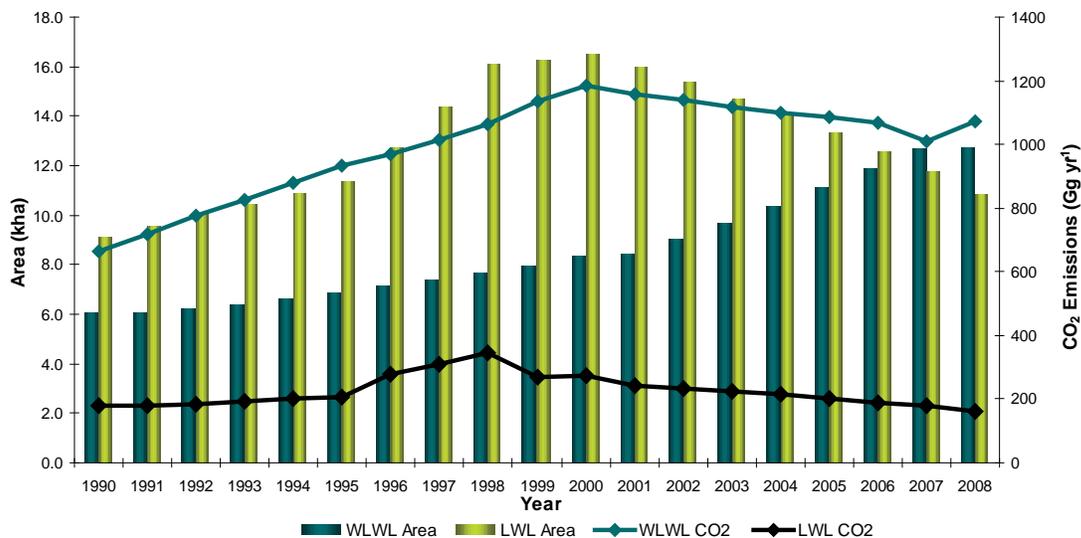
Agricultural grassland is defined under the Canadian LULUCF framework as pasture or rangeland on which the only land management activity has been the grazing of domestic livestock (i.e. the land has never been cultivated). It occurs only in geographical areas where the grassland would not naturally grow 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 (5600 kha in 2008), Montane Cordillera (200 kha in 2008), and Pacific Maritime (4 kha in 2008). 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 as not estimated. More details on the rationale for not estimating this category are provided in Annex 3.4. 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).

## 7.6. 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 cat-

Figure 7–3 Areas of Managed Peatlands and CO<sub>2</sub> Emissions from These Lands, 1990–2008 (LWL: Land Converted to Wetlands; WLWL: Wetlands Remaining Wetlands)



egories. 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>6</sup> approximately 24 kha are, or were at some point in the past, drained for peat extraction. Some 13 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; cited in Cleary 2003). Peat production is concentrated in the

provinces of New Brunswick, Quebec and Alberta. Canada produces only horticultural peat.

Since the 1980s, virtually all peat extraction in Canada has relied on 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. In the 1990s, peatland restoration activities took on greater significance.

Peat extraction activities expanded during the 1990–2008 period, with a 56% increase in the land area under active peat extraction, from 9.2 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 assessment period (Figure 7–3).

Emissions from managed peatlands are reported under land converted to wetlands for the first 20 years after conversion and under wetlands remaining wetlands thereafter.

<sup>6</sup> This area includes peatlands that would be classified as forest, cropland and grassland in the IPCC land classification.

### 7.6.1.2. Methodological Issues

CO<sub>2</sub> is the dominant GHG emitted from commercial peatlands and the only gas reported under this category. The general phases of peat extraction are 1) drainage, 2) vegetation clearing, 3) extraction, 4) stockpiling, 5) abandonment and 6) peatland restoration and establishment of natural vegetation. The main sources of emissions are vegetation clearing upon conversion, the continuing decay of dead organic matter and the rapid oxidation of exposed peat, resulting in a threefold increase in CO<sub>2</sub> emission rates (Waddington and Warner 2001). Estimates were developed using a Tier 2 methodology, based on domestic emission factors. They include emissions and removals during all five phases. More information on estimation methodology can be found in 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. A single estimate of preconversion forest biomass carbon density (20 t C/ha) was assumed; based on the characteristics of forest stands converted to peatland, an average 63% of above-ground biomass was deemed harvested at clearing.

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>7</sup> This introduces significant uncertainty about activity data. In addition, the fate of abandoned peatlands is not monitored in Canada; older peat fields could have been converted to other uses. Therefore, the area estimate of abandoned peatlands is probably conservative.

All estimates up to inventory year 2007 have been developed in a consistent manner. 2008 estimates incorporated improvements that could not be implemented to the remainder of the time series (see Section 7.6.1.6 Planned Improvements).

### 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

There were no recalculations to the 1990–2007 time series.

### 7.6.1.6. Planned Improvements

Improvements in the modelling of area under peat production for the 2008 estimates will be implemented to the entire time series in the next submission, thereby correcting the current inconsistency in the time series (see section 7.6.1.3 Uncertainties and Time-Series Consistency). These improvements prevent recalculations of the entire time series when activity data are incorporated for an additional year. Updated peat production data for 2007 from the Canadian Minerals Yearbook will also be incorporated.

## 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, 8, 10 and 14. The total land area flooded for 10 years or less declined from 830 kha in 1990 to 92 kha in 2008. In 2008, 59% of the 92 kha of reservoirs flooded for 10 years or less were previously forested (mostly un-managed forests).

Total emissions from reservoirs declined from 4.1 Mt in 1990 to 1.3 Mt in 2008.

<sup>7</sup> Gerry Hood, Canadian Sphagnum Peat Moss Association, personal communication to D. Blain, Environment Canada, 2006.

### 7.6.2.1. Methodological Issues

Two concurrent estimation methodologies were used to account for GHG fluxes from flooded lands—one for forest clearing and the other for flooding. When there was evidence of forest biomass clearing and removal prior to flooding, the corresponding carbon stock changes for all non-flooded carbon pools were estimated as in all forest conversion events, using the CBM-CFS3 (refer to Section 7.8 below and 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 recent construction of large reservoirs in northern Quebec (Toulnostuc, Eastmain-1, Peribonka), whose impoundment was completed in 2006 and 2007, 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. In keeping with good practice, only CO<sub>2</sub> emissions are included in the assessment. Emissions from the surface of flooded lands are reported for a period of 10 years after flooding, in an attempt to minimize the potential double counting of dissolved organic carbon lost from managed lands in the watershed and subsequently emitted from reservoirs. Therefore, only CO<sub>2</sub> emissions are calculated for hydro-electric reservoirs where flooding had been completed between 1981 and 2008.

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 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.

All estimates up to inventory year 2007 have been developed in a consistent manner. 2008 estimates incorporated improvements that could not be implemented to the remainder of the time series (see Section 7.6.2.4 Planned Improvements).

### 7.6.2.3. QA/QC and Verification

Annex 6 describes the general QA/QC procedures being implemented for Canada's GHG inventory; they apply to this category as well.

For forest land converted to wetlands, also refer to the corresponding subheading in Section 7.8, Forest Conversion.

Canada's approach to estimating emissions from forest flooding is more realistic temporally than the default approach (IPCC 2003), which assumes that all biomass carbon on flooded forests is immediately emitted. Canada's method is more refined in that it distinguishes forest clearing and flooding; emissions from the former are estimated as in all forest clearing associated with land-use change.

Further, in Canada's approach, emissions from the surface of reservoirs are derived from measurements, rather than from an assumption (decay of submerged biomass) that clearly is not verified.

#### 7.6.2.4. Planned Improvements

Correction of carbon transfer parameters for forest clearing prior to reservoir flooding for the 2008 estimates will be implemented to the entire time series in the next submission, thereby correcting the current inconsistency in the time series (see section 7.6.2.2 Uncertainties and Time-Series Consistency). This correction more accurately reflects the fate of flooded and non-flooded organic matter after impoundment.

A single temporal emission curve will replace the two regional curves used to determine CO<sub>2</sub> emissions from the surface of reservoirs (see Annex 3.4). This change results from a statistical assessment revealing that the curve parameters for the boreal and temperate regions were not significantly different from each other. Combining the datasets of the two regions will result in a larger sample and improve the derivation of annual emission factors.

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.

## 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 2008 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 2008, 420 kha of lands converted to settlements accounted for emissions

of a little less than 8 Mt. Forest land conversion to settlements represents 98% of these emissions. The conversion of cropland to settlements is known to occur in Canada; an estimation methodology is under development.

### 7.7.1. Settlements Remaining Settlements

This category includes estimates of carbon sequestration in urban trees. No modification has been made in activity data or methods since the last submission. This component, although approximate, makes a very minor contribution to the LULUCF Sector and represents a low priority for improvement.

### 7.7.2. Land Converted to Settlements

#### 7.7.2.1. Source Category Description

In 2008, emissions from land conversion to settlements amounted to a little less than 8 Mt. 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, the second forest conversion type in importance after forest conversion to cropland. On average, during the 1990–2007 period 22 kha of forest land are converted annually to settlements, predominantly in the Boreal Plains, Boreal Shield East and Atlantic Maritime reporting zones. Forest land conversion accounts for nearly 100% of emissions reported under this category. A consistent methodology was developed for all forest conversion, which is outlined in Section 7.8.

This 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 2008, the conversion of non-forest land to settlements in the Canadian north accounted for emissions of 0.15 Mt; 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 detection procedure was run on the entire area.

Emissions include only the carbon in preconversion above-ground biomass. In spite of the existing relevant literature, the estimation of actual or average biomass density over such a large area is challenging and remains fraught with uncertainty.

### 7.7.2.3. Uncertainties and Time-Series Consistency

For forest land converted to settlements, refer to the corresponding subheading in Section 7.8, Forest Conversion.

The uncertainty about the area of non-forest land converted to settlements in the Canadian north is estimated at 20%; the uncertainty about the preconversion standing biomass varies between 35% and 50%. 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 Improvements

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 2008, forest conversion to cropland, wetlands and settlements amounted to total emissions of about 19 Mt, down from 27 Mt in 1990. This decline includes a 5 Mt decrease in immediate and residual emissions due to forest conversion to cropland, a reduction of 2 Mt in emissions from forest conversion to settlements, and a 1.8 Mt decrease in emissions from forest conversion to reservoirs. Note that this assessment includes 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 deforestation rates (67 kha in 1990 and 46 kha in 2008) from the total area of forest land converted to other uses as reported in the CRF tables for each inventory year. The CRF figures encompass all forest land conversion for 20 years prior to the current inventory year (10 years for reservoirs) and hence are significantly higher than the annual rates of forest conversion to other land use.

Likewise, for the year 2008, emissions from the conversion of forest land differ from those due to deforestation reported under the Kyoto Protocol. This divergence is solely due to the differences in category definition, as opposed to methods or data. This is further explained in Annex 11.

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 2008, immedi-

ate emissions (7.7 Mt) represented only 51% 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, 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 25 kha, forest conversion to cropland accounts for the largest share of forest losses to other land categories. In 2008 conversion to settlement land (21 kha) was the second most important cause of deforestation, representing 46% of all forest area lost. The occasional impoundment of large reservoirs (e.g. La Forge 1 in 1995) may 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 and Boreal Shield East (reporting zones 10 and 5), which respectively accounted for 45% and 16% of the total forest area lost in 2008.

Forest conversion affects both managed and un-managed forests. Losses of un-managed forests occur mainly in reporting zone 4 (Taiga 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 deforestation on samples from remotely sensed Landsat images dated circa 1975, 1990 and 2000. For implementation purposes, all permanent forest removal wider than 20 m from tree base to tree base and at least 1 ha 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 records data were unavailable or of poor quality, or the remote sensing sample was insufficient. Expert judgement was also used to resolve differences among records and remote sensing information and to resolve apparent discrepancies between the 1975–1990 and 1990–2000 area estimates. A more detailed description of the approach and data sources is provided in Annex 3.4. Imagery post-2000 is being assembled and analysed to extend the time series.

All estimates of emissions from biomass and dead organic matter pools due to forest conversion were generated using the CBM-CFS3, 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

Based on expert judgement, an overall uncertainty of  $\pm 38\%$  bounds the estimate of the total forest area converted annually in Canada (Leckie et al. 2006b), placing with 95% confidence the true value of this area for 2007 between 30 kha and 66 kha. Care should be taken not to apply the 38% range to the cumulative area of forest land converted to another category over the last 20 years (land areas reported in the CRF tables). Annex 3.4 describes the main sources of uncertainty about area estimates derived from remote sensing and records.

Work is ongoing to improve uncertainty quantification.

All estimates up to inventory year 2007 have been developed in a consistent manner. 2008 estimates incorporated

improvements that could not be implemented to the remainder of the time series (see Section 7.8.5 Planned Improvements).

### 7.8.3. QA/QC and Verification

Annex 6 describes the general QA/QC procedures being implemented for Canada's GHG inventory; they apply to this category as well. In addition, detailed Tier 2 QA/QC procedures were carried out during estimate development procedures, involving documented QC of imagery interpretation, field validation, cross-calculations and detailed examination of results (Leckie et al. 2006a). The calculations, use of records data, and expert judgement are traceable through the compilation system and documented. More information is available in Annex 3.4.

### 7.8.4. Recalculations

There were no recalculations of the 1990–2007 time series.

### 7.8.5. Planned Improvements

The following planned improvements have been implemented in the 2008 estimates only, and limited to 15 reconciliation units resulting in an inconsistency in the time series (see Section 7.8.2 Uncertainties and Time-Series Consistency). Canada plans to apply these changes to all reconciliation units, and for the entire time series in the next annual submission.

As described in section 3.4.2.2 of Annex 3, annual rates of forest conversion are currently based on the interpretation of imagery for the 1975–1990 and 1990–2000 time periods. Mapping will be extended with a 2000–2008 time period to improve the post-2000 estimates currently derived from extrapolations.

Subject to the availability of resources, the post-2000 update will be enhanced with several improvements. Mapping from the two previous periods may be revised as part of the quality control process. Additional areas of Canada will be sampled for forest conversion with new data sets (imagery and other sources). Following the outcome of ongoing quality control activities and for the purpose of improving estimate accuracy, the sampling intensity may also increase in selected regions. Where technically feasible, mapping of specific types of deforestation could also replace records and expert opinion for the entire time series, especially when these data sources carry high

uncertainties or have inherent inconsistencies. Examples of such instances occur in Newfoundland and southern Quebec, where access to more high-resolution imagery enables greater confidence in estimates from remote sensing samples, leading to replacement of records data with mapping.

A new mapping strata boundary has been created around a hotspot in northern British Columbia due to intensified activity in the region, in order to reduce scaling errors.

Also subject to resource availability, additional field validation (field visits and aerial observation) will be conducted in challenging areas.

The deforestation interpretation protocol will be modified to include new pre-conversion forest types (recent clearcuts and burned areas) to better reflect pre-conversion carbon stocks. Post-conversion land use classes will be refined and expanded to facilitate policy-relevant analyses.

# Chapter 8

## Waste (CRF Sector 6)

### 8.1. Overview

This category includes emissions from the treatment and disposal of wastes. Sources include solid waste disposal on land (landfills), wastewater treatment and waste incineration. The categories evaluated are CH<sub>4</sub> emissions from solid waste disposal on land, CH<sub>4</sub> and N<sub>2</sub>O emissions from wastewater treatment, and CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O emissions from waste incineration.

Much of the waste treated or disposed of is biomass or biomass-based. CO<sub>2</sub> emissions attributable to such wastes are not included in inventory totals but are reported in the inventory as a memo item. CO<sub>2</sub> emissions of biogenic origin are not reported if they are reported elsewhere in the inventory or 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 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 2008, the GHG emissions from the Waste Sector contributed 22 Mt to the national inventory, compared with 19 Mt for 1990; an increase of 15%. In comparison, the national total emissions increased by 24% 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 2008, respectively.

Emissions from the Solid Waste Disposal on Land sub-sector, which consists of the combined emissions from municipal solid waste (MSW) landfills and wood waste landfills, accounted for 20 Mt or 95% of the emissions from this sector in 2008. The chief contributor to the Waste Sector emissions is the CH<sub>4</sub> released from MSW landfills, which, for 2008, amounted to 18 Mt (0.9 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 biennial survey of Canadian landfills, which collected 2006 and 2007 year data, approximately 28% of the CH<sub>4</sub> generated in Canadian MSW landfills in 2007 was captured and combusted (either for energy recovery, or flared). For the purposes of this inventory, the collected landfill gas data is assumed to be constant from 2007. The 2008 data will be revised once the next biennial survey, on the 2008 and 2009 data years, is performed this year.

Overall, the increase in the CH<sub>4</sub> generation rate from MSW landfills is primarily dependent upon the population growth, which in turn governs the waste generation rate,

Table 8-1 Waste Sector GHG Emission Summary, Selected Years

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)				
	1990	2005	2006	2007	2008
Waste Sector TOTAL	19 000	21 000	22 000	21 000	22 000
a. Solid Waste Disposal on Land	18 000	20 000	20 000	20 000	20 000
b. Wastewater Handling	740	900	910	930	940
c. Waste Incineration	400	240	240	250	250

Note: Totals may not add up due to rounding.

although other factors, such as increased gross domestic product, use of packaging materials and urbanization, could be in play. 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 2006, over 35 Mt of non-hazardous waste (residential, institutional, commercial, industrial, construction and demolition) was generated. Waste diversion initiatives began in the early 1990s and, based upon the national figures for 2006, approximately 22% of the waste generated is diverted from disposal (landfill or incineration) (Statistics Canada 2008a).

Table 8–1 summarizes the Waste Sector and subsector GHG contributions for the 1990, 2005, 2006, 2007 and 2008 inventory years.

## 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 landfills were established. Typically, these landfills do not require CH<sub>4</sub> collection systems, as the CH<sub>4</sub> generation rate is very low due to the minimal organic content in the waste stream. Therefore, these landfills are currently excluded from the analysis.

Wood waste landfills are mostly privately owned and operated by forest industries, such as saw mills and pulp and paper mills. These industries use the landfills to dispose of surplus wood residue, such as sawdust, wood shavings,

bark and sludges. Some industries have shown increasing interest in waste-to-energy projects that produce steam and/or electricity by combusting these wastes. In recent years, residual wood previously regarded as a waste is now being processed as a value-added product—e.g., wood pellets for residential and commercial pellet stoves and furnaces, and hardboard, fibreboard and particle board. Wood waste landfills have been identified as a source of CH<sub>4</sub> emissions; however, there is a great deal of uncertainty in the estimates. These landfills are a minor source of CH<sub>4</sub> emissions in comparison with MSW landfills.

The *Revised 1996 IPCC Guidelines 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 B.H. 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. A more detailed discussion of the methodologies is presented in Annex 3.5.

### 8.2.2.1. CH<sub>4</sub> Generation

The Scholl Canyon model was used to estimate the quantity of CH<sub>4</sub> generated. The model is based upon the following first-order decay equation (IPCC/OECD/IEA 1997):

Equation 8–1:

$$Q_{T,x} = k M_x L_0 e^{-k(T-x)}$$

where:

$Q_{T,x}$	=	amount of CH <sub>4</sub> generated in the current year (T) by the waste $M_x$ , kt CH <sub>4</sub> /year
X	=	the year of waste input
$M_x$	=	the amount of waste disposed of in year x, Mt
K	=	CH <sub>4</sub> generation rate constant, /year
$L_0$	=	CH <sub>4</sub> generation potential, kg CH <sub>4</sub> /t waste
T	=	current year

Equation 8–2:

$$Q_T = \sum Q_{T,x}$$

where:

$Q_T$	=	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  $Q_{T,x}$  for every section of waste landfilled in past years was taken (Equation 8–2), and the captured gas was subtracted for each province. A computerized model has been developed to estimate aggregate emissions on a regional basis (by province and territory) in Canada. The national CH<sub>4</sub> emission value is the summation of emissions from all regions.

## Waste Disposed of Each Year or the Mass of Refuse ( $M_x$ )

### *MSW Landfills*

Two primary sources were used in obtaining waste generation and landfill data for the GHG inventory. The amounts of MSW landfilled in the years 1941 through to 1990 were estimated by B.H. Levelton (1991). For the years 1998, 2000, 2002, 2004 and 2006, 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). For the intervening odd years (1999, 2001, 2003, 2005), 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 in 2007 and 2008 were trended from values derived from the Statistics Canada survey. Incinerated waste quantities were subtracted from the Statistics Canada disposal values in order to obtain the amounts of MSW landfilled for 1998–2008. For the years 1991–1997, with the exception of Prince Edward Island, the Northwest Territories, Nunavut and the Yukon, the quantities of waste disposed of were estimated from an interpolation using a multiple linear regression approach applied to the B.H. Levelton (1991) and Statistics Canada (2000, 2003, 2004, 2007a, 2008a) MSW landfill values. MSW landfill values for Prince Edward Island and the Northwest Territories, Nunavut and the Yukon for the period 1991–2008 are obtained by trending historical landfill data with the provincial populations for 1971–2008 (Statistics Canada 2006, 2009).

### *Wood Waste Landfills*

British Columbia, Quebec, Alberta and Ontario together landfill 93% of the wood waste in Canada (NRCan 1997). The amount of wood waste landfilled in the years 1970 through to 1992 has been estimated at a national level based on the National Wood Residue Data Base (NRCan 1997). Data for the years 1998 and 2004 were provided by subsequent publications (NRCan 1999, 2005). A linear regression trend analysis was conducted to interpolate the amount of wood residue landfilled in the years 1991–1997 and 1999–2008.

## 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  $-30^{\circ}\text{C}$  (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 B.H. 1991). From these precipitation values, k values were determined using a relationship prepared by the Research Triangle Institute (RTI) for the U.S. EPA (RTI 2004). 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 inch/year (< 500 mm), between 20–40 inch/year (500 to 1000 (average 750 mm)) and greater than 40 inch/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 (Environment Canada 1941–2007). The k values are related to precipitation, assuming that the moisture content of a landfill is a direct function of the annual precipitation. Based on the RTI relationship and the average annual precipitation at Canadian landfills surveyed by B.H. Levelton (1991), k values were calculated for each site. Then a provincial k value

Table 8–2 MSW Landfill k Value Estimates for Each Province/Territory

Province/ Territory	N.L.	P.E.I.	N.S.	N.B.	Que.	Ont.	Man.	Sask.	Alta.	B.C.	N.W.T	Nvt.	Yk.
<b>k Value Estimates</b>	0.078	0.06	0.077	0.062	0.056	0.045	0.019	0.01	0.012	0.082	0.005	0.005	0.001

was determined from an average of the k's within each of the provinces (Environment Canada 1941–2007).

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 2008, three different L<sub>0</sub>s were used to represent discrete time periods where studies showed significant changes in waste composition from one period to the next. L<sub>0</sub> is a function of degradable organic carbon (DOC), which is in turn determined from the composition of the waste, as described below.

The provincial and territorial DOCs were calculated from waste disposal composition values for three distinct time periods: 1941–1975, 1976–1989 and 1990–2008. Using waste composition data obtained from a Natural Resources Canada (NRCan) study, which was based on the 2002 data year (NRCan 2006), DOC values were derived and assumed to be constant over the period 1990–2004. Since waste diversion programs were not significant prior to 1990, a second set of DOCs were developed to represent the waste composition at disposal from 1976 to 1989 by adding the NRCan landfill to the 2004 Statistics Canada recycled waste composition data (Statistics Canada 2007a). A third set of DOCs were developed from a 1967 national study to cover the period from 1941 to 1975 (CRC Press 1973). A summary of the L<sub>0</sub> values for the provinces and territories over the three time periods is given in Table 8–3. The percentages of organic waste diverted in 2002 for all

Canadian provinces are also given as a reference for that year. As waste disposal practices in Canada change and as new information is made available, the L<sub>0</sub> values will be adjusted accordingly.

L<sub>0</sub> was determined employing the methodology provided by the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997) (Equation 8–3) using the provincial waste composition data as input to the degradable organic carbon (DOC) calculation:

Equation 8–3:

$$L_0 = \text{MCF} \times \text{DOC} \times \text{DOC}_F \times F \times \frac{16}{12} \times \frac{1000 \text{ kg CH}_4}{\text{t CH}_4}$$

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.

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	0.28	112.62	0.18	73.28	0.18	73.35
Prince Edward Island	N/A	0.27	108.74	0.17	67.19	0.16	64.63
Nova Scotia	29.7	0.25	100.89	0.16	62.35	0.16	64.10
New Brunswick	19.8	0.23	93.91	0.16	65.91	0.16	63.22
Quebec	13.7	0.36	144.45	0.21	82.52	0.20	81.23
Ontario	16.4	0.36	143.74	0.21	82.75	0.21	83.00
Manitoba	4.9	0.33	131.37	0.19	76.82	0.19	76.59
Saskatchewan	4.3	0.36	143.92	0.22	86.39	0.22	86.75
Alberta	16.7	0.39	157.63	0.26	104.46	0.18	71.87
British Columbia	23.3	0.28	111.86	0.17	69.89	0.16	63.71
Territories (Yk., N.W.T. and Nvt.)	N/A	0.22	87.59	0.15	58.54	0.16	65.13

Sources: All values are derived from data obtained from NRCan (2006), Statistics Canada (2007a) and CRC (1973), with the exception of the 2002 Organic Waste Diversion figures, which were obtained from Thompson et al. (2006).

N/A = Unavailable categorical information.

The DOC calculation is derived from the biodegradable portion of the MSW (Equation 8–4):

Equation 8–4:

$$\text{DOC} = (0.4 \times A) + (0.17 \times B) + (0.15 \times C) + (0.3 \times D)$$

where:

- A = fraction of MSW that is paper and textiles
- B = fraction of MSW that is garden or park waste
- C = fraction of MSW that is food waste
- D = fraction of MSW that is wood or straw

### Wood Waste Landfills

Equation 8–3 generated an L<sub>0</sub> value of 80 kg CH<sub>4</sub>/t of wood waste, which was used to estimate emissions from wood waste landfills by the Scholl Canyon model. IPCC defaults were used for MCF in unmanaged deep landfills (MCF = 1); the fraction of CH<sub>4</sub> in the landfill gas (F = 0.5); and the fraction 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> Then, for 1997–2003, data on the amount of landfill gas captured

<sup>1</sup> Personal communication with ME Perkin of Environment Canada's National Office of Pollution Prevention in 1998.

were collected directly from individual landfill operators biennially by Environment Canada's National Office of Pollution Prevention (Environment Canada 1997, 1999b, 2001, 2003a). As of 2006, beginning with the 2005 data year, this survey is now being conducted by Environment Canada's Greenhouse Gas Division (Environment Canada 2007).

Normally, the 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, the 2008 survey collected both 2006 and 2007 data from the facilities (Environment Canada 2009). These data were employed for the 2009 NIR submission estimates and are assumed unchanged for the 2010 NIR submission.

### 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 by ICF Consulting (2004) of the NIR. 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 *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 Tier 1 quality control review was conducted for this key category. No significant anomalies were identified.

### 8.2.5. Recalculations

No recalculations were conducted over the 1990–2006 time series for the MSW and Wood Waste Landfill subsectors affecting CH<sub>4</sub> emissions. A revision of the population data, used to evaluate the MSW landfill emissions, resulted in a very slight increase of 0.002% from the last submission, for the emission estimates of 2007 for the Solid Waste

Disposal on Land subsource.

## 8.2.6. Planned Improvements

Continuing its engagement to produce a biennial report on the status of landfill gas collection and utilization in Canada, the Greenhouse Gas Division will be conducting preparatory research in advance of a survey scheduled for summer 2010 to compile activity data for the 2008 and 2009 data years. The quantities of CH<sub>4</sub> gas captured, as obtained from the survey, will be used to update the 2011 NIR submission. The designation of methane generation decay constants that are specific to the same three periods used for the methane generation potential (i.e. 1941–1975, 1976–1989 and 1990–2008), which was a planned improvement for the 2010 submission, will be postponed until the 2011 submission.

A study is being considered to review the quantity of wood waste being placed in Canadian wood and pulp and paper industry landfills and to verify the methodology, emission factors and historical activity data currently employed.

A review of current data will be conducted for the evaluation of CH<sub>4</sub> from unmanaged landfills. Presently, the sole source of data for quantities of waste landfilled is the Statistics Canada biennial survey: Waste Management Industry Survey: Business and Government Sectors. The quantities of waste placed in unmanaged landfills make up a very small fraction of the total waste disposed of in Canada. Reporting of the estimates for this subsector will only be considered if, after the review, it is determined that there is no possibility of significant double counting (i.e. between wastes placed in managed versus unmanaged landfills).

## 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

A more detailed discussion of the methodologies is presented in Annex 3.5.

#### 8.3.2.1. CH<sub>4</sub> Emissions

##### Municipal Wastewater Treatment

The IPCC default method was not used because the required data were not available. A method developed for Environment Canada (ORTECH Corporation 1994) was used to calculate an emission factor. Based on the amount of organic matter generated per person in Canada and the conversion of organic matter to CH<sub>4</sub>, it was estimated that 4.015 kg CH<sub>4</sub>/person per year could potentially be emitted from anaerobically treated wastewater.

CH<sub>4</sub> emissions were calculated by multiplying the emission factors by the population of the respective province (Statistics Canada 2006, 2009) and by the fraction of wastewater that is treated anaerobically.

##### Industrial Wastewater Treatment

Owing to a lack of activity data, the CH<sub>4</sub> emissions from this category have not been evaluated. Although aerobic treatment of industrial wastewater is typically the standard practice, it is known that a few anaerobic treatment units had commenced operations in 2006. The methodology that will be applied, once the activity data is obtained, is presented in Annex 3.5.

### 8.3.2.2. N<sub>2</sub>O Emissions

#### Municipal Wastewater Treatment

The N<sub>2</sub>O emissions from municipal wastewater treatment facilities were calculated using the IPCC default method (IPCC/OECD/IEA 1997). This method estimates the N<sub>2</sub>O emission factor as the product of the annual per capita protein consumption, the assumed protein nitrogen content (16%), the quantity of N<sub>2</sub>O-N produced per unit of sewage nitrogen (0.01 kg N<sub>2</sub>O-N/kg sewage nitrogen) and the N<sub>2</sub>O/N<sub>2</sub>O-N conversion factor (1.57). Protein consumption estimates, in kg/person per year, were obtained from an annual food statistics report published by Statistics Canada (2007b, 2008b, 2009b). Data is provided for the years 1991, 1996 and 2001 to 2008. Protein consumption data for missing years is estimated by applying a multiple linear regression application to the Statistics Canada data. Emissions were calculated by multiplying the emission factor by the population of the respective provinces (Statistics Canada 2006, 2009). A summary of the values for these two parameters over the time series is given in Table 8–4.

Table 8–4 N<sub>2</sub>O Emission Factors

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
1995 <sup>a</sup>	25.01	0.063
1996 <sup>a</sup>	25.04	0.063
1997 <sup>a</sup>	25.50	0.064
1998 <sup>a</sup>	25.75	0.065
1999 <sup>a</sup>	26.01	0.065
2000 <sup>a</sup>	26.26	0.066
2001 <sup>b</sup>	26.63	0.067
2002 <sup>b</sup>	26.57	0.067
2003 <sup>b</sup>	26.19	0.066
2004 <sup>b</sup>	26.35	0.066
2005 <sup>b</sup>	25.90	0.065
2006 <sup>b</sup>	25.90	0.065
2007 <sup>c</sup>	26.14	0.066
2008 <sup>c</sup>	25.85	0.065

Sources: <sup>a</sup>Statistics Canada (2007b), <sup>b</sup>Statistics Canada (2008b) and <sup>c</sup>Statistics Canada (2009b). The data have been adjusted for retail, household, cooking and plate loss.

#### 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

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 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 wastewater treatment subsector was estimated to be in the range of –40% to +55%. The level uncertainty range provided by the ICF Consulting (2004) study is less than the ±60% span estimated with a 90% confidence level by a previous study, which used a Tier 1 approach based on 1990 data (McCann 1994). This is an improvement to the uncertainty as assessed for this category, since the uncertainty range quoted by ICF Consulting (2004) for a 95% confidence interval should typically show a larger value than that quoted for a 90% confidence interval. Based on 2001 data, the trend uncertainty associated with the total GHG emissions (comprising CH<sub>4</sub> and N<sub>2</sub>O) from the wastewater treatment systems was estimated to be in the range of about +12% to +13%. The extrapolation of trend uncertainty in 2001 to the 2008 inventory should be made with caution, as trend uncertainty is more sensitive than level uncertainty to the changes in the inventory estimate values for the more recent years.

Since the methods and data sources have remained unchanged over the time series, the estimates for this category are consistent over time.

### 8.3.4. QA/QC and Verification

A Tier 1 quality control review was conducted for this key category. An entry error was found and corrected under Subsection 6.B.2.2 Human Sewage of the CRF in the nitrogen fraction cell for 2006 and 2007. A value of 1.16 had been entered where it should have been 0.16. This error only implicated the implied emission factor in the CRF. The reported N<sub>2</sub>O emissions were not affected in any of the previous submissions. No significant anomalies were identified.

### 8.3.5. Recalculations

No recalculations were made over the 1990–2006 time series. N<sub>2</sub>O emissions from municipal wastewater treatment changed for 2007 due to a revision of the protein consumption that resulted in a very slight increase in emissions by 0.1% from the last submission. Slight changes in the CH<sub>4</sub> emissions from the same source in 2007 were due to population data updates.

### 8.3.6. Planned Improvements

A study has been commissioned for the purpose of providing, as some of its key tasks, more accurate emission factors for CH<sub>4</sub> and N<sub>2</sub>O; a quantification of uncertainties for activity data, emission factors and GHG emissions; and the development of a modified wastewater model. This study will be completed by spring 2010.

Research will be conducted to estimate the CH<sub>4</sub> emissions from the industrial wastewater treatment subsector to be reported in future submissions.

## 8.4. Waste Incineration (CRF Category 6.C)

### 8.4.1. Source Category Description

Emissions from both MSW and sewage sludge incineration are included in the inventory. Some municipalities in Canada utilize incinerators to reduce the quantity of MSW sent to landfills and to reduce the amount of sewage sludge requiring land application.

GHG emissions from incinerators vary, depending on factors such as the amount of waste incinerated, the composi-

tion 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 MSW incineration are assumed to be negligible and are not calculated owing to a lack of underlying emission research.

#### 8.4.1.2. Sewage Sludge Incineration

Two different types of sewage sludge incinerators are used in Canada: multiple hearth and fluidized bed. In both types of incinerators, the sewage sludge is partially de-watered prior to incineration. The de-watering is typically done in a centrifuge or using a filter press. Currently, municipalities in Ontario and Quebec operate sewage sludge incinerators. GHGs emitted from the incineration of sewage sludge include CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O, as in the case of MSW incinerators; however, since the carbon present in the wastewater sewage sludge is of biological origin, the CO<sub>2</sub> emissions are not accounted for in the inventory totals from this source.

### 8.4.2. Methodological Issues

The emission estimation methodology depends on waste type and gas emitted. A more detailed discussion of the methodologies is presented in Annex 3.5.

#### 8.4.2.1. CO<sub>2</sub> Emissions

The *Revised 1996 IPCC Guidelines 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.

The CO<sub>2</sub> generated from the incineration of sewage sludge is not reported in the inventory emission totals, since the sludge consists solely of biogenic matter.

#### 8.4.2.2. N<sub>2</sub>O and CH<sub>4</sub> Emissions

##### MSW Incineration

Emissions of N<sub>2</sub>O from MSW incineration were estimated using the IPCC default method (IPCC/OECD/IEA 1997). An average emission factor was calculated assuming that the IPCC five-stoker facility factors were most representative. To estimate emissions, the calculated emission factor was multiplied by the amount of waste incinerated by each province. CH<sub>4</sub> emissions from MSW incinerators are assumed to be negligible.

##### Sewage Sludge Incineration

Emissions generated from the incineration of sewage sludge are dependent on the amount of dried solids incinerated. To calculate the CH<sub>4</sub> emissions, the amount of dried solids incinerated is multiplied by an appropriate emission factor. Estimates of the amount of dried solids in the sewage sludge incinerated in the years 1990–1992 are based on a study completed in 1994, as related in a personal communication with W. Fettes in February of 1994 from an interchange between Senes Consultants and Puitan Bennet. Data for the years 1993–1996 were acquired through telephone surveys of facilities that incinerate sewage sludge. Data for the years 1997 and 1998 were obtained from a Compass Environmental Inc. study

prepared for Environment Canada (Environment Canada 1999a). Activity data for 1999, 2000 and 2001 were taken from a study conducted by A.J. Chandler and Associates Ltd. for Environment Canada (Environment Canada 2003c). To estimate the amount of sewage sludge incinerated in the years 2002–2008, 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 sector is based upon the results as reported in an uncertainty quantification study of the Canadian NIR (ICF Consulting 2004). This Tier 2 evaluation of uncertainty employed values from the 2001 inventory year (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 2008 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

A Tier 1 quality assessment review was conducted for the key category: CO<sub>2</sub> emissions from MSW incineration. No significant anomalies were identified.

#### 8.4.5. Recalculations

This year's recalculations resulted in no change for the 1990–2006 time series. For 2007, there was a reduction of the emission value of 1% from the previous submission due to a revision of the national population statistics.

#### 8.4.6. Planned Improvements

A follow-up study to an incineration survey conducted in 2008 is being considered to refine and broaden the collected activity data from incineration facilities in Canada covering the 1990 to 2009 time series. The study will include an analysis of the municipal incineration activity data (waste composition, annual throughputs for each unit etc.). It will also conduct a review and, if possible, develop country-specific or technology-based GHG emission factors, and revise the current inventory of Canadian MSW incinerators. These data will be considered for integration into the Waste Sector model and into the energy sector methodologies (where energy recovery systems are in place).

A review of current information will be conducted to quantify the CH<sub>4</sub> emissions from the incineration of municipal solid wastes and report them in future submissions.

An uncertainty quantification study is being considered to revise uncertainty values for activity data, model parameters and emission factors used in the development of emission estimates for the Waste Sector. It is expected that these values will provide inputs to the Tier 1 and Tier 2 Sector and national emission uncertainty estimates.

# Chapter 9

## Recalculations and Improvements

This chapter summarizes the recalculations implemented in Canada's national GHG inventory since its 2009 submission in order to facilitate an integrated view of changes in and impacts on emission levels and trends. A description of planned improvements for future inventories can be found in Section 9.2.

### 9.1. Explanations and Justifications for Recalculations

As required under the United Nations Framework Convention on Climate Change (UNFCCC), all Annex 1 Parties are required to continually improve their national greenhouse gas inventory. 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. 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. This work is carried out as part of continuous improvement efforts to integrate refined data or methods, incorporate new information or additional sources and sinks, implement any new guidance, and correct errors and omissions.

For this submission, there were no recalculations for the years 1990–2006. Recalculations for the 2007 inventory year are primarily based on revisions to activity data received from Statistics Canada, which affected the Energy, Industrial Process and Agriculture Sectors. There were no recalculations in the LULUCF Sector, and the Waste Sector recorded a recalculation of negligible impact in 2007 based on a revision to population data. However, Canada has identified planned improvements that, when implemented, will impact the inventory time series from 1990 onwards. For further details, see Section 9.2 as well as the planned improvement sections throughout Chapters 3 to 8.

#### 9.1.1. Implications for Emission Levels

Overall, total GHG emissions (excluding the LULUCF Sector) were upwardly revised by 0.44% in 2007. See Table 9–1 for additional details.

Table 9–1 Summary of Recalculations

	GHG Emissions per Year														
	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
<b>National Total<sup>2</sup></b>															
Current (Mt CO <sub>2</sub> eq)	592	641	659	672	678	691	717	711	717	741	741	731	718	750	734
2009 submission (Mt CO <sub>2</sub> eq)	592	641	659	672	678	691	717	711	717	741	741	731	718	747	-
Change (%)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.44%	-
<b>LULUCF</b>															
Current (Mt CO <sub>2</sub> eq)	-52	198	-48	-84	118	18	-80	-84	85	56	117	41	41	45	-13
2009 submission (Mt CO <sub>2</sub> eq)	-52	198	-48	-84	118	18	-80	-84	85	56	117	41	41	45	-
Change (%)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	-

## 9.1.2. Implications for Emission Trends

Overall, the recalculations of the total GHG estimates (excluding the LULUCF Sector) also had an upward effect on the trend between 1990 and 2007, now reported as a 26.8% increase in total GHG emissions since 1990 instead of the previously reported 26.2% increase.

## 9.2. Planned Improvements

The following are planned improvement activities that 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. These are highlighted in Table 9–2.

Table 9–2 Principal Planned Improvements

CRF#	Category	Description	Basis of Planned Improvement
1.A	Stationary Combustion	Review of coal emission factors based on detailed data analysis for coal mined in Canada.	New data and support from the Geological Survey of Canada have the potential to improve the accuracy of coal emission factors.
1.A.3.a	Civil Aviation	Development of a Tier 3a model to estimate aircraft emissions based on origin-destination data and aircraft-specific emission factors.	The T3a model will provide a more accurate disaggregation of emissions between civil aviation (domestic aviation) and aviation bunkers (international aviation).
1.A.3.d	Marine Transport	Development of an improved model to estimate marine emissions.	Based on an UNFCCC Expert Review Team recommendation.
2	Industrial Processes	Study on categories currently reported as "NE" in the CRF reporter (e.g. caprolactum and carbide production).	Based on an UNFCCC Expert Review Team recommendation.
2.B.1	Industrial Processes - Ammonia Production	Determination of the amounts of natural gas used as feedstock and as fuel, and update of the EF.	Based on QA/QC activities.
2.C.1	Industrial Processes - Iron and Steel Production	Review of assumptions relating to the agents used to reduce iron ore and use of country-specific values of pig iron and steel carbon contents.	It is known that reductants other than metallurgical coke (the current assumption) have been used by the iron and steel industry. Also, the use of country-specific carbon content values instead of IPCC default values will improve the accuracy of the emission estimates.
2.F	Industrial Processes - Consumption of Halocarbon and SF <sub>6</sub>	Updates to HFC emission factors and acquisition of information on the HFC recovery and recycling technologies.	HFCs: based on an UNFCCC Expert Review Team recommendation, this will improve the current estimation methodology.
4.A/4B	Enteric Fermentation/Manure Management	Recalculations of net energy (NE) contributions to gross energy (GE) balance due to weight loss during lactation in beef and dairy cattle, to be revised for the 1990 to 2007 time series.	Good practice: maintaining the consistency of time series calculations.
4.B	Manure Management	Improvement to the description of regional manure management systems.	Based on an UNFCCC Expert Review Team recommendation.

Table 9–2 Principal Planned Improvements (cont'd)

CRF#	Category	Description	Basis of Planned Improvement
4A/4B/4D	Enteric Fermentation, Manure Management and Agricultural Soils	Tier 2 uncertainty analyses will be updated, based on improved methods and integrated data management.	Based on an UNFCCC Expert Review Team recommendation.
4.D/4.F	Crop Residue Burning and Decomposition	Report containing a full-time series of estimates from crop residue burning, ensuring no double-counting of nitrogen emissions among the two categories.	Based on an UNFCCC Expert Review Team recommendation. Good practice in avoiding overestimating N emissions through integrated data management.
5.A/B	Forest Land, Cropland	Correction of time series inconsistencies.	Good practice.
5.A/B/D/E Information Item and CRF tables 5 (KP-1)A	Forest Conversion	Update for post-2000.	Post-2000 estimates use a projection of conversion rates.
5.A	Forest Land Remaining Forest Land	Modification to fire disturbance matrix parameters.	New research leading to improvements of fuel consumption equations.
5.A.2 and CRF tables 5 (KP-1)A	Land Converted to Forest Land	Review of area estimates of cropland converted to forestland.	Based on QA/QC activities.
5.B.2.1 and CRF tables 5 (KP-1)A	Forest Land Converted to Cropland	Modification to the method for FL-CL for the Prairies.	Based on the review the 2009 Annual Review. Report by an UNFCCC Expert Review Team.
5.D	Wetlands-Reservoirs	Use of a single curve for emissions from the surface of reservoirs.	Based on a statistical assessment of emission curve parameters.
5.D/E	Wetlands & Settlements	Completion of uncertainty assessments.	Based on an UNFCCC Expert Review Team recommendation.
6.A.2	Waste - Solid Waste Disposal on Land – Unmanaged Waste Disposal Sites	Planning of a study to provide estimates for waste quantities landfilled in unmanaged landfills in Canada over the 1941–2009 time series.	Highlighted in the Annual Review Report by the UNFCCC Expert Review Team on the 2009 NIR submission as a subsector emission not currently estimated.
6.B.1	Waste – Wastewater Handling – Industrial Wastewater	Planning of a study to provide greenhouse gas emission estimates from industrial wastewater treatment in Canada over the 1990–2009 time series.	Highlighted in the Annual Review Report by the UNFCCC Expert Review Team on the 2009 NIR submission as a subsector emission not currently estimated.
6.B.2	Waste – Wastewater Handling – Domestic and Commercial Wastewater	Conduct of a study to review and update, if necessary, the emission factors for CH <sub>4</sub> and N <sub>2</sub> O.	Highlighted in the Annual Review Report by the UNFCCC Expert Review Team on the 2009 NIR submission as an issue to be examined.
6.C	Waste – Waste Incineration	Planning of an internal study to collect and assess current activity data from waste incineration facilities in Canada.	To provide for more accurate emission estimates for more recent years in the time series and to appropriately portion the emissions generated as a result of energy recovery, within waste incineration facilities, to the Energy Sector.

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