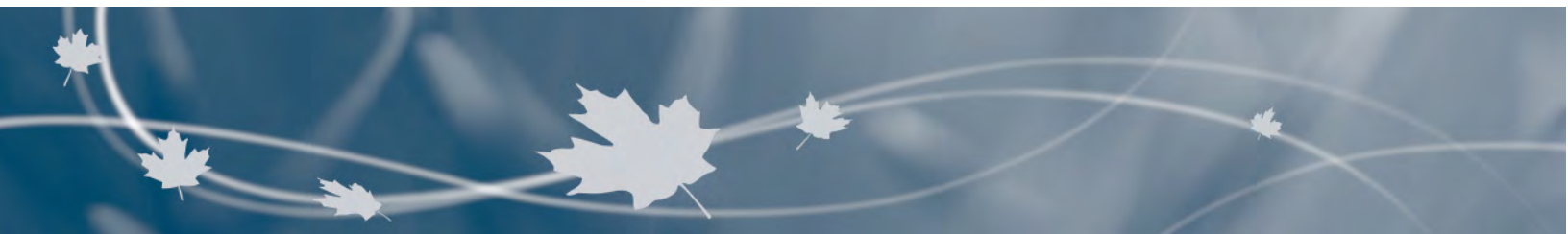




Environment
Canada

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National Inventory Report

1990–2011

GREENHOUSE GAS SOURCES
AND SINKS IN CANADA

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

Part 1



Canada 

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Chapter 2: Greenhouse Gas Emission Trends, 1990–2011

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Chapter 9: Recalculations and Improvements

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Annexes

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Foreword

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

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

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

Environment Canada, in consultation with a range of stakeholders, is responsible for preparing Canada's official national inventory. This National Inventory Report, prepared by the technical experts and scientists of the Pollutant Inventories and Reporting Division of Environment Canada, complies with the UNFCCC reporting guidelines on annual inventories. It represents the efforts of many years of work and builds upon the results of previous reports, published in 1992, 1994, and yearly from 1996 to

2012. In addition to the description and explanation of inventory data, the inventory report contains analysis of recent trends in emissions and removals, as well as information on Canada's National System.

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

April 2013

Director,
Pollutant Inventories and Reporting Division
Canada's National Greenhouse Gas Inventory Focal Point
Science and Risk Assessment Directorate
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Environment Canada

List of Acronyms, Abbreviations and Units

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

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

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

MgO	magnesia; dolomitic lime
Mha	megahectare, equivalent to a million hectares
MMIC	Motorcycle & Moped Industry Council
MODTF	Modeling and Database Task Force
mol	mole
MP	Total aluminum production
MS	manure system distribution factor
MSW	municipal solid waste
Mt	megatonne
MTOW	maximum takeoff weight
MW	megawatt
N	nitrogen
N ₂	nitrogen gas
Na ₂ CO ₃	sodium carbonate; soda ash
Na ₃ AlF ₆	cryolite
NA	not applicable
N/A	not available
NAICS	North American Industry Classification System
NCASI	National Council for Air and Stream Improvement
NCV	net calorific value
NE	not estimated
NEB	National Energy Board
NGL	natural gas liquid
NH ₃	ammonia
NH ₄ ⁺	ammonium
NH ₄ NO ₃	ammonium nitrate
NIR	National Inventory Report
NM VOC	non-methane volatile organic compound
N ₂ O	nitrous oxide
NO	nitric oxide; also used for not occurring
NO ₂	nitrogen dioxide
NO ₃	nitrate
NO _x	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 ₂	oxygen
ODS	ozone-depleting substance
OECD	Organisation for Economic Co-operation and Development
OEM	original equipment manufacturer
OS/HOU	oil sands and heavy oil upgrading
PC	Paste Consumption
PFC	perfluorocarbon
PJ	petajoule
POP	persistent organic pollutant
P/PE	precipitation/potential evapotranspiration
PTRC	Petroleum Technology Research Centre
QA	quality assurance
QC	quality control

RA	reference approach
RES D	Report on Energy Supply and Demand in Canada
RPP	refined petroleum product
RT	reduced tillage
RTI	Research Triangle Institute
SA	sectoral approach
Sa	Sulphur content in baked anodes
SAGE	System for assessing Aviation's Global Emissions
SBR	styrene-butadiene
Sc	Sulphur content in calcinated coke
SCR	selective catalytic reduction
SF ₆	sulphur hexafluoride
SIC	Standard Industrial Classification
SiC	silicon carbide
SLC	Soil Landscapes of Canada
SMR	steam methane reforming
SO ₂	sulphur dioxide
SO _x	sulphur oxides
SOC	soil organic carbon
Sp	Sulphur content in pitch
SUV	sport utility vehicle
t	tonne
TWh	terrawatt-hour
UNFCCC	United Nations Framework Convention on Climate Change
UPCIS	Use Patterns and Controls Implementation Section
UOG	upstream oil and gas
VCM	vinyl chloride monomer
VKT	vehicle kilometres travelled
VSS	vertical stud Söderberg
VS	volatile solids
WMO	World Meteorological Organization

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Executive Summary

ES.1 Canada's Greenhouse Gas Inventory: Context

The ultimate objective of the United Nations Framework Convention on Climate Change (UNFCCC) is to achieve stabilization of GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. In support of this goal the Convention commits all Parties to develop, periodically update, publish and make available to the Conference of the Parties national inventories of anthropogenic emissions by sources and removals by sinks of all GHGs not controlled by the Montreal Protocol. Development, publication and maintenance of a national inventory is a key obligation of UNFCCC signatories.

Canada's National Inventory Submission is the annual communication through which Canada meets its annual reporting obligations under the Convention and serves as the authoritative indicator and basis of comparison of national performance. It is a source of reliable, detailed information for Canadians on key emission trends for specific sources, sectors and regions; and provides a core set of data for setting baseline emissions and further analysis.

Canada's 2013 National Inventory Submission to the UNFCCC, which consists of the National Inventory Report (NIR) and the Common Reporting Format (CRF) Tables, has been prepared in accordance with the "Guidelines for the preparation of national communications by Parties included in Annex I to the Convention, Part I: UNFCCC reporting guidelines on annual inventories."

Canada is committed to tackling climate change through sustained action to build a low-carbon economy that includes reaching a post-2020 global climate change agreement, working with our North American partners and taking action domestically. Under the Copenhagen Accord, Canada has committed to reducing its GHG

emissions to 17% below the 2005 level by the year 2020.¹ As the underlying data and methodology for estimating emissions are revised over time, emissions levels in all years are subject to change as both data and methods are improved.

ES.2 Summary of National GHG Emissions and Trends

In 2011, the most recent annual dataset in this report, Canada's total greenhouse gas emissions were estimated to be 702 megatonnes carbon dioxide equivalent (Mt CO₂ eq²), an increase of approximately 1 Mt (0.14%) from the 2010 level of 701 Mt. Since 2005, Canadian GHG emissions have decreased by 36 Mt (4.8%).

Changes in emission trends since the early 2000s can be attributed to increases in efficiency, the modernization of industrial processes, and structural changes in the composition of the economy, which are long-term trends that have had an increased impact on emissions since the late 1990s.

The change in the rate of growth in emissions in Canada since about 2000 is notable and can be attributed to the following factors:

- A levelling off of emissions from electric power generation, which had been rising rapidly until then. In 2000, coal generation was at or close to its highest level ever. Since then, the contribution of coal-fired generation to the electricity supply mix has been declining (Statistics Canada 2011a).
- The increased prevalence of energy efficiency and emission reduction programs, including federal measures such as regulations for light-duty vehicles and provincial and territorial actions such as Alberta's *Specified Gas Emitters Regulation*.
- Structural changes involving a shift from an industrial-oriented economy to a more service-based economy. Between 2000 and 2008, the gross domestic product (GDP) of the service industries rose by 32%, while heavy industries and manufacturing together grew by only 3%. Service industries are less emission intensive than goods-producing industries, so this ongoing change has lowered Canadian GHG emissions.
- The peak in the production of conventional oil in 1998 in Canada and the levelling off of gas production in

¹ See <http://climatechange.gc.ca/cdp15-cop15/default.asp?lang=En&n=970E8B07-1>

² Unless explicitly stated otherwise, all emission estimates given in Mt represent emissions of GHGs in Mt CO₂ equivalent.

Figure S–1 Canadian Emissions in 1990–2011

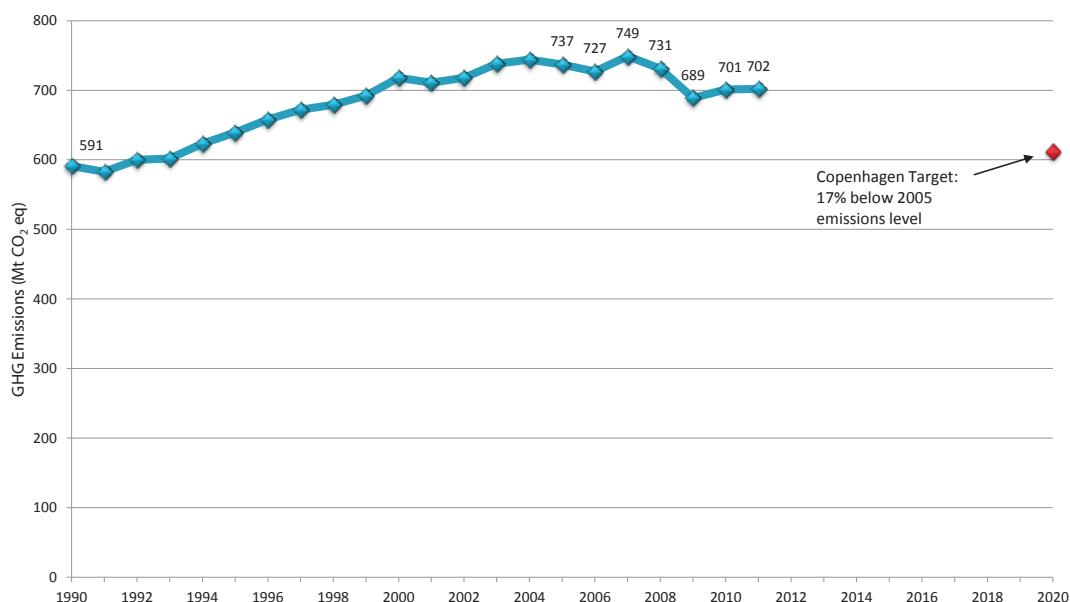
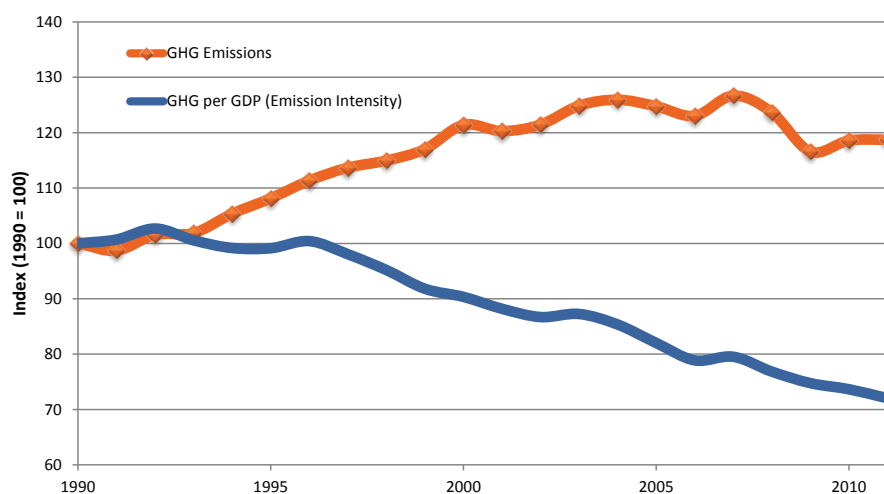


Figure S–2 Indexed Trend in GHG Emissions and GHG Emissions Intensity, 1990–2011



2002 (Statistics Canada 2011b). In both cases, this was the result of limited conventional reserves. More recently, conventional oil and natural gas production has fallen, which has reduced fugitive emissions and has offset the impact of rising non-conventional production to some extent.

Together, efficiency increases and technological and structural changes have resulted in a continuing weakening of the link between GDP growth and emissions, so that the GHG emissions per unit of GDP (or “GHG intensity of the economy”) have decreased on average by 2% per year

since 1996 (Figure S–2). This has resulted in the decoupling of economic growth and emissions.

While Canada represented only about 2% of total global GHG emissions in 2005 (CAIT 2012), it is one of the highest per capita emitters, largely as a result of its size, climate (i.e. climate-driven energy demands), and resource-based economy. In 1990, Canadians released 21.3 tonnes (t) of GHGs per capita. In 2005, this had risen to 22.9 t of GHGs per capita; however, by 2011, it had dropped to 20.4 t of GHGs per capita (Statistics Canada 2012) (Figure S–3).

Figure S-3 Canadian per Capita Emissions 1990–2011

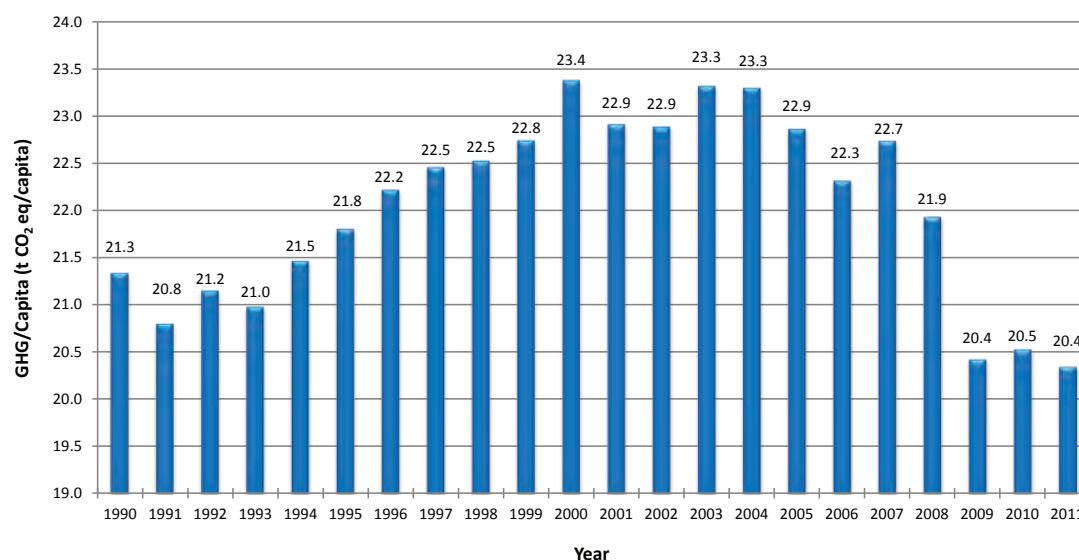
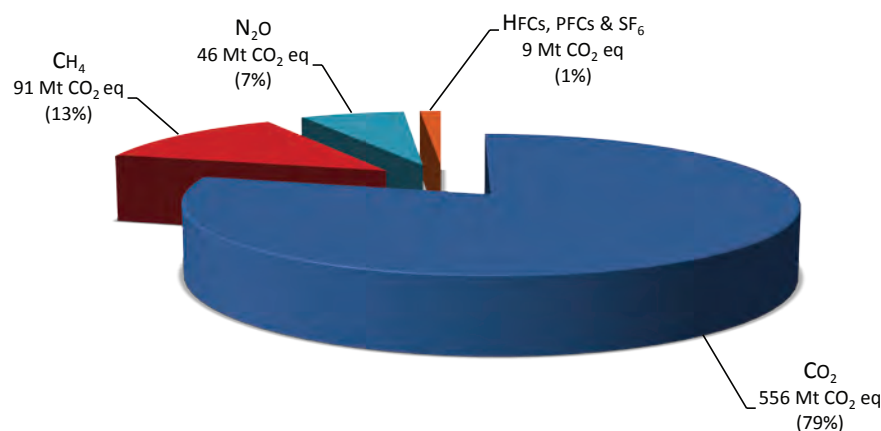


Figure S-4 Canada's Total Emissions Breakdown 2011, by Greenhouse Gas (Total = 702 Mt)



ES.3 Overview of Source and Sink Category Emissions and Trends

The primary GHG emitted from anthropogenic activities in 2011 was CO₂, which contributed 79% of Canada's total emissions (Figure S-4 and Table S-1). The majority of these emissions result from the combustion of fossil fuels. Methane (CH₄) accounted for 13% of Canada's total emissions, resulting from activities in the IPCC sectors of Agriculture and Waste, as well as fugitive emissions from oil and natural gas systems. Nitrous oxide (N₂O) emissions from activities such as agriculture soil management and transport accounted for 7% of the emissions. Perfluorocarbons

(PFCs), sulphur hexafluoride (SF₆) and hydrofluorocarbons (HFCs) constituted the remainder of the emissions (slightly more than 1%).

Using the definitions based on the IPCC categorization,³ the Energy Sector produced the majority of Canada's GHG total emissions in 2011, at 81% or 572 Mt, with emissions in this sector resulting from stationary combustion sources, transport and fugitive sources. The remaining 19% of total emissions was largely generated by sources within the Agriculture Sector (8% of total emissions) and

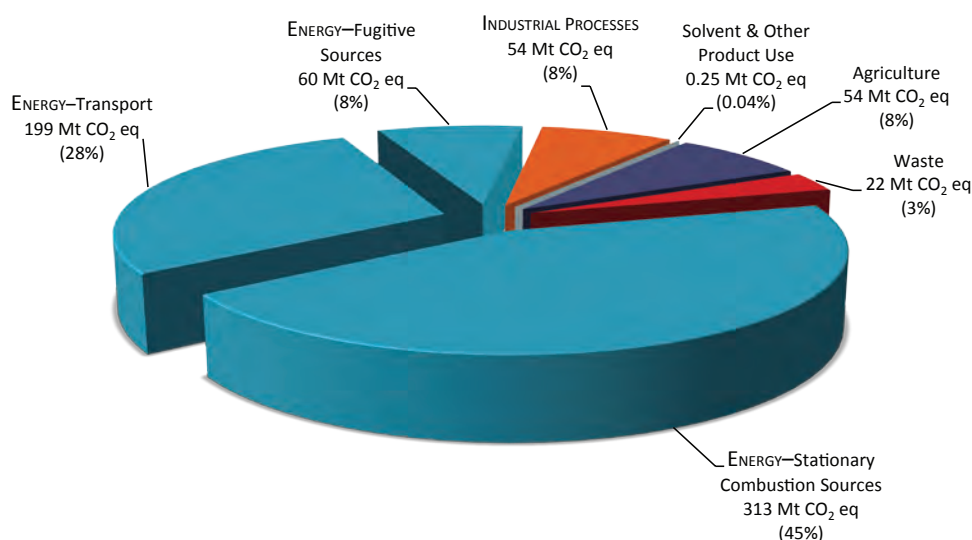
³ Throughout this report, the word "Sector" generally refers to the activity sectors as defined by the Intergovernmental Panel on Climate Change (IPCC) for national greenhouse gas inventories. Exceptions occur when the expression "economic sectors" are used in reference to the Canadian context.

Table S-1 Canada's GHG Emissions 1990–2011, by Greenhouse Gas

Greenhouse Gases	1990	2000	2005	2007	2008	2009	2010	2011
<i>Mt CO₂ equivalent</i>								
National GHG Total	591	718	737	749	731	689	701	702
CO ₂	459	565	579	595	577	542	554	556
CH ₄	72	94	98	96	94	91	90	91
N ₂ O	49	49	50	49	52	47	47	46
HFCs, PFCs & SF ₆	11	10	10	8	9	9	9	9

Note: Totals may not add up due to rounding.

Figure S-5 Canada's Emissions Breakdown 2011, by IPCC Sector (Total = 702 Mt)



Industrial Processes Sector (8%), with minor contributions from the Waste Sector (3%) and Solvent and Other Product Use Sector (Figure S-5 and Table S-2). The Land Use, Land-use Change and Forestry (LULUCF) Sector was a net source of 87 Mt in 2011, largely because of emissions from natural disturbances such as forest fires. However, in accordance with UNFCCC reporting guidelines, these emissions are excluded from national inventory totals. Table S-2 provides additional details about Canada's emissions and removals by IPCC sector for the years 1990, 2000, 2005 and 2007–2011. Further breakdowns by subsector and gas and a complete time series can be found in Annex 12.

To the extent possible, emissions are also allocated on the basis of the economic sector from which they originate, for the purposes of analyzing trends and policies (Figure S-6 and Table S-3). For example, emissions are categorized by economic sectors for the report *Canada's Emissions Trends*

(Environment Canada 2012),⁴ which provides emissions projections for Canada to the year 2020.

More information on the IPCC and economic sector definitions and trends, as well as a detailed cross-walk between categories, is provided in Chapter 2, Table 2-14.

ES.3.1 1990–2011 Trends Overview, IPCC Sectors

Almost all of the emission changes over the long term are attributable to six major areas: the fossil fuel (coal, oil and gas) industries,⁵ transport,⁶ electricity generation,

4 Canada's Emissions Trends 2012 report is available online at: <http://www.ec.gc.ca/Publications/default.asp?lang=En&xml=253AE6E6-5E73-4AFC-81B7-9CF440D5D2C5>

5 "Fossil fuel industries" comprise the sum of the subsectors of Mining and Oil and Gas Extraction, Fossil Fuel Production and Refining, Pipelines (Transportation), and Fugitive Releases.

6 The "Transport" subsector refers to Transportation minus Pipelines.

Table S-2 Canada's GHG Emissions 1990–2011, by IPCC Sector

Greenhouse Gas Categories		1990	2000	2005	2007	2008	2009	2010	2011
		Mt CO ₂ equivalent							
TOTAL^{1,2}		591	718	737	749	731	689	701	702
ENERGY		469	589	597	610	592	560	570	572
a.	Stationary Combustion Sources	281	346	341	352	336	315	316	313
	Electricity and Heat Generation	94	129	123	122	115	100	101	93
	Fossil Fuel Production and Refining	51	67	71	72	67	67	65	62
	Mining & Oil and Gas Extraction	6.6	12.1	18.9	28.9	30.0	31.7	35.0	36.4
	Manufacturing Industries	55.8	55.6	48.6	47.6	45.1	40.3	41.1	42.7
	Construction	1.9	1.1	1.4	1.4	1.4	1.2	1.5	1.3
	Commercial & Institutional	25.7	33.3	31.9	30.2	29.6	29.4	28.0	29.9
	Residential	43	45	44	47	46	44	41	44
	Agriculture & Forestry	2.4	2.5	2.1	2.6	2.6	2.5	2.9	3.6
b.	Transport	146	180	193	195	194	186	196	199
	Civil Aviation (Domestic Aviation)	7.1	7.4	7.6	7.7	7.3	6.4	6.4	6.0
	Road Transportation	97	118	130	133	132	132	134	135
	Railways	7.0	7.0	7.0	7.0	8.0	5.0	7.0	7.0
	Navigation (Domestic Marine)	5.0	5.1	6.7	6.8	6.5	6.7	7.0	6.0
	Other Transportation	30	43	41	41	41	36	42	45
c.	Fugitive Sources	42	63	63	63	62	59	59	60
	Coal Mining	2.0	1.0	1.0	1.0	0.9	0.9	1.0	1.0
	Oil and Natural Gas	40.2	62.1	62.4	62.0	61.0	57.9	57.6	58.7
INDUSTRIAL PROCESSES		56.0	52.1	60.5	59.8	58.5	50.8	53.3	54.3
a.	Mineral Products	8.4	9.8	9.9	9.8	9.0	7.0	7.6	7.7
b.	Chemical Industry	16.0	8.0	9.3	7.9	9.4	7.1	6.5	7.0
c.	Metal Production	22.6	22.5	19.7	18.9	18.5	15.4	15.8	16.6
d.	Production and Consumption of Halocarbons and SF ₆	1.0	3.2	5.5	5.7	5.8	6.5	7.3	7.7
e.	Other & Undifferentiated Production	7.6	8.6	16.0	17.0	16.0	15.0	16.0	15.0
SOLVENT & OTHER PRODUCT USE		0.18	0.45	0.38	0.33	0.34	0.26	0.24	0.25
AGRICULTURE		47	56	58	58	59	56	56	54
a.	Enteric Fermentation	16	20	22	21	20	19	19	18
b.	Manure Management	5.7	7.0	7.5	7.2	6.9	6.7	6.5	6.4
c.	Agriculture Soils	25	29	29	30	31	30	30	30
d.	Field Burning of Agricultural Residues	0.21	0.12	0.04	0.04	0.05	0.04	0.03	0.03
WASTE		19	20	21	21	21	21	22	22
a.	Solid Waste Disposal on Land	17	18	20	20	20	20	20	20
b.	Wastewater Handling	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0
c.	Waste Incineration	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.7
Land Use, Land-use Change and Forestry		-62	-52	63	52	-11	-10	100	87
a.	Forest Land	-88	-64	54	45	-18	-15	99	83
b.	Cropland	12	0	-4	-6	-7	-7	-8	-8
c.	Grassland	-	-	-	-	-	-	-	-
d.	Wetlands	5	3	3	3	3	3	3	3
e.	Settlements	9	8	9	10	10	9	9	9

Notes:

1. National totals exclude all GHGs from the Land Use, Land-use Change and Forestry Sector.
2. These summary data are presented in more detail in Annex 12.

manufacturing,⁷ commercial/institutional and agriculture. The relative contribution of each of these has varied somewhat, depending on the time period. The long-term trend of emission growth has been driven primarily by the fossil fuel industries and transport whereas the short-term

(2005–2011) emission decline has been driven by electricity generation and manufacturing.

Between 1990 and 2011 the fossil fuel industries and transport were responsible for about 51% and 49%, respectively, of the total 111-Mt growth in emissions. Major increases in oil and gas production (much of it for export),

7 "Manufacturing" includes the Manufacturing Industries subsector (in the Energy Sector) and the Industrial Processes Sector.

Figure S–6 Canada's Emissions Breakdown 2011, by Economic Sector (Total = 702 Mt)

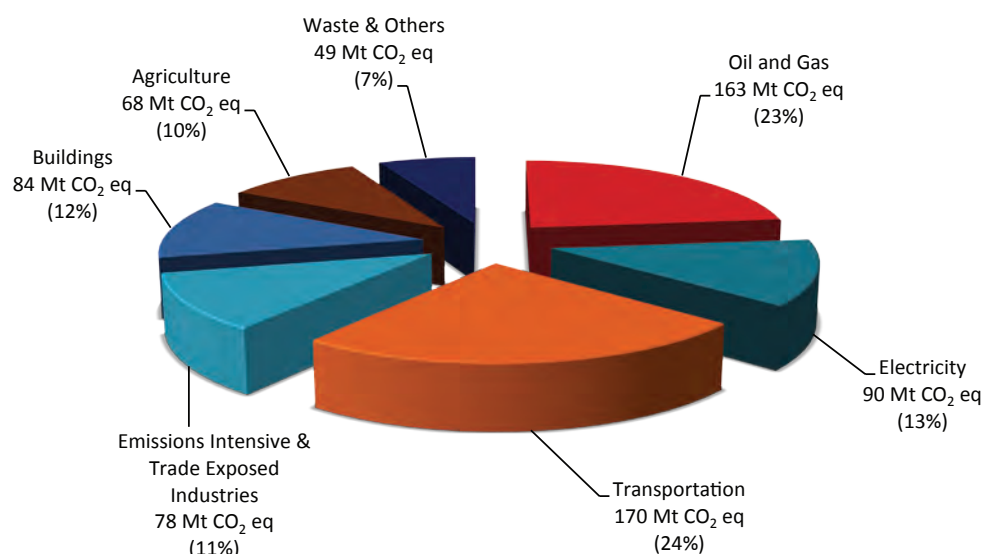


Table S–3 Canada's GHG Emissions 1990–2011, by Economic Sector

Greenhouse Gases	1990	2000	2005	2007	2008	2009	2010	2011
<i>Mt CO₂ equivalent</i>								
National GHG Total	591	718	737	749	731	689	701	702
Oil and Gas	101	150	162	170	164	162	164	163
Electricity	94	129	121	120	112	97	99	90
Transportation	128	155	168	169	166	163	167	170
Emissions Intensive & Trade Exposed Industries ¹	93	85	87	89	86	74	75	78
Buildings	70	82	84	84	83	82	79	84
Agriculture	54	66	68	69	71	67	69	68
Waste & Others ²	50	51	49	48	49	46	48	49

Note: Totals may not add up due to rounding.

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

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

as well as a large increase in the number of motor vehicles, especially light-duty gasoline trucks (vans, SUVs and pickups) and heavy-duty diesel vehicles (commercial transport trucks), have contributed to the significant rise in GHG emissions.

Emissions from the manufacturing area fell by about 15 Mt (13%), counteracting the dominant rising trend. Fuel-switching, efficiency and technology improvements,

and reductions in manufacturing output (especially in the Pulp and Paper and Other Manufacturing subsectors) resulted in the emission reductions.

Though in 2011 emissions from electricity generation were almost identical to what they were 20 years ago, they rose until 2003 and then fell rapidly to current levels. During the same period, electricity generation rose significantly. However, the amount of coal-based electricity within the

Table S-4 Trends in Emissions and Economic Indicators, Selected Years

	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011
Total GHG (Mt)	591	639	718	737	727	749	731	689	701	702
Change Since 2005 (%)	NA	NA	NA	NA	-1.4	1.5	-0.9	-6.6	-5.0	-4.8
Change Since 1990 (%)	NA	8.1	21.4	24.8	23.0	26.7	23.7	16.6	18.6	18.7
GDP (Billions 2007\$)	983	1072	1321	1495	1533	1566	1582	1533	1582	1620
Change Since 2005 (%)	NA	NA	NA	NA	2.5	4.7	5.8	2.5	5.8	8.4
Change Since 1990 (%)	NA	9.1	34.4	52.1	56.0	59.3	60.9	55.9	61.0	64.8
GHG Intensity (Mt/\$B GDP)	0.60	0.60	0.54	0.49	0.47	0.48	0.46	0.45	0.44	0.43
Change Since 2005 (%)	NA	NA	NA	NA	-3.8	-3.0	-6.3	-8.9	-10.2	-12.2
Change Since 1990 (%)	NA	-0.9	-9.7	-18.0	-21.1	-20.5	-23.2	-25.2	-26.3	-28.0

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

generation mix grew rapidly at first and then fell (most significantly after 2004), resulting in virtually zero net emissions growth.

Agriculture was responsible for a 7-Mt increase in emissions since 1990, largely the result of increasing use of fertilizers and larger populations of beef cattle and swine.

Though greenhouse gas emissions rose by 19% over the last two decades, Canada's economy grew much more rapidly, with GDP rising by 65% (Table S-4). As a result, the emission intensity for the whole economy (GHG per GDP) has improved considerably, dropping by 28%. There have been some variations over time, however.

In the early 1990s, energy prices were low (EIA 2004) and this significantly limited the economic incentives to improve energy efficiency. Between 1990 and 1994, emission intensity remained stable (see Figure S-2), with emissions rising nearly in step with economic growth (which was strengthening after a recession). In this time frame, emissions and GDP rose by about 5% and 6%, respectively. Beginning in 1995, however, there was a decoupling of GDP and emissions.

The trend in the years since the late 1990s demonstrates a decline in the rate of increase of GHG emissions (even if the steep drop in 2009 is ignored). For a decade the average annual growth in emissions was 2.0%, while in contrast, between 2000 and 2008, the average annual emission growth was close to 0.2% and between 2008 and 2011, the rate dropped to -1.3%.

ES.3.2 2005–2011 Trends Overview, IPCC Sectors

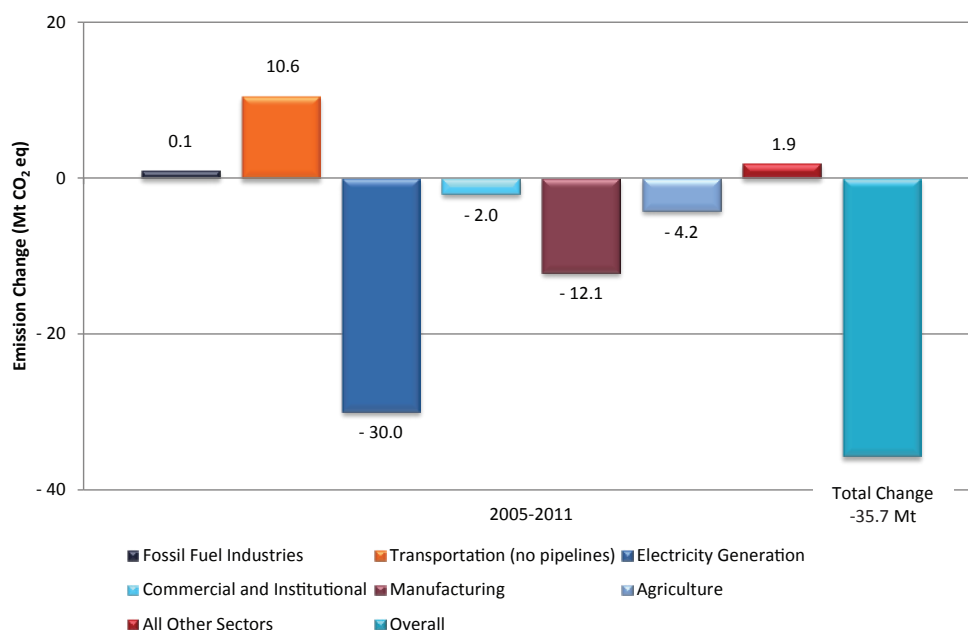
Since 2005, total Canadian GHG emissions have decreased by 35.7 Mt (4.8%). Fluctuations in emission levels since 2005 are due primarily to changes in the mix of sources used for electricity production, changing emissions from fossil fuel production, and varying demand for heating fuels.

Figure S-7 shows the major contributors to emission trends. Emissions from electricity and heat generation have been the largest driver of the overall downward trend, dropping by 30 Mt since 2005, primarily the result of reduced generation by coal, switching to renewable resources and improved efficiencies in combustion generation. Ontario has contributed significantly to this trend through efforts to reduce coal-fired generation of electricity: in 2005, Lakeview generating station was shut down and by the end of 2011, six units at other stations had also been permanently taken out of service.⁸ At the same time, fossil fuel generation varied with the availability of electricity from hydro, nuclear and, to some extent, wind power and solar energy sources. Overall, small-scale renewable energy sources are becoming more prevalent: by 2011 wind, tidal and solar power plants in Canada produced a total of about 10 000 GWh of electricity, or 1.7% of total generation.⁹

8 By December 31, 2011, 10 of 19 operating coal units in Ontario had been shut down ("Ontario Shutting Down Two More Coal Units", Ontario Government website, Dec. 1, 2011, Available online at <http://news.ontario.ca/mei/en/2011/12/ontario-shutting-down-two-more-coal-units.html>, accessed on February 24, 2013).

9 Source: Statistics Canada, CANSIM 127-0007 (2005–2010), accessed on Feb 24, 2013.

Figure S-7 Emission Trends for 2005–2011, Broken Down by Major Sector



Emissions from manufacturing decreased by 12.1 Mt (11%) between 2005 and 2011, due to significantly lowered production. Over the same period, emissions in the commercial and institutional subsector fell by about 2 Mt. In 2011, heating degree-days, an indicator of the necessity for space heating in response to the severity of cold weather, were down about 1.3% as compared to 2005.¹⁰ This served to reduce fossil fuel consumption and the emissions associated with it.

In contrast to these reductions, transport (not including pipelines) GHG emissions rose by 10.6 Mt (5.8%) between 2005 and 2011. The emission reductions brought on by reduced commercial vehicle activity in 2008–2009 were almost completely negated as increased economic activity brought emission levels back close to 2007 levels. In fact, emissions rose by about 3 Mt between 2010 and 2011. Most of this increase occurred in diesel transport, namely heavy-duty diesel on-road vehicles for shipping, and off-road industrial vehicles.

Although there was virtually no change in emissions from the fossil fuel industries (0.1% increase) between 2005 and

2011, there were significant changes in subsectors of the industry. For example, a decrease in natural gas production along with a reduction in conventional crude oil production contributed to emission decreases, but these were offset by emission growth from the increase in production of crude bitumen and synthetic crude oil from Canada's oil sands.¹¹

ES.3.3 IPCC Subsectors

Energy—2011 GHG Emissions (572 Mt)

Short-term Trends

In 2011, GHG emissions from the IPCC Energy Sector declined by 26 Mt (about 4.3%) when compared to 2005. Similar to the national trend, this decline was primarily driven by Electricity and Heat Generation and the Manufacturing Industries.

Public Electricity and Heat Generation¹² emissions shrank by 30 Mt (about 24%) from 2005 levels. Between 2005 and 2011, however, there were fluctuations in emissions, largely as a result of changes in the mix of electricity

10 Source: Adapted from a) Environment Canada, National Climate Data and Information Archive, available online at http://climate.weatheroffice.gc.ca/advanceSearch/searchHistoricData_e.html?timeframe=1&Prov=XX&StationID=9999&Year=2009&Month=12&Day=16 and b) Statistics Canada, 2006 Census data products, available online at <http://www12.statcan.gc.ca/census-recensement/2006/dp-pd/index-eng.cfm>; see Chapter 2.

11 Source: Alberta Energy Resources Conservation Board, ST98; see Chapter 2.

12 Public Electricity and Heat Generation includes all utility generation (as reported to Statistics Canada). As defined by the IPCC, this category does not include industrial cogeneration.

generation sources¹³ (see “ES.2 Summary of National GHG Emissions and Trends”). Decreased electricity demand contributed significantly to the decrease in emissions between 2008 and 2009.

GHG emissions from Manufacturing Industries dropped by 5.9 Mt (12%) between 2005 and 2011, due to significantly lowered production.

Long-term Trends

By far the largest portion of Canada’s total emission growth is observed in the Energy Sector. The long-term Sector emission trends (1990–2011) showed both declines and increases, for a net growth of 102 Mt, or 22%. As described above in Section ES.2, most of the growth in national emissions is observed in the fossil fuel industries and transportation, which fall under the Energy Sector. The fossil fuel industries (consisting of coal mining and the production, transmission, processing, refining and distribution of all oil and gas products) registered a net increase of about 56 Mt of GHG emissions from 1990 to 2011 (51% growth).

By 2011, total production of crude oil and natural gas had increased by 66% over 1990 levels. However, the oil sands industry has been reducing its per-unit emissions, and in 2011 intensity was 26% lower than in 1990. This reduction in GHG intensity is significant, as larger and larger portions of production are derived from oil sands.

Most transportation emissions in Canada are related to Road Transport, which dominated the GHG growth trend in this area. Emissions from Road Transport rose by 38.5 Mt (40%) between 1990 and 2011.

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 2009). However, the use of light trucks increased much more rapidly than cars. Since light trucks have less favourable fuel consumption than cars, this shift also drove emission increases (NRCAN 2009).

Emissions from heavy-duty diesel vehicles (large freight trucks) rose by 21.8 Mt (109%) between 1990 and 2011. Growth in emissions reflected a 137% increase in tonne-kilometres shipped by for-hire trucking between 1990 and 2003 (Statistics Canada 2013a). The quantity of goods

shipped by truck (as opposed to other transport modes) resulted in turn from customer requirements for just-in-time delivery and cross-border freight (NRCAN 2009). Between 2004 and 2010, tonne-kilometres shipped oscillated between +4% (2004–2005) and -7% (2008–2009) and ultimately resulted in zero growth across the 6-year period (Statistics Canada 2013b).

Industrial Processes—2011 GHG Emissions (54 Mt)

The Industrial Processes Sector covers GHG emissions arising from non-energy sources such as limestone calcination (CO₂) in cement production, or the use of hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) as replacement refrigerants for ozone-depleting substances (ODSs). The Sector has declined 1.7 Mt since 1990. In 2011 there was an increase of 1.9% from the 2010 level. Production increases were observed in the iron and steel and cement industries. Of note in this sector is the rapid increase in emissions from the use of HFCs as refrigerants in place of ODSs, an increase of 2.4 Mt (45%) since 2005.

In the Metal Production category, CO₂ emissions from production of iron and steel have been decreasing since the early 1990s, despite moderate increases in steel production in Canada. Reductions in emission intensities achieved by the steel industry in the period from 1990 to 2008 have been maintained. This is primarily due to increased use of recycled steel in the production process. The year 2009 saw a significant decline in production, followed by a partial comeback in 2010, and an almost complete recovery in 2011. The aluminium industry, while increasing its production by almost 100% since 1990, shows a reduction of its process emissions by 29%. The 57% reduction achieved overall in the GHG emissions from industrial chemical processes between 1990 and 2011 is primarily the result of the closure of the adipic acid plant in Ontario. Decreases were partly offset by increases in emissions from the Ammonia Production and Nitric Acid Production categories.

Agriculture—2011 Emissions (54 Mt)

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

¹³ The mix of electricity generation sources is characterized by the amount of fossil fuel vs hydro, other renewable and nuclear sources. In general, only fossil fuel sources generate net GHG emissions.

Emissions directly related to animal and crop production accounted for 54 Mt CO₂ eq or 8.0% of total 2011 GHG emissions for Canada, an increase of 7 Mt CO₂ eq or 15% since 1990. Agriculture accounts for 23% and 72% of the national CH₄ and N₂O emissions, respectively.

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.

Overall, the relative proportion of emissions coming from livestock has remained above 60% of total agricultural emissions, except very recently. From 2005 to 2008, emissions from the Agriculture Sector stabilized, with declines in emissions from livestock production being compensated for by increases in emissions from crop production. With the continued decline in livestock populations since 2008 and low crop yields in 2011, agriculture emissions are approximately 4 Mt CO₂ eq lower than the average level of emissions from 2005 to 2008.

Land Use, Land-use Change and Forestry—2011 (Net Source of 87 Mt)

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

In this sector, the net GHG flux is calculated as the sum of CO₂ emissions to, and removals from, the atmosphere, plus non-CO₂ emissions. In 2011, this net flux amounted to emissions of 87 Mt CO₂ eq, which would have increased the total Canadian GHG emissions by about 12%. 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 inter annual variability due to the erratic pattern of forest wildfires, which masks underlying patterns of interest in the Sector. Important subsectoral trends associated with human activities in managed forests include a 28% increase in the carbon removed in harvested wood between 1990 and the peak harvest year of 2004. Since then, significant reductions in forest management activities have occurred, with a 33% decline in harvest levels,

which in 2009 reached their lowest point for the 22-year period covered by this report (30 Mt C). Nonetheless, 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 trend.

The steady decline in emissions from cropland is noteworthy, from 12 Mt CO₂ eq in 1990 to a net removal of 8 Mt CO₂ eq in 2011. This pattern largely results from changing agricultural land management practices in western Canada, such as the extensive adoption of conservation tillage practices (over 13 Mha of cropland since 1990), reduction in summerfallow by 68% and an increase in perennial forage crops. The net CO₂ removals due to the management of mineral soils increased from 2.1 Mt in 1990 to 14 Mt in 2011. A decline in the conversion of forest land to cropland has also contributed to this trend.

Waste—2011 Emissions (22 Mt)

The primary source category in the Waste Sector consists of CH₄ Emissions from Solid Waste Disposal on Land, which accounted for about 92% of the emissions for this sector. The CH₄ emissions from publicly and privately owned municipal solid waste landfills make up the bulk of emissions in the Solid Waste Disposal on Land category (about 88%). A smaller part (about 12%) comes from pulp and paper and sawmill industries that landfill wood residues on-site; this practice is declining as markets for wood residues build up.

Since 1990, the overall emissions from the Sector grew by 14%, mostly from increases in emissions from landfill operations. The amount of landfill gas (LFG) captured increased by 81% to 349 kt of CH₄ in 2011. The LFG utilized in energy applications formed 51% of the overall total, and the rest was flared. The number of landfill sites with LFG capture systems is rapidly rising in Canada, with 68 such systems in operation in 2011 (about a 45% increase since 2005).

Wastewater treatment and waste incineration facilities in Canada are minor sources of CH₄ and N₂O emissions and have generally stayed stable.

ES.4 Provincial and Territorial GHG Emissions

While Ontario, with its large manufacturing base, started off as the largest-emitting province in 1990, it has been surpassed by Alberta in more recent years

(see Figure S–8). The province of Alberta has seen a 46% increase in its emissions since 1990, mostly driven by the enhanced production of petroleum resources for export markets.

In general, the year 2011 witnessed an increase in demand for industrial output when compared to 2010, and hence an increase in GHG emissions from manufacturing, particularly in Ontario. However, over the same period emissions from the electricity sector in Ontario decreased by 4.8 Mt (24%). Overall, Ontario's electricity sector experienced a decrease of 19 Mt (56%) from its 2005 emissions—largely due to the closures of coal plants.

In 2011, the combined emissions from Alberta and Ontario contributed 59% (35% and 24%, respectively) to the national total of 702 Mt. The provinces of Quebec and British Columbia, which rely on abundant hydroelectric resources for their electricity production, show more stable emission patterns across the time series, while Quebec exhibited a moderate decrease from its 1990 level. The latter profiles are more or less applicable to other Canadian provinces, except for Saskatchewan, where activities in the oil and gas industry, as well as potash and uranium mining, increased emissions by 67% between 1990 and 2011.

Finally, increases in transportation emissions were salient particularly in provinces that saw their population grow, i.e., Ontario, Alberta and British Columbia; transport

emissions in these provinces together increased by 38% between 1990 and 2011.

ES.5 National System and Quality Management

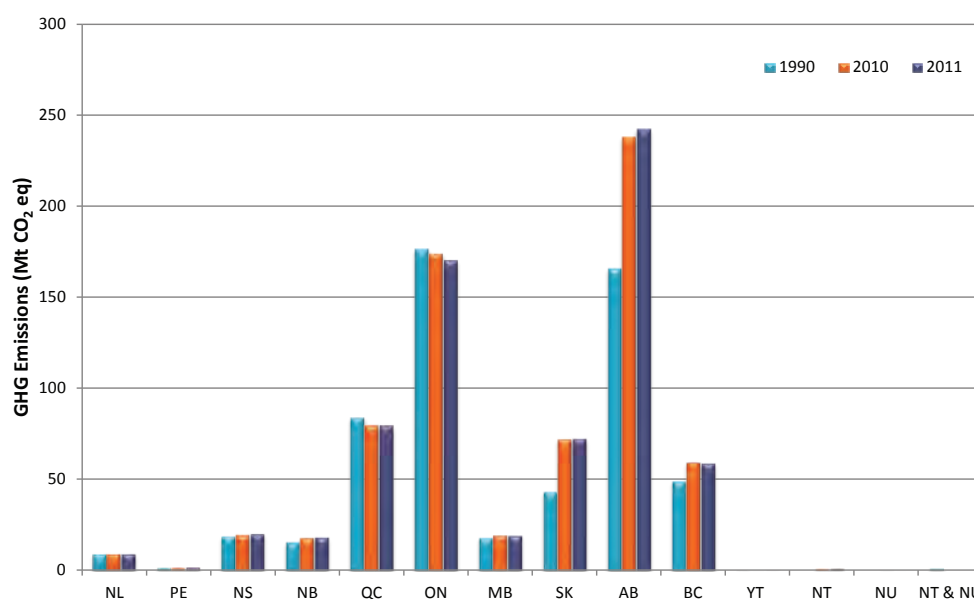
The *Canadian Environmental Protection Act, 1999* (Canada 1999) provides the legislative authority to designate Environment Canada as the single national entity with responsibility for the preparation and submission of the National Inventory Submission to the UNFCCC and for the establishment of a national system. Canada's national system covers the institutional arrangements for the preparation of the inventory, including

- the roles and responsibilities of the inventory agency and of the various players involved;
- the processes for inventory preparation, data collection and estimates development;
- quality management of the inventory; and
- the procedures for official approval of the inventory.

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

Quality assurance and quality control (QA/QC) is an integral part of the preparation of this inventory

Figure S–8 Emissions by Province in 1990, 2010 and 2011



(see Annex 6). Canada's quality system includes a QA/QC plan, an archiving system, documented processes for data collection and estimate development, identification of key sources through analysis (Annex 1), quantitative uncertainty assessments (Annex 7), and a process of performing recalculations for improvement of the inventory (Chapter 9). Recalculations resulting from changes to underlying activity data are presented in the chapter(s) associated with the sector where the changes occurred (Chapters 3–8).

Of particular note for this year's inventory, the revised 2010 estimate for Canada has increased by about 9 Mt from 692 Mt CO₂ eq. This revision is mainly due to refinements in underlying energy data and reflects updates in the consumption of natural gas for oil and gas operations. Details of this revision are presented in Chapter 3.

ES.6 Structure of Submission

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

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

Part 2 of the NIR consists of Annexes 1 to 10, which provide a key category analysis, detailed explanations of estimation methodologies, a comparison of the sectoral and reference approaches in the Energy Sector, quality assurance and quality control procedures, completeness

assessments, inventory uncertainty, emission factors, rounding procedures, and a summary of ozone and aerosol precursors.

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

Chapter 1

Introduction

1.1. Greenhouse Gas Inventories and Climate Change

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

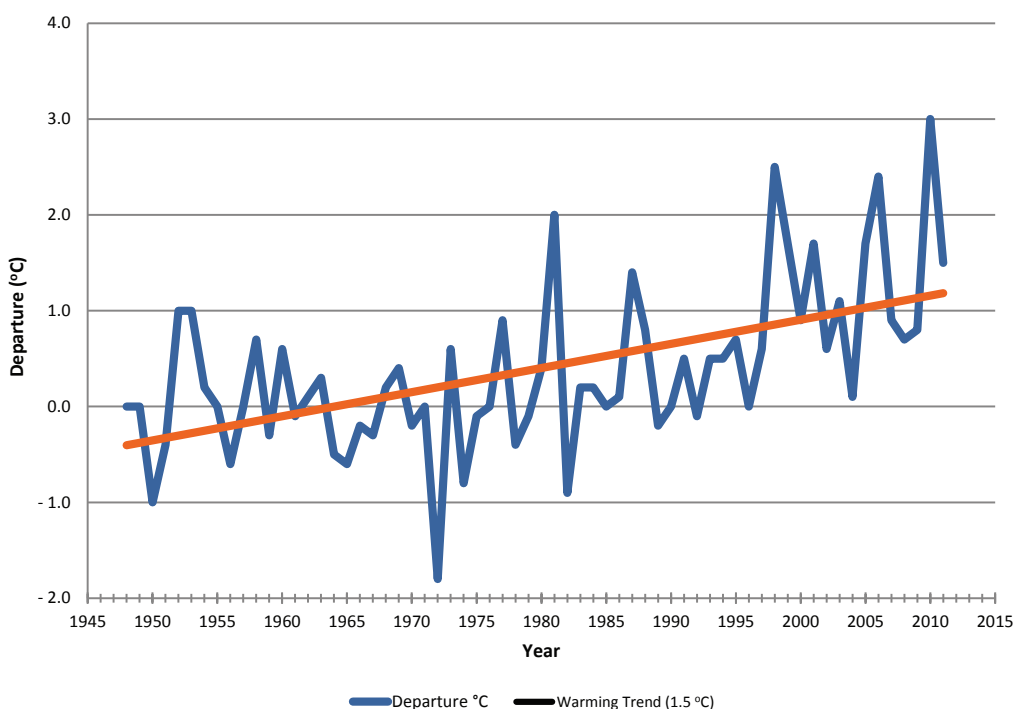
On the other hand, climate is the average pattern of weather (usually taken over a 30-year period) for a particu-

lar region. Climatic elements include precipitation, temperature, humidity, sunshine, wind velocity, phenomena such as fog, frost and hailstorms, and other measures of the weather. The term “climate change” refers to changes in long-term weather patterns caused by natural phenomena and human activities that alter the 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 (CO₂) has increased by 140%; of methane (CH₄) by 259%; and of nitrous oxide (N₂O) by 120% (WMO 2012). 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.

Figure 1–1 Annual Canadian Temperature Departures and Long-term Trend, 1948–2011 (°C)



Source data: Environment Canada (2012)

In general, temperatures and sea levels are expected to rise and the frequency of extreme weather events is expected to increase. In some regions, the impacts could be devastating, while other regions could benefit from climate change. The impacts will depend on the form and magnitude of the change and, in the case of adverse effects, the ability of natural and human systems to adapt to the changes. 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 2011 was 1.5°C above normal (see Figure 1–1). Annual temperatures in Canada have been at or above normal since 1993, with a warming trend of 1.5°C over the last 64 years (Environment Canada 2012).

1.1.1. Reporting of Canada's National Greenhouse Gas Inventory

Canada ratified the United Nations Framework Convention on Climate Change (UNFCCC) in December 1992, and the Convention came into force in March 1994. The ultimate objective of the UNFCCC is to stabilize atmospheric GHG concentrations at a level that would prevent dangerous interference with the climate system. In its actions to achieve its objective and to implement its provisions, the UNFCCC lays out a number of guiding principles and commitments. It requires governments to gather and share information on 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,¹ publish and make available to the Conference of the Parties national inventories of anthropogenic² emissions by sources and removals by sinks of all GHGs not controlled by the Montreal Protocol that use comparable methodologies.

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

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

This National Inventory Report (NIR) provides Canada's annual greenhouse gas emissions estimates for the period 1990–2011. The NIR, along with the Common Reporting Format (CRF) tables, comprise Canada's submission to the UNFCCC. The NIR and CRF tables have been prepared in accordance with the updated "*Guidelines for the preparation of national communications by Parties included in Annex I to the Convention, Part I: UNFCCC reporting guidelines on annual inventories*," which include the revisions to the Land Use, Land-use Change and Forestry Sector adopted by the Conference of the Parties (CoP) at its eleventh session.

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: CO₂, CH₄, N₂O, sulphur hexafluoride (SF₆), perfluorocarbons (PFCs) and hydrofluorocarbons (HFCs). In addition, and in keeping with the UNFCCC reporting guidelines for Annex I Parties, Annex 10 contains estimates of the following ozone and aerosol precursors: carbon monoxide (CO), nitrogen oxides (NO_x), non-methane volatile organic compounds (NMVOC) and sulphur oxides (SO_x).

1.1.2.1. Carbon Dioxide (CO₂)

CO₂ is a naturally occurring, colourless, odourless, combustible 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, CO₂ is constantly being removed from the air by its direct absorption into water and by plants through photosynthesis and, in turn, is naturally released into the air by plant and animal respiration, decay of plant and soil organic matter, and outgassing from water surfaces. Small amounts of carbon dioxide are also injected directly into the atmosphere by volcanic emissions and through slow geological processes such as the weathering of rock (Hengeveld et al. 2005). Although human-caused releases of CO₂ are relatively small (1/20) compared to the amounts that enter and leave the atmosphere due to the natural active flow of carbon (Hengeveld et al. 2005), human activities now appear to be significantly affecting this natural balance. This is evident in the measurement of the steady increase of atmospheric

CO₂ concentrations since preindustrial times across the globe. Anthropogenic sources of CO₂ 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 (CH₄)

CH₄ is a colourless, odourless, flammable gas that is the simplest hydrocarbon. CH₄ is present in the Earth's atmosphere at low concentrations and acts as a greenhouse gas. CH₄ 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). CH₄ is produced naturally during the decomposition of plant or organic matter in the absence of oxygen, as well as released from wetlands (including rice paddies), and through the digestive processes of certain insects and animals such as termites, sheep and cattle. CH₄ 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 (N₂O)

N₂O is a colourless, non-flammable, sweet-smelling gas that is heavier than air. Used as an anaesthetic in dentistry and surgery, as well as a propellant in aerosol cans, N₂O is most commonly produced via the heating of ammonium nitrate (NH₄NO₃). It is also released naturally from oceans, by bacteria in soils, and from animal wastes. Other sources of N₂O 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, semiconductor manufacturing and foam blowing.

1.1.2.6. Sulphur hexafluoride (SF₆)

SF₆ 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. SF₆ 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, SF₆ 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 forcing³ 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

³ The term "radiative forcing" refers to the amount of heat-trapping potential for any given GHG. It is measured in units of power (watts) per unit of area (metres squared).

Table 1–1 1995 IPCC GWPs and Atmospheric Lifetimes

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

Sources:
GWP: IPCC, 1995. Available online at http://unfccc.int/ghg_data/items/3825.php
Atmospheric Lifetime: IPCC, 1995, Table 2.9.

Note:
The CH₄ GWP includes the direct effect and those indirect effects due to the production of tropospheric ozone and stratospheric water vapour. Not included is the indirect effect due to the production of CO₂.

instantaneous release of 1 kg of the gas expressed relative to the radiative forcing from the release of 1 kg of CO₂. 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 CO₂. Often greenhouse gas emissions are calculated in terms of how much CO₂ would be required to produce a similar warming effect. This is called the carbon dioxide equivalent (CO₂ 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 (CH₄) used in this inventory is 21. As such, an emission of one hundred kilotonnes (100 kt) of methane is equivalent to 21 × 100 kt = 2100 kt CO₂ eq.

Consistent with Decision 2/CP.3, the 100-year GWPs, provided by the IPCC in its *Second Assessment Report*

(Table 1–1) and required for inventory reporting under the UNFCCC, are used in this report.

1.1.3. Canada's Contribution

While Canada represented only about 2% of total global GHG emissions in 2005 (CAIT 2012), it is one of the highest per capita emitters, largely as a result of its size, climate (i.e. energy demands due to climate), and resource-based economy. In 1990, Canadians released 21.3 tonnes (t) of GHGs per capita. In 2011, this had decreased to 20.4 t of GHGs per capita (Statistics Canada 2012) (Figure 1–2).

In terms of growth in total anthropogenic GHG emissions without Land Use, Land-use Change and Forestry (LULUCF), Canada ranks eighth among the Annex I Parties, with an increase in emissions of 17.4% over the 1990–2010 period (Figure 1–3), and ranks first among the G8 countries.

Figure 1–2 Per Capita GHG Emission Trend for Canada, 1990–2011

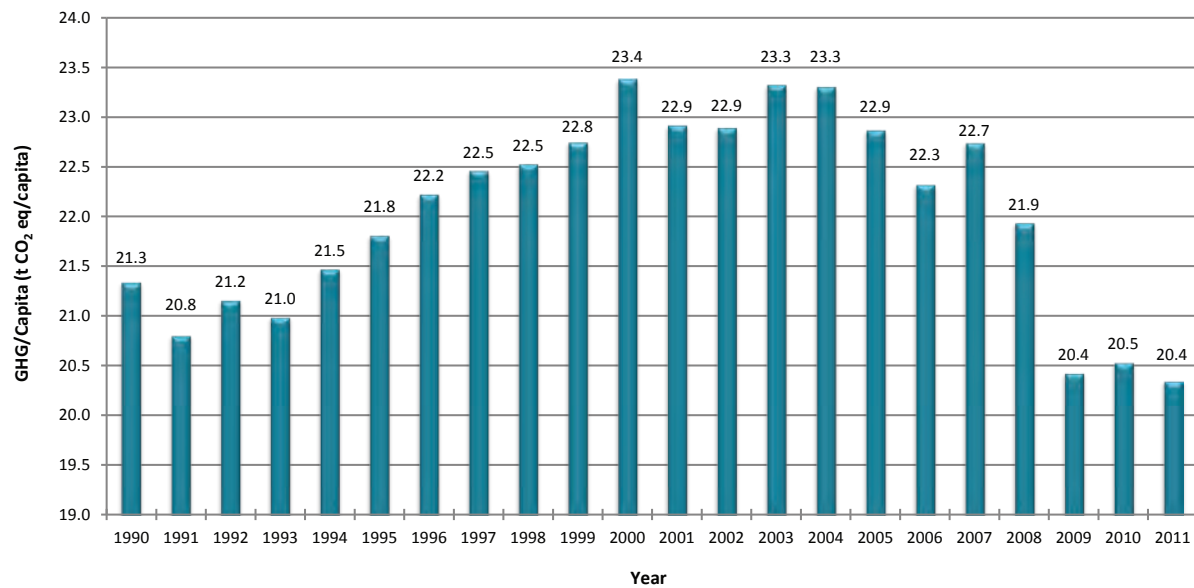
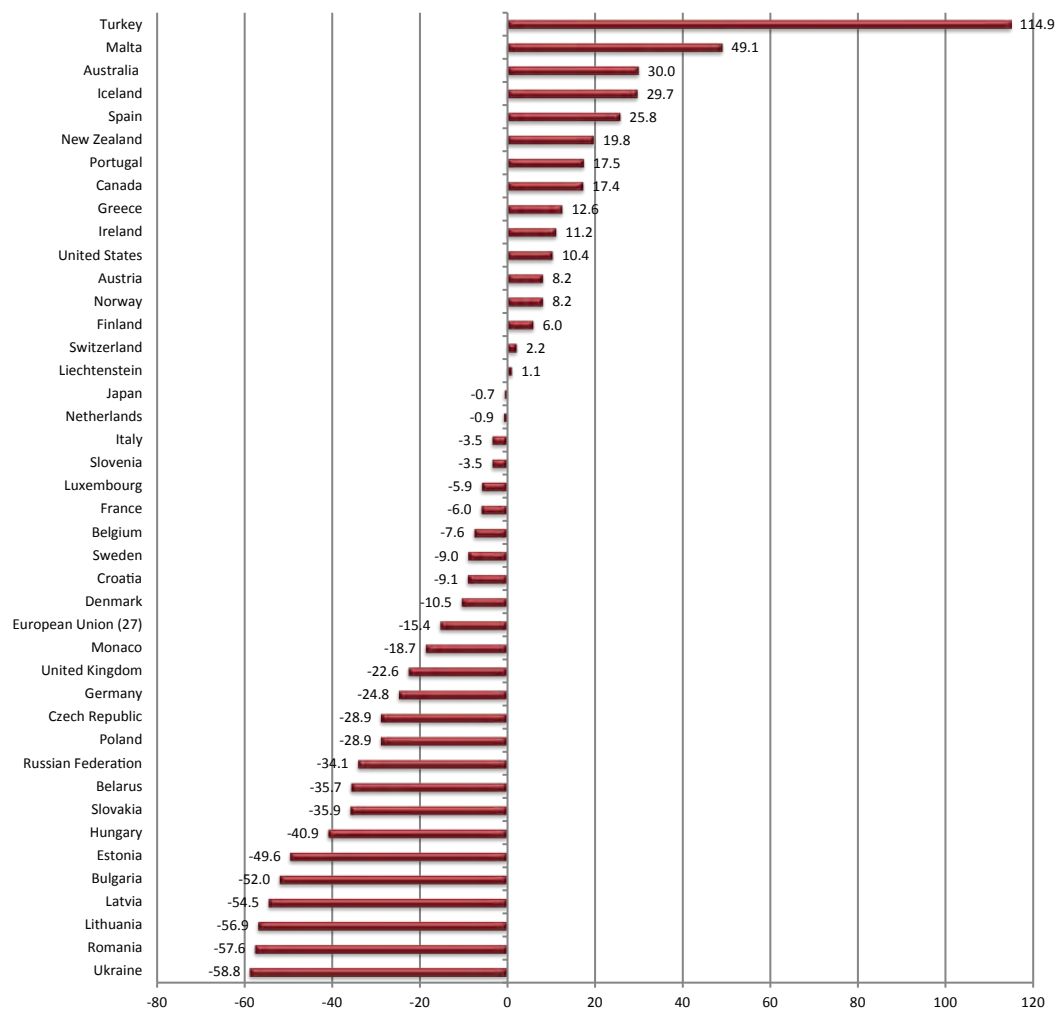


Figure 1–3 Percent Change in Aggregate GHG Emissions for Annex I Parties without LULUCF, 1990–2010



Source: UNFCCC (2012).

1.2. Institutional Arrangements for Inventory Preparation

The following section describes the national system and the roles and responsibilities of the various agencies and players in the implementation of the national system in Canada. The process for the preparation of the inventory is outlined in Section 1.3.

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

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

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

1.2.1. The National System

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

Canada's national system was examined in November 2007 during the in-country review of Canada's initial report. The review team concluded that Canada's national system contained all the necessary elements: institutional arrangements for the preparation of the inventory, including procedures for official approval; a quality assurance/quality control (QA/QC) plan; a working archives system; an adequate description of the process for collecting data and developing estimates; the ability to identify key categories and generate quantitative uncertainty analysis; and a process for performing recalculation for improvement of the inventory (UNFCCC 2008).

1.2.2. Institutional Arrangements

The *Canadian Environmental Protection Act, 1999* (CEPA 1999) provides the legislative authority for Environment Canada to implement a national inventory system; CEPA 1999 also provides the authority under which Environment Canada is responsible for preparing and submitting the national inventory to the UNFCCC (Canada 1999).

Recognizing the need to draw on the best available technical and scientific expertise and information in accordance with good practice and international quality standards, Environment Canada has defined roles and responsibilities for the preparation of the inventory, both internally and externally.

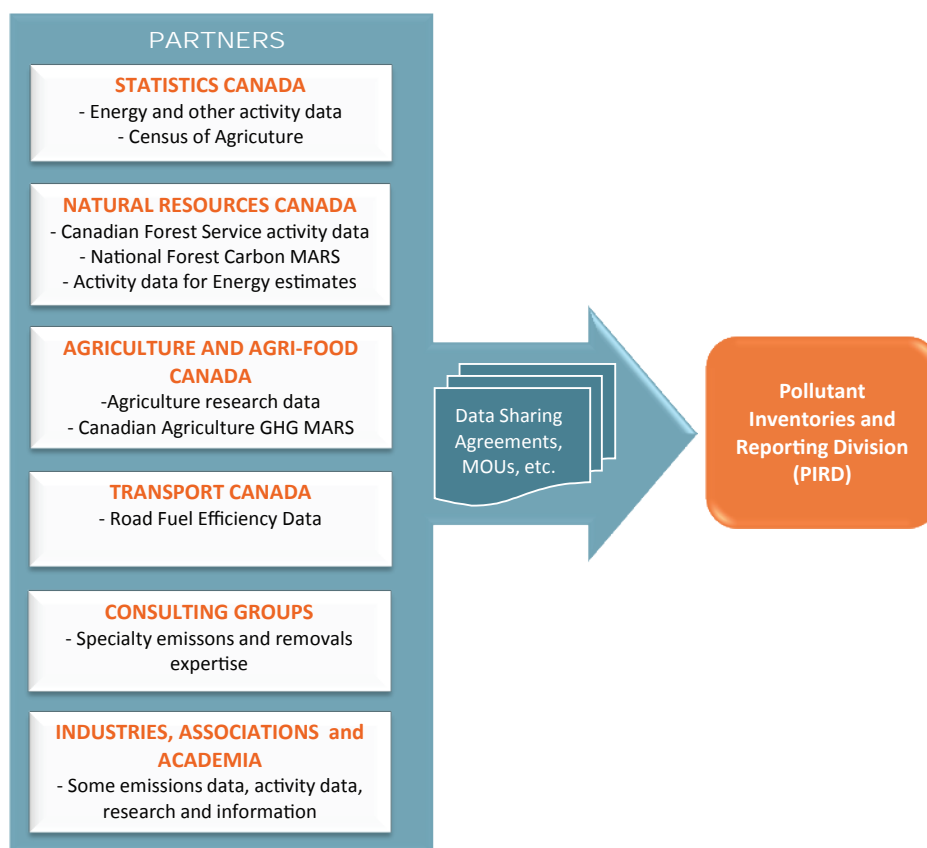
Sources and sinks of GHGs originate from a tremendous range of economic sectors and activities. As such, Environment Canada is involved in many partnerships with data providers and expert contributors in a variety of ways, ranging from informal to formal arrangements. These partnerships include other government departments: Statistics Canada, Natural Resources Canada and Agriculture & Agri-Food Canada. These agreements are described in greater detail in the following sections. Environment Canada also has arrangements with industry associations, consultants and universities, as described in Section 1.2.2.3, and collaborates with provincial and territorial governments on a bilateral basis.

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

1.2.2.1. Statistics Canada

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

Figure 1–4 Partners of the National System



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

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

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

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

Canada's Monitoring, Accounting and Reporting System (MARS) for LULUCF is overseen by an interdepartmental steering committee chaired by Environment Canada, with representatives from AAFC and NRCan/CFS. Technical working groups address the subsectors of Forestry, Agriculture and Land-use Change, to ensure that the best available information and data from scientific research are

integrated into the LULUCF Sector of the inventory. Under this framework, Environment Canada's MARS partners provide estimates, complete and transparent documentation, uncertainty analyses, and quality control and quality assurance of reports.

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

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

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

1.2.2.3. Other Partnerships

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

When required, and resources permitting, contracts are established with consulting firms and universities to conduct in-depth studies—for example, on updating emission factors. A bilateral agreement with the Aluminum Association of Canada (AAC) has been signed, under which process-related emission estimates for CO₂, PFCs and SF₆

are to be provided annually to Environment Canada. A similar agreement has been negotiated with the Canadian Electricity Association (CEA) for provision of SF₆ emissions and supplementary data relating to power transmission systems. Environment Canada has also been collaborating with magnesium casting companies and companies that import or distribute HFCs, with regard to their annual data on GHG emissions and/or supporting activity data.

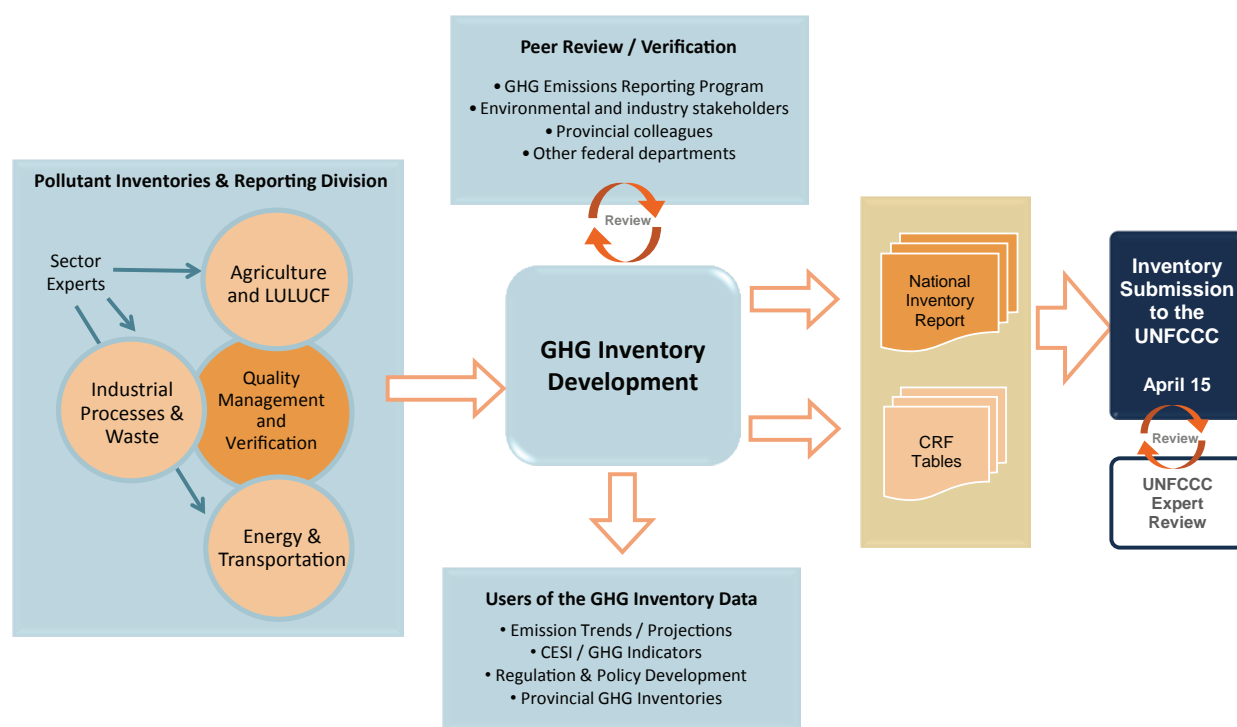
1.3. Process for Inventory Preparation

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

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

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 are calculated by designated inventory experts and sub-

Figure 1–5 Inventory Preparation Process



sequently internally reviewed. During February the NIR text and CRF tables are prepared according to UNFCCC guidelines. QC checks and estimates are signed off by sectoral managers before the report and national totals are prepared. The inventory process also involves key category assessment, recalculations, uncertainty calculation 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 reviews are documented and, where appropriate, incorporated in the NIR and CRF, which are normally submitted to the UNFCCC electronically prior to April 15 of each year. Initial checks of the April submission are performed by the UNFCCC in May and June. Once finalized, the NIR is then translated and made available in French.

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

In the process of considering the national inventory and the results, several briefings of senior officials take place prior to the report being sent to the Minister. Once reviewed and/or approved, the National Inventory Focal Point prepares a letter of submission to accompany the NIR and CRF tables, which are then sent electronically.

1.4. Methodologies and Data Sources

The inventory is structured to match the reporting requirements of the UNFCCC and is divided into the following six main Sectors: Energy, Industrial Processes, Solvent and Other Product Use, Agriculture, LULUCF, and Waste. Each of these Sectors is further subdivided within the inventory. The methods described have been grouped, as closely as possible, by UNFCCC Sector and subsector.

The methodologies contained in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/

OECD/IEA 1997), the *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000), and the *Good Practice Guidance for Land Use, Land-Use Change and Forestry* (IPCC 2003) are followed to estimate emissions and removals of each of the following direct GHGs: CO₂, CH₄, N₂O, HFCs, PFCs and SF₆. The 2006 *IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006) contains updated methodologies; however, these guidelines have not yet been implemented for UNFCCC reporting.

While not mandatory, the UNFCCC reporting guidelines encourage Annex I Parties to provide information on the following indirect GHGs: SO_x, NO_x, CO and NMVOCs. For all categories except LULUCF, these gases (referred to as criteria air contaminants, or CACs) are inventoried and reported separately. CAC emissions in Canada are reported to the United Nations Economic Commission for the Environment.⁴ As noted, a summary of these emissions is also included in the NIR (see Annex 10: Ozone and Aerosol Precursors).

In general, an emissions and removals inventory can be defined as a comprehensive account of anthropogenic sources of emissions and removals by sinks and associated data from source categories within the inventory area over a specified time frame. It can be prepared “top-down,” “bottom-up,” or using a combination approach. Canada’s national inventory is prepared using a “top-down” approach, providing estimates at a sectoral and provincial/territorial level without attribution to individual emitters.

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

Manipulated biological systems, such as agricultural lands, forestry and land converted to other uses, are sources or sinks diffused over very large areas. Processes that cause emissions and removals display considerable spatial and interannual variability, and they also span several years or decades. The most practical approach to estimating emis-

sions and removals requires a combination of repeated measurements and modelling. The need, unique to these systems, to separate anthropogenic impacts from large natural fluxes creates an additional challenge.

The methodologies (Annexes 2 and 3) and emission factors (Annex 8) described in this document are considered to be the best available to date, given the available activity data. That being said, in some cases, a more accurate method or emission factor may be available, but the necessary underlying data are lacking, so the more accurate method cannot be used. Some methods have undergone revision and improvement over time, and some new sources have been added to the inventory over time.

Methodology and data improvement activities, which take into account results of QA/QC procedures, reviews and verification, are planned and implemented on a continuous basis by the staff of Environment Canada’s Pollutant Inventories and Reporting Division. It should be noted that planned improvements are often implemented over the course of several years. These methodology and data improvement activities are carried out with a view to further refining and increasing the transparency, completeness, accuracy, consistency and comparability of the national inventory. As a result, changes in data or methods often lead to the recalculation of GHG estimates for the entire time series, from the 1990 base year to the most recent year available. Further discussion of recalculations and improvements can be found in Chapter 9.

1.4.1. Mandatory GHG Reporting

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

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

- provide Canadians with timely information on GHG emissions;
- validate estimates presented in the national GHG inventory;
- support provincial and territorial requirements for GHG emissions information; and
- support the development of regulations.

⁴ Available online at <http://www.ceip.at/>

Greenhouse gas information reported under the GHGRP is collected through Environment Canada's Single Window (SW) reporting system.⁵ Environment Canada launched this system to support integrated data collection to allow industry to submit information that is common to multiple programs and jurisdictions only once. This system was expanded to support an inclusive Canadian approach for GHG reporting in support of federal, provincial and territorial governments' collaborative efforts to minimize duplication and reduce the reporting burden for industry and governments. Provincial partners currently using this SW system to collect GHG information to meet their GHG reporting regulations include Alberta, British Columbia and Ontario. The types of large industrial facilities reporting GHG emissions to Canada's GHGRP include:

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

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

As per the legal notice published annually in the *Canada Gazette*, facilities that have emissions of 50 kt CO₂ eq or more annually are required to submit a GHG emission report by June 1 of the following year. Voluntary submissions from facilities with GHG emissions below the reporting threshold are accepted.

Specific estimation methods are not prescribed, and reporters can choose the quantification methodologies most appropriate for their own particular industry or application. However, reporting facilities must use methods for estimating emissions that are consistent with the guidelines adopted by the UNFCCC and developed by the IPCC and used in the preparation of the national GHG inventory.

1.4.1.1. Facility-reported Emissions and the National GHG Inventory

Environment Canada's GHGRP website⁶ provides public access to the reported GHG emission information (GHG totals by gas by facility). The total facility-reported GHG emissions for 2011 represent just over one third (36%) of Canada's total GHG emissions in 2011 (702 Mt) and over half (57%) of Canada's industrial GHG emissions.⁷ The degree of coverage from the facility-reported data of industrial GHG emissions at the provincial level varies significantly from province to province, depending on the size and number of industrial facilities in each province that have emissions above the 50-kt reporting threshold.

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

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

1.4.1.2. Reported 2011 Facility GHG Emissions

In the eighth year of reporting, the collected facility-level GHG data cover the period from 2004 to 2011. A total of 539 facilities reported GHG emissions for the 2011 calendar year, collectively emitting a total of 254 Mt of GHGs.⁸ Of these, 306 facilities reported GHG emission levels greater than 100 kt CO₂ eq, accounting for 95% of the total reported emissions. Of the reporting facilities, 28 reported their GHG emissions for the first time; their combined

⁶ The Greenhouse Gas Emissions Reporting Program website can be found at www.ec.gc.ca/ges-ghg/default.asp?lang=En&n=040E378D-1

⁷ Canada's "industrial GHG emissions" mentioned here include the following GHG categories from the *National Inventory Report 1990–2011: Greenhouse Gas Sources and Sinks in Canada*: Stationary Combustion Sources (except Residential), Other Transportation, Fugitive Sources, Industrial Processes and Waste.

⁸ Data presented are current as of December 6, 2012.

⁵ Environment Canada's Single Window reporting system is available online at <https://ec.ss.ec.gc.ca/>

Table 1–2 Facility-reported 2011 GHG Emissions by Province/Territory

Province	Number of Facilities	Total Emissions (kt CO ₂ eq)	% of Total Emissions
Newfoundland and Labrador	8	4 255	2%
Prince Edward Island	1	65	0.02%
Nova Scotia	13	9 893	4%
New Brunswick	13	7 854	3%
Quebec	78	20 199	8%
Ontario	141	49 310	19%
Manitoba	14	2 020	1%
Saskatchewan	36	22 461	9%
Alberta	160	123 271	48%
British Columbia	69	14 227	6%
Northwest Territories	4	554	0.2%
Nunavut	2	199	0.08%
Total	539	254 308	

Note: Totals may not add up due to rounding.

emissions account for 0.7% of the reported total. Facilities can voluntarily report their GHG emissions if their emissions are below the reporting threshold; 46 facilities did so in 2011. Reported emissions from voluntary reporters are included in the facility-level data presented in this section.

Facilities in Alberta accounted for the largest share of reported emissions, with approximately 48% of the total, followed by Ontario, Saskatchewan and Quebec, with 19%, 9% and 8% of reported emissions, respectively (Table 1–2). This regional breakdown of GHG emissions is reflective of the concentration of large industrial facilities in certain provinces relative to others and the relative use of fossil fuels for energy production.

When completing a report for the GHGRP, a reporter is required to identify the main activities occurring at its facility by selecting the North American Industry Classification System (NAICS)⁹ code that corresponds to these activities. In 2011, three NAICS-defined industrial sectors accounted for the majority of GHG emissions:

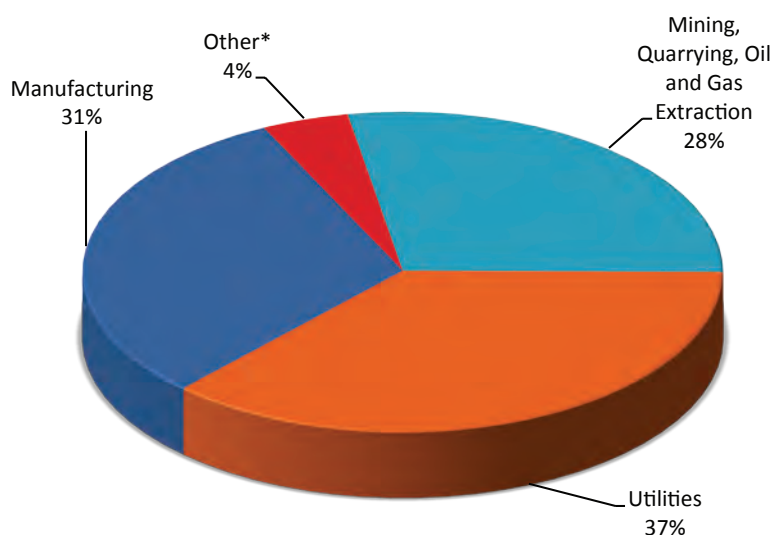
- Utilities, primarily those generating electricity from fossil fuels, representing 37% (94 Mt CO₂ eq);
- Manufacturing, accounting for 31% (78 Mt CO₂ eq); and
- Mining, Quarrying, and Oil and Gas Extraction, accounting for 28% (71 Mt CO₂ eq) (Figure 1–6).

⁹ The NAICS is an industry classification system that was developed by the statistics agencies of Canada, the USA and Mexico to enable the respective national agencies to collect comparable statistical data. The NAICS is a comprehensive system that uses six-digit codes that encompass all economic activities. In Canada, the NAICS consists of 20 sectors, 102 subsectors, 323 industry groups, 711 industries and 922 national industries.

The “Other” category includes various types of facilities such as natural gas transportation pipelines, solid waste landfills, airports, universities, hospitals and public administration buildings. These facilities account for the remaining 4% (11 Mt CO₂ eq) of emissions, with the majority of these emissions stemming from natural gas transportation pipelines (6 Mt CO₂ eq) and solid waste landfills (4 Mt CO₂ eq).

Other key highlights from the 2011 GHGRP data collection cycle include the following:

- The main emission sources contributing to the reported 2011 GHG emission total are stationary fuel combustion and industrial processes, accounting for 76% and 15% of the combined total for carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O).
- Total facility-reported emissions decreased overall by 3% (8 Mt CO₂ eq) from a slightly revised 2010 reported total of 262 Mt CO₂ eq. This decrease stems largely from a 12-Mt decrease in emissions from fossil-fuel electric power generation facilities, lessened by emission increases in the oil and gas and manufacturing sectors, and chemical manufacturers.
- Total emissions from all reporting facilities have decreased overall by 8% since 2005. Ontario-based facilities within the Utilities and Manufacturing sectors experienced the largest declines (18 and 9.5 Mt each) over this 7-year period, while emission increases occurred within the Mining, Quarrying and Oil and Gas Extraction sector, largely in Alberta. The majority of other provinces show overall decreases in facility-reported totals, ranging from less than 1 Mt to 5 Mt.

Figure 1–6 Facility-reported 2011 GHG Emissions by NAICS Industrial Sector (254 Mt CO₂ eq)

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

For more information on the facility data reported under Environment Canada's GHGRP, including short-term and long-term changes observed in facility emissions, please see the Environment Canada publication *Overview of Reported 2011 Greenhouse Gas Emissions*.¹⁰

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

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

(level assessment), the trend in emissions from the base year to the current year (trend assessment), or both. As much as possible, two important inventory aspects of key categories should receive special consideration:

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

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

For the 1990–2011 GHG inventory, level and trend key category assessments were performed according to the Tier 1 approach, as presented in the IPCC Good Practice Guidance (IPCC 2000, 2003). The emission and removal categories used for the key category assessment generally follow those in the CRF and the LULUCF CRF; however, they have been aggregated in some cases and are specific to the Canadian inventory.

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

¹⁰ The Overview Report is available online at www.ec.gc.ca/ges-ghg/default.asp?lang=En&n=8044859A-1

1.6. Quality Assurance/ Quality Control

The national inventory and NIR must be prepared in accordance with international reporting guidelines and methods agreed to by the UNFCCC, including methodological procedures and guidelines prescribed by the IPCC. QA/QC and verification procedures are an integral part of the preparation of the inventory. The Pollutant Inventories and Reporting Division annually conducts QA/QC activities and is committed to improving data and methods in collaboration with industry, the provinces and territories, the scientific community, and the international community to ensure that a credible and defensible inventory is developed. Improvement activities, which take into account results of QA/QC procedures, reviews and verification, are planned and implemented on a continuous basis to further refine and increase the transparency, completeness, accuracy, consistency and comparability of the national inventory. As a result, changes in data or methods often lead to the recalculation of GHG estimates for the entire time series, from the 1990 base year to the most recent year available.

The reader is referred to Annex 6 of this report for more information on 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. Uncertainties¹¹ in the inventory estimates may be caused by systematic and/or random uncertainties present within the input parameters or estimation models. Reducing uncertainty may require in-depth reviews of the estimation models, improvements to the activity data regimes and evaluation of emission factors and other model parameters. IPCC guidelines specify that the primary purpose of quantitative uncertainty information is to assist in setting priorities to improve future inventories and to guide decisions about which methods to use. Typically, the uncertainties associated with the trends and the national totals are much lower than those associated with individual gases and sectors.

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

Based on the Tier 1 error propagation method, the uncertainty for the national inventory, not including the LULUCF Sector, is $\pm 4\%$, consistent with the previously reported range of -3% to $+6\%$. The Energy Sector had the lowest uncertainty, at $\pm 3\%$, while the Agriculture Sector had the highest uncertainty, at $\pm 39\%$. The Industrial Processes, Solvent & Other Product Use, and Waste Sectors had uncertainties of ± 8 , ± 19 and $\pm 34\%$, respectively.

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

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

The uncertainty when the LULUCF emissions and removals are included in the national total was found to be 15%.

The trend uncertainty, not including LULUCF, was found to be 0.94%. Therefore, the total increase in emissions since 1990 has a 95% probability of being in the range of 17.8–19.7%. Given the high interannual variability in the LULUCF estimates, and the fact that it is primarily driven by highly variable natural disturbance factors, this sector is not considered in the analysis of anthropogenic GHG emissions and removals trends uncertainties.

¹¹ 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).

1.8. Completeness Assessment

The national GHG inventory, for the most part, is a complete inventory of the six GHGs required under the UNFCCC. The exclusion of some emissions for certain minor subcategories typically relates to the following:

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

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

The Energy Sector has, since the 2007 UNFCCC in-country review, included biodiesel in transport as recommended by the expert review team. In the Agriculture Sector, CH₄ and N₂O emissions from crop residue burning are estimated. In the LULUCF Sector, significant improvements have been implemented starting in 2006, but completeness has not yet been fully met.

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

Chapter 2

Greenhouse Gas Emission Trends, 1990–2011

2.1. Summary of Emission Trends

In 2011, Canada's greenhouse gas (GHG) emissions, excluding the Land Use, Land-use Change and Forestry (LULUCF) Sector, were 702 Mt, which is about a 19% increase over 1990 emissions. Between 2010 and 2011, emissions increased by 0.1% or 1 Mt.

The fossil fuel industries¹ were responsible for about 51% of the total 111-Mt growth since 1990, while transport² contributed 49%. Major increases in oil and gas production and a large increase in the number of motor vehicles have resulted in a significant rise in emissions. Although increases in emissions from the fossil fuel industries and transport

1 "Fossil fuel industries" comprise the sum of the subsectors of Mining and Oil and Gas Extraction, Fossil Fuel Production and Refining, Pipelines (Transportation), and Fugitive Releases.

2 The "transport" subsector refers to Transportation minus Pipelines.

account for most of the emission trends since 1990, there have been increases in the categories of Agriculture (7 Mt), Consumption of Halocarbons and SF₆ (7 Mt), and Commercial & Institutional (4 Mt), while the Manufacturing Industries and Industrial Processes showed emission declines of 15 Mt and 2 Mt, respectively. The growth in emissions since 1990—about 19%—is very similar to the growth in primary energy use, which rose by approximately 21%.

During this period, Canada's gross domestic product (GDP) grew much more (about 65%) than the emissions, and therefore economic GHG intensity (or GHGs per \$GDP) decreased by about 28% (Table 2–1). Together, efficiency increases and technological and structural changes (e.g. a shift from industrial-oriented to more service-based industries) have resulted in a continuing weakening of the link between growth in GDP and emissions, so that the GHG intensity of the economy has consistently declined.

GHG emissions were approximately 36 Mt lower in 2011 than in 2005. During this period, GHG emissions attributed to electric power decreased by 30 Mt, primarily the result of reduced generation by coal—which dropped to its lowest level since 1990, switching to renewable resources sources, and improved efficiencies in combustion generation. Increased hydroelectric generating capacity also contributed to reducing the amount of combustion-generated electricity and, consequently, emissions.

Industrial Process and Energy emissions from the manufacturing industries sector resulted in a total drop of 12 Mt (11%) between 2005 and 2011, due to significantly lowered production evidenced by falling manufacturing GDP, particularly in recent years.

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

Year	1990	2000	2005	2007	2008	2009	2010	2011
Total GHG (Mt)	591	718	737	749	731	689	701	702
Change Since 2005 (%)	NA	NA	NA	1.5	-0.9	-6.6	-5.0	-4.8
Change Since 1990 (%)	NA	21.4	24.8	26.7	23.7	16.6	18.6	18.7
GDP - (Billions 2007\$)	983	1321	1495	1566	1582	1533	1582	1620
Change Since 2005 (%)	NA	NA	NA	4.7	5.8	2.5	5.8	8.4
Change Since 1990 (%)	NA	34.4	52.1	59.3	60.9	55.9	61.0	64.8
GHG Intensity (Mt/\$B GDP)	0.60	0.54	0.49	0.48	0.46	0.45	0.44	0.43
Change Since 2005 (%)	NA	NA	NA	-3.0	-6.3	-8.9	-10.2	-12.2
Change Since 1990 (%)	NA	-9.7	-18.0	-20.5	-23.2	-25.2	-26.3	-28.0

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

Figure 2–1 Canada's GHG Emissions by Gas, 1990 and 2011 (excluding LULUCF)

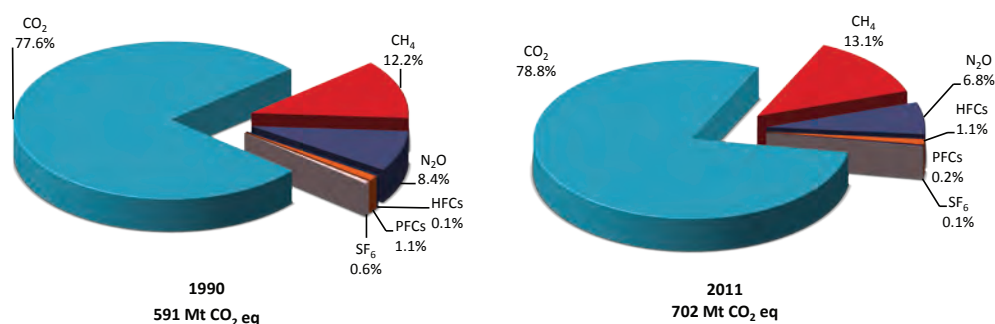


Table 2–2 GHG Emissions from Energy by IPCC category, Selected Years

GHG Sources/Sinks	GHG Emissions (Mt CO ₂ eq)							
	1990	2000	2005	2007	2008	2009	2010	2011
Energy	469	589	597	610	592	560	570	572
Fuel Combustion (Sectoral Approach) (1.A)	427	526	534	547	530	502	512	512
Energy Industries (1.A.1)	145	197	194	194	182	166	166	155
Mining (1.A.2.F.ii)	6.6	12.1	18.9	28.9	30.0	31.7	35.0	36.4
Manufacturing Industries and Construction (1.A.2) ¹	57.7	56.7	50.1	49.0	46.4	41.5	42.6	44.1
Transport (1.A.3)	146	180	193	195	194	186	196	199
Other Sectors (1.A.4)	71.6	80.7	78.4	79.3	78.1	75.9	72.2	77.9
Fugitive Emissions (1.B)	42.4	63.0	63.4	63.0	62.0	58.8	58.6	59.7
Solid Fuels (Coal) (1.B.1)	2.0	1.0	1.0	1.0	0.9	0.9	1.0	1.0
Oil and Natural Gas (1.B.2)	40.2	62.1	62.4	62.0	61.0	57.9	57.6	58.7

Note:

Totals may not add up due to rounding.

1. Mining subsector removed from Manufacturing Industries and Construction and shown separately because the majority of emissions in this subsector are from oil and gas extraction.

2.2. Emission Trends by Gas

CO₂ is the largest contributor to Canada's greenhouse gas emissions (Figure 2–1), but its relative contribution has changed little between 1990 and 2011 (78% vs 79%, respectively).

2.3. Emission Trends by Category

2.3.1. Energy Sector (2011 GHG emissions, 572 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 2011 (512 Mt and 60 Mt, respectively). Between 1990 and 2011, fuel combustion-related emissions increased 20%, while emissions from fugitive releases rose by 41% (Table 2–2).

The Energy Industries, Mining and Fugitive subsectors combined represent the largest contributor to Canada's emissions. These industries, consisting of Fossil Fuel Production and Refining, Public Electricity and Heat Generation and

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

GHG Source Category	GHG Emissions (Mt CO ₂ eq)								Change (%)
	1990	2000	2005	2007	2008	2009	2010	2011	1990–2011
Electricity Generation & Heat Generation	93.6	129.3	123.2	122.2	115.0	99.6	101.3	93.3	-0.3%

Note: Totals may not add up due to rounding.

Mining, generate both combustion emissions and fugitive emissions and are calculated as the sum of Fuel Combustion—Energy Industries, Fuel Combustion—Mining and Fugitive Emissions in Table 2–2. Due to the manner in which fuel consumption data are collected and aggregated, emissions from oil and gas extraction, as well as crude bitumen upgrading, make up the vast majority of energy-related emissions in the Mining subsector, with conventional mining (such as iron ore, nickel and diamonds) accounting for the remainder. As such, the Mining subsector is included with the Energy Industries category for trends analysis. Altogether, the Energy Industries category and the Mining and Fugitive Emissions subsectors contributed 251 Mt or 36% of Canada's total and about 44% of the Energy Sector's emissions in 2011.

The categorization of energy-related emission sources in Table 2–2 follows the *Revised 1996 Intergovernmental Panel on Climate Change's (IPCC) Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997); this breakdown corresponds to the United Nations Framework Convention on Climate Change (UNFCCC) Common Reporting Format (CRF) categories of Fuel Combustion and Fugitive Emissions. By this breakdown, fuel combustion in the Energy Industries and Mining subsectors accounted for 155 and 36.4 Mt in 2011, respectively, while fugitive emissions represented 59.7 Mt. In terms of relative growth, fuel combustion emissions in the Mining subsector have increased more rapidly than any other subsector in the Energy Sector. Between 1990 and 2011, these emissions rose by about 453%.

2.3.1.1. Emissions from Fuel Combustion (2011 GHG emissions, 512 Mt)

GHG emissions from fuel combustion rose from 427 Mt in 1990 to 512 Mt in 2011, a 20% increase. Fuel combustion emissions are divided into the following subsectors: Energy Industries, Mining, Manufacturing Industries and Construction, Transport, and Other Sectors.

The Other Sectors subsector comprises emissions from the Residential and Commercial categories, as well as contributions from stationary fuel combustion in Agriculture and Forestry.

Energy Industries and Mining (2011 GHG emissions, 191 Mt)

The sum of the Energy Industries and Mining subsectors accounts for the second-largest portion of Canada's fuel combustion emissions (27% of Canada's total), behind Transport. Emissions included in this subsector are from stationary sources producing, processing and refining energy. This source includes Public Electricity and Heat Generation, Petroleum Refining, Manufacture of Solid Fuels and Other Energy Industries, and Mining. In 2011, combustion emissions from the Energy Industries and Mining subsectors totalled 191 Mt, an increase of 26% from the 1990 level of 151 Mt.

Public Electricity and Heat Generation³ (2011 GHG emissions, 93 Mt)

This category accounts for 13% (93 Mt) of Canada's 2011 GHG emissions (Table 2–3) and for a 0.3% decrease in emissions between 1990 and 2011.

Emissions from electricity generation and distribution are unique in that electricity is generated to meet an instantaneous demand and, depending on the characteristics of that demand, the supply source can fluctuate from non-GHG-emitting to high-GHG-emitting sources. Even though emissions dropped slightly (0.3 Mt) between 1990 and 2011, electricity generation increased by 31%. Between 2005 and 2011, generation rose by 2%, while emissions fell by 30 Mt. The mix of sources used to generate electricity

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

since 1990 has tended to counteract increases in demand (see box below).

A more detailed analysis is possible by decomposing all of the major drivers that affect emission changes. The impacts of these different drivers on electricity-related emissions in 2011 (compared to 1990 and 2005 base

years) are shown in Figure 2–3 and Figure 2–4. In this case the drivers are Fuel Switching, Generation Mix, Demand, Energy Efficiency and Emission Factors.

2

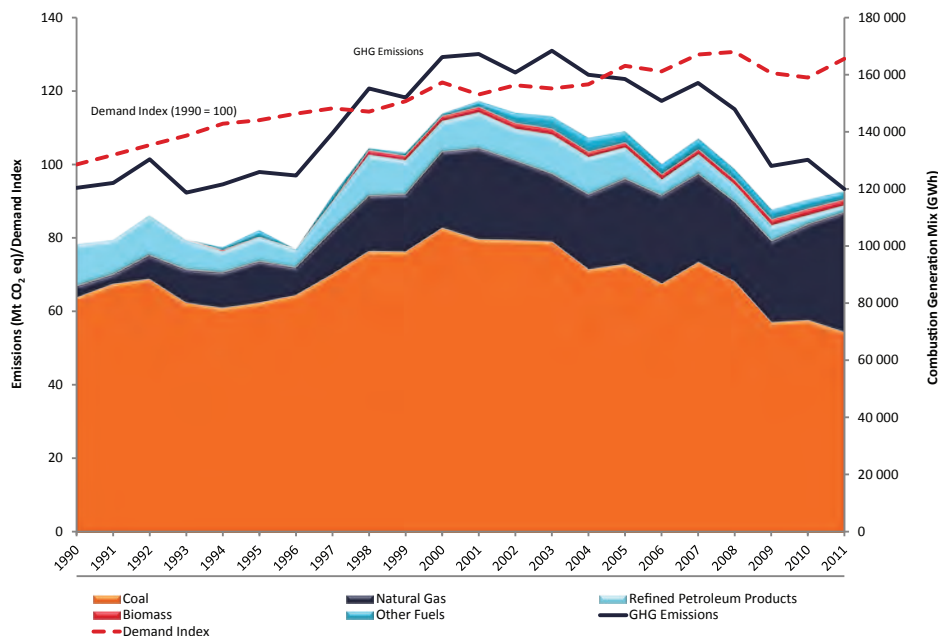
Combustion Generation and GHG Emissions

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

In the early 1990s, emissions from electricity generation oscillated above and below the level observed in 1990 (Figure 2–2). From 1994 to 2000, emissions rose 37%, although generation increased by only about 9%; however, coal, oil and natural gas use for generation increased rapidly during this time. Emissions peaked in 2003 and then decreased by 29% over the next eight years, during which time coal and oil generation rapidly dropped while the use of natural gas rose. The shift towards a lower carbon-containing fuel such as natural gas resulted in a decline in emissions. This illustrates the impact of fuel switching on GHG emissions.

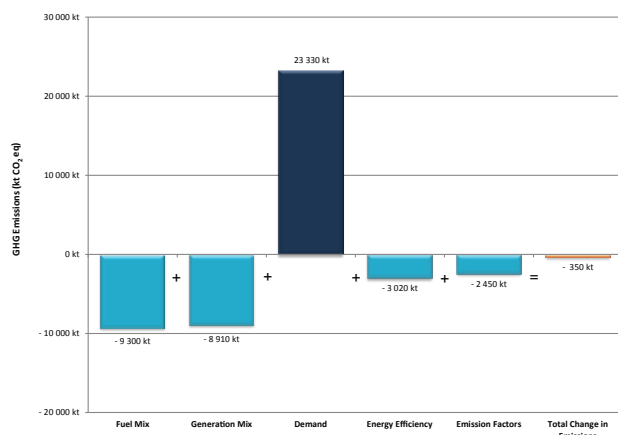
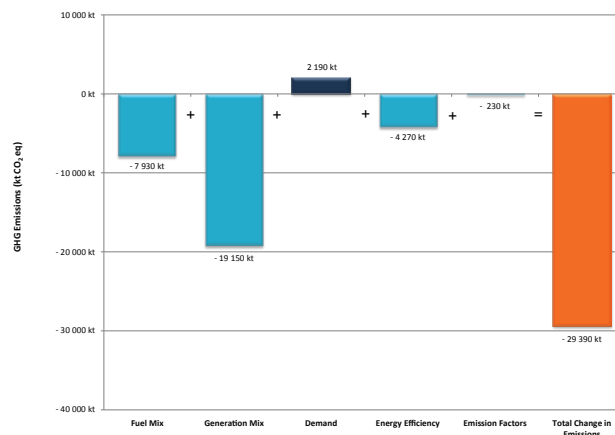
Likewise, non-combustion sources (such as hydro, nuclear and other renewables) are placed in service whenever they are available, so as the generation mix changes in their favour, GHG emissions also fall.

Figure 2–2 Utility-Generated Electricity by Source and GHG Emissions, 1990–2011



Notes:

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

Figure 2–3 Impact of Drivers on Change in Electricity Emissions, 1990–2011**Figure 2–4 Impact of Drivers on Change in Electricity Emissions, 2005–2011**

Note: Emissions shown in the figures include those from electricity generation, but exclude SF₆ emissions from power transmission and distribution.

The trends illustrated by Figure 2–3 and Figure 2–4 can be summarized as follows:

Fuel mix (combustion generation) –between 1990 and 2011 the quantity of electricity generated by natural-gas-fired units increased by over 1000%, while the amount generated by coal and refined petroleum products (RPPs) decreased by 15% and 84%, respectively. Coal plant electricity generation peaked in 2000 and has slowly decreased since that time.

In 1990 natural gas only accounted for 4% of the total fossil-fuel-generated electricity, with coal and RPPs accounting for the remainder; in 2011 natural gas was responsible for 35% of fossil fuel generation. Natural gas is about half as carbon-intensive as coal, and approximately 25% lower than most RPPs, so the switch from other fuels to natural gas resulted in significant decreases in GHG emissions. The trend was most significant in the latter part of the period, so the majority of its impact can be seen between 2005 and 2011. (See also box, Combustion Generation and GHG Emissions, above).

Generation mix – the generation mix refers to the shift between combustion and non-combustion (zero-GHG) sources to meet demand. Combustion and noncombustion sources respectively accounted for 14% and 80% of the increased generation between 1990 and 2011, improving the generation mix to one that became much less GHG-intensive. This increased level of zero-GHG sources in the generation mix in 2011 was a large contributor to

emission reductions since 1990, and the largest contributor since 2005.

Demand – the amount of electricity generated in 2011 was 31% higher than in 1990. Electricity demand has increased in all sectors between 1990 and 2011, with the major increase occurring in exports to the United States (184%). In the period between 2005 and 2011 energy use by the industrial sector fell, so overall demand increased by only 1%.

Energy efficiency and emission factors – Energy efficiency, or improvements in the efficiency of the equipment used in combustion-related generation of electricity, helped reduce emissions compared to 1990. Changes in energy content over time are reflected in emission factors. The change between 1990 and 2011 relates to variations in natural gas emission factors by province, variations in emission factors and energy contents of types of coal, and variations in the petroleum coke emission factor by year. Energy content variations over time for light and heavy fuel oil and still gas also have an influence.

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

Petroleum Refining, Fossil Fuel Production⁴ and Mining (2011 GHG emissions, 98 Mt)

The Petroleum Refining subsector mainly includes emissions from the combustion of fossil fuels during the production of refined petroleum products (RPPs), whereas the Fossil Fuel Production and Mining subsectors encompass fuel combustion emissions associated with the upstream oil and gas (UOG) industry. The Mining subsector includes emissions associated with oil (including crude bitumen from the oil sands), gas and coal extraction, as well as emissions associated with non-energy mining such as iron ore, gold, diamonds, potash and aggregates. As shown in Table 2–4, between 1990 and 2011, emissions from the Petroleum Refining, Fossil Fuel Production and Mining subsectors increased by about 40 Mt, or 70%. This growth is due to increases in natural gas and oil production, particularly crude bitumen and heavy crude oil, largely for export.

The breakdown of Canada's fossil fuel industries emissions by IPCC categories does not provide a transparent sectoral view of trends within Canada's oil and gas sector. In addition, fuel combustion emissions are not the only source of emissions for this sector, as fugitive emissions are also significant. Table 2–5 shows a breakdown of emissions from the Fossil Fuel Production and Mining subsectors into more relevant categories including Natural Gas Production and Processing, Conventional Oil Production, Oil Sands, Coal Production and Non-energy Mining. Note that the emissions presented in Table 2–5 are composed of not only the stationary fuel combustion emissions shown in Table 2–4, but also fugitive emissions (see Section 2.3.1.2), as well as some emissions from the off-road transportation subsectors (see Transport discussion) and emissions from cogeneration units. Furthermore, some cogeneration

units that serve Canada's oil sands are owned and operated by utility companies and as a result show up under Public Electricity and Heat Generation in the IPCC categories. These cogeneration units have been moved to the oil sands category in Table 2–5. Lastly, in order to be complete, emissions from the oil and gas transmission sectors (Pipelines) are added along with the associated fugitive emissions.

The data show that the coal production and non-energy mining industries account for a comparatively small portion of the overall emissions from IPCC categories Fossil Fuel Production and Mining.

Emissions from the production, transmission and processing of oil and gas equalled 163 Mt CO₂ eq in 2011 (23% of Canada's total emissions), a 62% increase from 1990. In the 2011 data year, approximately 88% of the total oil and gas sector emissions can be attributed to the upstream fossil fuel industry, which includes crude oil production (both conventional,⁵ as well as bitumen and synthetic crude oil from oil sands operations), natural gas production and processing, and oil and gas transmission. The downstream portion, which 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, contributed the remaining 12% of total emissions.

In 2011, the largest contributions to total oil and gas sector emissions were Oil Sands (Mining, Upgrading and *In-situ* Extraction) (32%), Natural Gas Production and Processing (30%), Conventional Oil Production (18%) and Petroleum Refining (11%), with Oil and Gas Transmission and Natural Gas Distribution making up the remaining 9%. The primary drivers of emissions within the oil and gas sector are

⁴ In the National Inventory Report (NIR), the Fossil Fuel Industries subsector encompasses both the Petroleum Refining and Fossil Fuel Production (also known as Manufacture of Solid Fuels and Other Energy Industries) categories.

⁵ In this discussion, "conventional" oil production includes light, medium and heavy oil as well as pentanes plus and condensate.

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

GHG Source Category	GHG Emissions (Mt CO ₂ eq)								Change (%)
	1990	2000	2005	2007	2008	2009	2010	2011	1990–2011
Petroleum Refining	16.8	16.2	20.2	20.7	19.4	19.0	17.8	16.1	-4%
Fossil Fuel Production	34.4	51.2	50.6	51.5	47.2	47.6	47.0	45.5	32%
Mining	6.6	12.1	18.9	28.9	30.0	31.7	35.0	36.4	453%
Total	58	80	90	101	97	98	100	98	70%

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

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

GHG Source Category	GHG Emissions (Mt CO ₂ eq)							
	1990	2000	2005	2007	2008	2009	2010	2011
Upstream Oil and Gas	82	130	138	145	140	139	142	143
Natural Gas Production and Processing	34	55	56	58	55	50	49	47
Conventional Oil Production	22	34	32	32	30	29	29	30
Conventional Light and Frontier Oil Production	11	13	12	12	12	11	11	12
Conventional Heavy Oil Production	11	21	21	20	19	18	18	18
Oil Sands (Mining, Upgrading and In-Situ Extraction)	15	25	34	41	42	48	52	55
Mining and Extraction	4	5	9	11	11	13	14	14
In-situ	5	8	11	14	17	18	21	23
Upgrading	7	12	14	16	14	17	18	18
Oil and Gas Transmission	11	17	16	14	13	12	11	11
Downstream Oil and Gas	19	20	24	25	23	23	22	20
Petroleum Refining	18	18	22	23	21	21	20	18
Natural Gas Distribution	1	2	2	2	2	2	2	2
Total Oil and Gas	101	150	162	170	164	162	164	163
Coal Production	4	2	2	3	3	3	4	4
Non-energy Mining	5	6	5	7	8	7	7	8

Note: Totals may not add up due to rounding.

production growth and production characteristics (emissions intensity).

Production Growth

Production rates of fossil fuels are greatly influenced by both export and domestic market demands; in 1990 and 2011, net exports⁶ of crude oil and natural gas equalled 49% and 39% of total production, respectively. From 1990 to 2011, the production of total crude oil and natural gas increased by 89% and 45%, respectively. Conventional crude oil production increased by 6.5%, although (after increasing steadily up until 1998) production was relatively constant until 2004, and has been generally declining since that time (Statistics Canada 2012). In contrast, bitumen and synthetic crude oil production from Canada's oil sands has increased by 393%, with most of the growth occurring from 1996 onward (ERCB 2012 – Figure 2–5).

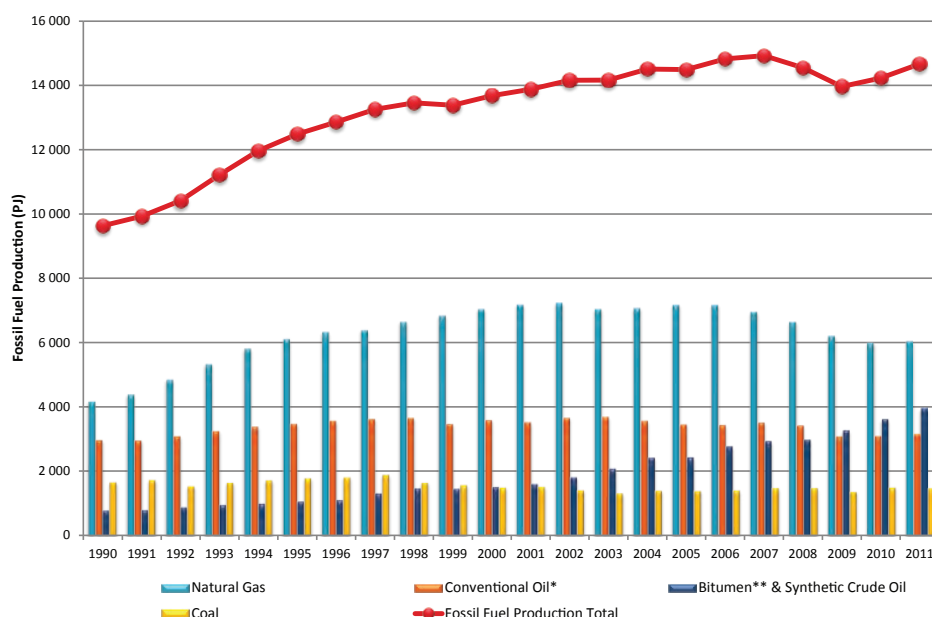
Natural gas production increased rapidly from 1990 to peak production levels in 2002. However, from 2002 to 2011, production decreased by 16%; this was wholly from decreasing conventional natural gas production due to declines in output from the Alberta portion of the Western Canada Sedimentary Basin (WCSB), the largest gas-producing area in Canada (Nyboer and Tu 2010). In fact, unconventional natural gas production, including tight gas, coalbed methane and shale gas, has been increasing rapidly. In 2011, unconventional natural gas represented approximately 41% of total gas production, with tight gas, coalbed methane and shale gas accounting for 79%, 14% and 8% of total unconventional gas, respectively. In comparison, in 2002 unconventional gas accounted for 20% of total production, with tight gas making up 98%. Since 2002 unconventional gas production has increased by 73%, while conventional gas has decreased by 38%.

Since 2002 crude oil production showed an overall growth of about 30%. This growth, which was accompanied by a 148% rise in the price of crude oil,⁷ was almost wholly in the export market of oil sands products. While

⁶ 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.

⁷ Prices (Canadian dollars) rose from an average of about \$32 a barrel in 2002 to \$78.54 in 2011 (CAPP 2012).

Figure 2-5 Canadian Production of Fossil Fuels, 1990–2011



Notes:

* Conventional oil includes light, medium and heavy oil production and pentanes plus and condensates.

** Bitumen from oil sands operations.

conventional crude oil exports increased by 12%, exports of unconventional crude oil (crude bitumen and synthetic crude oil) increased by 128%. In addition, domestic crude consumption declined by 11% between 2002 and 2011. In 2011, the decline in conventional crude oil production in the WCSB was effectively halted for the first time in over 10 years and can be attributed to the increased use of horizontal wells and multi-stage fracturing techniques. This technology has yielded better-than-expected results in recent years and has been encouraged by a higher price environment and favourable royalty changes in the province of Alberta (CAPP 2011).

Production Characteristics (Emissions Intensity)

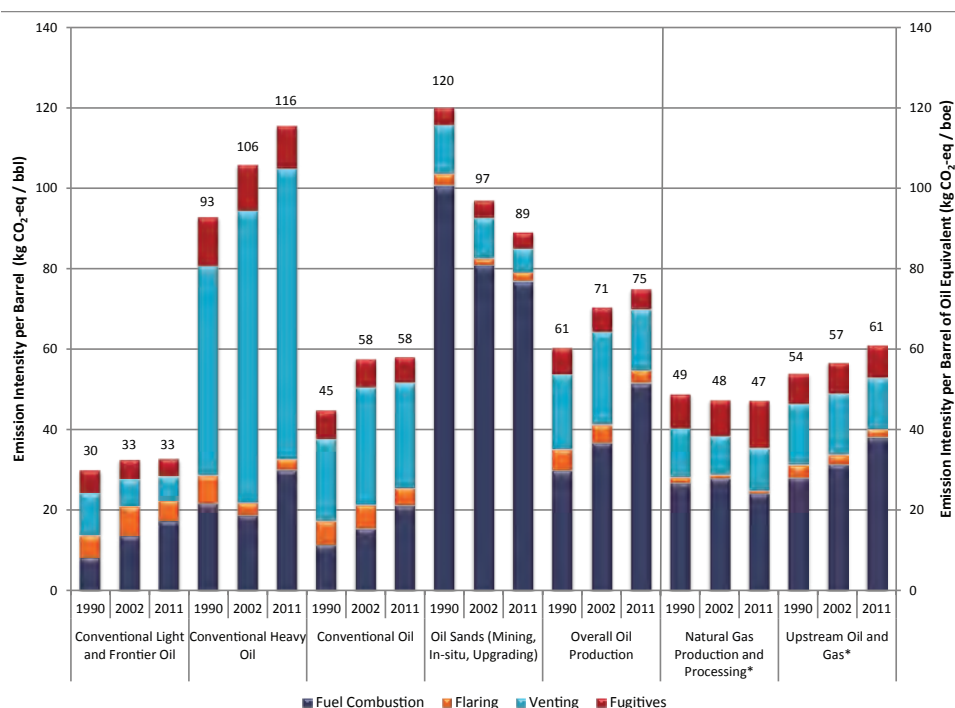
Other contributors to the emission trend include a reduction in easily removable reserves of conventional crude oil, which are being replaced with more energy- and GHG-intensive sources, including synthetic crude oil (i.e. oil sands) production and heavier or more difficult-to-obtain conventional oils such as those from offshore sources or those extracted using enhanced oil recovery (EOR) operations. Between 1990 and 2000, the energy requirements per barrel of conventional light oil extracted rose by about 60% (Nyboer and Tu 2010). Emission intensity is defined as the average amount of GHG emissions generated per

barrel of oil equivalent. The emission intensity of oil (including both conventional and unconventional) produced in Canada increased by about 24% between 1990 and 2011. When natural gas is included, the emission intensity for the upstream oil and gas sector (not including transmission) increased by 13% in the same period.

Highlights related to the emissions intensity of fossil fuel industries:

- The overall emission intensity from oil sands operations declined by 26% between 1990 and 2011. This reduction is due to technological innovation and equipment turnover, increased reliability across operations and the avoidance of upgrading emissions by exporting more crude bitumen. The most significant factor contributing to this overall trend has been declining rates of emissions associated with fuel combustion. For each barrel of oil produced from the oil sands, emissions associated with fuel combustion declined by approximately 24%.
- 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 data from the Energy Resources and Conservation Board in Alberta, which show the ratio of bitumen to synthetic crude oil production in Canada rising by 29% between 2002 and 2011 (ERCB 2012). As a result of this growing quantity

Figure 2–6 Emission Intensity by Source Type for Oil and Gas (1990, 2002 and 2011)



Notes:

Intensities are based on total subsector emissions and relevant production amounts. They represent overall averages, not facility intensities.

*Natural Gas Production and Processing and Upstream Oil and Gas emission intensities calculated on a barrel of oil equivalent (boe) basis. Boe calculated by converting natural gas and crude oil production volumes to energy basis and then dividing by energy content of light crude oil (38.5 TJ / 10³ m³).

1 barrel (bbl) = 0.159 m³

of bitumen in the production mix and the large majority of processing capacity existing in the U.S., more emissions associated with the upgrading and refining of bitumen are taking place outside of the country.

- The 30% increase in the production of oil between 2002 and 2011 was completely driven by oil sands operations, which showed a 117% growth in output while conventional oil production decreased by about 13%. Coinciding with the net production increases, emissions from overall oil production showed an increase of about 38% (23 Mt CO₂ eq), with oil sands increasing by 27 Mt while conventional oil decreased by 4 Mt. The rise in emission intensity for overall oil production results from efficiency gains in the oil sands being offset by increased intensities in conventional oil production, particularly conventional heavy oil production.
- *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. A number of technological improvements have been made in this area, from cyclic steam stimulation (CSS) to steam-assisted gravity drainage (SAGD). In addition, in-situ operators are also testing experimental techniques such

as vapour extraction processes (VAPEX), toe-to-heel air injection (THAI) and combustion overhead gravity drainage (COGD). 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 bitumen upgrading (where the extracted material is converted into synthetic crude oil).⁸

- Though gas production has declined somewhat since its peak in 2002, natural gas production and processing contributed 30% to the oil and gas sector emissions total. Since 1990, emissions have increased 40%, with a corresponding increase of 45% in natural gas production. However, as a result of reduced amounts of facilities' own use of natural gas (i.e. raw natural gas consumed by the facility that produced it), the emission

8 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 standalone upgraders, while gasification has also been used to develop appropriate fuels needed in the upgrading process.

intensity for natural gas production and processing has decreased by 3%.

Manufacturing Industries and Construction (2011 GHG emissions, 44.1 Mt)

Emissions from the Manufacturing Industries and Construction subsector include the combustion of fossil fuels by the iron and steel; non-ferrous metals; chemicals; cement; pulp, paper and print; construction; and all other manufacturing industries. In 2011, GHG emissions were 44.1 Mt (Table 2–6). Overall, this subsector was responsible for 6.3% of Canada's total GHG emissions in 2011, down 14 Mt from 1990.

Between 1990 and 2011, there were changes in both directions in the emissions produced by the various categories within the Manufacturing Industries and Construction subsector (Table 2–6). The Chemicals and Cement categories increased by 2.0 and 0.1 Mt, respectively. The remaining categories have all shown long-term decreases, from 57% in the Pulp, Paper and Print category to 4.4% in the Non-ferrous Metals category. These decreases can be attributed to decreased output (much of which occurring in the 2008–2009 period), fuel switching and changes in manufacturing operations.

Between 2005 and 2011, notable decreases in GHG emissions occurred in the Pulp, Paper and Print (29%), Iron and Steel (21%), Cement (25%) and Non-ferrous Metals (13%) categories (Table 2–6). These decreases reflect pressures from the global economic environment.

Transport (2011 GHG emissions, 199 Mt)

Transport is a large and diverse subsector, accounting for 28% of Canada's GHG emissions in 2011. This subsector includes emissions from fuel combustion for the transport of passengers and freight in five distinct categories:

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

From 1990 to 2011, GHG emissions from transport, driven primarily by energy used for personal transportation, rose 36%, or 52 Mt. Overall, the transport category in 2011 contributed 199 Mt, which accounted for 47% of Canada's emission growth from 1990 to 2011.

Emissions from light-duty gasoline trucks (LDGTs), the subcategory that includes sport utility vehicles (SUVs), pickups and minivans, increased 111% between 1990 and 2011 (from 20.3 Mt in 1990 to 42.7 Mt in 2011), while emissions from cars (light-duty gasoline vehicles or LDGVs) decreased 13% (from 45.5 Mt in 1990 to 39.5 Mt in 2011) (Table 2–7).

As shown in Table 2–8, the growth in road transport emissions is due not only to the 50% increase in the total vehicle fleet since 1990 (12% since 2005), but also to a shift in light-duty vehicle purchases from cars (LDGVs) to trucks (LDGTs), which, on average, emit 44% more GHGs per kilometre.

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

GHG Source Category Year	GHG Emissions (Mt CO ₂ eq)									Change (%)
	1990	2000	2005	2006	2007	2008	2009	2010	2011	1990–2011
Iron and Steel	4.95	6.05	5.57	5.54	5.99	5.76	4.28	4.44	4.41	-11%
Non-ferrous Metals	3.26	3.23	3.57	3.40	3.75	3.75	2.81	2.95	3.11	-4%
Chemicals	8.22	9.40	8.29	8.83	8.67	8.75	8.83	9.91	10.23	24%
Cement	3.92	4.33	5.38	5.71	5.04	4.91	4.48	4.03	4.05	3%
Construction	1.87	1.07	1.44	1.39	1.39	1.37	1.21	1.50	1.33	-29%
Pulp, Paper and Print	14.5	12.3	8.8	7.6	7.8	6.4	6.5	6.1	6.2	-57%
Other Manufacturing	21.0	20.3	17.1	15.4	16.3	15.5	13.4	13.7	14.7	-30%
Total	57.7	56.7	50.1	47.8	49.0	46.4	41.5	42.6	44.1	-24%

Note: Totals may not add up due to rounding.

Table 2–7 GHG Emissions from Transport, Selected Years

GHG Source Category	GHG Emissions (Mt CO ₂ eq)							
	1990	2000	2005	2007	2008	2009	2010	2011
Transport (Total)	146	180	193	195	194	186	196	199
Civil Aviation (Domestic Aviation)	7.1	7.4	7.6	7.7	7.3	6.4	6.4	6.0
Light-duty Gasoline Vehicles	45.5	42.1	40.2	40.0	39.5	39.7	40.0	39.5
Light-duty Gasoline Trucks	20.3	36.4	42.7	42.7	42.3	42.5	42.9	42.7
Heavy-duty Gasoline Vehicles	7.44	5.47	6.54	6.75	6.80	6.91	7.02	7.13
Motorcycles	0.152	0.162	0.254	0.262	0.263	0.266	0.271	0.273
Light-duty Diesel Vehicles	0.469	0.466	0.574	0.616	0.652	0.699	0.750	0.798
Light-duty Diesel Trucks	0.702	1.660	1.920	2.010	2.020	2.030	2.090	2.160
Heavy-duty Diesel Vehicles	20.0	30.9	37.6	39.5	39.2	39.0	40.2	41.8
Propane & Natural Gas Vehicles	2.20	1.10	0.72	0.83	0.88	0.78	0.78	0.82
Railways	7	7	7	7	8	5	7	7
Navigation (Domestic Marine)	5.0	5.1	6.7	6.8	6.5	6.7	7.0	6.0
Off-road Gasoline	7.8	8.8	8.3	8.0	7.3	7.3	7.9	9.4
Off-road Diesel	16	23	23	24	26	23	28	30
Pipelines	6.85	11.20	10.10	8.38	7.46	6.31	5.67	5.60

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

Table 2–8 Trends in Vehicle Populations for Canada, 1990–2011

Number of Vehicles (000s)								
Year	LDGVs	LDGTs	HDGVs	MCs	LDDVs	LDDTs	HDDVs	Total
1990	10 646	3 308	518	261	109	112	402	15 356
2000	10 863	6 065	376	288	123	224	649	18 587
2005	10 961	7 386	435	437	159	277	856	20 510
2007	11 429	7 715	455	456	166	291	897	21 409
2008	11 663	7 879	465	465	170	298	918	21 858
2009	11 897	8 043	476	475	173	305	939	22 308
2010	12 130	8 208	486	484	177	312	960	22 757
2011	12 267	8 304	491	490	179	318	975	23 025
Change Since 1990	15%	151%	-5%	87%	65%	185%	142%	50%

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.

Over the 1990–2011 period, the increase of 22 Mt and 22 Mt for LDGTs and heavy-duty diesel vehicles (HDDVs), respectively, reflects the trend towards the increasing use of SUVs, minivans and pickups for personal transportation and heavy-duty trucks for freight transport (Table 2–8).

In 2011, emissions from heavy-duty diesel vehicles (HDDVs) contributed 42 Mt to Canada's total GHG emissions (an increase of about 109% from 1990 and 11%

from 2005). Emissions from heavy-duty gasoline vehicles (HDGVs) were lower for 2011, at 7 Mt; this figure represents a decrease of 4% 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 emissions⁹ in the Other Transportation subsector increased by 66% between 1990 and 2011, 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. Since 2005, emissions have been steadily decreasing, mainly due to a 32% reduction in natural gas throughput volumes (Statistics Canada 2011).

Other Sectors (2011 GHG emissions, 77.9 Mt)

The Other Sectors subsector comprises fuel combustion emissions from the Residential and Commercial categories, as well as stationary fuel combustion emissions in Agriculture and Forestry.¹⁰ Overall, this subsector exhibited a 9% increase in GHG emissions from 1990 to 2011, while individual categories 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 categories¹¹ accounted for 6.3% (44 Mt) and 4.3% (30 Mt), respectively, of all GHG emissions in 2011.

As shown in Figure 2–7, residential emissions fluctuate on an annual basis and overall, have increased by 0.9 Mt between 1990 and 2011. Over the short term, residential emissions also increased by 3.1 Mt between 2010 and 2011. Commercial emissions increased 4.2 Mt between 1990 and 2011. Combined, the two categories exhibited an overall increase of 5.1 Mt or 7.4% between 1990 and 2011.

GHG emissions, particularly in the Residential category, track heating degree-days (HDDs)¹² closely (as shown in Figure 2–7). 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.

There are several major factors that influenced the changes in energy-related GHG emissions in the Residential category (Figure 2–8). For example, the number of homes in Canada has increased by about 3.7 million since 1990

9 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.

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

11 Commercial category emissions are based on fuel use as reported in the *Report on Energy Supply–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.

12 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 and weighting this figure by population.

Figure 2–7 GHG Emissions and Heating Degree-Days (HDDs) from Residential and Commercial Categories, 1990–2011

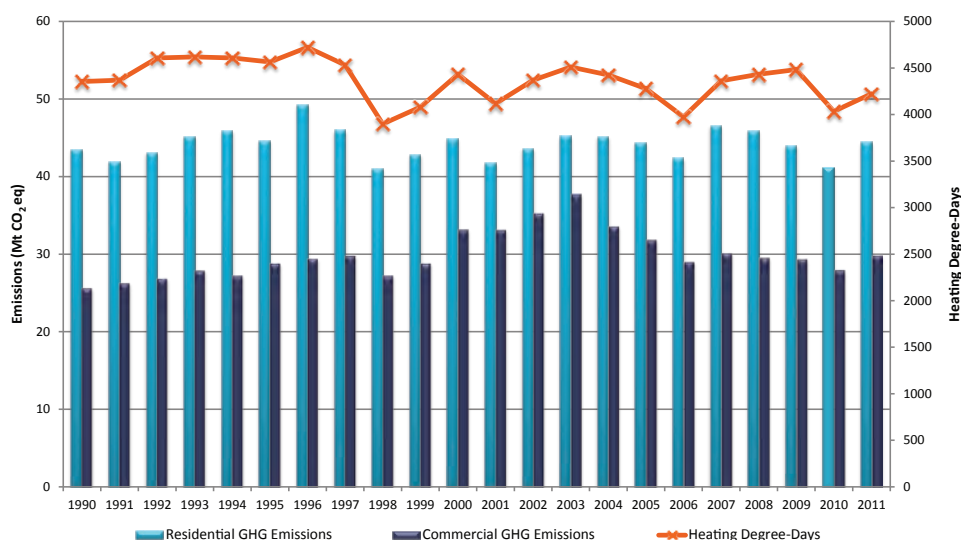
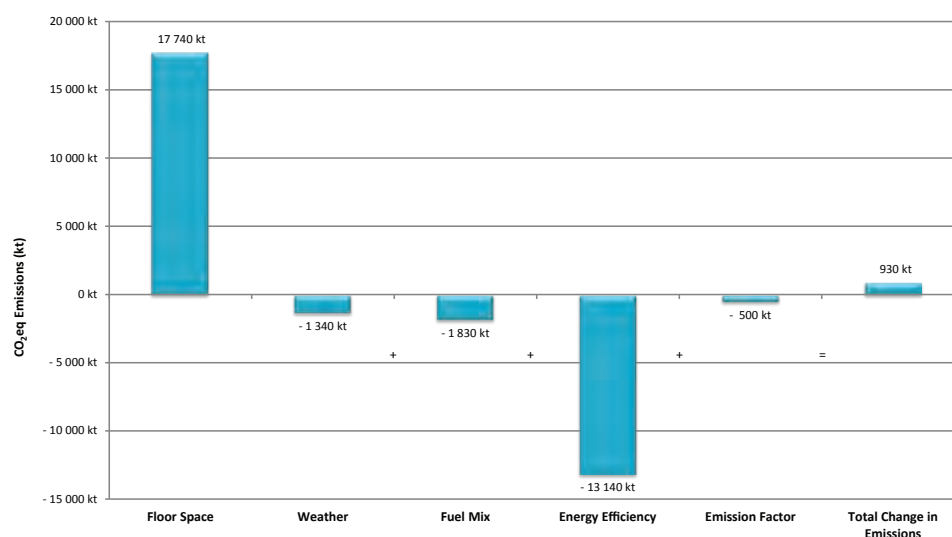


Figure 2–8 Major Influences on Stationary GHG Emissions from the Residential category between 1990 and 2011

(NRCan 2012a), with a corresponding 50% increase in floor space.¹³ By decomposition analysis, the impact of this increased floor space can be isolated and shown to represent an increase in GHG emissions of approximately 18 Mt between 1990 and 2011, everything else being equal.

The GHG emission increases from increased floor space have been offset by changes in the fuel mix from RPPs and coal to natural gas (resulting in a 1.8-Mt reduction) and energy efficiency improvements (better construction methods, increased insulation and higher-efficiency heating systems). Energy-efficient new homes have been encouraged through programs such as the R-2000 initiative and residential home improvement incentive programs such as the EnerGuide for Homes (replaced by the ecoENERGY Retrofit program in 2007). These have been important because residential space heating requires the most energy of any end-use in Canadian homes, meaning that these changes led to significant reductions in GHG emissions. These improvements have resulted in a total emission reduction of approximately 13 Mt.

In addition, the impacts of weather on energy requirements (as measured by annual heating degree-days or HDDs) caused an additional decrease in GHG emissions of approximately 1.3 Mt. (See box, “Reducing Heating Requirements in Commercial and Residential Buildings,” for links between temperature and energy demand).

The Residential category is also a large consumer of electricity; therefore, efforts to increase efficiency in electricity use can have significant indirect impacts on reducing the requirements for electricity generation. The most significant of these changes have occurred with large appliances used in Canadian households. For example, although total appliance energy use has increased 3% since 1990, energy use by major appliances¹⁴ has improved by approximately 24% since 1990. This is offset by a 148% increase in energy use from other appliances¹⁵ (NRCan 2012a).

Agriculture and Forestry

Stationary fuel combustion related emissions in Agriculture and Forestry amounted to 3.6 Mt in 2011, an increase of 49% from 1990. Emissions from these categories contributed approximately 0.5% of the total for 2011.

2.3.1.2. Fugitive Emissions from Fuels (2011 GHG emissions, 59.7 Mt)

As stated above, fugitive emissions from fossil fuels are the intentional or unintentional releases of GHGs from the production, processing, transmission, storage and delivery of fossil fuels. Released gases that are combusted before disposal (e.g. flaring of natural gases at oil and gas production and processing facilities) are also considered fugitive emissions. Fugitive emissions have two sources:

14 Major appliances include refrigerators, freezers, dishwashers, clothes washers, clothes dryers and ranges.

15 Other appliances include microwaves, televisions, cable boxes, video cassette recorders, stereo systems and computers.

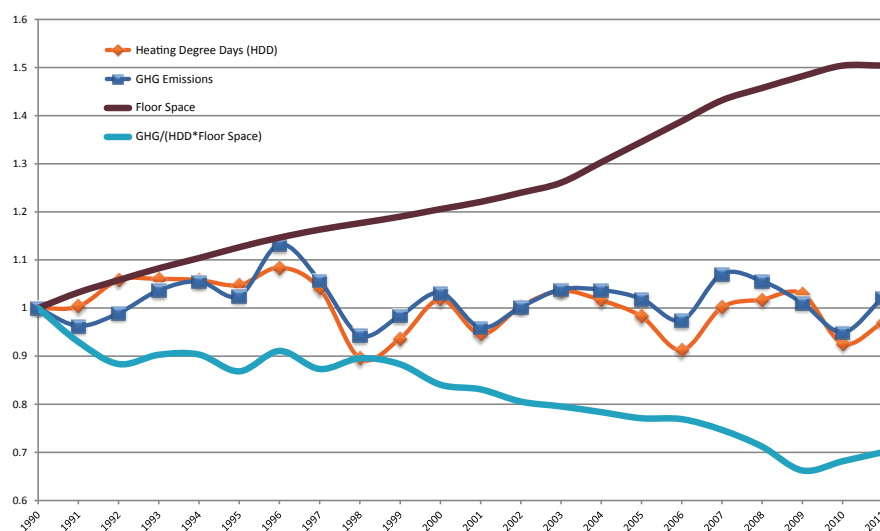
13 Data on number of homes and floor space were available to 2010 at time of publishing.

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.

In general, there is a strong correlation between HDDs in Canada and the energy-related GHG emissions originating from the Residential category (see Figure 2-9). 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 2-9 Relationship between HDDs and Residential GHG Emissions, 1990–2011



Notes:

1. 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 2009. This illustrates how building efficiency improvements and fuel switching produced GHG emission reductions.
2. Residential floor space data taken from NRCan (2013b).

coal mining and handling, and activities related to the oil and natural gas industry. They constituted 8.5% of Canada's total GHG emissions for 2011 and contributed 16% to the growth in emissions between 1990 and 2011.

Table 2-9 summarizes the changes in fugitive emissions from the Coal Mining and Oil and Natural Gas categories. In total, fugitive emissions grew by about 41% between 1990 and 2011, from 42.4 to 59.7 Mt, with emissions from the Oil and Natural Gas category contributing 98% of the total fugitive emissions in 2011, far overshadowing the

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

	1990	2000	2005	2007	2008	2009	2010	2011
COAL PRODUCTION								
Fugitive Emissions (Mt CO ₂ eq)	2.2	1.0	1.0	1.0	0.9	0.9	1.0	1.0
% Change since 1990	NA	-55.9%	-54%	-56%	-57%	-61%	-54%	-55%
Production (PJ)	1 673	1 510	1 401	1 495	1 490	1 372	1 509	1 485
% Change since 1990	NA	-9.8%	-16%	-11%	-11%	-18%	-10%	-11%
Fugitive Emissions Intensity (kt CO ₂ eq / PJ)	1.31	0.64	0.72	0.65	0.63	0.63	0.67	0.67
% Change since 1990	NA	-51.1%	-46%	-51%	-52%	-52%	-49%	-49%
UPSTREAM OIL AND GAS PRODUCTION								
Fugitive Emissions (Mt CO ₂ eq)	38.0	58.8	58.6	58.1	57.3	54.2	53.7	55.0
% Change since 1990	NA	54.6%	54%	53%	51%	43%	41%	45%
Production (PJ)	7 958	12 171	13 091	13 429	13 059	12 593	12 721	13 181
% Change since 1990	NA	52.9%	65%	69%	64%	58%	60%	66%
Fugitive Emissions Intensity (kt CO ₂ eq / PJ)	4.78	4.83	4.47	4.33	4.39	4.31	4.22	4.17
% Change since 1990	NA	1.1%	-6%	-9%	-8%	-10%	-12%	-13%
Conventional Oil Production								
Fugitive Emissions (Mt CO ₂ eq)	16.2	25.2	23.0	21.8	20.5	18.6	18.2	18.9
% Change since 1990	NA	56.1%	42%	35%	27%	15%	13%	17%
Production (PJ)	2 973	3 590	3 459	3 517	3 418	3 089	3 098	3 167
% Change since 1990	NA	20.7%	16%	18%	15%	4%	4%	7%
Fugitive Emissions Intensity (kt CO ₂ eq / PJ)	5.44	7.03	6.65	6.21	6.00	6.02	5.88	5.95
% Change since 1990	NA	29.3%	22%	14%	10%	11%	8%	9%
Oil Sands Mining, Extraction and Upgrading								
Fugitive Emissions (Mt CO ₂ eq)	2.5	4.2	5.4	6.6	6.4	7.0	7.3	7.6
% Change since 1990	NA	72.8%	119%	168%	162%	186%	198%	209%
Production (PJ)	801	1 520	2 440	2 938	2 980	3 274	3 616	3 952
% Change since 1990	NA	89.7%	204%	267%	272%	309%	351%	393%
Fugitive Emissions Intensity (kt CO ₂ eq / PJ)	3.06	2.79	2.19	2.23	2.15	2.14	2.02	1.92
% Change since 1990	NA	-8.9%	-28%	-27%	-30%	-30%	-34%	-37%
Natural Gas Production and Processing								
Fugitive Emissions (Mt CO ₂ eq)	15.1	23.7	24.5	23.9	24.6	22.9	22.5	22.8
% Change since 1990	NA	57.3%	63%	59%	63%	52%	49%	51%
Production (PJ)	4 184	7 062	7 192	6 975	6 661	6 229	6 007	6 062
% Change since 1990	NA	68.8%	72%	67%	59%	49%	44%	45%
Fugitive Emissions Intensity (kt CO ₂ eq / PJ)	3.61	3.36	3.41	3.43	3.69	3.68	3.74	3.77
% Change since 1990	NA	-6.8%	-5%	-5%	2%	2%	4%	4%
Natural Gas Transmission								
Fugitive Emissions (Mt CO ₂ eq)	4.3	5.6	5.7	5.8	5.7	5.7	5.7	5.8
% Change since 1990	NA	29.4%	32%	34%	34%	33%	33%	34%
Pipeline Length (km)	64 222	81 390	83 245	84 362	84 077	84 013	84 345	84 679
% Change since 1990	NA	26.7%	30%	31%	31%	31%	31%	32%
Fugitive Emissions Intensity (kt CO ₂ eq/km)	0.067	0.068	0.068	0.068	0.068	0.068	0.068	0.068
% Change since 1990	NA	2.1%	2%	2%	2%	2%	2%	1%
DOWNSTREAM PRODUCTION								
Fugitive Emissions (Mt CO ₂ eq)	2.1	3.3	3.8	3.9	3.7	3.7	3.8	3.7
% Change since 1990	NA	53.3%	77%	83%	76%	73%	78%	72%
Production (PJ)	3 907	4 341	4 699	4 783	4 586	4 489	4 572	4 359
% Change since 1990	NA	11.1%	20%	22%	17%	15%	17%	12%
Fugitive Emissions Intensity (kt CO ₂ eq / PJ)	0.54	0.75	0.80	0.81	0.82	0.82	0.83	0.84
% Change since 1990	NA	38.0%	47%	50%	50%	50%	52%	54%
Petroleum Refining								
Fugitive Emissions (Mt CO ₂ eq)	0.9	1.7	2.0	2.0	1.8	1.7	1.8	1.6
% Change since 1990	NA	93.4%	127%	133%	113%	101%	108%	89%
Production (PJ)	3 907	4 341	4 699	4 783	4 586	4 489	4 572	4 359
% Change since 1990	NA	11.1%	20%	22%	17%	15%	17%	12%
Fugitive Emissions Intensity (kt CO ₂ eq / PJ)	0.22	0.38	0.42	0.42	0.40	0.38	0.39	0.37
% Change since 1990	NA	74.1%	89%	90%	81%	75%	78%	70%
Natural Gas Distribution								
Fugitive Emissions (Mt CO ₂ eq)	1.3	1.6	1.8	1.9	1.9	2.0	2.0	2.0
% Change since 1990	NA	26.2%	43%	49%	51%	54%	57%	61%
Pipeline Length (km)	168 813	212 991	241 344	252 371	254 512	259 844	265 431	271 290
% Change since 1990	NA	26.2%	43%	49%	51%	54%	57%	61%
Fugitive Emissions Intensity (kt CO ₂ eq / km)	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
% Change since 1990	NA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Notes: NA = Not applicable.

1.7% contribution from Coal Mining. Although fugitive releases from the Solid Fuels category (i.e. coal mining) decreased by 1.2 Mt (55%) between 1990 and 2011 as a result of the closing of many mines in eastern Canada, emissions from oil and natural gas increased 46% 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 due to increased worldwide demand for energy products. Since 1990, there has been a very large increase in the net energy exported from Canada (refer to Section 3.5.4 in Chapter 3 for a discussion of emissions associated with the export of oil and natural gas), accompanied by a 187% increase in GHG emissions associated with those net energy exports.

Although overall fugitive emissions associated with oil and gas production have increased substantially since 1990, the overall fugitive emissions intensity (emissions per unit of energy produced) of upstream oil and gas production has decreased by 13% (see Table 2–9). This reduction is due to a 37% decrease in oil sands fugitive emissions intensity, which was somewhat offset by a 9% 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.

2.3.2. Industrial Processes Sector (2011 GHG emissions, 54.3 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 SF₆, and Other and Undifferentiated Production. GHG emissions from the Industrial Processes Sector contributed 54.3 Mt to the 2011 national GHG inventory, compared with 56.0 Mt in 1990. Figure 2–10 illustrates the changes in each of the subsectors over the period 1990–2011, and Table 2–10 provides an emission breakdown by category for selected years.

Between 1990 and 2011, the overall sector emissions decreased by approximately 1.7 Mt (3.0%). This change could be explained by significant emission reductions in adipic acid production (N₂O), aluminium production (PFCs), and magnesium production (SF₆), which were offset by growths in other and undifferentiated production (CO₂),¹⁶ emissions from consumption of HFCs, and ammonia production (CO₂).

2.3.2.1. Mineral Products

Between 1990 and 2011, there is a slight increase in emissions from the category of Cement Production of 5.6% (0.31 Mt CO₂ eq). The slight increase represents the net effect of significant decrease in clinker production to its lowest level (9.9 Mt) in 2009, followed by a rebound in clinker production to 11.1 Mt in 2011 (Statistics Canada,

¹⁶ Other and Undifferentiated Production is an emission category composed mainly of petrochemical production that uses hydrocarbons as feedstock.

Figure 2–10 GHG Emissions from Industrial Processes by Subsector, 1990–2011

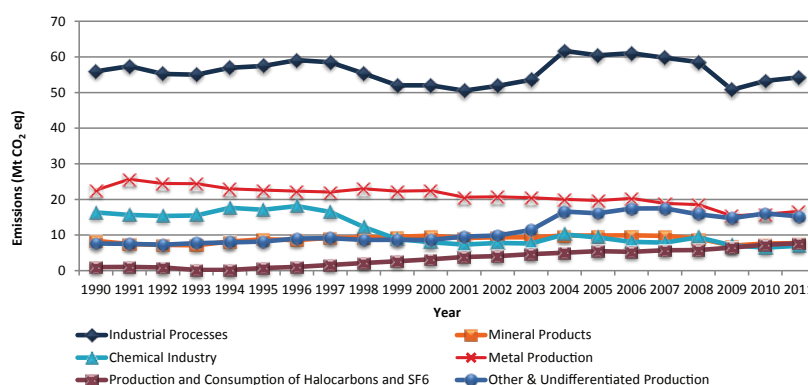


Table 2–10 GHG Emissions from Industrial Processes by Category, Selected Years

GHG Source Category	GHG Emissions (Mt CO ₂ eq)							
	1990	2000	2005	2007	2008	2009	2010	2011
Total - Industrial Processes	56.0	52.1	60.5	59.8	58.5	50.8	53.3	54.3
Mineral Products	8.4	9.8	9.9	9.8	9.0	7.0	7.6	7.7
Cement Production	5.4	6.7	7.2	7.3	6.6	5.1	5.7	5.7
Lime Production	1.8	1.9	1.7	1.6	1.5	1.2	1.4	1.4
Limestone and Dolomite Use	0.80	0.77	0.64	0.59	0.67	0.54	0.36	0.36
Soda Ash Use	0.25	0.25	0.18	0.19	0.16	0.11	0.10	0.10
Magnesite Use	0.147	0.181	0.175	0.067	0.057	0.069	0.081	0.091
Chemical Industry	16.3	8.0	9.3	7.9	9.4	7.1	6.5	7.0
Ammonia Production	4.5	5.7	5.3	5.2	5.6	5.2	5.3	5.7
Nitric Acid Production	1.01	1.23	1.25	1.13	1.28	1.15	1.10	1.16
Adipic Acid Production	10.7	0.9	2.6	1.5	2.4	0.7	0.0	0.0
Petrochemical Production	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Metal Production	22.6	22.5	19.7	18.9	18.6	15.4	15.8	16.6
Iron and Steel Production	10.2	11.5	10.2	11.1	10.7	8.0	9.0	9.9
Aluminium Production	9.3	8.2	8.2	7.3	7.4	7.2	6.6	6.6
Magnesium Production	2.87	2.31	1.09	0.32	0.18	0.00	0.00	0.00
Magnesium Casting	0.236	0.471	0.201	0.198	0.280	0.193	0.193	0.193
Production and Consumption of Halocarbons	0.8	2.9	5.3	5.5	5.6	6.3	7.1	7.5
SF ₆ Use in Electric Utilities and Semiconductors	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1
Other and Undifferentiated Production	7.6	8.6	16.1	17.5	15.8	14.8	16.1	15.2

Note: Totals may not add up due to rounding.

44-001, 303-0060 and 303-0061). The varying production levels for clinker can be attributed to the domestic and mainly U.S. demand for cement.

The increase in emissions from cement production for the years 1990–2011 is more than offset by an 18% decrease (0.31 Mt CO₂ eq) in emissions from the Lime Production category. The decrease can be attributed to reduction in overall production capacity. From 1990 to 2011, lime production capacity has decreased by 22%. The year 2009 had the lowest lime production, 1.6 Mt, with production rebounding in 2011 to 2.0 Mt.¹⁷

The category of Mineral Products (which is made up of uses of limestone and dolomite, soda ash and magnesite) experienced a decrease in emissions of 0.65 Mt CO₂ eq (54%) from 1990 to 2011. Important industrial consumers of limestone and soda ash are pulp and paper mills and glass manufacturers. Significant decline in pulp and paper production and the increased use of recycled glass (Cullet – NRCan 2007) resulted in the declining use of these mineral products and associated emissions. Reductions in emissions from limestone and dolomite use resulted from

reduced production in the iron and steel sector, particularly in 2001–2002 and 2006–2007.

Emissions from magnesite use occur when mined magnesite is calcined to produce magnesia (magnesium oxide) for use in various applications, or is chemically treated to form the intermediate product magnesium chloride to produce magnesium metal (AMEC 2006). The closure of all magnesium production facilities, the last one shutting down in 2008, contributed to significant decreases in emission since 1990.¹⁸ However, the plant that produces magnesia for industrial, environmental and agriculture application is still operational, and the 2011 emissions resulting from magnesite use are purely from magnesia production for these applications (Baymag 2011). As a result, emissions from magnesite use in 2011 have decreased by 38% compared to 1990 (0.06 Mt CO₂ eq).

2.3.2.2. Chemical Industry

The main driver of emission reduction in the chemical industry from 1990 to 2011 was adipic acid production. Emissions from adipic acid production were zero in 2011 because the Ontario plant became indefinitely idled in

17 Natural Resources Canada 2011, provided by Doug Pangapko from Natural Resources Canada via email to Pollutant Inventories and Reporting Division, dated July 13, 2012.

18 Timminco 2009, provided by Greg Donaldson from Timminco via email to Alice Au, Greenhouse Gas Division, dated November 27, 2009.

2009; this represents a decrease of 10.7 Mt CO₂ eq from the 1990 level.¹⁹ The same plant was responsible for significant emission reduction in the late 1990s due to the incorporation of stringent controls on N₂O emissions. A decrease of 57% (9.4 Mt CO₂ eq) from 1990 to 2011 is observed for the chemical industry as a whole.

Emissions from the ammonia production industry have increased by 28% (1.24 Mt CO₂ eq) from 1990 to 2011. The increase is mainly the result of new capacity that was commissioned in 1992 and an increase in demand for ammonia coming from agriculture activities (Cheminform 2006).

2.3.2.3. Metal Production

Emissions reductions in the Magnesium, Aluminium and Iron and Steel categories contributed to the 26% (6.0 Mt CO₂ eq) overall reduction in emissions from Metal Production between 1990 and 2011. Magnesium production decreased 2.87 Mt CO₂ eq as compared to 1990 levels.

The aluminium industry has succeeded in bringing down its perfluorocarbon (PFC) emissions by 5.1 Mt CO₂ eq (78%), while increasing production by 90% between 1990 and 2011. Reductions in PFC emissions have been achieved through the incorporation of computerized sensors and automated alumina feeders, which have helped reduce the occurrence of anode effects. In addition, the data show that the industry continued to increase its production from more modern plants (i.e. with prebaked technology), rather than from older plants (i.e. with Söderberg technology). However, the increase in aluminium production also gave rise to an increase in CO₂ emissions of 2.4 Mt CO₂ eq (or 87%), since CO₂ comes from the reduction of alumina with carbon anodes, an essential reaction in the production process that cannot be avoided. Overall emissions from aluminium production have decreased by 29% (2.7 Mt CO₂ eq) from 1990 to 2011.

Overall, from 1990 to 2011 the iron and steel industry experienced an emission decrease of 3.3% (0.33 Mt CO₂ eq), which contributed to the overall decrease in emissions for the Metal Production subsector. Emissions decreased considerably (25% or 2.6 Mt CO₂ eq) between 2008 and 2009, due to reduced production, but this was followed by a strong rebound, and by 2011 emissions had increased 23% (1.8 Mt CO₂ eq) compared to 2009.

¹⁹ Invista 2011, provided by Steve Lauridsen from Invista via email to Mohamed Abdul, Pollutant Inventories and Reporting Division, dated August 8, 2011.

2.3.2.4. Production and Consumption of Halocarbons and SF₆

There has been an emission growth of 6.95 Mt CO₂ eq (950%) for consumption of hydrofluorocarbons (HFCs) since 1995. This can be explained by the displacement of ozone-depleting substances (ODSs) by HFCs within the refrigeration and air conditioning (AC) markets since the Montreal Protocol came into effect in 1996. Although a 1990 value is shown for Production and Consumption of Halocarbons in Table 2–10, this value represents only HFC-23 emissions from the production of HCFC-22, as emissions from the consumption of HFCs were negligible in 1990. Production of HCFC-22 ceased in 1993, and HFC emissions reported after this year are only from consumption.

2.3.2.5. Other and Undifferentiated Production

The Other and Undifferentiated category demonstrated an increase in emissions of 7.6 Mt CO₂ eq (100%) from 1990 to 2011. The increase can be attributed to the greater use of petroleum fuels as feedstock to meet increased demand for petrochemical products. The feedstock use of waxes, paraffin and unfinished petrochemical derivatives has increased by 870% (4.5 Mt CO₂ eq) (Statistics Canada 57-003 – RESD), the use of ethane has increased by 132% (1.6 Mt CO₂ eq), the use of petrochemical feedstock has increased by 19.6% (0.4 Mt CO₂ eq), and the use of butane has increased by about 166% (0.5 Mt CO₂ eq).

2.3.3. Solvent and Other Product Use Sector (2011 GHG emissions, 0.25 Mt)

The Solvent and Other Product Use Sector accounts for emissions related to the use of N₂O as an anaesthetic in medical applications and as a propellant in aerosol products. It contributed 247 kt CO₂ eq to the 2011 national GHG inventory, compared to 179 kt CO₂ eq in 1990. The emission trends were primarily driven by the domestic demand for N₂O for anaesthetic or propellant purposes.

2.3.4. Agriculture Sector (2011 GHG emissions, 54 Mt)

The main sectors in Canadian agriculture are livestock and crop production. The livestock sector is dominated

by the beef, dairy, poultry and swine production, while crop production is mainly dedicated to the production of cereals and oil seeds. Canada also produces a wide variety of specialty crops and animals, but these represent a very small portion of the overall agricultural economy. Agricultural production is highly regionalized; approximately 70% of beef cattle and more than 90% of wheat, barley and canola are produced in the Prairies' Semi-arid to Subhumid ecozone. On the other hand, approximately 70% of dairy cattle, 60% of swine and poultry, 95% of corn and 90% of soybeans are produced in the humid Mixedwood Plains ecozone in eastern Canada. Traditionally Canada's Agriculture Sector has been composed of small family farms, but over the past 30 years, intensification has occurred in the Agriculture Sector and as a consequence, the number of farms has decreased and farm size and productivity have increased.

Non-energy emissions directly related to animal and crop production accounted for 54 Mt CO₂ eq or 8% of total 2011 GHG emissions for Canada, an increase of 7 Mt CO₂ eq or 15% since 1990. Agriculture accounted for 23% and 72% of the national CH₄ and N₂O emissions, respectively. Nitrous oxide accounted for 62% of estimated sectoral emissions and CH₄ for 38% in 2011. All these emissions are from non-energy sources. Emissions from energy used during the agricultural production process and the energy and fugitive emissions occurring during the production of nitrogen (N) fertilizers are discussed in the Energy and Industrial Processes Sectors.

The processes and activities that produce GHG emissions included in this discussion of the Agriculture Sector are

enteric fermentation, application of nitrogen fertilizers, and manure storage and application.

Agricultural emissions are attributed to either the livestock sector, which includes enteric fermentation emissions (CH₄) and all emissions (CH₄ and N₂O) from the storage and application of manure; or the crop production sector, which consists of N₂O emissions from the application of synthetic N fertilizers, crop residue decomposition and other management practices (Table 2–11). Generally, agricultural emissions result from losses and inefficiencies in the production processes, either losses of nutrition energy during animal digestion or losses of nutrient N.

In 2011, livestock emissions consisted of 18 Mt CO₂ eq from enteric fermentation and 14 Mt CO₂ eq from manure management, storage and application (56% and 44% of livestock emissions, respectively). Crop production produced N₂O emissions during the application of synthetic nitrogen fertilizers (14 Mt CO₂ eq,) and from crop residue decomposition (7.3 Mt CO₂ eq), representing 66% and 34% of crop production emissions, respectively (Table 2–11).

A discussion of GHG trends in agricultural production must also take into account the complex interconnections between the two dominant branches of agriculture: livestock and crop production. These two sub-industries both compete for the same land base and contribute resources to and from that land base. For instance, high beef prices may stimulate more conversion of marginally arable annual cropland to perennial pasture and vice versa. Over the past decades, agriculture has undergone a continual process of intensification. In the crop production industry

Table 2–11 GHG Emissions from Agriculture by Production Systems for Selected Years¹

Production System	GHG Emissions (Mt CO ₂ eq)							
	1990	2000	2005	2007	2008	2009	2010	2011
Livestock	29	36	39	37	36	34	33	32
Dairy Cows	5.8	5.0	4.7	4.5	4.5	4.5	4.6	4.6
Beef Cattle	19	25	28	27	26	25	24	23
Swine	2.4	3.1	3.5	3.3	2.9	2.8	2.7	2.8
Other Livestock ²	1.5	2.1	2.3	2.3	2.3	2.2	2.2	2.2
Crop	18	20	19	21	23	22	22	22
Synthetic Nitrogen Fertilizers	9.2	12	11	13	13	13	14	14
Crop Residue Decomposition	7.5	7.2	7.7	7.7	9.1	8.2	8.5	7.3
Other Management Practices ³	1.3	0.9	0.4	0.3	0.2	0.2	0.1	0.1
Agriculture (Total)	47	56	58	58	59	56	56	54

1. Totals may not add up due to rounding.

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

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

intensification has involved an increased reliance on off-farm inputs such as fertilizers, herbicides and pesticides and has resulted in increased productivity per hectare and reduction of summerfallow. In the livestock industry this has also involved increased reliance on processed feeds and medicinal and non-medicinal supplements that have also increased output per animal. At the same time, over the past 30 years there has been an increased focus on soil conservation through conservation tillage and crop rotation. For these reasons, a comprehensive discussion of trends in emissions from agricultural production must at least touch on the dominant emissions from production practices, farm inputs, land management practices and land-use change.

The main drivers of the emission trend in the Agriculture Sector are the expansion of the beef cattle and swine populations, and increases in the application of synthetic nitrogen fertilizers in the Prairies. Beef, swine and poultry populations in Canada are 16%, 17% and 39% higher, respectively, than in 1990. The increase in livestock populations largely accounts for the 12% increase, from 29 to 32 Mt CO₂ eq, in emissions associated with animal production over the 1990–2010 period (Table 2–11). In the case of beef cattle, emissions increased at greater rates than cattle populations as herd improvements resulted in an increase in live weight; consequently, an average animal now consumes more feed and also emits more GHGs.

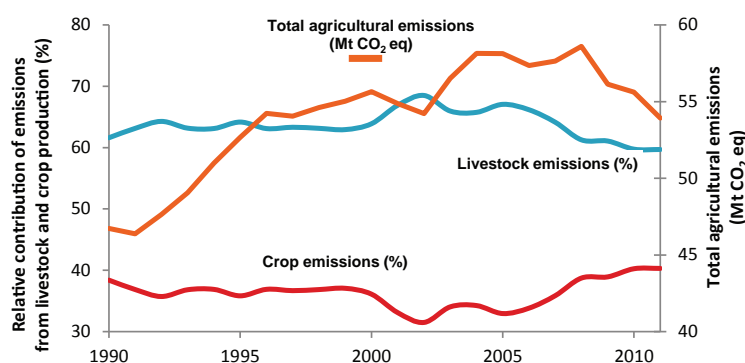
Increases from beef production were, however, partially offset by a 28% reduction in the dairy population. The dairy quota systems encouraged the dairy industry to invest in herd improvement in order to increase industry profitability. Emissions associated with dairy cows have fallen by approximately 20% since 1990, as the decline in

the dairy herd has been partly offset by a 32% increase in average milk productivity, due to improved genetics and changes in feeding and/or management practices. Therefore, even though the decrease in dairy population is driving the emission decline in this category, as was the case with non-dairy cattle, an average cow produces more milk today than in 1990, and also emits more GHGs.

Emissions attributed to crop production are due mainly to either the application of synthetic nitrogen fertilizers or to crop residue decomposition, which is directly proportional to crop yields. The use of synthetic nitrogen fertilizer has increased from 1.2 Mt N to 2.0 Mt N from 1990 to 2011 due mainly to a reduction in summerfallow and an intensification of cropping systems in western Canada. Major crops grown in Canada—corn, wheat, barley and canola—require high rates of fertilization to achieve and sustain high levels of production. As a consequence, emissions from synthetic nitrogen fertilizer consumption have increased substantially, from 9.2 Mt CO₂ eq in 1990 to 14 Mt CO₂ eq in 2011.

Emissions from crop residue decomposition varied between 5.0 Mt CO₂ eq (in 2002) and 9.1 Mt CO₂ eq (in 2008). Severe drought for most regions of the Canadian Prairies in 2001 and 2002 resulted in very poor crop production and, in turn, lower emissions for these years. The impact of the drought is observed in both the emission trend and the relative proportion of emissions attributed to crop or animal growth (Figure 2–11). On the other hand, since 2005, favourable weather conditions along with good commodity prices resulted in record production for soybean, corn, pulse and canola and consequently greater emissions of nitrous oxide (N₂O).

Figure 2–11 Relative GHG Contribution from Livestock and Crop Production and Total Agricultural Emissions, 1990–2011



Overall, during the 1990–2005 period, the combination of increased livestock populations and increasing emissions per animal in some animal categories resulted in a change in the relative proportion—from 62 to 69%—of GHGs coming from the livestock sector, increasing to the high of 69% during the drought years of 2001 and 2002 (Figure 2–11), but has decreased since the peak in 2002.

Recent Trends

Beef prices were strong from 1990 until 2003, when the occurrence of bovine spongiform encephalopathy (BSE, or mad cow disease) resulted in a worldwide ban on Canadian beef products. A sudden 9% increase in domestic animal populations occurred between January 2003 and January 2004. The BSE crisis was not completely resolved until 2005, and since the peak of the crisis in 2005, beef populations have decreased by 18%.

The prices of hogs were also strong from 1990 to 2003 (Statistics Canada 2009), and increases in population numbers occurred. However, prices have also decreased in recent years, and as a result, populations have decreased by 21% since their peak in 2005. These population decreases, combined with continued decreasing trends in dairy cattle populations, have decreased emissions from livestock by 15%, or roughly 5.7 Mt CO₂ eq since 2005. At the same time, since 2005, due to improved crop yields and strong grain commodity prices, emissions from crop production have increased by 13%, roughly 2.6 Mt CO₂ eq.

From 2005 to 2008, total emissions from agriculture, overall, were stable. However, emissions in 2011 are 4.5 Mt CO₂ eq lower than in 2005 and 4.7 Mt CO₂ eq lower than

in 2008. Lower emissions in 2011 are due to the continued decrease in animal populations and also to lower crop yields in 2011 that reduced crop residual emissions of N₂O. Record production of canola (14 Mt in 2011) was more than offset by a decline in corn and soybean production due to wet conditions and flooding during the spring and early summer of 2011.

The continued decline in animal populations has reversed the trend of an increasing proportion of emissions coming from livestock production (Figure 2–11). The proportion of emissions from livestock in 2011 was less than 60% of total agriculture emissions, a smaller proportion than in 1990 (62%) and considerably lower than the proportion in 2005 (67% of total emissions).

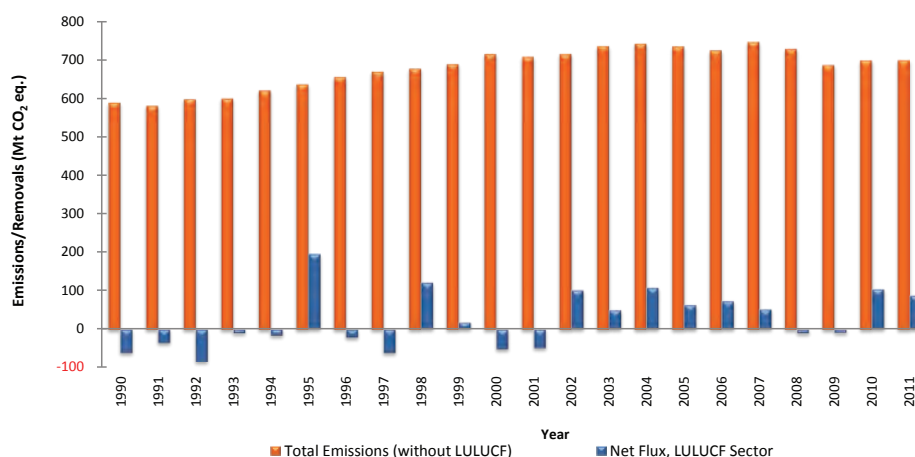
2.3.5. Land Use, Land-use Change and Forestry Sector

(2011 net GHG emissions, 87 Mt, not included in national totals)

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

The net LULUCF flux, calculated as the sum of CO₂ emissions and removals and non-CO₂ emissions, displays high interannual variability over the reporting period. In 2011, this net flux amounted to emissions of 87 Mt (Figure 2–12).

Figure 2–12 GHG Emissions from LULUCF Relative to Total Canadian Emissions, 1990–2011



All emissions and removals in the LULUCF Sector are excluded from the national totals. In 2011, the estimated 87 Mt would, if included, increase the total Canadian GHG emissions by about 12%.

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

The Forest Land category includes GHG emissions from and removals by Canada's managed forests. Due to a methodological artefact, the net flux in forest land displays an important annual variability due to the erratic pattern of forest wildfires, which masks underlying patterns of interest in the Sector. Important subsectoral trends associated with human activities in managed forests include a 28% increase in the carbon removed in harvested wood biomass between 1990 and the peak harvest year, 2004. Since then, significant reductions in forest management activities have occurred, with a 33% decline in harvest levels in 2011, which in 2009 reached their lowest point for the 22-year period covered by this report (30 Mt CO₂ eq). This trend reflects a deep restructuring of the Canadian forest economic sector, aggravated by the consequences of the economic recession in the United States, Canada's main export market.

The high variability in the net flux from managed forests is associated with the immediate impact of wildfires, which are random, natural events; these wildfires alone represented annual emissions of between 11 and 264 Mt CO₂ eq over the period from 1990 to 2011 (Figure 2-13). Likewise,

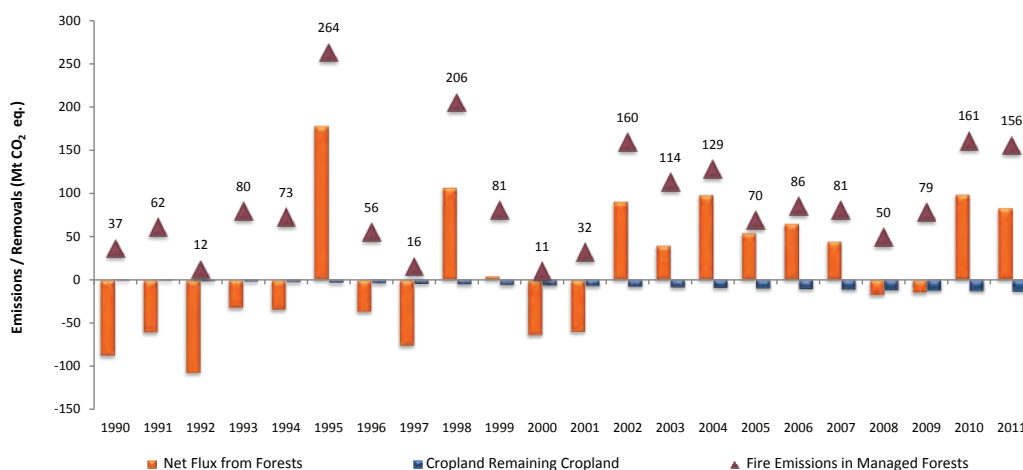
the immediate and long-term effect of the catastrophic Mountain Pine Beetle infestation in Western Canada will undoubtedly continue to influence the GHG trends.

Note that the current default approach to estimating emissions associated with harvesting ignores long-term carbon storage in wood products. Taking into account this storage, emission estimates from harvesting in the year 2011 alone could be reduced by 30 Mt.

The Cropland subcategory includes the effect of agricultural practices on CO₂ emissions from, and removals by, arable soils and the immediate and long-term impacts of forest and grassland conversion to cropland. The steady decline in emissions from cropland is noteworthy, from 12 Mt CO₂ eq in 1990 to a net removal of 8 Mt CO₂ eq in 2011. This pattern largely results from changing agricultural land management practices in western Canada, such as the extensive adoption of conservation tillage practices (over 13 Mha of cropland since 1990), reduction in summerfallow by 68% and an increase in perennial forage crops. The net CO₂ removals due to the management of mineral soils increased from 2.1 Mt in 1990 to 14 Mt in 2011. A decline in forestland conversion to cropland has also contributed to this trend.

CO₂ emissions from peatlands managed for peat extraction and from land flooding are reported under the Wetlands category. Emissions from managed peatlands increased 71% from 1990 to 2000; since then, they have shown a slight decline amounting to 1.2 Mt in 2011. Emissions from land conversion to flooded lands (reservoirs) do not show a consistent trend. Higher values above

Figure 2-13 Selected GHG Emissions and Removals in LULUCF, 1990–2011



4 Mt/year were observed over the 1990–1993 period, explained by residual emissions from the creation of large reservoirs before 1990; emissions have since then declined, with moderate peaks in 1999 and 2005, decreasing to 1.5 Mt in 2011. Note that emissions from the surface of reservoirs flooded for more than 10 years are excluded from the accounting (IPCC 2003).

The conversion of forests to other land is a prevalent yet declining practice in Canada. It is driven by a great variety of circumstances across the country, including policy and regulatory frameworks, market forces and resource endowment. The economic drivers of forest conversion are diverse and result in heterogeneous spatial and temporal patterns of forest conversion. Since 1990, more than one million hectares of forest have been lost in Canada. GHG emissions from forest conversion have dropped from 26 Mt CO₂ eq in 1990 to 19 Mt CO₂ eq in 2011. Geographically, the highest average rates of forest conversion occur in the Boreal Plain (24 kha yr⁻¹) and the Boreal Shield East (9 kha yr⁻¹), which account for 45% and 16% of the total forest area lost in Canada since 1990, respectively.

Primary drivers of forest conversion include agricultural expansion, resource extraction and hydroelectric development. Forest conversion for agricultural expansion accounted for 43% of the cumulative area of forest conversion since 1990. Annual rates of deforestation to agriculture, however, have dropped from 42 kha in 1990 to 19 kha in 2011 (Figure 2–14). This decrease predominantly took place in the Boreal Plains, Subhumid Prairies and Montane Cordillera of western Canada, following a period of active agricultural expansion in the previous decades.

Forest clearing for resource extraction, which includes oil and gas extraction, forestry roads, mining, and peat extraction, is the second-largest driver of forest conversion. Resource extraction expanded at the expense of over 330 kha of forests and accounts for 28% of the cumulative area of forest conversion since 1990. Forest clearing for oil and gas extraction has more than doubled, from 4.4 kha per year in 1990 to 11.1 kha per year in 2011 (Figure 2–14) and has largely occurred in the Boreal Plains of the northern Prairies.

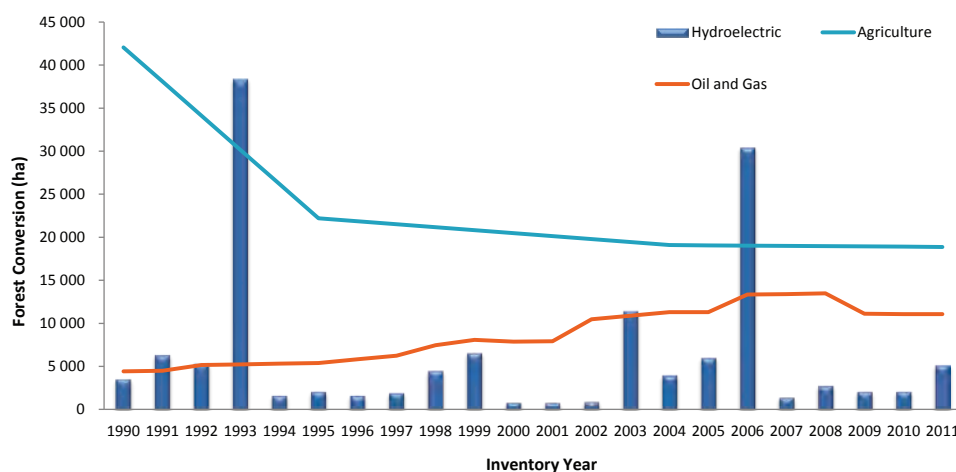
Forest conversion due to hydroelectric development is episodic, corresponding to the occasional impoundment of large reservoirs (e.g. La Forge 1 in 1993 and Eastmain1 in 2006) (Figure 2-14). Cumulative areas of forests converted for the creation of hydro reservoirs and associated infrastructure equal 141 kha, which accounts for 12% of forest conversion over the time period. Hydroelectric development occurs mainly in the Taiga Shield East and the Boreal Shield East.

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

2.3.6. Waste Sector (2011 GHG emissions, 22 Mt)

From 1990 to 2011, GHG emissions from the Waste Sector increased by 14%, which is less than the population growth of 24%, or the growth of total national GHG emissions of 19%. The contribution of this sector in 2011 to the total national GHG emissions is 3.1%, which is the same

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



as in 1990. Of the 22 Mt total emissions from this sector in 2011, Solid Waste Disposal on Land, which includes municipal solid waste (MSW) landfills and wood waste landfills, accounted for 20 Mt. CH₄ emissions, produced by the decomposition of biomass in MSW landfills, represent 92% of the emissions from the Waste Sector. Emissions from municipal wastewater treatment and incineration of waste (excluding emissions from incineration of biomass material) contributed 1.0 Mt and 0.69 Mt, respectively, to the total from the Waste Sector (Table 2–12). Figure 2–15 presents the emission trends for each of the three subsectors compared with the total emissions for the Waste Sector over the 1990 to 2011 time series. The tables in Annex 12 summarize this information nationally by CO₂ equivalent and by category (i.e. individual gas and source).

CH₄ emissions from MSW landfills increased by 18% between 1990 and 2011, despite an 81% increase in landfill gas capture and combustion. Approximately 349 kt of CH₄ (or 7334 kt CO₂ eq) are captured by the 68 landfill gas collection systems operating in Canada (Environment

Canada 2011).²⁰ Of the total amount of CH₄ collected in 2011, 51% (179 kt) was utilized for various energy purposes and the remainder was flared. As shown in Figure 2–16, Canada has considerably increased the number of landfill sites collecting gas since facility data collection was initiated in 1997.

Over the time series, the distribution of the collected landfill gas being utilized vs. flared has changed (Figure 2–17). The decline in relative gas utilization from 70% to 51% between 1997 and 2011 is due to a greater number of facilities initiating gas collection and which are flaring in preparation to starting up utilization units.

GHG emissions from landfills were estimated for two solid waste types: MSW and wood waste landfills, both of which

20 Four landfill gas capture facilities did not provide data for the 2007 landfill gas inventory by December 31, 2008. 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 was being constructed and for which no landfill gas collection quantity information was available. Data collection for 2010 and 2011 were not available for the present submission; therefore, in lieu of available current information it is assumed that the landfill gas collection values for 2010 and 2011 remain constant at 2009 levels.

Table 2–12 GHG Emissions from Waste, Selected Years

GHG Source Category	GHG Emissions (Mt CO ₂ eq)							
	1990	2000	2005	2007	2008	2009	2010	2011
Waste Sector	19	20	21	21	21	21	22	22
Solid Waste Disposal on Land	17	18	20	20	20	20	20	20
Wastewater Handling	0.80	0.90	0.90	1.00	1.00	1.00	1.00	1.00
Waste Incineration	0.74	0.75	0.70	0.66	0.71	0.68	0.69	0.69

Note: Totals may not add up due to rounding.

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

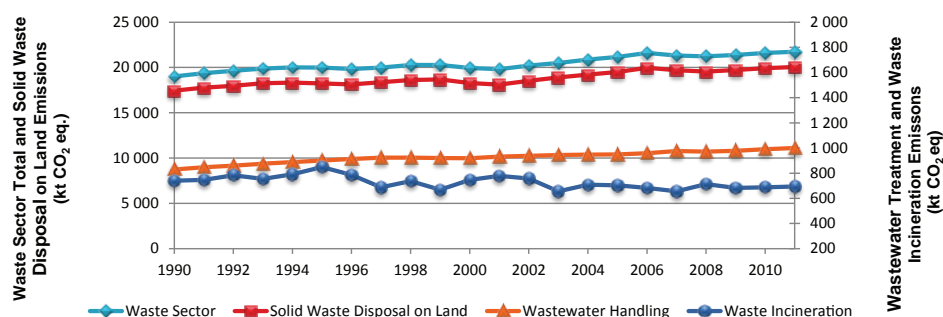
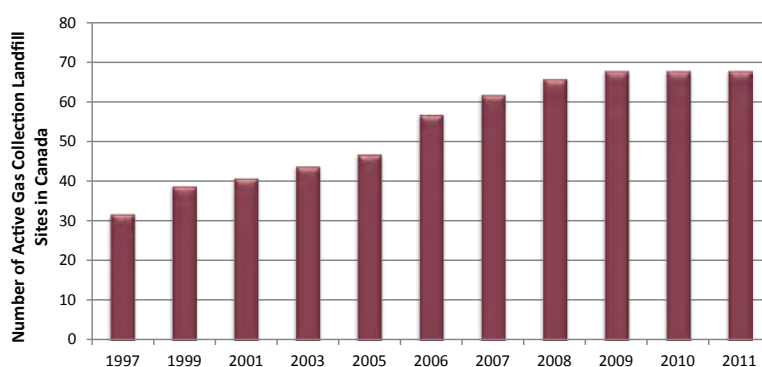
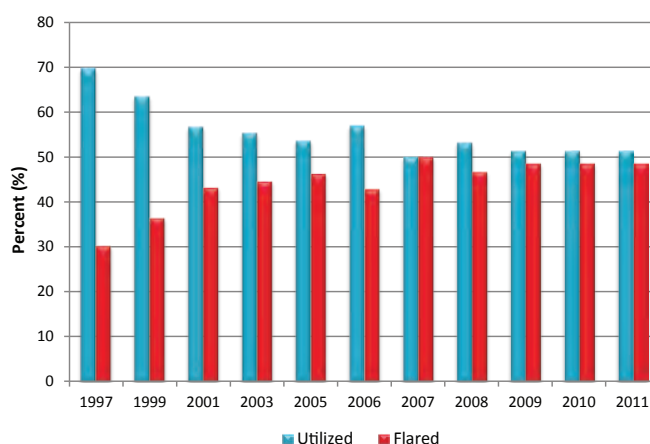


Figure 2–16 Number of Active Gas Collection Landfill Sites in Canada



Note: 2010 and 2011 data assumed constant from 2009 survey results.

Figure 2–17 Proportion of Landfill Gas Utilized vs Flared



Note: 2010 and 2011 data assumed constant from 2009 survey results.

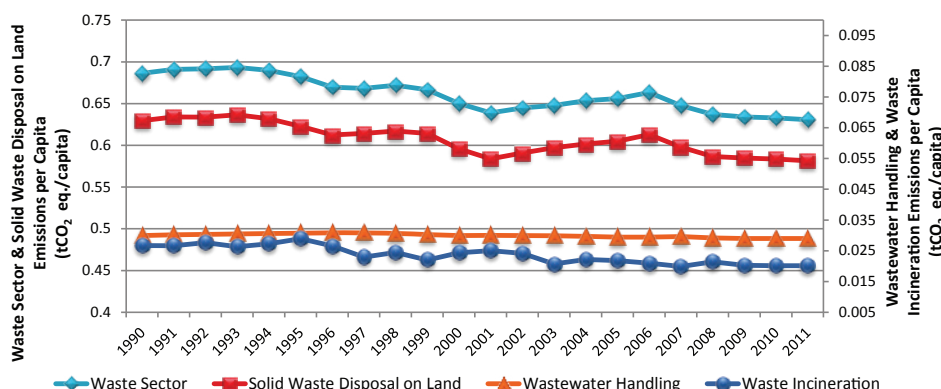
produce CH₄ anaerobically.²¹ The CH₄ production rate at a landfill is a function of several factors, including the mass and composition of biomass being landfilled, the landfill temperature, and the moisture entering the site from rainfall.

CH₄ capture and waste diversion programs at landfills can make significant contributions to reductions in emissions. The quantity of CH₄ captured at MSW landfills for flaring or combustion for energy recovery purposes in 2011

amounted to 29% of the total generated emissions from this source, as compared to 21% in 1990. Per capita emissions from the Waste Sector decreased by 8.0% from 1990 to 2011, owing primarily to the increasing quantities of CH₄ captured at landfill sites (Figure 2–18). The amount of waste diverted as a percentage of the waste generated has fluctuated from 22% to 25% over the period between 1998 and 2008 (Statistics Canada 2000, 2003, 2004, 2007, 2008, 2010). Although the quantity of waste placed in MSW landfills increased by 39% from 1990 to 2011, the landfilled quantity per capita increased by only 11%. The amount of waste exported from Canada to the United States for the years 1990 and 2011 was estimated at 127 kt and 2516 kt, respectively, giving about a 2400% increase in the amount of waste (residential and non residential) exported over this period. However, emissions from MSW landfills

21 When waste consists of biomass, the CO₂ 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 CO₂ will be sequestered when the biomass regenerates in crop reproduction). In the case of biomass from forest products, the emissions of CO₂ are accounted for as part of the LULUCF Sector (forest harvests). However, waste that decomposes anaerobically produces CH₄, which is not used photosynthetically and therefore does not sequester carbon in biomass regeneration and is not accounted for in forest harvest estimates. The production and release of unburned CH₄ from waste are therefore accounted for in GHG inventories.

Figure 2–18 Per Capita GHG Emission Trend for Waste, 1990–2011



are expected to increase in coming years as a result of an agreement between the State of Michigan and the Province of Ontario, calling 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 2005.²² Municipally managed wastes do not include institutional, commercial or industrial wastes.

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 2-18. The 2006–2011 drop in emissions from Solid Waste Disposal on Land seems to lend support to the effect of waste diversion programs and landfill gas collection initiatives. In addition, the per capita waste generation rate has also been slowing down from about 2004. However, based on the historical variation of the waste generation values over the time series, a more accurate confirmation of the continuation of this trend should be available in subsequent NIR submissions as new data are made available from the biennial Statistics Canada waste surveys and Environment Canada's landfill gas collection and utilization surveys.

In terms of trends in emissions per capita from the Wastewater Handling subsector, there was an overall decrease of 3.3% from 1990 to 2011. Over this time series the fluctuations in wastewater per capita emissions were small.

In contrast, the Waste Incineration subsector showed a significant decrease in GHG emissions over the 1990–2011 time series (Figure 2–18). Total incineration emissions (MSW, sewage sludge and hazardous waste) per capita decreased by 25% over the time series, due mainly to declines in emissions from the closure of aging MSW incinerators between 1992 and 1997. A buffering factor to the significant drop in emissions from MSW incinerators was the increased use of dedicated hazardous waste incinerators. Emissions from the latter source rose from 1990 to 1995 then roughly plateaued thereafter.

2.4. Economic Sector Emission Tables

In this report, emissions estimates are primarily grouped into the activity sectors defined by the IPCC (i.e. Energy; Industrial Processes; Solvent and Other Product Use; Agriculture; Land-Use, Land-use Change and Forestry; and Waste). While it is necessary to use this method of categorization for consistency with UNFCCC reporting guidelines, it is also useful to reallocate emissions into economic sector definitions since most people associate GHG emissions with a particular economic activity (e.g. creating electricity, farming, driving a car, etc.). This reallocation approach takes the relevant proportion of emissions from various IPCC sub-categories to create a comprehensive emission profile for a specific economic sector. This is the approach taken for reporting against Canada's Copenhagen target in Canada's Emissions Trends. Table 2–14 details the relationship between economic sectors and IPCC categories.

Examining the historical path of Canadian greenhouse gas emissions by economic sectors facilitates the identification

22 Ontario Ministry of Environment provided by Jim Hiraish from the Ontario Ministry of the Environment to Craig Palmer, Environment Canada, Nov. 30, 2007.

of pressure points and emerging issues with respect to emissions growth. Moreover, this allows for a better understanding of the connection between economic activities and GHG emissions for the purposes of analyzing trends and for policy and public analysis.

For example, the transportation economic sector represents emissions arising from the mobility requirements of people driving cars, trucks, trains, planes and ships and also includes the mobility service emissions from heavy-duty trucks and other commercial vehicles. However, unlike the IPCC categorization, the transportation economic sector does not contain offroad transportation emissions related to farming, mining, construction, forestry or other industrial activities. Excluding off-road in the transportation economic sector ensures that emissions related to industrial activities do not appear as trends associated with on-road passenger and freight transportation requirements. For example, if there were any upward trend in farming or mining activity, emissions arising from the increased use in mobile farming machinery or mining trucks would be reflected in the agricultural or mining sectors. This section reports emissions by the following economic sectors: oil and gas, electricity, transportation, emissions intensive trade exposed industries,²³ buildings, agriculture, and waste and other. It is important to note that this re-allocation simply re-categorizes emissions under different headings but does not change the overall magnitude of Canadian emissions estimates. Table 2–13 shows the distribution of emissions allocated on the basis of the economic sector from which they originate. Each economic sector includes emissions from energy-related and non-energy-related processes. Specifically, the oil and gas sector represents all emissions that are created in the exploitation, distribution, refining and upgrading of oil and gas products; the electricity sector represents all emissions from electric utility generation and transmission for residential, industrial and commercial users; the transportation sector represents all emissions arising from the tailpipes of domestic passenger and freight transport; the emissions-intensive trade-exposed industry sector represents emissions arising from mining activities, smelting and refining, and the production and processing of industrial goods such as paper or cement; the building sector represents emissions arising directly from residential homes and commercial buildings; the waste and other

sector represents emissions that arise from solid and liquid waste, from waste incineration, and from coal production, light manufacturing, construction and forestry activities; and finally, the agriculture sector represents all emissions arising from farming activities including those related to energy combustion for farming equipment as well as those related to crop and animal production.

Greenhouse gas emissions from the oil and gas, transportation, buildings and agriculture economic sectors increased by 62%, 32%, 19% and 26%, respectively, between 1990 and 2011, while emissions intensive trade exposed industries, electricity and waste & others declined by approximately 17%, 4% and 3%, respectively. The rate of growth in emissions is tied closely to Canadian energy use, which is determined by factors such as population growth, weather conditions, economic activity, and the energy intensity of that economic activity. The recent global economic downturn (occurring over the period of 2008 to 2009) is reflected in the emissions decrease in every sector of the Canadian economy around that time period. The economic downturn, coupled with factors such as government action to reduce emissions, changes to energy efficiency technology, and a decrease in the energy intensity of the economy, has resulted in a decline in GHG emissions between 2005 and 2011 in most economic sectors.

Canada's transportation sector is the largest contributor to Canada's greenhouse gas emissions, representing 24% of total emissions in 2011. Although there was a small increase in GHG emissions arising from transportation between 2010 and 2011 (2.4 Mt), the rate of growth in emissions has not returned to its trend prior to the economic downturn. Emissions rose by 39 Mt between 1990 and 2005, an increase of around 30% over the period. These trends in GHG emissions in the overall transportation sector are driven by differing trends in subsectors such as heavy-duty vehicles and light-duty vehicles. For example, although the average fuel efficiency of light-duty vehicles has been increasing, the number of light trucks on the road continues to rise. Other factors affecting these emissions include changing demographics, changes in personal travel demand, higher gasoline prices, and government policies.

In 2011, the oil and gas economic sector produced the second-largest share of greenhouse gas emissions in Canada (23%). Emissions from this sector increased by 61 Mt over the 1990 to 2005 time period as the sector expanded and adopted new extraction processes. However, GHG emis-

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

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

	1990	2000	2005	2007	2008	2009	2010	2011
<i>Mt CO₂ equivalent</i>								
NATIONAL GHG TOTAL	591	718	737	749	731	689	701	702
Oil and Gas	101	150	162	170	164	162	164	163
Upstream Oil and Gas	82	130	138	145	140	139	142	143
Natural Gas Production and Processing	34	55	56	58	55	50	49	47
Conventional Oil Production	22	34	32	32	30	29	29	30
Conventional Light Oil Production	11	12	10	10	10	9	10	10
Conventional Heavy Oil Production	11	21	21	20	19	18	18	18
Frontier Oil Production	0*	1	2	2	2	2	2	2
Oil Sands (Mining, In-situ, Upgrading)	15	25	34	41	42	48	52	55
Mining and Extraction	4	5	9	11	11	13	14	14
In-situ	5	8	11	14	17	18	21	23
Upgrading	7	12	14	16	14	17	18	18
Oil and Natural Gas Transmission	11	17	16	14	13	12	11	11
Downstream Oil and Gas	19	20	24	25	23	23	22	20
Petroleum Refining	18	18	22	23	21	21	20	18
Natural Gas Distribution	1	2	2	2	2	2	2	2
Electricity	94	129	121	120	112	97	99	90
Transportation	128	155	168	169	166	163	167	170
Passenger Transport	78	91	96	97	96	96	97	96
Cars, Trucks and Motorcycles	69	83	87	88	87	87	88	88
Bus, Rail and Domestic Aviation	8	8	9	9	9	8	8	8
Freight Transport	39	48	57	60	59	57	60	61
Heavy-duty Trucks, Rail	32	41	49	52	52	49	52	54
Domestic Aviation and Marine	6	6	8	8	7	7	8	7
Other: Recreational, Commercial and Residential	12	17	14	12	10	10	11	13
Emissions Intensive & Trade Exposed Industries	93	85	87	89	86	74	75	78
Mining	5	6	5	7	8	7	7	8
Smelting & Refining (Non-ferrous Metals)	17	14	12	12	12	10	10	11
Pulp & Paper	15	13	9	8	7	7	6	6
Iron & Steel	16	18	20	21	19	15	16	17
Cement	9	11	13	12	12	10	10	10
Lime & Gypsum	3	3	3	4	3	2	3	3
Chemicals & Fertilizers	28	20	24	25	26	22	23	24
Buildings	70	82	84	84	83	82	79	84
Service Industry	27	37	39	37	38	38	38	39
Residential	43	45	44	47	46	44	41	45
Agriculture	54	66	68	69	71	67	69	68
On-farm Fuel Use	8	10	9	12	12	10	13	14
Crop Production	18	20	19	21	23	22	22	22
Animal Production	29	36	39	37	36	34	33	32
Waste & Others	50	51	49	48	49	46	48	49
Waste	19	20	21	21	21	21	22	22
Coal Production	4	2	2	3	3	3	4	4
Light Manufacturing, Construction & Forest Resources	28	29	25	24	24	21	22	23

Note:

Totals may not add up due to rounding.

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

* Less than 0.5 Mt CO₂-eq

sions from the oil and gas sector have increased by only 1 Mt between 2005 and 2011. This short-term decrease is the result of a number of factors, including the economic downturn that resulted in a lower global demand for petroleum products, as well as the gradual exhaustion of traditional natural gas and oil resources in Canada.

Emissions from the electricity sector increased in parallel to rising demand for electricity both domestically and to satisfy export to the United States over the earlier years of the time period. Additionally, fossil fuel power generation increased its share over non-emitting sources such as hydro and nuclear power in the generating portfolio. Emissions from the electricity sector increased by 27 Mt over the 1990 to 2005 time period. More recently, electricity-related emissions have declined because of measures such as a return to service of a number of nuclear units and fuel switching to natural gas, as well as the closure of some coal-fired electricity generation facilities in Ontario. Further measures such as incremental fuel switching to natural gas and efficiency incentives coupled with the economic downturn have seen emissions decreased by a further 30 Mt between 2005 and 2011.

The emissions intensive trade exposed industry sector experienced some fluctuation in emissions over the time period. Emissions from this sector were responsible for 16% of total Canadian emissions in 1990, falling to 12% in 2005. In more recent years, emissions have fallen further as a result of the economic downturn and the continued evolution of Canadian production towards other sectors and services, representing a decrease of 9 Mt between 2005 and 2011. GHG emissions from the buildings sector had increased with population and commercial development but like all sectors of the economy, have fallen marginally in the recessionary period. Emissions from the agriculture sector and the waste and other sector have generally continued a slow upward or relatively stable trend throughout the time period, respectively.

The relationship between economic sectors and IPCC categories is demonstrated in Table 2–14.

2.5. Emission Trends for Ozone and Aerosol Precursors

Emissions of ozone and aerosol precursors fell over the 1990–2011 period. Sulphur oxides (SO_x) decreased by 60%, non-methane volatile organic compound (NMVOC) emissions declined by 28%, nitrogen oxides (NO_x) emissions were down by 24% and carbon monoxide emissions fell by 45%. (See Annex 10 for 2011 data tables.)

Table 2–14 2011 Greenhouse Gas Emissions by *National Inventory Report* category and economic category

National Inventory Category ^a												
ECONOMIC CATEGORY	Economic Category Total	Energy								Industrial Processes		
		Energy: Fuel Combustion				Energy: Fugitive				Mineral Products ^d	Chemical Industry ^e	Metal Production ^f
		Stationary Combustion			Transport	Fugitive (Unintentional)	Flaring	Venting (Production and Process)	Total			
		Stationary	Industrial Cogeneration ^c	Steam for Sale								
National Inventory total ^{a,b}	702	301	9.0	1.2	201	26.4	4.6	28.7	572	7.7	7.0	16.6
Oil and Gas	163	86.9	5.7	0.1	11.4	25.4	4.6	28.7	162.8			
Upstream Oil and Gas	143	71.3	5.3	-	11.3	23.2	4.5	27.4	142.9			
Natural Gas Production and Processing	47	22.4	0.6	-	1.0	11.6	0.8	10.4	46.9			
Conventional Oil Production	30	8.5	0.5	-	2.0	3.2	2.2	13.4	29.8			
Conventional Light Oil Production	10	3.4	0.1	-	1.5	1.5	1.4	2.1	10.0			
Conventional Heavy Oil Production	18	4.1	-	-	0.6	1.7	0.4	11.2	18.1			
Frontier Oil Production	2	0.9	0.4	-	0.0	0.0	0.4	0.0	1.7			
Oil Sands (Mining, In-situ, Upgrading) ^c	55	40.4	4.2	-	2.7	2.5	1.4	3.6	54.9			
Mining and Extraction	14	7.2	1.2	-	2.7	2.5	0.2	-	13.8			
In-situ	23	19.1	2.1	-	-	0.0	0.6	1.0	22.9			
Upgrading	18	14.1	0.9	-	-	0.0	0.7	2.6	18.3			
Oil and Natural Gas Transmission	11	-	-	-	5.5	5.8	0.0	0.0	11.3			
Downstream Oil and Gas	20	15.6	0.4	0.1	0.1	2.2	0.2	1.3	19.8			
Petroleum Refining	18	15.6	0.4	0.1	-	0.1	0.2	1.3	17.7			
Natural Gas Distribution	2	-	-	-	0.1	2.0	-	-	2.1			
Electricity	90	90.0		0.2					90.2			
Transportation ^b	170				167.1				167.1			
Passenger Transport	96				94.2				94.2			
Cars, Light Trucks and Motorcycles	88				86.2				86.2			
Bus, Rail and Domestic Aviation	8				8.0				8.0			
Freight Transport	61				59.9				59.9			
Heavy-duty Trucks, Rail	54				53.1				53.1			
Domestic Aviation and Marine	7				6.8				6.8			
Other: Recreational, Commercial and Residential	13				13.0				13.0			
Emissions Intensive & Trade Exposed Industries	78	30.7	2.6	0.9	3.0				37	7.7	7.0	16.6
Mining	8	4.4	0.7	-	2.7				7.8			
Smelting & Refining (Non-ferrous Metals)	11	3.1	0.0	0.0	0.1				3.2	0.0		6.8
Pulp & Paper	6	4.9	1.1	0.2	0.1				6.2	0.0		
Iron & Steel	17	4.4	0.0	-	0.1				4.6	0.1		9.8
Cement	10	4.0	-	-	0.0				4.1	5.7		
Lime & Gypsum	3	1.1	-	-	-				1.1	1.4		
Chemicals & Fertilizers	24	8.7	0.8	0.7	0.0				10.3	0.3	7.0	
Buildings	84	74.0	0.3						74.3			
Service Industry	39	29.6	0.3						29.9			
Residential	45	44.4							44.4			
Agriculture	68	3.4	0.0		10.9				14.4			
On-farm Fuel Use	14	3.4	0.0		10.9				14.4			
Crop Production	22											
Animal Production	32											
Waste	22								-			
Solid Waste	20								-			
Waste Water	1								-			
Waste Incineration	1								-			
Coal Production	4	1.1	-	-	1.8	1.0	-	-	3.9			
Light Manufacturing, Construction & Forest Resources	23	14.7	0.4	0.0	6.7				21.8	-	-	-
Light Manufacturing	15	13.2	0.4	0.0	0.8				14.4	-	-	-
Construction	6	1.3	-	-	4.6				5.9			
Forest Resources	2	0.1	0.0	-	1.3				1.5			

Notes: Totals may not add up due to rounding

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

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

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

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

d. A portion of emissions associated with diesel fuel used by the oil industry, reported as stationary combustion in the IPCC Sector categories, has been allocated to transport in the oil sands mining and extraction economic category.

National Inventory Category ^a												
Industrial Processes			Agriculture				Waste					
Consumption of Halocarbon and SF ₆	Other & Undifferentiated Production	Total	Manure Management	Enteric Fermentation	Agriculture Soils	Total	Solid Waste Disposal on Land	Waste Water Handling	Waste Incineration	Total	LULUCF ^b	
Mt CO ₂ equivalent												
7.7	15.3	54.3	6.4	18.0	29.5	53.9	20.1	1.0	0.7	21.7	87.3	National Inventory total ^{a,b}
	0.2	0.2										Oil and Gas
												Upstream Oil and Gas
												Natural Gas Production and Processing
												Conventional Oil Production
												Conventional Light Oil Production
												Conventional Heavy Oil Production
												Frontier Oil Production
												Oil Sands (Mining, In-situ, Upgrading) ^c
												Mining and Extraction
												In-situ
												Upgrading
												Oil and Natural Gas Transmission
	0.2	0.2										Downstream Oil and Gas
												Petroleum Refining
												Natural Gas Distribution
0.2		0.2										Electricity
2.5	0.1	2.6										Transportation ^h
1.6	0.1	1.6										Passenger Transport
1.5	0.1	1.5										Cars, Light Trucks and Motorcycles
0.1	0.0	0.1										Bus, Rail and Domestic Aviation
0.9	0.0	0.9										Freight Transport
0.8	0.0	0.8										Heavy-duty Trucks, Rail
0.1	0.0	0.1										Domestic Aviation and Marine
												Other: Recreational, Commercial and Residential
-	9.5	40.8										Emissions Intensive & Trade Exposed Industries
	0.1	0.1										Mining
-	0.6	7.4										Smelting & Refining (Non-ferrous Metals)
	-	0.0										Pulp & Paper
	2.8	12.8										Iron & Steel
		5.7										Cement
		1.4										Lime & Gypsum
	6.0	13.3										Chemicals & Fertilizers
4.1	5.1	9.2										Buildings
4.0	5.1	9.1										Service Industry
0.1		0.1										Residential
	0.0	0.0	6.4	18.0	29.5	53.9						Agriculture
						-						On-farm Fuel Use
					21.7	21.7						Crop Production
			6.4	18.0	7.8	32.2						Animal Production
							20.1	1.0	0.7	21.7		Waste
							20.1			20.1		Solid Waste
								1.0		1.0		Waste Water
									0.7	0.7		Waste Incineration
												Coal Production
0.9	0.4	1.3										Light Manufacturing, Construction & Forest Resources
0.9	0.1	1.0										Light Manufacturing
	0.1	0.1										Construction
	0.1	0.1										Forest Resources
											87.3	

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

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

g. Metal production includes iron and steel production, aluminum production, and SF₆ used in magnesium smelters and casters.

h. Emissions from the consumption of propane and natural gas in transportation are allocated to cars, light trucks and buses

* Less than 0.5 Mt CO₂ eq

Chapter 3

Energy (CRF Sector 1)

3.1. Overview

Overall, the Energy Sector contributed about 81% (or 572 Mt) of Canada's total greenhouse gas (GHG) emissions in 2011 (Table 3–1). The Energy Sector accounts for all GHG (CO₂, CH₄ and N₂O) emissions from stationary and transport fuel combustion activities as well as fugitive emissions from the fossil fuel industry.¹ Fugitive emissions associated with the fossil fuel industry are the intentional (e.g. venting) or unintentional (e.g. leaks, accidents) releases of GHGs that may result from production, processing, transmission and storage activities. Emissions from flaring activities by the oil and gas industry are reported in the Fugitive category, since their purpose is not to produce heat or to generate mechanical work (IPCC/OECD/IEA 1997).

Emissions resulting from stationary fuel combustion include, for example, the use of fossil fuels by the electricity generating industry, the oil and gas industry, the manufacturing and construction industry, and the residential and commercial sector. Only CH₄ and N₂O emissions result-

ing 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 CO₂ emissions resulting from the combustion 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 regard to aviation and marine) are reported as a memo item in the CRF tables.

As a result of efforts directed toward continuous improvements of methodologies and updates to underlying data, Energy Sector estimates have changed compared to Canada's last submission. These changes, or recalculations, are outlined in Table 3–2.

The most significant emission changes have resulted from updates to the background energy data, as documented in Canada's energy balances.² The energy balances are compiled annually; the most recent year's data are considered preliminary and are updated the following year. In this submission the most significant changes are observed to the 2010 data. For example, the source of the 11-Mt

1 Emissions associated with the non-energy use of fossil fuels are allocated to Industrial Processes.

2 The energy balances are reported in Statistics Canada's *Report on Energy Supply–Demand in Canada* (RES-D, #57003),

Table 3–1 GHG Emissions from Energy, Selected Years

GHG Source Category	GHG Emissions (kt CO ₂ eq)							
	1990	2000	2005	2007	2008	2009	2010	2011
Energy Sector	469 000	589 000	597 000	610 000	592 000	560 000	570 000	572 000
Fuel Combustion (1.A)	427 000	526 000	534 000	547 000	530 000	502 000	512 000	512 000
Energy Industries (1.A.1)	145 000	197 000	194 000	194 000	182 000	166 000	166 000	155 000
Manufacturing Industries and Construction (1.A.2)	64 300	68 800	69 000	77 900	76 400	73 200	77 700	80 500
Transport (1.A.3)	146 000	180 000	193 000	195 000	194 000	186 000	196 000	199 000
Other Sectors (1.A.4)	71 600	80 700	78 400	79 300	78 100	75 900	72 200	77 900
Fugitive Emissions from Fuels (1.B)	42 400	63 000	63 400	63 000	62 000	58 800	58 600	59 700

Note: Totals may not add up due to rounding.

Table 3–2 GHG Emission Recalculations in Energy Sector (2013 Submission Compared to 2012 Submission)

GHG Source Category	GHG Emissions (kt CO ₂ eq)						
	1990	2000	2005	2007	2008	2009	2010
Energy Sector	1 956	868	-2 006	-1 726	1 184	195	8 485
Fuel Combustion (1.A)	1 953	869	-2 040	-1 699	1 212	231	8 537
Energy Industries (1.A.1)	2 294	1 233	2 077	2 915	5 759	3 856	11 447
Manufacturing Industries and Construction (1.A.2)	-339	-548	-2 020	-2 886	-2 523	-2 678	-3 345
Transport (1.A.3)	0.0	0	-13	-419	180	-384	878
Other Sectors (1.A.4)	-2.8	184	-2 084	-1 309	-2 204	-563	-443
Fugitive Emissions from Fuels (1.B)	3.3	-1.2	35	-27	-29	-36	-51

Note: Totals may not add up due to rounding.

recalculation of emissions from the Energy Industries³ in 2010 is related to an update of energy consumption in the oil and gas industry. Additional updates (having lesser impacts on the recalculations) have been incorporated into the energy balances. These are described in Section 3.2.1.5.

As indicated above, methodological improvements have also affected the recalculations. In this year's submission, these updates have all consisted of emission factor updates (see Section 3.2.1.5).

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 2011, about 512 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

have increased by 20% since 1990 and have remained steady since 2010. Between 1990 and 2011, combustion-related emissions from the Energy Industries and from the Transport category increased by about 7% 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 2011, the Energy Industries subsector accounted for 155 Mt (or about 22%) of Canada's total GHG emissions, an increase of about 7% since 1990. The Public Electricity and Heat Production subsector accounted for 60% (or 93 Mt) of the Energy Industries' GHG emissions, while Petroleum Refining, and the Manufacture of Solid Fuels and Other Energy Industries contributed 10% (16 Mt) and 29% (45 Mt), respectively (Table 3-3). Additional discussions on trends in emissions from the Energy Industries subsector are to be found in the Emission Trends chapter (Chapter 2).

The Energy Industries subsector includes all emissions from stationary fuel combustion sources related to utility electricity generation and many of the emissions from the production, processing and refining of fossil fuels. All of the emissions associated with the fossil fuel industry are estimated, although a portion of emissions from coal

³ The change is a result of a restatement of natural gas consumption in the category of Manufacture of Solid Fuel and Other Energy Industries, which is reported as *Fossil Fuel Production* in Annex 12 and Table S-1.

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

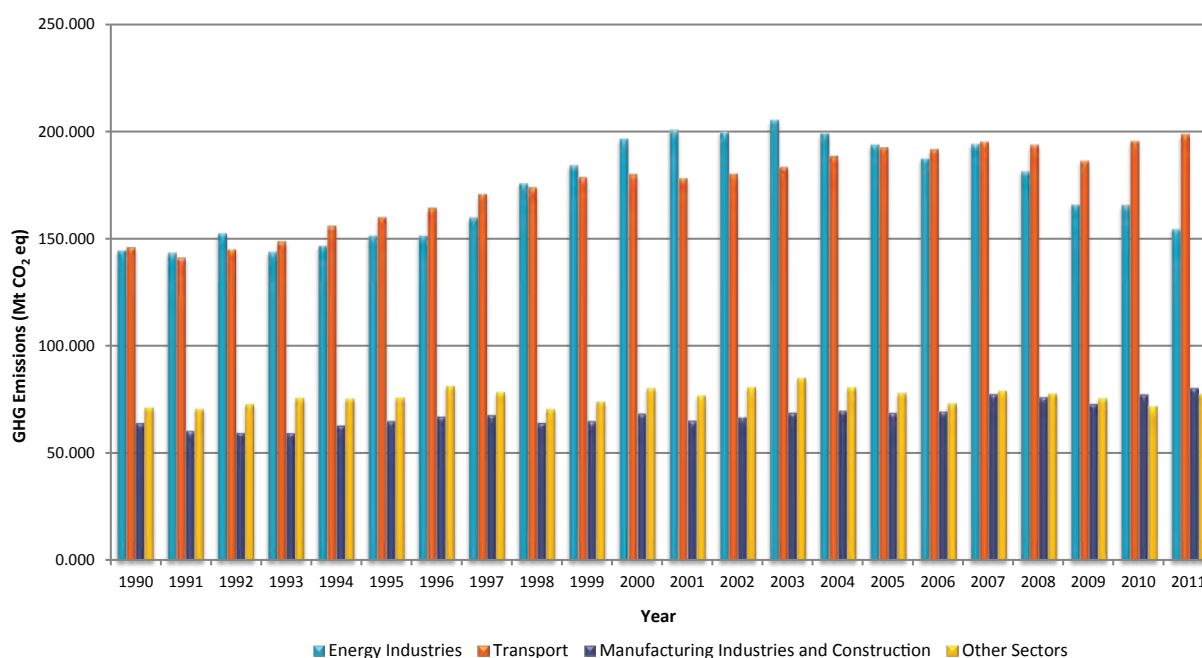


Table 3–3 Energy Industries GHG Contribution

GHG Source Category	GHG Emissions (kt CO ₂ eq)							
	1990	2000	2005	2007	2008	2009	2010	2011
Energy Industries TOTAL (1.A.1)	145 000	197 000	194 000	194 000	182 000	166 000	166 000	155 000
Public Electricity and Heat Production	93 600	129 000	123 000	122 000	115 000	99 600	101 000	93 300
Petroleum Refining	17 000	16 000	20 000	21 000	19 000	19 000	18 000	16 000
Manufacture of Solid Fuels and Other Energy Industries	34 000	51 000	51 000	51 000	47 000	48 000	47 000	45 000

Notes: Totals may not add up due to rounding.

mining and from oil and gas extraction (including oil sands mining, extraction and upgrading) associated with the Manufacture of Solid Fuels and Other Energy Industries category have been allocated to the Manufacturing Industries and Construction—Mining and the Transport—Other subsectors, because fuel consumption data at a lower level of disaggregation are not available. Combustion emissions associated with the pipeline transmission of oil and natural gas are included under Other Transportation according to the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997).

Although actually associated with the Energy Industries, emissions from venting and flaring activities related to the production, processing and refining of fossil fuels are reported as fugitive emissions (refer to Section 3.3, Fuel Combustion (CRF Category 1.A)).

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

The Public Electricity and Heat Production category includes emissions associated with the production of electricity and heat from the combustion of fuel in public utility thermal power plants.⁴ The estimated GHG emissions from this sector do not include emissions from industrial generation; rather, these emissions have been allocated to the specific industrial sectors.

The electricity supply grid in Canada includes combustion-derived electricity as well as hydro, nuclear and other renewables (wind, solar and tidal power). Total power generated from wind, tidal and solar resources is

⁴ Category as defined by Statistics Canada.

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

Emissions of CH₄ and N₂O from the combustion of landfill gas (LFG) for heat, steam and electricity generation are included, while CO₂ 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). CO₂ generated as a by-product during the production of hydrogen in the steam reforming of natural gas is reported in the Fugitive category (Section 3.3).

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

The Manufacture of Solid Fuels and Other Energy Industries category comprises fuel combustion emissions associated with the crude oil, natural gas, oil sands mining, bitumen extraction and upgrading, and coal mining industries. A portion of emissions associated with coal mining and oil and gas extraction (which includes oil sands mining, extraction and upgrading) are reported in the Manufacturing Industries and Construction–Mining category, whereas emissions associated with pipeline transmission and with the use of transport fuels (such as gasoline and diesel oil) in off-road applications in the mining and the oil & gas mining and extraction industry are reported under Other Transportation, since the fuel data cannot be further

disaggregated in the national energy balance as compiled by Statistics Canada.

Upgrading facilities are responsible for producing synthetic crude oil based on a feedstock of bitumen produced by oil sands mining, extraction and *in-situ* recovery activities (e.g. thermal extraction). The synthetic (or upgraded) crude oil has a hydrocarbon composition similar to that of conventional crude oil, which can be refined to produce RPPs such as gasoline and diesel oil. Upgrading facilities also rely on natural gas as well as internally generated fuels such as process 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). Landfill gas 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 are allocated to the industry that produces the energy under the appropriate industrial category within the Energy Sector, regardless of whether the energy is for sale or for internal use. The rationale for this is that the IPCC recognizes that it is difficult to disaggregate emissions in cogeneration facilities (i.e. to separate the electricity component from the heat component of fuel use). Statistics Canada fuel-use data in the RESD do distinguish industrial electricity generation data, but aggregate the data into one category titled industrial electricity generation. Industrial electricity generation emissions were reallocated to their respective industrial subsectors using the RESD input data. The methodology is described in greater detail in Annex 2.

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

Emissions for this category are calculated using all fuel use attributed to the petroleum refining industry and include all petroleum products (including still gas, petroleum coke

and diesel) reported as producerconsumed/own consumption 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 (refer to Section 3.3.2). The fuel-use and emission data associated with flaring are subtracted to avoid double counting.

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

Emissions for this category are calculated using all fuel use attributed to fossil fuel producers (including petroleum coke, still gas, natural gas, natural gas liquids [NGLs] and coal 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 range for the Energy Industries subsector is $\pm 7\%$ for all gases and $\pm 7\%$ for CO₂ alone.

The uncertainties for the Energy Industries subsector are largely dependent on the collection procedures used for the underlying activity data as well as on the representativeness of the emission factors for specific fuel properties. Commercial fuel volumes and properties are generally well known, whereas there is greater uncertainty surrounding both the reported quantities and properties of non-marketable fuels (e.g. *in-situ* use of natural gas from the producing wells and the use of refinery fuel gas). For example, in the Petroleum Refining category, the CO₂ 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 CO₂ factors for commercial fuels. New coal CO₂ emission factors were developed using statistical methods and 95% confidence intervals.

Approximately 68% of the 2011 emissions from the Manufacture of Solid Fuels and Other Energy Industries category are associated with the consumption of natural gas in the natural gas production and processing, conventional crude oil and *in-situ* bitumen extraction industries. The uncertainty for this fuel is influenced by the CO₂ emission factors ($\pm 6\%$) and CH₄ emission factors (0% to +240%) for the consumption of unprocessed natural gas. Provincially

weighted natural gas emission factors were used to estimate emissions for the natural gas industry due to a lack of plant-level information, such as the physical composition of unprocessed natural gas (which will vary from plant to plant). Thus, the overall uncertainty estimate is based on a rather broad assumption as well.

The estimated uncertainty for CH₄ ($\pm 39\%$) and N₂O ($\pm 38\%$) emissions for the Energy Industries subsector is influenced by the uncertainty associated with the emission factors (ICF Consulting 2004). Additional expert elicitation is required to improve the CH₄ and N₂O uncertainty estimates for some of the emission factor uncertainty ranges and probability density functions developed by ICF Consulting, since insufficient time was available to have these assumptions reviewed by industry experts. The estimates for the Energy Industries subsector are consistent over time and calculated using the same methodology. A discussion on activity data based on RESD fuel use information is presented in Section 3.2.1.5, Recalculations.

3.2.1.4. QA/QC and Verification

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

Minor activity data revisions 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

Several improvement activities have contributed to increased accuracy of the data, as well as to their comparability and consistency with that of the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997) and UNFCCC requirements. As discussed below in more detail, revised

activity data and improved emission factors contributed to recalculations along with the reallocation of emissions in the Public Electricity and Heat Production, the Petroleum Refining, and the Manufacturing of Solids and Other Energy Industries categories.

Activity Data: The 2004–2010 RESD fuel-use data were revised by Statistics Canada, and estimates were recalculated accordingly. Statistics Canada implemented several important methodological enhancements to the RESD based on the following:

- direct use of the annual Industrial Consumption of Energy (ICE) survey to better account for the manufacturing industries' fuel consumption values;
- reallocation of refined petroleum products resulting from the Survey of Secondary Distributors; and
- use of the North American Industrial Classification System (NAICS).

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

Although these improvements have increased the quality of information available for reporting and analysis purposes, data for 1995 to 2003 have not yet been revised to complete the historical trend. Work is underway to address the resultant time series consistency (prior to 2003).

Emission Factors: Revisions to the following emission factors resulted in recalculations:

- Coal: A more accurate and statistically verified methodology to determine coal CO₂ emission factors was developed for the 2011 submission. In the 2013 submission these emission factors have been updated and are within 6% of the preliminary values.
- Landfill Gas: emission factors for CO₂, CH₄ and N₂O were updated. Previously these factors were based on energy units, but landfill gas activity data are reported in mass units, which led to additional unnecessary and inaccurate conversions. The updated landfill gas emission factors have been accurately converted to equivalent values in mass units.
- Natural Gas: a typo in the emission factor for CH₄ for producer consumption was corrected in the stationary model. The corrected factor is within 1.6% of the previous value.
- Petroleum Coke – refineries & others: the N₂O emission factor was corrected. The original emission factor was calculated using an energy conversion factor meant for aviation gasoline rather than petroleum coke –

refineries. This correction results in an overall increase of less than 1 kt in total CO₂ eq emissions in 2011.

- Petroleum Coke – upgraders: the N₂O emission factor was corrected. The original emission factor was calculated using an energy conversion factor meant for aviation turbo fuel rather than petroleum coke – upgraders. This correction results in an overall increase of about 4 kt in total CO₂ eq emissions in 2011.
- Propane: the rounding of the CO₂ emission factor was corrected from 1510 kg/m³ to 1507 kg/m³.
- Coke Oven Gas: A new emission factor, based on a fully documented country-specific approach (McCann 2000) was adopted for this submission.
- Waste Fuel: Emission factors for CO₂, CH₄ and N₂O were added to replace the waste tire emission factors. The 1996 IPCC Guideline default values were used for CH₄ and N₂O. The emission factor for CO₂ was determined using fuel composition data collected from the Cement Association of Canada and emission factors from the WBCSD Cement Sustainability Initiative (WBCSD 2011).

All emission factors are documented in Annex 8.

Public Electricity and Heat Production: The method developed to properly reallocate the fuels used to generate electricity by industry (as discussed in Annex 2) to their respective industrial sources was modified in order to ensure all of the fuel was reallocated. This change ensures that the overall energy balance is maintained, and is consistent with the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997).

IPCC Fuel Categorization: In the Expert Review Team's (ERT) 2012 (and previous) Annual Review Reports of Canada's National Inventory (UNFCCC 2012), it was recommended that Canada report all fuels in standard IPCC reporting categories. Following the ERT's recommendations, emissions in the CRF table are presented by IPCC fuel categorization, rather than Canada's previous practice that took into consideration the physical state of the fuel at time of use. This reallocation approach is not a recalculation. Though it may give the appearance of a recalculation in the CRF tables, it is simply a redistribution by fuel categories (e.g. liquid, solid and gaseous fuels).

3.2.1.6. Planned Improvements

With the proliferation of publicly reported data, Tier 3 methods for the Public Electricity and Heat Production category are being investigated with the eventual goal of developing a bottom-up inventory. Increases in the usage of combined heat and power plants (and co-generation

systems) require additional research and investigation to ensure that emissions are appropriately allocated.

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

3.2.2.1. Source Category Description

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

In 2011, the Manufacturing Industries and Construction subsector accounted for 81 Mt (or 11%) of Canada's total GHG emissions, with a 25% (16.2 Mt) increase in overall emissions since 1990 (refer to Table 3–4 for more details). Within the Manufacturing Industries and Construction subsector, 56.6 Mt (or 70%) of the GHG emissions are from the Others category. The Others category is made up of cement, mining, construction and other manufacturing activities. This category is followed by (in order of decreasing contributions) the Chemical Industries; Pulp, Paper and Print; Iron and Steel; and Non-ferrous Metals categories, at

10 Mt (or 12.7%), 6.2 Mt (or 7.7%), 4.4 Mt (or 5.5%), and 3.1 Mt (or 3.9%), respectively. Emissions from Food Processing, Beverages and Tobacco are included in the Other Manufacturing subcategory due to fuel-use data not being available at the appropriate level of disaggregation.

Industrial emissions resulting from fuel combustion for the generation of electricity or steam for sale have been assigned to the appropriate industrial subsector. Emissions generated from the use of fossil fuels as feedstocks or chemical reagents such as for use as metallurgical coke during the reduction of iron ore are reported under the Industrial Processes Sector to ensure that the emissions are not double counted.

3.2.2.2. Methodological Issues

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

Table 3–4 Manufacturing Industries and Construction GHG Contribution

GHG Source Category	GHG Emissions (kt CO ₂ eq)							
	1990	2000	2005	2007	2008	2009	2010	2011
Manufacturing Industries and Construction TOTAL (1.A.2)	64 300	68 800	69 000	77 900	76 400	73 200	77 700	80 500
Iron and Steel	4 950	6 050	5 570	5 990	5 760	4 280	4 440	4 410
Non-ferrous Metals	3 260	3 230	3 570	3 750	3 750	2 810	2 950	3 110
Chemicals	8 220	9 400	8 290	8 670	8 750	8 830	9 910	10 200
Pulp, Paper and Print	14 500	12 300	8 770	7 850	6 400	6 510	6 090	6 190
Food Processing, Beverages and Tobacco ¹	IE	IE	IE	IE	IE	IE	IE	IE
Others	33 400	37 800	42 800	51 600	51 700	50 700	54 300	56 600
Cement	3 920	4 330	5 380	5 040	4 910	4 480	4 030	4 050
Mining	6 590	12 100	18 900	28 900	30 000	31 700	35 000	36 400
Construction	1 870	1 070	1 440	1 390	1 370	1 210	1 500	1 330
Other Manufacturing	21 000	20 300	17 100	16 300	15 500	13 400	13 700	14 700

Note:

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

IE = included elsewhere.

Totals may not add up due to rounding.

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

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

Non-ferrous Metals (CRF Category 1.A.2.b)

All fuel-use data for this category were obtained from the RESD.

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

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

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

Fuel-use data include industrial wood wastes and spent pulping liquors combusted for energy purposes. Emissions of CH₄ and N₂O from the combustion of biomass are included in the pulp and paper industrial category. CO₂ emissions from biomass combustion are not included in totals but are reported separately in the UNFCCC CRF tables as a memo item.

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

This category includes the remainder of industrial sector emissions, including the 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 is $\pm 2\%$ for all gases.

The underlying fuel quantities and CO₂ emission factors have low uncertainty because they are predominantly commercial fuels, which have consistent properties and a more accurate tracking of quantity purchased for consumption. Coal CO₂ emission factor uncertainties were recently updated with 95% confidence intervals (as discussed in Section 3.2.1.3).

As stated in the Energy Industries subsector uncertainty discussion, additional expert elicitation is required to improve the CH₄ and N₂O uncertainty estimates for some of the emission factor uncertainty ranges and probability density functions developed by the ICF Consulting study (ICF Consulting 2004), since these assumptions were not reviewed by industry experts owing to a lack of available time in the study's preparation.

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

3.2.2.4. QA/QC and Verification

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

Tier 1 QC checks were completed on the entire stationary combustion GHG estimation model, which included checks of emission factors, activity data and CO₂, CH₄ and N₂O estimates for the entire time series. No mathematical or reference errors were found during the QC checks. The data, methodologies and changes related to the QC activities are documented and archived in both paper and electronic form.

3.2.2.5. Recalculations

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

Emission Factors: Several emission factors were revised, which resulted in recalculations. Refer to Section 3.2.1.5 for more details.

3.2.2.6. Planned Improvements

As this is an activity that is continuously being improved, Environment Canada, Natural Resources Canada and Statistics Canada are working jointly to improve the underlying quality of the national energy balance and to further disaggregate fuel-use information.

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

Transport-related emissions account for 28% of Canada's total GHG emissions (199 Mt—refer to Table 3–5 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 111% (22.4 Mt) for LDGTs and 109% (21.8 Mt) for HDDVs. A long-term decrease in some Transport categories has also been registered: specifically, reductions in emissions from light-duty gasoline vehicles (LDGVs, i.e. cars), propane and natural gas vehicles, pipelines, domestic aviation, heavy-duty gasoline vehicles (HDGVs) and railways, for a combined decrease of 10.2 Mt since 1990. Generally, emissions from the Transport subsector have increased 36% and have contributed the equivalent of 47% 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).

Table 3–5 Transport GHG Contribution

GHG Source Category	GHG Emissions (kt CO ₂ eq)							
	1990	2000	2005	2007	2008	2009	2010	2011
Transport TOTAL (1.A.3.)	146 000	180 000	193 000	195 000	194 000	186 000	196 000	199 000
Civil Aviation (Domestic Aviation)	7 100	7 400	7 600	7 700	7 300	6 400	6 400	6 000
Road Transport	96 700	118 000	130 000	133 000	132 000	132 000	134 000	135 000
Light-duty Gasoline Vehicles	45 500	42 100	40 200	40 000	39 500	39 700	40 000	39 500
Light-duty Gasoline Trucks	20 300	36 400	42 700	42 700	42 300	42 500	42 900	42 700
Heavy-duty Gasoline Vehicles	7 440	5 470	6 540	6 750	6 800	6 910	7 020	7 130
Motorcycles	152	162	254	262	263	266	271	273
Light-duty Diesel Vehicles	469	466	574	616	652	699	750	798
Light-duty Diesel Trucks	702	1 660	1 920	2 010	2 020	2 030	2 090	2 160
Heavy-duty Diesel Vehicles	20 000	30 900	37 600	39 500	39 200	39 000	40 200	41 800
Propane & Natural Gas Vehicles	2 200	1 100	720	830	880	780	780	820
Railways	7 000	7 000	7 000	7 000	8 000	5 000	7 000	7 000
Navigation (Domestic Marine)	5 000	5 100	6 700	6 800	6 500	6 700	7 000	6 000
Other Transport	30 000	43 000	41 000	41 000	41 000	36 000	42 000	45 000
Off-road Gasoline	7 800	8 800	8 300	8 000	7 300	7 300	7 900	9 400
Off-road Diesel	16 000	23 000	23 000	24 000	26 000	23 000	28 000	30 000
Pipelines	6 850	11 200	10 100	8 380	7 460	6 310	5 670	5 600

Note: Totals may not add up due to rounding.

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) and the Aviation Greenhouse Gas Emission Model (AGEM). These models incorporate a version of the IPCC-recommended methodology for vehicle modelling (IPCC/OECD/IEA 1997) and are used to calculate all transport emissions with the exception of those associated with pipelines (energy necessary to propel oil or natural gas).

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

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

The methodologies for the Civil Aviation category are fuel-type dependent. They follow a modified IPCC Tier 1 approach for aviation gasoline and a modified IPCC Tier 3 approach for aviation turbo fuel. Emissions estimates employ a mix of country-specific, plane-specific and IPCC default emission factors. The estimates attributed to aviation gasoline consumption are performed within MGEM, while those attributed to aviation turbo fuel are generated using AGEM. The estimates are calculated based on the reported quantities of aviation gasoline and turbo fuel consumed (IPCC/OECD/IEA 1997), as published in the RESD (Statistics Canada #57-003). Aviation fuel sales are reported in the RESD; these figures represent aviation fuels sold to Canadian airlines, foreign airlines, public adminis-

tration and commercial/institutional sectors. All aviation gasoline use is designated domestic, other than that reported under foreign airlines (refer to Annex 2 for a description of the methodology).

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

The methodology used to estimate road transportation GHG emissions is a detailed IPCC Tier 3 method (except for propane and natural gas vehicles, for which an IPCC Tier 1 method is followed), as outlined in IPCC/OECD/IEA (1997). MGEM disaggregates vehicle data and calculates emissions of CO₂, CH₄, and N₂O from all mobile sources except pipelines (refer to Annex 2 for a description of the methodology).

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

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

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

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

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

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

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

Off-road Transport

Non-road or off-road transport⁵ (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 drilling and extraction activities) both operate significant numbers of heavy non-road vehicles and are the largest diesel fuel users in the group.

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

Pipeline Transport

Pipelines⁶ 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 consumed as a backup during power failures.

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

3.2.3.3. Uncertainties and Time-Series Consistency

The Transport subsector employs a Monte Carlo uncertainty analysis, established upon the recommendations and results reported in *Quantitative Assessment of Uncertainty*

in *Canada's National GHG Inventory Estimates for 2001* (ICF Consulting 2004). Several modifications were introduced into the original model in order to more accurately reflect uncertainties in the latest Transport subsector emissions estimates.

Modifications to the original assessment include the addition of biofuel emission factor uncertainties, based on the assumption of similarities in emission control technologies between conventional transport fuels and biofuels. Biofuel activity data uncertainties were based on expert judgement. Aviation turbo fuel CH₄ and N₂O emission factor uncertainties have been updated from those recommended in the ICF Consulting report to better reflect the improvements made by implementing AGEM. A number of on-road CH₄ and N₂O emission factor uncertainties have also been modified from their values in the original Monte Carlo simulation based on recent laboratory data. Additionally, a thorough verification of the 2004 ICF Consulting report revealed a number of discrepancies in referenced uncertainty ranges. In these instances, the discrepancy was corrected to coincide with the original reference.

Transport 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 2011 estimates for the mobile Transport subsector (not including pipelines) was estimated to be between -1.9% and +5.0%.

The uncertainty for Transport fuel combustion CO₂ emissions was $\pm 0.4\%$. In contrast, and similar to the stationary fuel combustion sources, CH₄ and N₂O emission uncertainty ranges were two to three orders of magnitude greater than that of CO₂. Hence, the overall uncertainty for the mobile Transport subsector reflects the predominance of CO₂ in total GHG emissions.

Emissions from Civil Aviation (Domestic Aviation)

The uncertainty associated with overall emissions from domestic aviation was estimated to be within the range of -1% to +5%. This implied that the source category was more likely underestimated than overestimated. The high uncertainties associated with jet kerosene CH₄ (-50% to +50%) and N₂O emission factors (-70% to +150%) resulted in a downward bias on the inventory. These effects were somewhat reduced by the large contribution of jet

⁵ Referred to as non-road or off-road vehicles. The terms "non-road" and "off-road" are used interchangeably.

⁶ Consisting of both oil and gas types.

kerosene CO₂ emissions and its comparatively low emission factor uncertainty. The Civil Aviation category only contributed approximately 3% to total Transport GHG emissions and therefore did not greatly influence overall uncertainty levels.

Emissions from Road Transportation

The uncertainty related to the overall emissions from on-road vehicles was estimated to be within the range of $\pm 1\%$, driven primarily by the relatively low uncertainties in gasoline and diesel activity data and their related CO₂ emissions. Conversely, the high uncertainties associated with CH₄ and N₂O emissions, as well as biofuel activity data, did not greatly influence the analysis due to their comparatively minor contributions to the inventory. Approximately 68% of the Transport subsector's GHG emissions were attributable to on-road transportation. Accordingly, the Transport subsector's relatively low inventory uncertainty is justified through the results of the Road Transportation category uncertainty analysis.

Emissions from Railways

The uncertainty associated with emissions from rail transport was estimated to be between -11% and +31%, indicating that this category was potentially underestimated. The greatest influence was exerted by the high N₂O emission factor uncertainty (-90% to +900%), whereas the relatively low uncertainties in diesel activity data and CO₂ emission factors contributed very little. It is important to note that railway emissions only accounted for approximately 3% of the Transport subsector GHG inventory and therefore did not greatly influence the overall uncertainty results.

Emissions from Navigation (Domestic Marine)

The uncertainty associated with emissions from the domestic marine source category ranged from -7% to +14%, suggesting that GHGs were potentially underestimated. The high N₂O emission factor uncertainty (-90% to +900) represented the largest contribution to uncertainty, while CO₂ 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 -8% to +25%, indicating that the 2013 submission likely underestimates total emissions from this subcategory. 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 offroad 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 N₂O emission uncertainty for gasoline and diesel fuels (-90% to +900%), which indicated a downward bias in the GHG estimate. Approximately 20 % of the Transport subsector's GHG emissions were attributable to off-road transportation and therefore it had a significant effect on the overall uncertainty analysis.

Summary

Generally, for the Transport subsector, the ICF Consulting study incorporated uncertainty values for CO₂, CH₄ and N₂O emission factors from two other reports—McCann (2000) and SGA Energy Ltd. (2000). The ICF Consulting study included values determined in these reports, along with limited expert elicitations addressing the uncertainty of the activity data contributing to the Transport subsector estimates within its Monte Carlo analysis. A number of incremental improvements have been incorporated into the original analysis, as described in the opening paragraphs of Section 3.2.3.3.

Some of the weaker components of the uncertainty analysis surround the acquisition of expert opinions on non-fuel-quantity-type activity estimates (e.g. vehicle populations, kilometres travelled, motorcycle numbers). Although it was suggested that the vehicle population data supplied by an outside consultant to Environment Canada are 100% accurate, this is unlikely, and there are indications that compilation errors exist. Presently, inventory practitioners are conducting a study to re-establish the time series for the Canadian fleet. The current fleet uncertainty will introduce only marginal errors in a fuelconstrained model, but it has considerable impact on the attribution of that fuel to specific vehicle types.

3.2.3.4. QA/QC and Verification

Tier 1 QC checks as elaborated in the framework for the QA/QC plan (see Annex 6) were performed on all categories in Transport, not just those designated as “key.” No significant mathematical errors were found. The QC activities are documented and archived in paper and electronic form.

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

3.2.3.5. Recalculations

Transportation estimates were revised for the 2004–2010 period according to the following factors:

Statistics Canada Fuel Consumption Data: A revised data set for energy consumption was released, resulting in minor adjustments of estimates for those years. A discussion on updated RESD fuel use data is presented in Section 3.2.1.5, Recalculations.

Statistics Canada Taxed Fuel Sales Data: A revised data set for 2010 was received. Minor adjustments resulted for that year.

3.2.3.6. Planned Improvements

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

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

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

3.2.4.1. Source Category Description

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

Biomass⁷ combustion is a significant source of emissions in the residential sector, and CH₄ and N₂O emissions are included in the subsector estimates. However, CO₂ emissions from biomass combustion are reported separately in the CRF tables as memo items and are not included in Energy Sector totals. This method is consistent with the treatment of biomass in the Pulp, Paper and Print category.

In 2011, the Other Sectors subsector contributed 77.9 Mt (or 11%) of Canada's total GHG emissions, with an overall growth of about 8.8% (6.3 Mt) since 1990. Within the Other Sectors subsector, residential emissions contributed about 44 Mt (or 57%), followed by a 29.9 Mt (or 38%) contribution from the Commercial/Institutional category, which also includes emissions from the public administration sec-

⁷ Typically firewood.

Table 3–6 Other Sectors GHG Contribution

GHG Source Category	GHG Emissions (kt CO ₂ eq)							
	1990	2000	2005	2007	2008	2009	2010	2011
Other Sectors TOTAL (1.A.4)	71 600	80 700	78 400	79 300	78 100	75 900	72 200	77 900
Commercial/Institutional	25 700	33 300	31 900	30 200	29 600	29 400	28 000	29 900
Commercial and Other Institutional	23 700	31 000	29 900	28 100	27 600	27 400	26 200	28 000
Public Administration	1 980	2 290	2 050	2 090	2 000	2 030	1 800	1 880
Residential	43 000	45 000	44 000	47 000	46 000	44 000	41 000	44 000
Agriculture/Forestry/Fisheries	2 390	2 540	2 100	2 610	2 610	2 530	2 880	3 550
Forestry	60	70	160	180	170	170	190	140
Agriculture	2 300	2 500	1 900	2 400	2 400	2 400	2 700	3 400

Note: Totals may not add up due to rounding.

tor (i.e. federal, provincial and municipal establishments). Since 1990, GHG emissions have grown by about 16% in the Commercial/Institutional category, while GHG emissions in the Residential category have increased by about 2%. Refer to Table 3–6 for additional details. Additional trend discussion for the Other Sectors subsector is presented in the Emission Trends chapter (Chapter 2).

3.2.4.2. Methodological Issues

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

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

Emissions are based on fuel-use data reported as commercial and public administration in the RESD.

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

Emissions are based on fuel-use data reported as residential in the RESD. The methodology for biomass combustion from residential firewood is detailed under CO₂ Emissions from Biomass (Section 3.4.2); although CO₂ emissions are not accounted for in the national residential GHG total (but reported as a memo item), the CH₄ and N₂O emissions are reported here.

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

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

3.2.4.3. Uncertainties and Time-Series Consistency

The estimated uncertainty range for the Other Sectors subsector is $\pm 5\%$ for all gases and $\pm 5\%$ for CO₂.

The underlying fuel quantities and CO₂ emission factors have low uncertainties, since they are predominantly commercial fuels, which have consistent properties and accurate tracking. Although the non-CO₂ emissions from biomass combustion contributed only 6% to the total Residential category, its CH₄ (-90% to +1500%) and N₂O (-65% to +1000%) uncertainties are high due to the uncertainty associated with their emission factors (ICF Consulting 2004). As stated in the Energy Industries subsector, additional expert elicitation is required to improve the CH₄ and N₂O uncertainty estimates for some of the emission

factor uncertainty ranges and probability density functions developed by the ICF Consulting study, since insufficient time was available to have these assumptions reviewed by industry experts.

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

3.2.4.4. QA/QC and Verification

The Other Sectors subsector underwent Tier 1 QC checks in a manner consistent with IPCC Good Practice Guidance (IPCC 2000). No mathematical or referencing errors were observed during the QC checks, while minor data errors were discovered and corrected. The data, methodologies, and changes related to the QC activities are documented and archived in both paper and electronic form.

3.2.4.5. Recalculations

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

Emission Factors: Several emission factors were revised, which resulted in recalculations. Refer to the emission factor discussion in Section 3.2.1.5 for more details.

3.2.4.6. Planned Improvements

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

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

The UNFCCC reporting guidelines assign military fuel combustion to this subsector. Turbo fuel emissions generated by military air transportation are estimated by AGEM and are included under this category. However, military emissions generated by consuming aviation gasoline are included under Civil Aviation (CRF Category 1.A.3.a), since the current data source for this type of fuel consolidates military and civil fuel use. As in previous submissions, emissions related to military vehicles have been included in the Transport subsector, whereas stationary military fuel

use has been included under the Commercial/Institutional category (Section 3.2.4) due to fuel data allocation in the RESD (Statistics Canada #57-003). This is a small source of emissions.

3.3. Fugitive Emissions (CRF Category 1.B)

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

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

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

In 2011, the Fugitives category accounted for about 59.7 Mt (or 8.5%) of Canada's total GHG emissions, with about a 41% growth in emissions since 1990. Between 1990 and 2011, fugitive emissions from oil and natural gas increased 46% to 58.7 Mt, and those from coal decreased by about 1.2 Mt from about 2.2 Mt in 1990. The oil and gas production, processing, transmission and distribution activities contributed 98% of the fugitive emissions. Refer to Table 3–7 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 CH₄. In coal deposits, CH₄ is either trapped under pressure in porous void spaces within the coal formation or is adsorbed to the coal. The pressure and amount of CH₄ in the deposit vary depending on the grade, the depth and the surrounding geology of the coal seam. During coal mining, post-mining activities and coalhandling activities, the natural geological formations are disturbed, and pathways are created that release the pressurized CH₄ to the atmosphere. As the pressure on the coal is lowered,

Table 3–7 Fugitive GHG Contribution

GHG Source Category	GHG Emissions (kt CO ₂ eq)							
	1990	2000	2005	2007	2008	2009	2010	2011
Fugitive Emissions from Fuels (1.B)	42 400	63 000	63 400	63 000	62 000	58 800	58 600	59 700
Solid Fuels—Coal Mining (1.B.1)	2 000	1 000	1 000	1 000	900	900	1 000	1 000
Oil and Natural Gas (1.B.2)	40 200	62 100	62 400	62 000	61 000	57 900	57 600	58 700
a. Oil ¹	4 190	5 440	5 660	5 830	5 550	5 540	5 710	5 920
b. Natural Gas ¹	11 400	17 700	19 200	19 700	19 700	19 300	19 300	19 400
c. Venting and Flaring ²	24 600	38 900	37 600	36 500	35 800	33 100	32 500	33 300
Venting	20 200	33 500	32 100	31 200	30 700	28 700	28 200	28 700
Flaring	4 400	5 400	5 500	5 300	5 100	4 400	4 300	4 600

Notes:

1. All other fugitives except venting and flaring.

2. Both oil and gas activities.

Totals may not add up due to rounding.

the adsorbed CH₄ is released until the CH₄ in the coal has reached equilibrium with the surrounding atmospheric conditions.

Emissions from mining activities are from exposed coal surfaces, coal rubble and the venting of CH₄ from within the deposit. Post-mining activities such as preparation, transportation, storage and final processing prior to combustion also release CH₄.

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 CH₄ 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 CH₄ emissions from coal mining were identified as a key category and underwent Tier 1 QC checks in a manner consistent with IPCC Good Practice Guidance (IPCC 2000). Checks included a review of activity data, time-series consistency, emission factors, reference material, conversion factors and units labelling, as well as sample emission calculations. No mathematical errors were found during the QC checks. The data and methods related to the

QC activities are documented and archived in paper and electronic form.

3.3.1.5. Recalculations

Estimates for fugitive emissions from coal mining were revised based on updated production data for 2010.

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

The Oil and Natural Gas source category has three main components: Upstream Oil and Gas (UOG), Oil Sands / Bitumen, and Downstream Oil and Gas.

Upstream Oil and Gas

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

The sources of emissions have been divided into major groups:

Oil and Gas Well Drilling and Associated Testing: Oil and gas well drilling is a minor emission source. The emissions are

from drill stem tests, release of entrained gas in drilling fluids and volatilization of invert drilling fluids.

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

Natural Gas Production: Natural gas is produced exclusively at gas wells or in combination with conventional oil, heavy oil and crude bitumen production wells with gas conservation schemes. The emission sources associated with natural gas production are wells, gathering systems, field facilities and gas batteries. The majority of emissions result from equipment leaks, such as leaks from seals; however, venting from the use of fuel gas to operate pneumatic equipment and linecleaning 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/m³). 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/m³. Production of this viscous liquid requires a special infrastructure. There are generally two types of heavy oil production systems: primary and thermal. The emission sources from both types are wells, flow lines, batteries (single and satellite) and cleaning plants. The largest source is venting of casing and solution gas.

In-situ Bitumen Production: Crude bitumen is a highly viscous, dense liquid that cannot be removed from a well using primary production means. Enhanced heavy oil recovery is required to recover the hydrocarbons from the formation, including primary production (or cold flow), cyclic steam stimulation (CSS), steam-assisted gravity drainage (SAGD); and experimental methods such as toe-to-heel air injection (THAI), vapour extraction process (VAPEX) and combustion overhead gravity drainage (COGD). The sources of emissions are wells, flow lines,

satellite batteries and cleaning plants. The main source of emissions is the venting of casing gas.

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

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

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

Oil Sands / Bitumen

This component includes emissions from oil sand open pit mining operations and heavy oil/bitumen upgrading to produce synthetic crude oil and other derived products for sale. Fugitive emissions are primarily from hydrogen production, flue gas desulphurization (FGD), venting and flaring activities, storage and handling losses, fugitive equipment leaks, and CH₄ from the open mine surfaces and from methanogenic bacteria in the mine tailings settling ponds.

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

Downstream Oil and Gas

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

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

Natural Gas Distribution: The natural gas distribution system receives high-pressure gas from the gate of the transmission system and distributes this through local pipelines to the end user. The major emission sources are fugitive emissions from main and service pipelines and meter/regulator stations, which account for about 42% and 33% of emissions, respectively.

3.3.2.2. Methodological Issues

Upstream Oil and Gas

Fugitive emission estimates from the UOG industry are based on the Canadian Association of Petroleum Producers' (CAPP) study of the industry: *A National Inventory of Greenhouse Gas (GHG), Criteria Air Contaminant (CAC) and Hydrogen Sulphide (H₂S) Emissions by the Upstream Oil and Gas Industry* (CAPP 2005a) – referred to here as the UOG report. The complete methodology is presented in volumes 1, 3 and 5 of the report.

For the year 2000, emissions were identified at the facility level for over 5000 facilities. These estimates were then extrapolated to approximately 370 000 primary sources from flaring, venting, equipment leaks, formation CO₂ 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 2001–2011 fugitive emissions were estimated using annual industry activity data from conventional UOG production and the 2000 emission results. The 1990–1999 estimates and method are presented in Volume 1 of the UOG report. A consistent UOG estimation model (hereafter referred to as the UOG model) for 2001 and onwards was developed for use in estimating annual national- and provincial-level GHG estimates. The emissions for both time spans were estimated using emission data from the year 2000 together with the annual production and activity data for the relevant years. A detailed description of the methodology can be found in the UOG report (CAPP 2005a) and the UOG model report (CAPP 2005b). A summary of the estimation method of the UOG model is represented in Annex 3.

Natural Gas Transmission

Fugitive emissions from natural gas transmission for 1990–1996 are from the conventional UOG industry study, *CH₄ and VOC Emissions from the Canadian Upstream Oil and Gas Industry* (CAPP 1999). This study is considered to follow a rigorous IPCC Tier 3 approach in estimating GHG emissions. Fugitive emission estimates for 1997 onward were estimated based on length of natural gas pipeline and leakage rates, as developed based on the results from the original study. The methodology can be found in Annex 3.

Oil Sands / Bitumen

Fugitive GHG emissions from oil sands mining, bitumen extraction, heavy oil/bitumen upgraders and integrated cogeneration facilities are from the bitumen study, *An Inventory of GHGs, CACs, and H₂S Emissions by the Canadian Bitumen Industry: 1990 to 2003* (CAPP 2006). The bitumen study is a compilation of GHG emissions from the following companies: Suncor Energy Inc., Syncrude Canada Ltd., Shell Canada Ltd. and Husky Energy Inc. Methods used to estimate fugitive emissions from *in-situ* bitumen extraction are from CAPP's UOG study (CAPP 2005a) (see Section 3.3.2.1).

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

A bitumen estimation model (hereafter referred to as the bitumen model) was developed to allow annual updating of fugitive emissions from oil sands mining and bitumen/heavy oil upgrading activities from 2004 onwards. The bitumen model was developed based on relevant parameters and results from the original bitumen study along with annual activity data. The activity data required by the model are published in the following reports: *Alberta Mineable Oil Sands Plant Statistics* from the Energy Resources Conservation Board (ERCB 2012) and the National Energy Board's (NEB 1998–2011) online statistics: *Estimated Production of Canadian Crude Oil and Equivalent*. These data are updated annually and used to estimate GHG emissions. Refer to both the bitumen study (CAPP 2006) and the bitumen model (Environment Canada 2007) for a detailed

description of the methodology. A summary of the estimation method of the bitumen model is also presented in Annex 3.

Emissions for oil sands facilities not included in the original bitumen model, such as the CNRL Horizon Mine and Upgrader, Nexen Long Lake Upgrader, Fort Hills Mine, and Shell Jackpine Mine have been estimated using activity data from the ERCB (2012) and emission factors from similar facilities.

Downstream Oil and Gas Production

Fugitive emissions from refineries are based on the Canadian Petroleum Products Institute (CPPI) study, *Economic and Environmental Impacts of Removing Sulphur from Canadian Gasoline and Distillate Production* (CPPI 2004). Refer to the CPPI report for full details on the study. Historical fuel, energy and emission data were gathered from the Canadian Industrial Energy End-Use Data Analysis Centre (CIEEDAC) and directly from refineries for the years 1990 and 1994–2002. Fugitive, venting and flaring emissions for the years 1991–1993 were interpolated, and emissions for 2003–2009 were extrapolated, using data in the CPPI report and the petroleum refinery energy consumption and production data from the RESD published by Statistics Canada (#57-003). A detailed description of the methodology used to estimate emissions from 1991 to 1993 and from 2003 onward can be found in Annex 3.

Natural Gas Distribution

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

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

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

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

General emission factors were developed for the distribution system based on the study data (CGA 1997; GRI 2000) and gas distribution pipeline distances by province⁸ provided by Statistics Canada. More details on the methodology used to estimate fugitive emissions from natural gas distribution systems are presented in Annex 3.

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

3.3.2.3. Uncertainties and Time-Series Consistency

Upstream Oil and Gas

The UOG fugitive emissions for 2000 are taken directly from CAPP's UOG study (CAPP 2005a). The emissions from 1990–1999 and from 2001–2011 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 3–8 and Table 3–9, respectively. The detailed uncertainties for each gas can be found in the UOG report (CAPP 2005a).

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

Downstream Oil and Gas

The emission data used in the inventory for fugitive emissions from refineries for 1990 and for 1994–2002 are taken directly from the CPPI (2004) study. There is greater uncertainty for the 1991–1993 and the 2003–2011 periods due to the available level of disaggregation of the activity data. Tier 1 and Tier 2 uncertainty analyses were performed, for comparison purposes, of the emission factors and activity

⁸ Statistics Canada. 2011. Pipeline distances provided by email from Fagan S, Manufacturing and Energy Division, Statistics Canada to Smyth S, Pollutant Inventories and Reporting Division, Environment Canada, dated 19 Oct 2011.

Table 3–8 Uncertainty in Oil Production Industry Fugitive Emissions

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

Table 3–9 Uncertainty in Natural Gas Production Industry Fugitive Emissions

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

Source: CAPP (2005b).

Table 3–10 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

data, for an overall CO₂ uncertainty in the 2002 data (CPPI 2004).

The results of these analyses are as follows: For the Tier 1 analysis, the overall uncertainty was ±8.3%. The Tier 2 analysis determined that the overall uncertainty was ±14%. The difference between the Tier 1 and Tier 2 uncertainties may be due to the high level of variability in some of the emission factors. The uncertainty results can be found in Table 3–10.

Oil Sands / Bitumen

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

3.3.2.4. QA/QC and Verification

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

Tier 1 QC checks consistent with IPCC Good Practice Guidance (IPCC 2000) were performed on the CO₂ and CH₄ estimates for the following key subcategories:

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

No significant mathematical errors were found during the QC checks. The data, methodologies and changes related to the QC activities are documented and archived in both paper and electronic form.

3.3.2.5. Recalculations

Petroleum Refining: Fugitive emissions from refineries for the years 1990–2011 were recalculated based on updated activity data from Statistics Canada. These recalculations affected all years for CRF category 1.B.2.A.4 Refining/Storage and 2004–2010 for CRF categories 1.B.2.c.i Venting – Oil and 1.B.2.c.i Flaring – Oil.

Upstream Oil and Gas: Updated 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; this resulted in changes in emissions for the 2007 to 2010 data years.

3.3.2.6. Planned Improvements

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

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 and extraction, *in-situ* production and upgrading in Canada. The new study will also develop a robust method for updating emission estimates in the rapidly expanding oil sands industry, as prioritized in recent expert review team (ERT) reviews.

Natural Gas Transmission and Distribution: Improvements to the natural gas transmission and distribution emissions model will be investigated with a focus on developing

a method that will better reflect the improvements in efficiency made by the industry. The current models are not capable of capturing equipment changes or technology improvements, as emissions are estimated based on pipeline lengths and static emission factors.

3.4. Memo Items (CRF Category 1.C)

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

According to the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997), emissions resulting from fuels sold for international marine and aviation transportation should not be included in national inventory totals, but should be reported separately as emissions from international bunkers. Historically, in the Canadian inventory, any fuel reported by Statistics Canada as having been sold to foreign-registered marine or aviation carriers was excluded from national inventory emission totals. However, this assumption is no longer necessary due to the implementation of a true origin-destination aviation model.

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

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

Emissions (Table 3–11) 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

Table 3–11 GHG Emissions from Domestic and International Aviation

	GHG Emissions (kt CO ₂ eq)							
	1990	2000	2005	2007	2008	2009	2010	2011
Aviation Bunkers (International)	6 100	9 000	10 000	9 900	9 300	8 800	9 300	9 200
Civil Aviation (Domestic)	7 100	7 400	7 600	7 700	7 300	6 400	6 400	6 000
Total	13 200	16 400	17 600	17 600	16 600	15 200	15 700	15 200

Note: Totals may not add up due to rounding.

Table 3–12 GHG Emissions from Domestic and International Navigation

	GHG Emissions (kt CO ₂ eq)							
	1990	2000	2005	2007	2008	2009	2010	2011
Marine Bunkers (International)	3 100	3 600	3 100	3 000	2 900	2 300	2 400	1 800
Navigation (Domestic)	5 000	5 100	6 700	6 800	6 500	6 700	7 000	6 000
Total	8 200	8 700	9 700	9 700	9 400	8 900	9 300	7 900

Note: Totals may not add up due to rounding.

Table 3–13 Ethanol Used for Transport in Canada

Year	1990	2000	2005	2007	2008	2009	2010	2011
Ethanol Consumed (ML)	7	227	267	1 311	1 364	1 529	1 874	2 612

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

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

Emissions (Table 3–12) 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. CO₂ Emissions from Biomass

As per the UNFCCC reporting guidelines, CO₂ emissions from the combustion of biomass used to produce energy are not included in the Energy Sector totals but are reported separately as memo items. They are accounted for in the Land Use, Land-use Change and Forestry (LULUCF) Sector and are recorded as a loss of biomass (forest) stocks. CH₄ and N₂O emissions from the combustion of biomass fuels for energy are reported in the fuel combustion section in the appropriate categories.

Biomass emissions have been grouped into three main sources: residential firewood, industrial wood wastes, and fuel ethanol/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 CO₂, CH₄ and N₂O emissions, which are considered technology-dependent. The main types of residential wood combustion devices considered are stoves, fireplaces, furnaces and other equipment (i.e. pellet stoves).

3.4.2.2. Industrial Wood Wastes

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

3.4.2.3. Fuel Ethanol

Amounts of fuel ethanol used in transportation are presented in Table 3–13. 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/m³ density.

Fuel ethanol was introduced and modelled as if it were mixed into the total gasoline for the region(s). Total fuel ethanol available per province was allocated to each mode (on-road, by vehicle technology classes, and offroad as a

Table 3–14 Biodiesel Used for Transport in Canada

Year	1990	2000	2005	2007	2008	2009	2010	2011
Biodiesel Consumed (ML)	0	0	4	54	141	164	394	408

whole) as per the percentage of total gasoline calculated traditionally with MGEM. In lieu of reviewed emission factors for CH₄ and N₂O for ethanol, the representative gasoline emission factor was applied as per mode and technology class. CO₂ emission factors used are those based upon true chemical characteristics mentioned previously and a 99% oxidation rate.

In earlier inventory years (pre-2011 submissions), it was assumed that the RESD gasoline fuel use totals did not include ethanol. However, based on feedback from Statistics Canada, it is now confirmed that ethanol is included in RESD gasoline fuel consumption data. MGEM allocates ethanol based on this information, such that the total sum of gasoline and ethanol for each mode is equivalent to the total amount of gasoline reported in the RESD.

3.4.2.4. Fuel Biodiesel

The amounts of biodiesel fuel used in transportation (TFIS Inc. 2011) are presented in Table 3–14. 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/m³ density.

Biodiesel was introduced and modelled as if it were mixed into the total petrodiesel for the region(s). Total fuel available per province was allocated to each mode (on-road, by vehicle technology classes, and off-road, railways and domestic marine as a whole) as per the percentage of total petrodiesel calculated traditionally with MGEM. In lieu of reviewed emission factors for CH₄ and N₂O for biodiesel, the representative petrodiesel emission factor was applied as per mode and technology class. CO₂ emission factors used are those based upon true chemical characteristics mentioned previously and a 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 nonenergy 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, CO₂ from anthropogenic sources is used as a flooding agent in enhanced oil recovery (EOR) operations to increase crude oil production volume at two depleting oil reservoirs. CO₂ flooding started in 2000 at the Weyburn site and in 2005 at the Apache Midale site in order to extend the life of these mature reservoirs by another 30 years. CO₂ is purchased from the Dakota Gasification

Company located in North Dakota (U.S.), transported via pipeline to the field and this fresh supply is then combined with recycled CO₂ for re-injection back into the reservoir. Currently about 2.8 Mt per year of CO₂ is injected at the Weyburn-Midale operations.⁹ The Weyburn site has, from 2000 to 2011, injected about 20 Mt of fresh CO₂ as purchased from the Dakota gasification plant with a current injection rate of 7000 t of CO₂ per day (PTRC 2011). Since 2005, the Midale site has injected more than 2 Mt of fresh CO₂, with an injection rate of 1800 t of CO₂ per day (PTRC 2004).

CO₂ 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 CO₂ at high pressure also results in CO₂ being trapped in the voids that were previously occupied by hydrocarbon molecules. This process is commonly known as geological storage of CO₂.

In addition to being a CO₂ EOR operation, Weyburn is also the site of a full-scale geological CO₂ storage research program led by the International Energy Agency's Greenhouse Gas (IEA GHG) Research and Development Programme with the support of various industries, research organizations and governments. Modelling and simulation results from the first phase (from 2000 to 2004) of the IEA GHG's CO₂ monitoring and storage project, as managed by the Petroleum Technology Research Centre (PTRC), indicates that over 98% of CO₂ will remain trapped in the Weyburn reservoir after 5000 years and only 0.14% will be released to the atmosphere (Mourits 2008). Additional details on the findings of the first phase of the research project are available on the PTRC website (www.ptrc.ca—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 CO₂.

9 Mourits F. 2010. *CO₂ Injected for Weyburn and Midale Operation* information provided by F. Mourits IEA GHG Weyburn-Midale CO₂ Monitoring and Storage Project, Natural Resources Canada. January 2010.

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

Canada exports a large proportion of its produced fossil fuel resources, mostly to the United States. In 2011, Canada exported approximately 65% (energy equivalent) of its gross natural gas and crude oil production. The 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). 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 employs pre-existing models currently used in assembling the national emission estimates, as well as annually updated activity data from a variety of sources. The emissions/sectors included within the two main fuel stream estimates are as follows:

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

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

The results demonstrate that between 1990 and 2011, the sum total of oil and gas energy exports increased by 180% (Table 3–17). Over that period, oil exports grew by 228%¹⁰

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

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

Crude Oil Trends	1990	2002	2005	2007	2008	2009	2010	2011
Domestic Production (PJ)	3 774	5 480	5 899	6 454	6 398	6 363	6 714	7 119
Growth Since 1990	NA	45%	56%	71%	70%	69%	78%	89%
Energy Import (PJ)	1 198	1 985	2 071	1 919	1 896	1 804	1 722	1 518
Growth Since 1990	NA	66%	73%	60%	58%	51%	44%	27%
Energy Exported (PJ)	1 531	3 377	3 804	4 173	4 181	4 294	4 582	5 020
Growth Since 1990	NA	121%	149%	173%	173%	181%	199%	228%
Apparent Domestic Consumption (PJ)	3 441	4 087	4 166	4 201	4 113	3 873	3 853	3 617
Growth Since 1990	NA	19%	21%	22%	20%	13%	12%	5%
Emissions Associated with Gross Exports (Mt CO ₂ eq.)	21.4	50.4	53.7	52.7	54.5	59.3	60.9	66.7
Growth Since 1990	NA	135%	151%	146%	155%	177%	184%	211%
Emissions Associated with Gross Imports (Mt CO ₂ eq.)	10.7	15.5	16.7	15.2	16.7	14.6	16.3	14.7
Growth Since 1990	NA	44%	56%	42%	55%	36%	52%	37%

Notes:

NA = Not applicable.

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

Natural Gas Trends	1990	2002	2005	2007	2008	2009	2010	2011
Domestic Production (PJ)	4 184	7 250	7 192	6 975	6 661	6 229	6 007	6 062
Growth Since 1990	NA	73%	72%	67%	59%	49%	44%	45%
Energy Import (PJ)	24.2	252	364	480	597	794	869	1 204
Growth Since 1990	NA	939%	1405%	1883%	2364%	3178%	3489%	4871%
Energy Exported (PJ)	1 537	4 103	4 066	4 106	3 941	3 660	3 673	3 563
Growth Since 1990	NA	167%	164%	167%	156%	138%	139%	132%
Apparent Domestic Consumption (PJ)	2 671	3 398	3 491	3 349	3 317	3 363	3 203	3 702
Growth Since 1990	NA	27%	31%	25%	24%	26%	20%	39%
Emissions Associated with Gross Exports (Mt CO ₂ eq.)	11.5	34.9	33.4	31.6	31.3	28.0	26.2	25.6
Growth Since 1990	NA	203%	190%	174%	172%	143%	127%	122%
Emissions Associated with Gross Imports (Mt CO ₂ eq.)	0.4	5.0	6.2	7.5	9.0	11.3	11.1	14.9
Growth Since 1990	NA	1236%	1569%	1913%	2299%	2923%	2877%	3884%

Notes:

NA = Not applicable.

Table 3–17 Combined Crude Oil and Natural Gas: Production, Export and GHG Emission Trends, Select Years

Crude Oil & Natural Gas Trends	1990	2002	2005	2007	2008	2009	2010	2011
Domestic Production (PJ)	7 958	12 730	13 091	13 429	13 059	12 593	12 721	13 181
Growth Since 1990	NA	60%	65%	69%	64%	58%	60%	66%
Energy Import (PJ)	1 222	2 236	2 435	2 400	2 493	2 598	2 591	2 721
Growth Since 1990	NA	83%	99%	96%	104%	113%	112%	123%
Energy Exported (PJ)	3 068	7 481	7 870	8 280	8 122	7 954	8 256	8 583
Growth Since 1990	NA	144%	157%	170%	165%	159%	169%	180%
Apparent Domestic Consumption (PJ)	6 112	7 485	7 656	7 550	7 430	7 236	7 056	7 319
Growth Since 1990	NA	22%	25%	24%	22%	18%	15%	20%
Emissions Associated with Gross Exports (Mt CO ₂ eq.)	33.0	85.3	87.1	84.4	85.9	87.3	87.1	92.4
Growth Since 1990	NA	159%	164%	156%	161%	165%	164%	180%
Emissions Associated with Gross Imports (Mt CO ₂ eq.)	11.1	20.4	23.0	22.7	25.6	25.9	27.4	29.6
Growth Since 1990	NA	84%	107%	105%	131%	133%	147%	166%

Notes:

NA = Not applicable.

(approximately two and half times the rate of growth of oil production) Table 3–15), while exports of natural gas increased 132% (almost three times the rate of growth of natural gas production) (Table 3–16).¹¹

Natural gas exports did not substantially change from 2000 to 2008, but from 2008 to 2011, exports dropped by 10%. This was due to declining U.S. demand, affected by increased shale gas production in the United States, along with decreasing production and diminishing reserves in Canada's largest natural gas reservoir (the Western Sedimentary Basin) (Nyboer and Tu 2006).

Whereas conventional crude oil production is generally on the decline in Canada, with peak production occurring in 2003, production and exports from Canada's oil sands have been increasing steadily. From 1990 to 2002, exports

of conventional crude oil in energy terms increased by 108%, followed by a period of stability between 2002 and 2010 and then an increase of 293 PJ between 2010 and 2011. (Table 3–18). In contrast, exports of unconventional crude oil¹² from Canada's oil sands have been consistently increasing (Table 3–19). From 1990 to 2011, exports of unconventional crude oil have increased by 476%, with an average annual increase of approximately 11% since 2002.

Increased Canadian fossil fuel exports have been offset, in part, by increased fossil fuel imports. Indeed, 27% more energy from crude oil was imported in 2011 than in 1990; however, this has decreased 27% from a peak in 2004. 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 2011 (Table 3–17).

11 The source for all export and energy production data is Statistics Canada's *Report on Energy Supply–Demand in Canada* (RESO, #57003). The 1990–2011 GHG emissions associated with net exports are from Smyth (2010).

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

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

Crude Oil Trends	1990	2002	2005	2007	2008	2009	2010	2011
Domestic Production (PJ)	2 973	3 657	3 459	3 517	3 418	3 089	3 098	3 167
Growth Since 1990	NA	23%	16%	18%	15%	4%	4%	7%
Energy Import (PJ)	1 198	1 985	2 071	1 919	1 896	1 804	1 722	1 518
Growth Since 1990	NA	66%	73%	60%	58%	51%	44%	27%
Energy Exported (PJ)	1 112	2 319	2 293	2 240	2 153	2 310	2 315	2 608
Growth Since 1990	NA	108%	106%	101%	94%	108%	108%	134%
Apparent Domestic Consumption (PJ)	3 058	3 323	3 237	3 196	3 161	2 583	2 505	2 076
Growth Since 1990	NA	9%	6%	5%	3%	-16%	-18%	-32%
Emissions Associated with Gross Exports (Mt CO ₂ eq.)	12.7	32.1	31.7	24.9	26.6	30.2	30.7	35.5
Growth Since 1990	NA	153%	150%	96%	110%	138%	142%	180%
Emissions Associated with Gross Imports (Mt CO ₂ eq.)	10.7	15.5	16.7	15.2	16.7	14.6	16.3	14.7
Growth Since 1990	NA	44%	56%	42%	55%	36%	52%	37%

Notes:

NA = Not applicable.

Table 3–19 Unconventional Crude Oil: Production, Export and GHG Emission Trends, Select Years

Crude Oil Trends	1990	2002	2005	2007	2008	2009	2010	2011
Domestic Production (PJ)	801	1 822	2 440	2 938	2 980	3 274	3 616	3 952
Growth Since 1990	NA	127%	204%	267%	272%	309%	351%	393%
Energy Exported (PJ)	418	1 058	1 511	1 933	2 029	1 984	2 268	2 412
Growth Since 1990	NA	153%	261%	362%	385%	374%	442%	476%
Apparent Domestic Consumption (PJ)	383	764	929	1 004	951	1 291	1 348	1 540
Growth Since 1990	NA	100%	143%	162%	148%	237%	252%	302%
Emissions Associated with Gross Exports (Mt CO ₂ eq.)	8.7	18.3	22.0	27.9	27.9	29.1	30.2	31.2
Growth Since 1990	NA	109%	152%	219%	220%	234%	246%	257%

Notes:

NA = Not applicable.

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 CO₂, CH₄, N₂O, and perfluorocarbons (PFCs), can be released (IPCC/OECD/IEA 1997). Certain halocarbons (HFCs and PFCs) and SF₆ are also consumed in industrial processes or used as alternatives to ozone-depleting substances (ODS) in various applications; these emissions are also included in the Industrial Processes Sector.

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

The processes addressed in the Industrial Processes Sector include production and use of mineral products; metal production; chemical production (including CH₄ and N₂O from petrochemicals); consumption of SF₆; halocarbon production and use as alternatives to ozone-depleting substances; and other and undifferentiated production.

CO₂ emissions resulting from use of fossil fuels as feedstock in the production of chemicals, other than ammonia, are reported in the Other and Undifferentiated Production subsector (Section 4.2.2). This subsector also includes CO₂ emissions from other non-energy uses of fuels in the min-

ing and processing of metals (exception is use of coke in iron and steel, which is a separate category).

Indirect GHGs (such as CO, non-methane volatile organic compounds [NMVOC] and SO₂) from industrial process activities, including asphalt roofing, road paving with asphalt, pulp and paper production, and production of food and drink have not been estimated. However, these emissions and the indirect GHG emissions associated with energy activities are reported under Annex 10 of this National Inventory Report, as produced by Environment Canada's air pollutants inventory group.

As shown in Table 4-1, GHG emissions from the Industrial Processes Sector contributed 54.3 Mt to the 2011 national GHG inventory, compared with 56.0 Mt in 1990. The 2011 industrial process emissions represented 7.7% of the total Canadian GHG emissions in 2011. The contributing factors of the long-term and short-term trends in this Sector are discussed in detail in Chapter 2, and highlights of these are provided below.

The production of adipic acid ceased in 2009; this resulted in a decrease of 10.7 Mt CO₂ eq from 1990 to 2011 for the Adipic Acid Production source category, which contributed to an overall decrease of 57% (9.3 Mt CO₂ eq) for the Chemical Production subsector. Another notable source of decrease in emissions from 1990 to 2011 is the aluminium industry, which has decreased its PFC emissions by 78% (5.1 Mt CO₂ eq) through implementing emission control technologies, while almost doubling its production during the same time period. In addition, the industry has tried to gradually reduce its use of the old Söderberg production technology. The last magnesium production plant ceased operation in 2008; this resulted in the decrease of 2.9 Mt CO₂ eq for the Magnesium Production source category from 1990 to 2011.

Another notable industry that has experienced a decrease in emissions between 1990 and 2011 is the lime production industry (18%, 0.31 Mt CO₂ eq).

The emission decreases mentioned above were partly offset by significant increases in emissions from the Consumption of Halocarbons and from the Other and Undifferentiated Production subsectors between 1990 and 2011. Emissions from the consumption of halocarbons grew by 1500% (7.05 Mt CO₂ eq) since 1995 because of the progressive replacement of ODS, such as chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs),

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

GHG Source Category	GHG Emissions (kt CO ₂ eq)							
	1990	2000	2005	2007	2008	2009	2010	2011
Industrial Processes TOTAL	56 000	52 100	60 500	59 800	58 500	50 800	53 300	54 300
a. Mineral Products	8 400	9 800	9 900	9 800	9 000	7 000	7 600	7 700
<i>Cement Production</i>	5 400	6 700	7 200	7 300	6 600	5 100	5 700	5 700
<i>Lime Production</i>	1 800	1 900	1 700	1 600	1 500	1 200	1 400	1 400
<i>Limestone and Dolomite Use</i>	800	770	640	590	670	540	360	360
<i>Soda Ash Use</i>	250	250	180	190	160	110	100	100
<i>Magnesite Use</i>	147	181	175	67	57	69	81	91
b. Chemical Industry	16 300	8 000	9 300	7 900	9 400	7 100	6 500	7 000
<i>Ammonia Production</i>	4 500	5 700	5 300	5 200	5 600	5 200	5 300	5 800
<i>Nitric Acid Production</i>	1 010	1 230	1 250	1 130	1 280	1 150	1 100	1 160
<i>Adipic Acid Production</i>	10 700	900	2 650	1 450	2 400	660	0	0
<i>Petrochemical</i>	110	100	80	80	70	60	60	60
c. Metal Production	22 600	22 500	19 700	18 900	18 500	15 400	15 800	16 600
<i>Iron and Steel Production</i>	10 200	11 500	10 200	11 100	10 700	8 000	9 000	9 900
<i>Aluminium Production</i>	9 300	8 200	8 200	7 300	7 400	7 200	6 600	6 600
<i>Magnesium Production</i>	2 870	2 310	1 090	315	175	0	0	0
<i>Magnesium Casting</i>	236	471	201	198	280	193	193	193
d. Production and Consumption of Halocarbons (HFCs & PFCs)	770	3 000	5 300	5 500	5 600	6 300	7 100	7 600
e. SF ₆ Use in Electric Utilities and Semiconductors	230	220	180	240	220	190	190	145
f. Other and Undifferentiated Production	7 600	8 600	16 100	16 700	15 800	14 800	16 100	15 200

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.

by hydrofluorocarbons (HFCs), as per the requirements of the Montreal Protocol. On a similar magnitude, emissions from the Other and Undifferentiated Production subsector have increased by 100% (7.6 Mt CO₂ eq) since 1990, largely as a result of increases in the consumption of refinery output, and due to their use as feedstock in petrochemical manufacturing and as solvents in industrial and commercial applications.

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

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

To keep up with the principle of continuous improvement, and to address comments made by the Inventory Expert Review Team (ERT) on our 2012 NIR submission, improve-

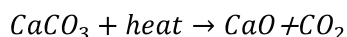
ments to activity data, and rectification of transcription and calculation errors were made. Calculation and transcription errors that were identified in the 2012 submission as part of the QC measures were rectified. Detailed explanations for the changes in estimates as a result of the mentioned improvements are described in the recalculation sections of the respective source categories in this chapter.

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

4.2.1. Source Category Description

CO₂ is generated during the production of clinker, an intermediate product from which cement is made. Calcium carbonate (CaCO₃) from limestone, chalk, or other calcium-rich materials and other raw ingredients, such as silicates,

are heated in a high-temperature kiln, forming lime (CaO) and CO₂. This process is called calcination or calcining. It occurs in the lower-temperature section of the kiln (800–900°C) and can be represented as follows:



The lime is then combined with silica-containing materials in the higher-temperature section of the kiln (1350–1450°C) to produce clinker (greyish-black pellets about the size of 12 mm diameter marbles). The clinker is removed from the kiln, cooled and pulverized, and gypsum is added to produce Portland cement. According to Statistics Canada's publications (catalogue #44-001 and CANSIM tables 303-0060 and 3030061), 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.

CO₂ emissions from cement production are essentially directly proportional to lime content. The emissions resulting from the combustion of fossil fuels to generate the heat to drive the reaction in the kiln fall under the Energy Sector and are not considered here.

4.2.2. Methodological Issues

To estimate CO₂ emissions from cement production at national level, the equation recommended in the IPCC Good Practice Guidance (IPCC 2000), as shown below, was used:

Equation 4–1:

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

where:

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

The IPCC default EF_{clinker} of 0.5071 kt CO₂/kt clinker produced was applied. This factor was developed based on an average CaO content of 64.6% and the molecular weight ratio of CO₂ to CaO in the raw material, which is 0.785 (IPCC/OECD/IEA 1997). The IPCC Good Practice Guidance (IPCC 2000) suggests 1.02 (i.e. adding 2% to the CO₂ calculated for clinker) as the default CKD correction factor.

Clinker production data for 1990–1996 were obtained from *A Review of Energy Consumption and Related Data: Canadian Cement Manufacturing Industry, 1990 to 2008* (CIEEDAC 2010). Clinker production data for 1997–2004 were obtained from Statistics Canada (#44-001) and for 2005–2011 from CANSIM tables 303-0060 and 303-0061 (Statistics Canada 2005-2011). Applying Equation 4–1 above to the clinker production data is considered a Tier 2 type approach.

To estimate CO₂ provincial/territorial emissions, data on clinker capacity of cement plants across Canada were used. The source of 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 2007–2010 data¹). These data were used to derive the percentage of total national clinker capacity attributed to each province/territory. CO₂ emissions on a provincial/territorial level were estimated by multiplying the percentage attributed to each province/territory by the national emission estimate.

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 CO₂ 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 CO₂ estimate for cement production was ±33%. 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

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

consistently applied over the time series. The activity data sources are described in Section 4.2.2.

4.2.4. Category-Specific QA/QC and Verification

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

4.2.5. Category-Specific Recalculations

No recalculation occurred for the Cement Production source category.

4.2.6. Category-Specific Planned Improvements

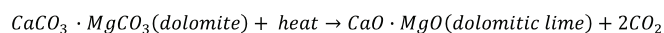
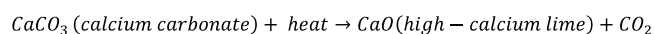
No improvement activity for the source category is planned.

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 CO₂ 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 (CaCO₃) and dolomite (CaCO₃·MgCO₃), 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)₂ and Ca(OH)₂·Mg(OH)₂, 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 CO₂ 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 CO₂ 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 CO₂ 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.²

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 2007–2011). 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 $1 - (x \cdot y)$, where x is the proportion of hydrated lime production to total lime production and y is the water content in the hydrated lime.

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

Canadian hydrated lime has a y value (i.e. water content) of 28.25%.³ Furthermore, the corrected lime production data were divided into high-calcium lime and dolomitic lime production based on the data on calcining capacities of lime production facilities across Canada. National CO₂ 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 CO₂ emissions at the provincial level, the national emissions were allocated by province, according to the calcining capacity of each province.

4.3.3. Uncertainties and Time-Series Consistency

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

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

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

4.3.4. Category-Specific QA/QC and Verification

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

4.3.5. Category-Specific Recalculations

No recalculation occurred for the Lime Production source category.

4.3.6. Category-Specific Planned Improvements

There are currently no improvements planned for this category.

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

4.4.1. Source Category Description

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

Since limestone at high temperatures is calcined to lime in these industries, CO₂ 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.

³ Kenefick W. Personal communication (email from Wayne Kenefick to Amy Shen, Greenhouse Gas Division, dated October 22, 2008). Canadian Lime Institute.

4.4.2. Methodological Issues

CO₂ 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 CO₂ 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 CO₂/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 (CaCO₃) and magnesite (MgCO₃). A major Canadian producer of dolomite reported the composition of its dolomite to range from 56% to 58% CaCO₃ and from 38% to 41% MgCO₃. An overall emission factor of 468 g CO₂/kg of dolomite used was derived based on the emission factors for pure limestone (440 kg CO₂/tonne) and magnesite (522 kg CO₂/tonne), and the assumption that dolomite is composed of 58% CaCO₃ and 41% MgCO₃ (AMEC 2006).

Data on raw stone use in iron and steel furnaces, non-ferrous smelters, glass factories, pulp and paper mills, and other chemical uses were obtained from the *Canadian Minerals Yearbook* (NRCan 1990–2006) or from the author of the stone section of the Yearbook (for 2007–2011). Moreover, data for stone use as flux in iron and steel furnaces for all years were disaggregated into limestone and dolomite based on a 70/30 split (AMEC 2006). National CO₂ emissions were estimated by multiplying the quantities of limestone and dolomite consumed by the corresponding emission factors.

It is not possible to present a comprehensive breakdown of “other chemical uses” due to the inability to retrieve relevant data from Natural Resources Canada. However, limited Web-based research and recent email correspondence with Environment Canada have revealed that FGD and wastewater treatment/neutralization may be important uses of limestone and dolomite as is the case in the United States. Furthermore, the United States NIR provides activity data and estimates GHG emissions for “FGD” and “Other miscellaneous uses.” Starting with the previous NIR—and following the ERT’s recommendation to fully account for CO₂ emissions from “other chemical uses”—

this subcategory has been assumed emissive and has been duly accounted for.

Provincial emission estimates were obtained by apportioning the national emissions according to the sum of the provincial gross output values for the major sectors in which limestone and 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 ±11% to ±34%, with data on the use of limestone and dolomite in the chemical sector and as flux in iron and steel furnaces being the largest contributors.

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

4.4.4. Category-Specific QA/QC and Verification

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

4.4.5. Category-Specific Recalculations

Updates to activity data for 2010 resulted in the recalculation of emissions for that year.

4.4.6. Category-Specific Planned Improvements

Currently there is no improvement planned for this category.

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

4.5.1. Source Category Description

Soda ash (sodium carbonate, Na_2CO_3) is a white crystalline solid that is used as a raw material in a large number of industries, including glass manufacture, chemical production, soap and detergents, pulp and paper manufacture, flue gas desulphurization, and wastewater treatment (AMEC 2006). Based on the information on soda ash use by sector in AMEC (2006) and the *Non-Metallic Mineral Products Industries* (Statistics Canada #44-250) publication, it appears that soda ash in Canada is used mainly in the glass products manufacturing industry. CO_2 is emitted as the soda ash decomposes at high temperatures in a glass manufacturing furnace.

CO_2 is also released during the Solvay process in which soda ash is produced. However, as the CO_2 is a necessary component in the carbonation stage of the production process, it is usually recovered and recycled for use.

4.5.2. Methodological Issues

Based on the carbon mass balance, there is one mole CO_2 emitted for each mole of soda ash used. The emission factor (EF) for the mass of CO_2 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_2 emissions were calculated by applying the emission factor of 415 g CO_2 /kg to the national soda ash consumption data, and by assuming that the soda ash used in Canada has a purity of 100%. Quantities of soda ash used were estimated based on soda ash production, import and export data. Canada stopped its soda ash production in 2001. Production before 2002 was assumed to be equal to the capacity of the only soda ash plant in Canada. Import and export data were obtained from Global Trade Information Services (GTIS 1995–2006,

2007–2009) and Statistics Canada's Canadian International Merchandise Trade Database (Statistics Canada 2010–2011). It should be noted that, since GTIS did not report trade data before 1995, it was assumed that the trade data for the years 1990–1994 were the average of the 1995–2000 trade data. The total quantities of soda ash used were distributed by application type, based on the U.S. pattern of soda ash consumption. According to the U.S. Geological Survey, soda ash can be used in the following sectors: glass, chemical, soaps and detergents, pulp and paper, flue gas desulphurization and others.

This method is considered to be Tier 1 type, as it is based on the use of national consumption data and an emission factor derived from the stoichiometry of the process. Methodological issues for calculating CO_2 emissions from soda ash use are not addressed specifically in the IPCC Good Practice Guidance (IPCC 2000).

Provincial emission estimates were obtained by apportioning the national emissions according to provincial gross output values of the sectors in which soda ash was used (i.e. glass, pulp and paper and inorganic chemical sectors).

There is currently no soda ash production in Canada. The only soda ash producing plant, which produced soda ash using the Solvay process, closed in 2001. Although most CO_2 emitted from this facility was recovered for reuse (as mentioned in Section 4.5.1), some CO_2 may have been released from vents on absorbers, scrubbers and distillation units. However, the amount of net CO_2 emissions from soda ash production in Canada is assumed to be negligible (AMEC 2006).

4.5.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has been performed for the category of Soda Ash Use. It took into account the uncertainties associated with the production data (for years before 2001), import and export data. The uncertainty associated with the category as a whole for the time series ranged from $\pm 10.2\%$ to $\pm 13.8\%$.

The same emission factor was consistently applied over the time series. The activity data source is provided in Section 4.5.2.

4.5.4. Category-Specific QA/QC and Verification

The Tier 1 QC checklist was not completed for the category of Soda Ash Use, as it was not a key category. However, several checks that were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC 2000) were done. No anomalies were observed.

4.5.5. Category-Specific Recalculations

There were no recalculation performed for this source category.

4.5.6. Category-Specific Planned Improvements

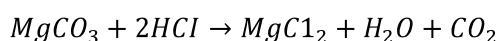
There are currently no improvements planned specifically for estimating CO₂ emissions from soda ash production and use.

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

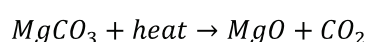
4.6.1. Source Category Description

Magnesite, or magnesium carbonate (MgCO₃), 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).

CO₂ 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). CO₂ is generated along with magnesia when magnesium carbonate decomposes at high temperatures:



Three facilities in Canada have reported use of magnesite in their processes at different moments during the 1990–2008 period. One of them was closed in 1991 and another one in 2007.

4.6.2. Methodological Issues

In the 5th *Strategic Diversification Newsletter* (SIDEX 2004), one of the facilities (users of magnesite) reported that the purity fraction of the magnesite it used was 97%, and this magnesite was mined by the facility's parent company. Therefore, it was assumed that all three facilities used magnesite with a purity fraction of 97%. Taking the purity of magnesite into account, an overall emission factor of 506 g CO₂/kg was derived and used in estimating CO₂ emissions from magnesite use.

For the plant that had operated between 1990 and 1991, as no magnesite use data were available, the amount used was backcalculated from the amount of magnesium produced. The amount produced was assumed to be half of the 1990 capacity reported in the Minerals and Metals Foundation Paper, 1999 (AMEC 2006)

For the other two plants, the 1990–2005 facility-specific magnesite use data came from British Columbia's Ministry of Energy, Mines and Petroleum Resources (2006) and Environment Canada, Quebec Region, Environmental Protection Branch.⁴ For 2006 and 2007, activity data were not available; hence, to estimate the use of magnesite for these two plants, some assumptions were made.

For the plant that was closed in 2007, the ratio of magnesite use to magnesium production was first calculated for each year of the 1990–2005 period.⁵ The average of the calculated (magnesite use / magnesium production) ratios was then taken. This average was multiplied by the plant's 2006 and 2007 magnesium production to yield the 2006 and 2007 magnesite use, respectively.

For the other plant (the only one still in operation in 2011), the 2006–2011 magnesite use data came from British

4 Banville J. 2006. Personal communication (email from Banville J to Renata Zaremba, Greenhouse Gas Division, dated March 3, 2006). Environment Canada, Environmental Protection Branch, Quebec Region.

5 Banville J. 2007. Personal communication (email from Banville J. to Maryse Pagé, Greenhouse Gas Division, dated October 4, 2007). Environment Canada, Environmental Protection Branch, Quebec Region.

Columbia's Ministry of Energy, Mines and Petroleum Resources.⁶

Finally, multiplying the consumption data (either actual or estimated, depending on the years) by the above-mentioned emission factor gave the national and provincial emission estimates for this subsector.

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

4.6.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has been performed for the category of Magnesite Use. It took into account the uncertainties associated with the activity data (for years before 2001) and emission factor. The uncertainty associated with the category as a whole for the time series ranged from $\pm 5.0\%$ to $\pm 8.1\%$, with data on the use of magnesite being the largest contributor.

The same emission factor was consistently applied over the time series. The activity data source is provided in Section 4.6.2.

4.6.4. Category-Specific QA/QC and Verification

The Tier 1 QC checklist was not completed for the category of Magnesite Use, as it was not a key category. However, several checks that were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC 2000) were done. No anomalies were observed.

4.6.5. Category-Specific Recalculations

Updates to activity data for 2010 resulted in the recalculation of emissions for that year.

4.6.6. Category-Specific Planned Improvements

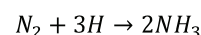
There are currently no improvements planned specifically for estimating CO₂ emissions from magnesite use.

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

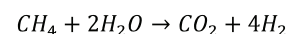
4.7.1. Source Category Description

Ammonia (NH₃) is gaseous at standard temperature and pressure. It is toxic and corrosive, and has a pungent odour. Commercially used ammonia is referred to as "anhydrous ammonia," which must be stored under pressure or at low temperature to remain a liquid. It is used mainly in the production of fertilizers, explosives and polymers.

To produce anhydrous ammonia, nitrogen (N₂) and hydrogen (H₂) 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 CH₄ (and minor amounts of other hydrocarbons) contained in natural gas. CO₂ is also generated, as a by-product gas, during the steam methane reforming (SMR) process:

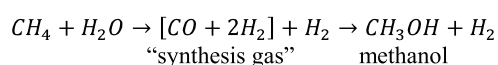


CO₂ is then removed from the process gas by absorption, usually with a solution of monoethanolamine or potassium carbonate (K₂CO₃). The primary release of CO₂ occurs during the regeneration (for reuse) of the CO₂-rich absorption solution by steam stripping or boiling. The stripping gas, which contains CO₂ and other impurities, is then vented to the atmosphere. Alternatively, it can be directed to a neighbouring urea plant, where the CO₂ is recovered and utilized as a feedstock gas. Since the carbon will only be stored for a short period, no account should be taken for intermediate binding of CO₂ 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

⁶ Meredith-Jones S. 2010. Personal communication (email from Meredith-Jones S. to Shanta Chakrovorty, Greenhouse Gas Division, dated June 21, 2010). B.C. Ministry of Energy, Mines and Petroleum Resources. (Also, see link: http://minfile.gov.bc.ca/report.aspx?f=PDF&r=Production_Detail.rpt&minfilno=082JNW001)

can generate hydrogen in sufficient quantities to support large-scale ammonia production. However, some plants may use by-product hydrogen to feed into the Haber-Bosch reaction, thereby eliminating release of CO₂ from the ammonia production process. In other words, the hydrogen needed for producing ammonia can also be obtained in ways that do not involve an on-site SMR operation. For instance, at methanol plants, a synthesis gas (or “syn gas”) consisting of one part CO and two parts hydrogen is prepared by using a variation of the SMR reaction. The reaction (as depicted below) produces an excess of hydrogen that is more than what is required for methanol production:



This excess of hydrogen is often purged from the methanol plant and used at neighbouring ammonia plants. Also, ethylene plants generate hydrogen as a co-product from cracking furnaces in making ethylene and other chemicals (e.g. propylene, butadiene). This hydrogen stream can be used at the nearby ammonia plants as well (Cheminfo Services 2006).

4.7.2. Methodological Issues

The Ammonia Production source category only estimates CO₂ emissions resulting from the feedstock use of natural gas, from ammonia-producing facilities that employ the SMR process. The emissions resulting from the energy use of natural gas are accounted for in the Energy Sector. The feedstock use of natural gas is determined by multiplying the facility-specific annual ammonia production and the facility-specific ammonia-to-feed fuel conversion factor. The facility-specific annual ammonia production data for 1990–2004 were gathered in a study conducted by Cheminfo Services (2006); those for 2005–2009 were collected by Environment Canada’s GHG Division through a voluntary data submission process with the fertilizer industry; and those for 2008–2011 were obtained from the micro data of Statistics Canada’s Industrial Chemical and Synthetic Resin Survey (Statistics Canada 2008–2011). The facility-specific ammonia-to-feed fuel conversion factors were developed from the facility-specific data collected between 2005 and 2009 as part of Environment Canada’s GHG Division voluntary data submission. The determined natural gas amount (used as feed) by each facility is then

multiplied by the respective province’s natural gas carbon content factor and the ratio of carbon to CO₂, to determine the resulting CO₂ emission. The equations (shown below) are employed to estimate CO₂ emissions: first for each facility using ammonia production statistics, and then for the nation by summing up estimates across all facilities.

$$\begin{aligned} \text{CO}_2 \text{ from facility} &= \text{facility annual ammonia production} \\ &\times \text{facility ammonia-to-feed fuel factor} \\ &\times \text{Natural gas carbon content} \times 44/12 \end{aligned}$$

$$\text{Process CO}_2 \text{ emission} = \sum_{i=1}^n \text{CO}_2 \text{ from facility}_i$$

The employed estimation technique is similar to the Tier 1 methodology found in the IPCC (2006) Guidelines, with the added improvement of using facility-level (vice national-level) ammonia production values.

Finally, the quantity of natural gas used to produce hydrogen for ammonia production was also recorded by Statistics Canada with all other non-energy uses of natural gas. Therefore, to avoid double counting, the natural gas amounts allocated by Statistics Canada for hydrogen production are systematically removed from the non-energy use of natural gas reported under the Other and Undifferentiated Production subsector. To ensure the confidentiality of facility-specific data, only national level CO₂ emissions from ammonia production are reported.

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

4.7.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has been performed for the category of Ammonia Production. It took into account the uncertainties associated with the national and facility-specific ammonia production data, ammonia-to-feed fuel factor, and the carbon content of natural gas. The uncertainty associated with the category as a whole was evaluated at ±4% and is applicable to all years of the time series.

4.7.4. Category-Specific QA/QC and Verification

Ammonia production was a key category that has undergone Tier 1 QC checks as developed in the QA/QC plan (see Annex 6). The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined

in the IPCC Good Practice Guidance (IPCC 2000). No issues of importance were detected from the Tier 1 QC process.

4.7.5. Category-Specific Recalculations

Updates to activity data for 2009 and 2010 resulted in the recalculation of emissions for these years.

4.7.6. Category-Specific Planned Improvements

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

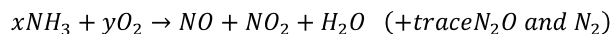
4.8. Nitric Acid Production (CRF Category 2.B.2)

4.8.1. Source Category Description

Nitric acid (HNO₃) 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 (NH₃) to nitrogen dioxide (NO₂) and then subsequent formation of nitric acid by addition of water (H₂O) to NO₂. As shown below, the first stage is the reaction of ammonia gas with oxygen (O₂) (from air) at high temperatures:

Stage 1 (Reaction):

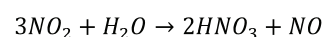
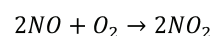


The hot gases pass through many sheets of wire gauze catalyst. These are usually made from platinum, palladium, gold or rhodium alloy wire knitted into a fine mesh surface. The reaction products are a mixture of nitric oxide (NO), NO₂, and water vapour, with trace amounts of N₂O and nitrogen (N₂) (Cheminfo Services 2006). An excess of oxygen may drive the NO to be converted to NO₂. Nitrogen oxidation steps under reducing conditions are sources of

N₂O. More specifically, NO, an intermediate in the production of nitric acid, can readily decompose to N₂O and NO₂ at high pressures and at a temperature range of 30–50°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 NO₂ and to scrub the gases. As shown below, hydration of cooled NO₂ with water forms a 60–65% solution of nitric acid, leaving the bottom of the tower. To complete the conversion of NO to NO₂, excess air (oxygen) is introduced at the bottom tray of the absorber tower. The NO₂ 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 N₂O, NO, NO₂, and other nitrogen oxides (NO_x). The concentration of N₂O in the exhaust gases depends on the type of plant and its emission controls (Cheminfo Services 2006).

There exist two basic types of nitric acid production technology: high pressure and dual pressure. Both technologies can be found in Canadian nitric acid plants. The high-pressure design, commonly used in North America, applies a single pressure throughout the reaction and absorption stages. High-pressure process plants can function with a non-selective catalytic reduction (NSCR) or selective catalytic reduction (SCR) system. The emission abatement systems are classified as “non-selective” when natural gas is used as reductant to reduce all NO_x. In contrast, a “selective” catalytic reduction (SCR) uses ammonia, which selectively reacts only with NO and NO₂ gases, and not with N₂O (hence a higher N₂O 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

Table 4–2 Nitric Acid Industry-Typical Emission Factors

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

1. Collis G. 1992. Personal communication (letter from Collis G. to Director, Greenhouse Gas Division, dated March 23, 1992). Canadian Fertilizer Institute.

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 N₂O emissions from nitric acid production for 1990–2004 were gathered through a study conducted for Environment Canada (Cheminfo Services 2006), those for 2005–2009 were obtained by the Department’s GHG Division from industry through a voluntary data submission process, and those for 2008–2011 were obtained from the micro data of Statistics Canada’s Industrial Chemical and Synthetic Resin Survey. The collected data were used in the country-specific hybrid emission estimation methodology, which could be described as three categories:

1. Plant-specific production data and plant-specific emission factors (i.e. Tier 3 type method) when these were available from companies (estimates made from 2008 onwards, for few of the larger HNO₃ producers, fall under this category); or
2. Plant-specific production data and production technology-specific emission factors that are national average values (i.e. Tier 2 type method) when plant-specific emission factors were not available; or
3. Estimated production data and national average technology-specific emission factors (i.e. Tier 1 type method) when limited or no plant-specific data were available (only one plant).

In all three scenarios, the equation applied was as follows:

Equation 4–3:

$$N_2O \text{ Emission (t)} = \text{Production} \times \text{Based Emission Factor (kg N}_2\text{O/t HNO}_3\text{)} \times \text{Production (kt HNO}_3\text{)}$$

To estimate emissions in scenarios 2 and 3, the types of production process and emission control technology of a plant were first determined. The reported or estimated production was then multiplied by the corresponding emission factor. The industry-typical emission factors used had been obtained from the Canadian Fertilizer Institute in the early 1990s. These were confirmed again, as being applicable, by industry representatives during the recent (Cheminfo Services 2006) study. In addition, another industry-typical emission factor is provided in the IPCC Good Practice Guidance (IPCC 2000) and was confirmed through the 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 overall capacity utilization of other known plants. The estimated production was multiplied by what was believed to be the most appropriate industry-typical emission factor to estimate emissions coming from plants for which no or few data were available. For 1990–2004, the raw activity data and plant-specific emission factors (when available) used to develop emission estimates were collected through the 2006 Cheminfo study (Cheminfo Services 2006). For 2005–2011, the data used were reported by companies to Environment Canada’s Greenhouse Gas Division on a voluntary basis in conjunction with the micro data from Statistics Canada’s Industrial Chemical and Synthetic Resin Survey.

Finally, the estimates of N₂O 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 $\pm 10\%$, with the emission factors being the largest contributors. The uncertainty value is applicable to all years of the time series.

The same emission factors were consistently applied over the time series. The activity data source is provided in Section 4.8.2.

4.8.4. Category-Specific QA/QC and Verification

Nitric acid production was a category that has undergone Tier 1 QC checks as developed in the QA/QC plan (see Annex 6). The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC 2000). No issues of importance were detected from the Tier 1 QC process.

4.8.5. Category-Specific Recalculations

No recalculation occurred for the Nitric Acid Production source category

4.8.6. Category-Specific Planned Improvements

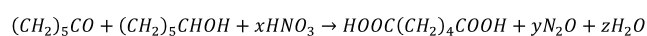
There are currently no improvements planned for this category. Additional explanations respecting the levels of use of various production technologies by Canadian companies are provided in this NIR. It is expected that further information will be obtained from the operators and will be reported in the next NIR. Also production data for one plant—which are currently not available in Statistics Cana-

da's survey and are therefore estimated based on previous years' data—will be included in the subject survey.

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

4.9.1. Source Category Description

Adipic acid ($\text{HOOC}(\text{CH}_2)_4\text{COOH}$) is a dicarboxylic acid used primarily in the production of Nylon 66, resins and plasticizers. It is produced via a two-stage oxidation process. The first step involves the oxidation of cyclohexane to form a cyclohexanone ($(\text{CH}_2)_5\text{CO}$) / cyclohexanol ($(\text{CH}_2)_5\text{CHOH}$) mixture. The mixture is then oxidized by a 50–60% nitric acid solution in the presence of a catalyst (e.g. vanadium or copper) to form adipic acid. N₂O is generated as a byproduct in the second oxidation reaction, as shown below:



Emissions of N₂O 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 N₂O generated is generally vented to the atmosphere in a waste gas stream. Adipic acid production also results in emissions of nonmethane volatile organic compounds (NMVOC), CO, and NO_x (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 N₂O emissions since 1997, when a catalytic N₂O 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

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 genera-

tion factor of 0.3 kg N₂O/kg adipic acid.

As mentioned above, in 1997, Invista installed an N₂O abatement system with a continuous emission monitor on the controlled off-gas stream at the abatement system outlet. Since then, the emission estimation method applied by Invista has become the following:

Equation 4–4:

$$\begin{aligned} \text{Total Emissions (t)} \\ &= \text{N}_2\text{O Emissions (t) with abator} \\ &+ \text{N}_2\text{O Emissions (t) without abator} \end{aligned}$$

The first term accounts for emissions that occur when the abator is operating, and the second for emissions that occur when the abator is not operating because of maintenance or technical problems.

N₂O Emissions with Abator:

Equation 4–5:

$$\begin{aligned} \text{N}_2\text{O Emissions (t) with Abator} \\ &= (\text{Production(t)}) \times \left(\frac{0.3t \text{ N}_2\text{O}}{t \text{ adipic acid}} \right) \\ &\times (1 - \text{Destruction Efficiency}) \times (\text{Abatement Utilization Ratio}) \end{aligned}$$

where:

Destruction Efficiency is determined based on the difference between the amount of N₂O 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 N₂O goes through the abator divided by the total operating time.

N₂O Emissions without Abator:

Equation 4–6:

$$\begin{aligned} \text{N}_2\text{O Emissions (t) without Abator} \\ &= (\text{Production(t)}) \times \left(\frac{0.3t \text{ N}_2\text{O}}{t \text{ adipic acid}} \right) \\ &\times (1 - \text{Abatement Utilization Ratio}) \end{aligned}$$

It is important to note that the in-line continuous emission monitor has never been used to directly monitor net N₂O emissions. This is because the analyzer is limited to

accurately measuring relatively low concentrations of N₂O only when the reactor is online and abating N₂O gas. The analyzer is not capable of measuring the full range of N₂O concentrations that could potentially exist in the stack. The N₂O concentration can vary from a low nominal level of 0.3% when the stream leaves the abator to a high nominal level of 35–39% N₂O in the unabated stream. When the abatement reactor is bypassed, there is no N₂O abatement occurring, and the analyzer will not record N₂O stack emissions (Cheminfo Services 2006).

The calculation techniques used to estimate emissions for the periods 1990–1997 and 1998–2009 are basically the same as the default methods presented in the IPCC Good Practice Guidance (IPCC 2000) and the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997).

4.9.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has been performed for the category of Adipic Acid Production. It took into account the uncertainties associated with the adipic acid production data, the emission factor, the destruction efficiency and the abatement utilization factor. The uncertainty associated with the category as a whole was evaluated at ±11%, with the emission factor being the largest contributor. The uncertainty value is applicable to all years of the time series.

As explained in Section 4.9.2, two methods were applied in the time series: one for the period of time during which the plant operated *with* the emission abatement system and another for the period of time during which the plant operated *without* the emission abatement system.

4.9.4. Category-Specific QA/QC and Verification

Adipic Acid Production was a key category that has undergone Tier 1 QC checks as developed in the QA/QC plan (see Annex 6). The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC 2000). No issues of importance were detected from the Tier 1 QC process.

4.9.5. Category-Specific Recalculations

There were no recalculations of N_2O 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. Petrochemical Production – Carbide Production (CRF Category 2.B.4)

4.10.1. Source Category Description

Two kinds of carbide are considered in this section: silicon carbide (SiC) and calcium carbide (CaC_2). SiC and CaC_2 are no longer produced in Canada, since the last of two SiC plants closed in 2002 and the only CaC_2 plant closed in 1992. Silicon carbide (SiC) is widely used as an abrasive and is also increasingly being used in electronics. It is produced by reducing silicon quartz (SiO_2) using carbon as a reducing agent (reductant). Petroleum coke is usually used as a carbon source because of its high carbon content.

Calcium carbide (CaC_2) is produced mainly as a precursor for the production of acetylene (C_2H_2). It is produced by reducing lime (CaO) using carbon as the reductant. Petroleum coke is commonly used as the carbon source. Approximately 67% of the carbon from the petroleum coke used is bound in the product.

The use of coke as a reductant has the potential to release small amounts of methane (CH_4) gas in the high operating temperatures (1600–2500°C) of the electric resistance reduction furnaces used for carbide production. CH_4 can be released directly from the decomposition of coke (which still contains trace levels of methane absorbed in its structure) and can also be generated from the thermal decomposition (in the presence of hydrogen) of trace volatile compounds still contained in coke. Most CH_4 is likely to be released in the initial stages of carbide reduction when the coke is at high temperatures, particularly from

the top layers of coke exposed directly to the atmosphere. When coke is manufactured from coal in coke ovens, most of the volatile matter in the coal is driven off as raw coke oven gas and recovered as liquids and fuel gas. Once the tars, liquid oils and ammonia are removed from raw coke oven gas, the remaining coke oven gas typically contains 60% hydrogen and 25% methane. This is an indication that: i) CH_4 is present in volatile organic matter contained in coal; and ii) significant hydrogen is present to contribute to methane formation from the thermal decomposition of heavier volatile compounds. The coking process removes the vast majority of volatile matter from coal, but the large solid masses of coke still contain trace amounts of volatile matter (Cheminform Services 2010).

4.10.2. Methodological Issues

To estimate CH_4 emissions from carbide production at national and provincial/territorial levels, a Tier 1 method (i.e. with the application of Tier 1 IPCC default emission factors) was applied. Since no survey of active facilities was possible, research was conducted by Cheminform Services, on behalf of the GHG Division, to identify and establish the production capacities of the three carbide production facilities. A time series of process CH_4 emissions was estimated for the two silicon carbide facilities from 1990 to 2001, and one calcium carbide facility from 1990 to 1991, based on assumed capacity utilization and CH_4 emission factors. Only (SiC and CaC_2) production capacity data during the time series were identified during the study. As such, the following equation was used to estimate total CH_4 emissions from carbide production:

Equation 4-7:Total CH₄ emissions (t) =

$$\sum_y [(SiC \text{ capacity} \times \text{capacity utilization} \times \text{Emission Factor}_{SiC}) + (CaC_2 \text{ capacity} \times \text{capacity Emission Factor}_{CaC_2})]$$

where:

y	=	companies
SiC or CaC ₂	=	data collected from the industry, kt capacity
Capacity utilization	=	based Cheminfo Services's knowledge of the industry, %
Emission Factor _{SiC}	=	11.6 kg CH ₄ /t SiC (IPCC 2006)
Emission Factor _{CaC₂}	=	4.8 kg CH ₄ /t CaC ₂ , derived from CH ₄ emission factor for silicon carbide and the ratio of IPCC default Calcium Carbide CO ₂ emission factor to IPCC default Silicon Carbide CO ₂ emission factor (i.e. 11.6 (kg CH ₄ /t SiC) * (1.09 tCO ₂ /tCaC ₂ / 2.62 tCO ₂ /tSiC))

4.10.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has been performed for the category of Carbide Production (Cheminfo Services 2010), following the 2006 IPCC Guidelines - Propagation of error method for combining uncertainties. The Guidelines state that this method is applicable when the contributing variable uncertainties are below $\pm 30\%$.

Since there is no longer carbide production in Canada, a set of default uncertainties (based on Cheminfo Services' knowledge of the industry) was used in the Cheminfo Services' Tier 1 uncertainty assessment. Regarding the carbide capacity data, an uncertainty of $\pm 5\%$ was applied when survey uncertainties were not provided. The uncertainty associated with the category as a whole for the time series ranged from $\pm 0\%$ to $\pm 27\%$ (Cheminfo Services 2010).

4.10.4. Category-Specific QA/QC and Verification

The category of Carbide Production has undergone Tier 1 QC checks as developed in the QA/QC plan (see Annex 6). The checks performed are consistent with the Tier 1 General Inventory Level QC Procedure outlined in the IPCC

Good Practice Guidance (IPCC 2000). No issues of importance were detected from the Tier 1 QC process.

4.10.5. Category-Specific Recalculations

No recalculations were performed for this source category.

4.10.6. Category-Specific Planned Improvements

There are currently no improvements planned specifically for this category, as Canadian carbide production stopped in 2002.

4.11. Petrochemical Production – Carbon Black Production (CRF Category 2.B.5.1)

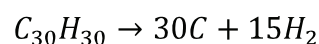
4.11.1. Source Category Description

Carbon black is a solid product consisting of fine particles of carbon with small amounts of inorganic impurities. Carbon black is used in rubber compounding (e.g. tires), pigments, printing inks, and in many other additives. There are four facilities that have produced carbon black in Canada since 1990. Three facilities are currently operating.

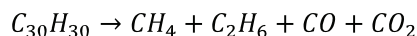
Carbon black is made from the pyrolysis or thermal cracking of various hydrocarbon feedstocks. Cracking reactions, which separate the hydrogen from the carbon, occur between 1200°C and 1600°C. There are two main carbon black processes used in Canada: 1) pyrolysis of liquid hydrocarbon feedstock; and 2) pyrolysis of natural feedstock, from which CH₄ can be emitted.

During pyrolysis of liquid hydrocarbon feedstock in the furnace black process, hydrogen atoms are separated from the carbon to yield the carbon black product particles (Cheminfo Services 2010).

Furnace Black Pyrolysis:



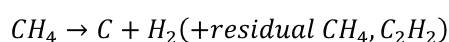
Side Reactions:



The vent gas from the furnace black process contains different products as hydrogen, methane, acetylene, carbon monoxide, carbon dioxide, sulphur compounds, carbon-sulphur compounds and water (IPCC 2006). A portion of the tail gas is burned for energy recovery for the process.

During pyrolysis of natural feedstock, purchased natural gas is injected into one of a pair of reactors that is preheated to a temperature of 1300°C, and decomposed to solid carbon particles, hydrogen and residual hydrocarbons.

Thermal Black Pyrolysis:



The mixture of solid carbon particles and hydrogen-rich by-product gas is cooled with water injection and the carbon is separated from the hydrogen by-product gas in a baghouse. The hydrogen by-product gas is used as fuel to preheat the second reactor of the unit up to the reaction temperature of 1300°C. As the process of producing the carbon black consumes energy, the first reactor cools to a point where the reaction becomes inefficient. This is when the production mode is switched, reactors trade roles and the second one, now hot, becomes the producing reactor while the first one is reheated (Cheminfo Services 2010).

4.11.2. Methodological Issues

To estimate CH₄ emissions from carbon black production, a consulting study has been performed by Cheminfo Services (2010). A survey was sent to the three operating carbon black facilities requesting 1990–2009 data on carbon black capacity and production, and on process GHG emissions. All three facilities reported 1990–2009 data for carbon black capacity, but not all facilities reported process CH₄ emissions. From the received responses, two facility-specific Tier 3 emission factors were derived as weighted averages of the reported 2007–2009 data. One sector-wide process CH₄ emission factor was also calculated as a weighted average based on the same set of data reported by the two facilities. It was applied when facility-specific emission factors could not be used. When process emissions were reported directly by a facility, the reported data were used in the inventory. When reported emission data were not available, estimates were calculated based on the unreported carbon black production (allocated to

each non-reporting facility by its share of capacity) and the Tier 3 sector average emission factor (either facility-specific or sector-wide). The unreported carbon black production was calculated from total national carbon black production less the sum of all reported carbon black production. National carbon black production data were taken from Camford's CPI Product Profile for 1990–1995 and company-reported production for 2007–2009. Interpolations were made for years in between (i.e. 1996–2006) based on a sector average growth rate for 1990–1994. The total sector production for each year of 1996–2006 was calculated by multiplying the sector average growth rate by the total sector production of the preceding year (starting from 1995). Facility-specific production data for 2010 and 2011 were obtained from the micro data of Statistics Canada's Industrial Chemical and Synthetic Resin Survey.

4.11.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has been performed by Cheminfo Services for the category of Carbon Black Production following the 2006 IPCC Guidelines - Propagation of error method for combining uncertainties. The Guidelines state that this method is applicable when the contributing variable uncertainties are below ±30%.

In the Cheminfo Services (2010) study, respondents were asked to provide their best estimate of the uncertainty of each variable reported. Very few survey respondents provided uncertainty estimates for their data. As such, a set of default uncertainties (based on Cheminfo Services' knowledge of the industry) was used in the analysis.

The following default uncertainties were applied when survey uncertainties were not provided:

- capacity data: ± 5%;
- reported production data: ±2%;
- capacity share fractions used for allocation of national production data: ±10%;
- reported process CH₄ emissions: ±20%; and
- reported process N₂O emissions: ±30%.

The Tier 1 uncertainty associated with the CH₄ emission estimates ranged from ±9% to ±11%.

4.11.4. Category-Specific QA/QC and Verification

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

4.11.5. Category-Specific Recalculations

There was no recalculation of CH₄ emissions from Carbon Black Production.

4.11.6. Category-Specific Planned Improvements

There is no improvement planned specifically for this category.

4.12. Petrochemical Production – Ethylene Production (CRF Category 2.B.5.2)

4.12.1. Source Category Description

There have been five ethylene facilities operated by four companies in Canada since 1990, but one of these, Pétromont Varennes, was shut down in 2008. Ethylene is the key building block in the basic organic chemicals industry since it is a precursor to several high-volume industrial chemicals and resins. The most important ethylene derivatives include polyethylene, ethylene oxide/ethylene glycol, ethylene dichloride/vinyl chloride, styrene, linear alpha olefins, vinyl acetates and alcohols.

Ethylene is produced by thermally cracking natural gas liquids (NGLs) such as ethane (C₂H₆), propane (C₃H₈), or butanes (C₄H₁₀) or petroleum-based liquid feedstocks, such as naphthas or gas oils. The production of ethylene is a two-stage process in which the first stage is to thermally crack the bonds in the raw materials and the second stage is to separate the products of the thermal cracking

reaction through distillation. The cracking reaction occurs in specially designed high-temperature, tubular furnaces. Each of the feedstocks requires different amounts of energy per unit of ethylene produced (or amount of feedstock used). Therefore, each feedstock has different GHG emission intensities.

Process CH₄ emissions from ethylene production come mainly from combustion of process off-gases, flaring of process materials containing methane, and fugitive emissions of volatile hydrocarbon streams that contain methane. Process N₂O emissions come mainly from the combustion of fuel gas derived from the feedstock (Cheminfo Services 2010).

4.12.2. Methodological Issues

A consulting study has been performed by Cheminfo Services Inc to estimate CH₄ and N₂O emissions from ethylene production. Cheminfo Services, on behalf of the GHG Division, sent a questionnaire to the four companies that have had ethylene production operation in Canada, requesting 1990–2009 data on ethylene capacity and production, and on process CH₄ and N₂O emissions. Responses were received from two companies for three of the four operating plants, representing 90% of Canadian ethylene capacity in 2009. Sector-wide CH₄ and N₂O GHG emission factors were estimated as weighted averages based on the reported process emissions and production data from three facilities for 2007–2009. When possible, for 1990–2009, weighted average facility-specific process GHG emission factors were developed and applied to estimated facility ethylene production, because there was a significant difference between the calculated emission factors for each facility. Facility-specific ethylene production data for 2008–2011 were obtained from the micro data of Statistics Canada's Industrial Chemical and Synthetic Resin Survey.

When process GHGs were reported directly by a facility, the reported data were used in the inventory. When reported emission data were not available, emissions were estimated based on the unreported ethylene production (allocated to each non-reporting facility by share of capacity) and the corresponding emission factors. The unreported production was calculated by subtracting the sum of reported production by the total national production. National ethylene production data were taken from Camford's CPI Product Profile for 1990–1995 and company-reported production for 2007–2009. For 2008–2011,

production data were obtained from the micro data of Statistics Canada's Industrial Chemical and Synthetic Resin Survey. It should be noted that the emission factors applied should be kept confidential, as they were derived from business-sensitive data.

Equation 4–8:

$$CH_4 \text{ or } N_2O \text{ emissions (t)} = \sum_y \left(\text{Reported emissions} + (\text{allocated unreported production} \times \text{Emission Factor } CH_4/N_2O) \right)$$

where:

y	=	companies
allocated unreported production (kt)	=	remaining unreported ethylene production x ethylene capacity of a specific company/total unreported ethylene capacity
remaining unreported ethylene production (kt)	=	total production – total reported sample

4.12.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has been performed by Cheminfo Services (2010) for the category of Ethylene Production following the 2006 IPCC Guidelines - Propagation of error method for combining uncertainties. The Guidelines state that this method is applicable when the contributing variable uncertainties are below $\pm 30\%$.

In the Cheminfo Services (2010) study, respondents were asked to provide their best estimate of the uncertainty of each variable reported. Very few survey respondents provided any uncertainty estimates for their data. As such, a set of default uncertainties (based on Cheminfo Services' knowledge of the industry) was used in the analysis. The following default uncertainties were applied when survey uncertainties were not provided:

- capacity data: $\pm 5\%$;
- reported production data: $\pm 2\%$;
- capacity share fractions used for allocation of national production data: $\pm 10\%$;
- reported process CH_4 emissions: $\pm 20\%$; and
- reported process N_2O emissions: $\pm 30\%$.

The uncertainties for the time series ranged from $\pm 8\%$ to

$\pm 12\%$ for CH_4 emission estimates and from $\pm 12\%$ to $\pm 21\%$ for N_2O emission estimates.

4.12.4. Category-Specific QA/QC and Verification

This category has undergone Tier 1 QC checks as developed in the QA/QC plan (see Annex 6). The checks performed are consistent with the Tier 1 general inventory level QC procedure outlined in the IPCC Good Practice Guidance (IPCC 2000).

4.12.5. Category-Specific Recalculations

There were no recalculation of CH_4 and N_2O emissions from the category of Ethylene Production

4.12.6. Category-Specific Planned Improvements

There is no improvement planned specifically for this category.

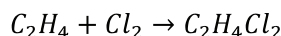
4.13. Petrochemical Production – Ethylene Dichloride (EDC) Production (CRF Category 2.B.5.3)

4.13.1. Source Category Description

Ethylene dichloride (EDC, $C_2H_4Cl_2$) is the old name for 1,2-dichloroethane, a large-volume chlorinated hydrocarbon intermediate derived from ethylene that is used in the manufacture of vinyl chloride monomer (VCM, C_2H_3Cl , $CH_2=CHCl$), the precursor of polyvinyl chloride resins. Three EDC production facilities had operated in Canada during different periods of time between 1990 and 2009, but they are all closed now.

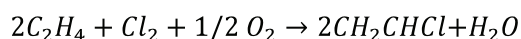
Two processes had been used for the production of EDC in Canada. One is the direct chlorination of ethylene in a vapour or liquid phase reaction using ethylene dibromide as catalyst.

Direct Chlorination:

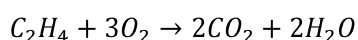


The second process is called oxychlorination. In this process the ethylene feed is chlorinated in the liquid phase. EDC vapours produced are condensed, degassed and a portion is withdrawn from the unit. The balance of the feed is passed onto the vinyl chloride section of a production plant where hydrochloric acid and oxygen in a fluidized catalyst bed reactor produce crude EDC. The crude EDC from both streams is combined and cracked in a reactor to form vinyl chloride with the by-product hydrochloric acid being recycled back into the oxychlorination unit.

Balanced EDC/VCM Reaction:



Feedstock Oxidation Reaction:



Regarding emissions, the process off-gas that contains the chlorinated hydrocarbons is combusted within the plant prior to release, so any carbon in this off-gas is converted to CO₂. The process CO₂ emissions from EDC production come from the side reaction of feedstock oxidation. The process CH₄ emissions would most likely come from light hydrocarbons from distillation operations that are not captured by a flare gas recovery system. These emissions are vented to the atmosphere (Cheminfo Services 2010).

4.13.2. Methodological Issues

Cheminfo Services Inc has been retained by the GHG Division to estimate 1990–2009 CH₄ emissions from EDC production. Since all EDC plants are currently closed and no survey response could be provided for historical data, a Tier 1 calculation approach (i.e. annual production * Tier 1 IPCC default emission factor) was taken to develop 1990–2006 process CH₄ emission estimates. The annual EDC production data come from the Canadian C₂+ Petrochemical Report, which was obtained via the Cheminfo Services (2010) study. According to the study, the last plant closed in 2006. The default process CH₄ emission factor for EDC as applied comes from Table 2-10 of the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997), under the name “dichloroethylene.” The Canadian C₂+ Petrochemical Report was prepared and published by an independent

consultant who supplies market intelligence to the Canadian chemical industry. It provides balances of ethylene and its derivatives using total production, dispositions and Canadian trade statistics. For the purpose of emission estimation at the provincial level, the annual EDC production was allocated by Cheminfo Services to each plant based on the capacity share (calculated from production capacity data reported by companies during the Cheminfo Services [2010] study).

4.13.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has been performed by Cheminfo Services (2010) for the category of EDC production following the 2006 IPCC Guidelines - Propagation of error method for combining uncertainties. The Guidelines state that this method is applicable when the contributing variable uncertainties are below ±30%.

As no plant-specific uncertainty estimates could be collected by Cheminfo Services (2010), a set of default uncertainties (based on Cheminfo Services’ knowledge of the industry) was used in the analysis. The uncertainty associated with the category as a whole for the time series is estimated at ±21% (Cheminfo Services 2010).

4.13.4. Category-Specific QA/QC and Verification

This category has undergone Tier 1 QC checks as developed in the QA/QC plan (see Annex 6). The checks performed are consistent with the Tier 1 general inventory level QC procedure outlined in the IPCC Good Practice Guidance (IPCC 2000). No issues of importance were detected from the Tier 1 QC process.

4.13.5. Category-Specific Recalculations

There was no recalculation of CH₄ emissions from EDC Production.

4.13.6. Category-Specific Planned Improvements

There are currently no improvements specifically planned for this category, as there is no more EDC production in Canada.

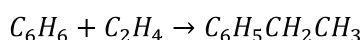
4.14. Petrochemical Production – Styrene Production (CRF Category 2.B.5.4)

4.14.1. Source Category Description

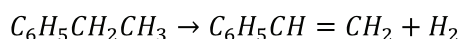
Styrene is a cyclic hydrocarbon liquid that is the precursor monomer for polystyrene and several copolymers, such as ABS resins, styrene-butadiene (SBR) rubber, styrene-butadiene latex and styreneacrylonitrile resin (SAN). These materials are used in rubber, plastic, insulation, fibreglass, pipes, automobile and boat parts, food containers, and carpet backing. There have been three styrene facilities that have produced styrene in Canada since 1990, but one facility closed in 1998.

Styrene is an organic chemical intermediate that is manufactured in a two-stage process in the same industrial facility. The first stage involves the alkylation of benzene (C_6H_6) with ethylene (C_2H_4) to produce ethylbenzene, a chemical intermediate. The second stage is the catalytic dehydrogenation of the ethylbenzene to produce styrene, as shown below:

Ethylbenzene Reaction:



Styrene Reaction:



The styrene is produced in multiple sequential dehydrogenation reactors operated under vacuum to increase conversion and selectivity towards styrene. Steam is used in the dehydrogenation reaction to provide the reaction energy, dilute the reactants and remove any coke build-up from the catalyst. The by-products from the reaction include process off-gas, benzene (recycled) and toluene, steam condensate, and tars, which must be separated from the product stream.

Process CO_2 emissions can come from the combustion of the process off-gas (fuel gas) as fuel or from flaring of over-pressured process streams. Methane (CH_4) could be present along with the process reactants ethylene and benzene and would be emitted if there was any venting of

these process or recycle streams. Fugitive emissions from these streams would also contain methane (Cheminfo Services 2010).

4.14.2. Methodological Issues

Cheminfo Services Inc has been retained by the GHG Division to estimate 1990–2009 CH_4 emissions from styrene production. A survey was sent to the two operating facilities, but none of them provided a response with respect to emission estimates. Since survey responses were not available, a Tier 1 calculation approach (i.e. annual production * Tier 1 IPCC default emission factor) was taken to develop process CH_4 emissions estimates. Annual styrene production data come from the Canadian C_2+ Petrochemical Report, which was obtained via the Cheminfo (2010) study. This report was prepared and published by an independent consultant to supply market intelligence to the Canadian Chemical Industry. It provides balances of ethylene and its derivatives using total production, dispositions and Canadian trade statistics. For the purpose of emission estimation at provincial level, the annual styrene production was allocated by Cheminfo Services to each plant based on capacity share (calculated from production capacity data reported by companies during the Cheminfo [2010] study). The default process CH_4 emission factor for styrene (4 kg/t) comes from Table 2-10 of the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997). As the 2006 IPCC Guidelines do not cover styrene production under its petrochemicals section, a more recent emission factor could not be found. No 2011 styrene production data could be found; as a result it was assumed that the 2010 production data (in turn assumed equal to 2009 data) would be applicable to 2011. The 2011 CH_4 estimates were calculated accordingly.

4.14.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has been performed by Cheminfo Services (2010) for the category of Styrene Production, following the 2006 IPCC Guidelines - Propagation of error method for combining uncertainties. The Guidelines state that this method is applicable when the contributing variable uncertainties are below $\pm 30\%$.

As no plant-specific uncertainty estimates could be collected by Cheminfo Services, a set of default uncertainties (based on Cheminfo Services' knowledge of the industry) was used in the analysis. The Tier 1 uncertainty associated

with the category as a whole for the time series was estimated at $\pm 30\%$ (Cheminfo Services 2010).

4.14.4. Category-Specific QA/QC and Verification

The category of Styrene Production has undergone Tier 1 QC checks as developed in the QA/QC plan (see Annex 6). The checks performed are consistent with the Tier 1 general inventory level QC procedures outlined in the IPCC Good Practice Guidance (IPCC 2000). No issues of importance were detected from the Tier 1 QC process.

4.14.5. Category-Specific Recalculations

There was no recalculation of CH_4 emissions from Styrene Production.

4.14.6. Category-Specific Planned Improvements

Facility-specific data will be included in the micro data of Statistics Canada's Industrial Chemical and Synthetic Resin Survey and will be available starting 2012.

4.15. Petrochemical Production – Methanol Production (CRF Category 2.B.5.5)

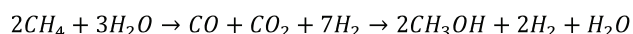
4.15.1. Source Category Description

Methanol (CH_3OH) is a flammable, highly volatile liquid alcohol at room temperature. It is primarily used as a chemical building block to manufacture formaldehyde, the key precursor of industrial thermoset resins and diverse products. There were three methanol production facilities operating in Canada during the 1990–2006 period. One was closed as of 2001, one as of 2005 and the other as of 2006. Methanol was last produced in Canada in 2006.

Methanol is produced by one of these two processes: 1) conventional reforming; and 2) combined (conventional and partial oxidation).

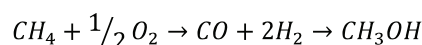
In conventional reforming, methanol is produced in a two-stage process by reacting a synthesis gas (syn gas) containing hydrogen (H_2), carbon monoxide (CO), and carbon dioxide (CO_2) over a copper/zinc oxide/alumina catalyst, then separating the product from water and other by-products.

Overall:

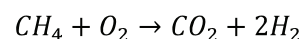


In combined reforming, a catalytic partial oxidation step is added to the conventional reforming process to achieve a better ratio of CO to H_2 in the synthesis gas. The catalytic partial oxidation reaction produces less hydrogen than the conventional reforming reactions step and eliminates by-product hydrogen.

Partial Oxidation Reaction:



Feedstock Oxidation Side Reaction:



Process GHG (CO_2 , CH_4 and N_2O) emissions come mainly from process off-gas that is separated from methanol and combusted on-site for energy recovery. The process off-gas contains excess CO , CO_2 and light hydrocarbons. Additional CH_4 emissions can occur in venting of process gases containing CH_4 from the methanol distillation train and methanol storage tanks and fugitive emissions from equipment leaks (Cheminfo Services 2010).

4.15.2. Methodological Issues

To estimate CH_4 emissions from methanol production, a consulting study has been performed by Cheminfo Services. A survey was sent to former employees of the methanol facilities who still have access to the facilities' records, requesting 1990–2009 data on methanol production capacity, production and process GHG emissions. A sector-wide process emission factor was developed as a weight-average using the reported data on CH_4 emissions. It was calculated by dividing the process CH_4 emission data set by the production data set obtained for the period 2004–2006. The sector-wide process emission factor was used, when necessary, to estimate CH_4 emissions for the 1990–2006 period (there has been no methanol production after 2006).

When CH₄ emission data directly reported by former employees for methanol production facilities were available, they were used in this submission. In the case where there were no reported data, emissions were estimated by multiplying the “unreported” methanol production by the sector-average emission factor. The “unreported” methanol production of a facility was calculated by multiplying its production capacity share (%) by the difference between total national methanol production and the sum of all reported methanol production. National methanol production values were taken from Camford’s CPI Product Profile for 1990–1999 and estimated based on assumed capacity utilization for 2000–2006 (Cheminfo Services 2010).

4.15.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has been performed by Cheminfo Services (2010) for the category of Methanol Production, following the 2006 IPCC Guidelines - Propagation of error method for combining uncertainties. The Guidelines state that this method is applicable when the contributing variable uncertainties are below $\pm 30\%$.

As no plant-specific uncertainty estimates could be collected by Cheminfo Services (Cheminfo Services 2010), a set of default uncertainties (based on Cheminfo Services’ knowledge of the industry) was used in the analysis:

- national methanol production: 5%;
- reported methanol production: 2%;
- facility methanol capacities: 5%;
- facility fraction of total sector unreported production: 10%;
- reported process CH₄ emissions: 20%;
- reported process N₂O emissions: 30%.

The uncertainty associated with the category as a whole for the time series ranged from 0% (for the years with no production) to $\pm 20\%$ for CH₄ emissions and ranged from 0% (for the years with no production) to $\pm 30\%$ for N₂O emissions.

4.15.4. Category-Specific QA/QC and Verification

This category has undergone Tier 1 QC checks as developed in the QA/QC plan (see Annex 6). The checks performed are consistent with the Tier 1 general inventory

level QC procedures outlined in the IPCC Good Practice Guidance (IPCC 2000). No issues of importance were detected from the Tier 1 QC process.

4.15.5. Category-Specific Recalculations

There was no recalculation of CH₄ emissions from Methanol Production.

4.15.6. Category-Specific Planned Improvements

There are currently no improvements planned for this category, as there is no more methanol production in Canada.

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

4.16.1. Source Category Description

Crude (pig) iron is produced in a blast furnace through the reduction of iron oxide (ore), with the carbon in coke or other carbonaceous material as the reducing agent. In most iron furnaces, the process is aided by the use of limestone fluxes (IPCC 2000). Steel can be made in electric arc furnaces (EAFs), basic oxygen furnaces or cupola furnaces. Low-carbon steel is produced in basic oxygen furnaces (BOFs), where a mixture of pig iron and iron scrap is remelted in the presence of pure oxygen, which oxidizes the dissolved carbon to CO or CO₂. Carbon and alloy steels are produced in EAFs, refractory-lined pots that utilize electric heating through graphite electrodes, which are consumed in the process (IPCC/OECD/IEA 1997).

In the production of pig iron, carbon plays the dual role of fuel and reductant. Emissions from the combustion of fuels such as coke oven gas are not reported in this category, but rather under the appropriate industrial category in the Energy Sector. CO₂ emissions from carbon oxidation, which occurs when iron ore is reduced to pig iron, are included in this category. Also accounted for in this category are emissions during steel production, which occur to a much lesser extent. These come from the oxidation of carbon in crude iron and electrode consumption. Additional CO₂

given off by limestone flux in the blast furnace is covered under the Limestone and Dolomite Use category (Section 4.4.1).

4.16.2. Methodological Issues

A new set of emission parameters—reflecting Canada-specific circumstances, e.g., emission factor for coke, carbon content of pig iron, and carbon content of pig iron entering the steelmaking process—has been used to develop the 1990–2011 estimates. The methodology used for the Iron and Steel Production category follows the IPCC Tier 2, as described in the IPCC Good Practice Guidance (IPCC 2000), with the addition of a term to account for emissions arising from the ladle metallurgy stage—further processing, in electric arc furnaces, of steel output from basic oxygen furnaces. The fate of carbon is tracked throughout the production process, with emissions from iron production and steel production being calculated separately. The following equation was used to estimate emissions from pig iron production:

Equation 4–9:

$$\begin{aligned} \text{Emissions}_{\text{pig iron}} &= (\text{Emission Factor}_{\text{reductant}} \times \text{mass of reductant}) \\ &+ (\text{mass of carbon in the ore} - \text{mass of carbon in pig iron}) \times \left(\frac{44}{12}\right) \end{aligned}$$

where:

Emissions _{pig iron}	=	emissions from pig iron production, kt
Emission factor _{reductant}	=	year-specific emission factors (t CO ₂ / t coke used) obtained from Cheminfo Services (2010) study
mass of reductant	=	mass of metallurgical coke used in the process, kt
mass of carbon in the ore	=	zero; according to IPCC (2000), kt
mass of carbon in pig iron	=	total pig iron production, kt × carbon content in pig iron
44/12	=	ratio of the molecular weight of CO ₂ 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 under Other and Undifferentiated Production 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; for 2004–2011: #41-019). The emission factors for coke use are yearspecific; they come from the Cheminfo Services (2010) study. During the study, Cheminfo Services surveyed four integrated steel mills in Canada for their coke consumption and their emission estimates for the years 1990–2009. The emission factors were calculated as ratios of CO₂ emissions to coke consumption. No Canada-specific coke carbon content is available for 2011; as a result, the 2009 coke carbon content is used for 2011. (Being a calcined product, coke is not expected to vary greatly with regard to its carbon content.) The coke carbon contents were then applied to the set of coke use data provided by Statistics Canada. With respect to the carbon content in pig iron, the Canadian Steel Producers Association (CSPA)⁷ provided an industry-average content value, which has to be kept confidential.

Emissions from steel production were estimated using the following equation:

Equation 4–10:

$$\begin{aligned} &(\text{Carbon \% in iron charged to steel furnaces} \times \text{charge}) \\ &+ (\text{Carbon \% in scrap steel charge to steel furnace} \times \text{scrap steel}) \\ &- (\text{Carbon \% in steel prodBOF} \times \text{steel production in BOF}) \\ &- (\text{Carbon \% in steel prodEAF} \times \text{steel production in EAF}) \times \frac{44}{12} \\ &+ (\text{Emission Factor for EAF} \times \text{steel produced from EAF}) \\ &+ (\text{Emission Factor for BOF Ladle Metallurgy} \times \text{Steel produced from BOF}) \end{aligned}$$

According to Equation 4–10, part of the amount of CO₂ emitted from the steel production process is estimated based on the difference between the amount of carbon in the iron and in scrap steel used to make steel and the amount of carbon in the steel produced in BOFs and EAFs. It should be noted that the amount of pig iron fed to steel furnaces (used in Equation 4–10) is not equal to the amount of total pig iron production (used in Equation 4–9). As part of the steel production process, there are also emissions coming from consumption of

⁷ Chan K. 2009. Personal communication (email from Chan K. to Maryse Pagé, Greenhouse Gas Division, dated July 21, 2009). Canadian Steel Producers Association.

electrodes in EAFs and in the secondary ladle metallurgy. These are accounted for in the last two terms of the equation.

Data on the total pig iron charged to steel furnaces, on total steel production, and on the amount of steel produced in EAFs were obtained from Statistics Canada (for 1990–2003: #41-001, for 2004–2011: #41-019). The values of the carbon contents and emission factors mentioned in Equation 4–10 were all provided by the CSPA.⁸

The total emission from the category of Iron and Steel Production is the sum of Equation 4–9 and Equation 4–10 above.

Data on metallurgical coke use at provincial/territorial levels from the RESD (Statistics Canada #57-003) were used to derive the percentage of total reductant consumption attributed to each province and territory. CO₂ emissions at provincial/territorial levels were then estimated by multiplying the percentage derived by the national emission estimate.

It should be noted that RESD data (Statistics Canada #57-003) published for any given year are preliminary and subject to revision in subsequent publications.

The method described above does not account for additional CO₂ given off by the use of limestone as flux in blast furnaces, since the limestone consumption-related emissions are included in the subsector of Limestone and Dolomite Use.

The use of petroleum coke in EAF electrodes is reported by Statistics Canada with all other nonenergy uses of petroleum coke. To avoid double counting, the CO₂ emissions from the consumption of electrodes in the steel production process in EAFs are therefore subtracted from the total non-energy emissions. It is assumed that there are no imported electrodes used for steel production in EAFs in Canada. If electrodes are imported, the portion of CO₂ generated by the imported electrodes will need to be subtracted from the emissions from electrode

consumption before being subtracted from the total non-energy emissions.

4.16.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has been performed for the category of Iron and Steel Production. It took into account the uncertainties associated with all the parameters used in the equations stated above, such as data on metallurgical coke use, emission factor of coke, data on pig iron and steel production and carbon contents of pig iron and steel. The assessment also considered the error associated with the non-response rate of the Statistics Canada surveys. The uncertainty associated with the category as a whole for the time series is around $\pm 5.4\%$.

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

4.16.4. Category-Specific QA/QC and Verification

Iron and Steel Production is a key category that has undergone Tier 1 QC checks as developed in the QA/QC plan (see Annex 6). The checks performed are consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC 2000). No issues of importance were detected from the Tier 1 QC process.

4.16.5. Category-Specific Recalculations

The revision of Statistics Canada's coke use data for the years 2004–2010 resulted in the recalculation of emissions for these years.

4.16.6. 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 CO₂ emissions coming from non-energy use of fossil fuels, currently reported under the Other and Undifferentiated Production subsector and also those reported under the Energy Sector, may be reallocated to the category of Iron and Steel Production.

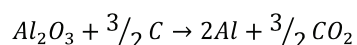
⁸ Chan K. 2009. Personal communication (email from Chan K. to Maryse Pagé, Greenhouse Gas Division dated July 21, 2009). Canadian Steel Producers Association.

4.17. Aluminium Production (CRF Category 2.C.3)

4.17.1. Source Category Description

Primary aluminium is produced in two steps. In the first stage, bauxite ore is ground, purified and calcined to produce alumina (Al_2O_3). The latter is then, in the second stage, electrically reduced to aluminium in large pots with carbon-based anodes. The pot itself (a shallow steel container) forms the cathode, while the anode consists of one or more carbon blocks suspended within it. Inside the pot, alumina is dissolved in a cryolite (Na_3AlF_6) 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.

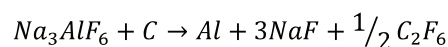
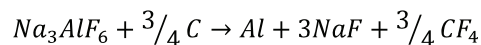
As the anode is consumed, CO_2 is formed in the following reaction, provided that enough alumina is present at the anode surface:



Although most of the CO_2 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_2 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_2 emissions, primary aluminium smelting is a major source of carbon tetrafluoride (CF_4) and carbon hexafluoride (C_2F_6). 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_4

and C_2F_6 .



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 “centrebreak” types, also tend to reduce emissions (Øye and Huglen 1990).

Besides CO_2 , CF_4 and C_2F_6 , a small amount of SF_6 is also emitted from its use as cover gas at some aluminium plants that produce high magnesium-aluminium alloys.⁹

Aluminium plants are characterized by the type of anode technology employed. In general, older plants with Söderberg technology have higher emissions than newer plants, which usually use pre-baked anodes. The trend in the Canadian aluminium industry has been towards modernizing facilities, since production efficiency has improved. In some cases, this has meant taking old lines out of production as new ones are installed to meet increasing demand.

Finally, even though aluminium production consumes extremely large quantities of electrical energy, currently estimated to be 13.5 kWh/kg of aluminium (AIA 1993), GHG emissions associated with its electricity consumption are not necessarily high in a Canadian context. All of Canada’s primary aluminium smelters are located in Quebec and British Columbia, where almost all (95%) of the electricity generated is produced by hydraulic generators; these are believed to emit a negligible amount of GHGs compared with conventional fossil fuel-based electricity generators.

4.17.2. Methodological Issues

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

⁹ Chaput P. 2007. Personal communication (email from Chaput P. to A. Au, Greenhouse Gas Division, dated Oct 12, 2007). Aluminum Association of Canada.

methodologies used by the aluminium producers to calculate CO₂, PFC and SF₆ emissions and plant-specific production data for the time series were obtained from companies via the AAC. The estimation techniques applied may be Tier 3, Tier 2 or Tier 1 type, as described below, depending on data availability; a Tier 3 type technique has mostly been applied for estimating emissions for recent years.

Calculating CO₂ emissions:

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

Equation 4–11: for pre-baked anode consumption

$$CO_2 \text{ Emissions (t)} = \left[\frac{CC \times MP \times (100 - \%S_a - \%Ash_a - \%Imp_a)}{100} \right] \times \left[\frac{44}{12} \right]$$

where:

CC	=	baked anode consumption per tonne of aluminium (t C/t Al)
MP	=	total aluminium production (t)
S _a	=	sulphur content in baked anodes (wt%)
Ash _a	=	ash content in baked anodes (wt%)
Imp _a	=	fluorine and other impurities (wt%)*
44/12	=	ratio of the molecular weight of CO ₂ to the molecular weight of carbon

*The weight percentage of fluorine and other impurities may not be a parameter considered by all the smelters.

Equation 4–12: for Søderberg anode consumption

$$CO_2 \text{ Emissions (t)} = \left[(PC \times MP) - \left(\frac{BSM \times MP}{1000} \right) - \left(\frac{\%BC}{100} \times PC \times MP \times \frac{\%S_p + \%Ash_p + \%H_2}{100} \right) - \left(\frac{(100 - \%BC)}{100} \times PC \times MP \times \frac{(\%S_c + \%Ash_c)}{100} \right) \right] \times \left[\frac{44}{12} \right]$$

where:

PC	=	paste consumption (t paste/t Al)
MP	=	total aluminium production (t)
BSM	=	emissions of benzene-soluble matter (kg/t Al)
BC	=	average binder content in paste (wt%)
S _p	=	sulphur content in pitch (wt%)
Ash _p	=	ash content in pitch (wt%)
H ₂	=	hydrogen content in pitch (wt%)
S _c	=	sulphur content in calcinated coke (wt%)
Ash _c	=	ash content in calcinated coke (wt%)
44/12	=	ratio of the molecular weight of CO ₂ 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 (EFs) for a Tier 1 method (as shown below) can be used. These factors depart slightly from the IPCC default factors, because the IPCC Tier 1 default factors reflect 1990 emissions and would produce considerable errors if applied to current production. The factors below reflect the considerable progress that has been made over the period from 1990 to 2001 (AAC 2002b; IAI 2006):

Søderberg: EF = 1.7 t CO₂/t Al produced; and

Pre-baked: EF = 1.6 t CO₂/t Al produced.

To calculate CO₂ emissions resulting from anode baking (i.e. pitch volatiles combustion and combustion of baking furnace packing material), the following equations are used (AAC 2002a):

Table 4–3 Default Tier 2 Parameter Values for the Estimation of CO₂ Emissions from Anode Consumption

Parameter	Industry-Typical Value	Source
For Pre-baked Anode Consumption:		
sulphur content in baked anodes (wt %) - Sa	2%	IAI 2006
ash content in baked anodes (wt %) - Asha	0.4%	IAI 2006
fluorine and other impurities (wt %) - Impa	0.4%	AAC 2002b
For Søderberg Anode Consumption:		
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 %) - Sp	0.6 %	IAI 2006
ash content in pitch (wt %) - Ashp	0.2%	IAI 2006
hydrogen content in pitch (wt %) - H ₂	3.3%	IAI 2006
sulphur content in calcinated coke (wt %) - Sc	1.9%	IAI 2006
ash content in calcinated coke (wt %) - Ashc	0.2%	IAI 2006

* HSS = Horizontal Stud Søderberg; VSS = Vertical Stud Søderberg.

Equation 4–13: for Pitch Volatiles Combustion

$$CO_2 \text{ Emissions } (t) = (GAW - BAP - HW - RT) \times \left(\frac{44}{12}\right)$$

where:

GAW	=	green anode weight (t)
BAP	=	baked anode production (t)
HW	=	weight of hydrogen from pitch (t) = %H ₂ / 100 * PC / 100 * GAW
H ₂	=	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 ₂ to the molecular weight of carbon

Equation 4–14: For Packing Coke

$$CO_2 \text{ Emissions}(t) = \left[PCC \times BAP \times \frac{(100 S_{pc} Ash_{pc})}{100} \right] \times \left[\frac{44}{12} \right]$$

where:

PCC	=	packing coke consumed (t coke/ t of baked anode)
BAP	=	baked anode production (t)
S _{pc}	=	sulphur content in packing coke (wt%)
Ash _{pc}	=	ash content in packing coke (wt%)
44/12	=	ratio of the molecular weight of CO ₂ to the molecular weight of carbon

Table 4–4 Default Tier 2 Parameter Values for the Estimation of CO₂ Emissions from Anode Baking

Parameter	Industry-Typical Value	Source
For Pitch Volatiles Combustion:		
hydrogen content in pitch (wt%) - %H ₂	0.5%	IAI 2006
waste tar collected (t) - RT	For Riedhammer furnaces only; all others are insignificant	IAI 2006
For Packing Coke:		
packing coke consumed (t coke/ t of baked anode) - PCC	0.015 t/ t	IAI 2006
sulphur content in packing coke (wt%) - S _{pc}	2%	IAI 2006
ash content in packing coke (wt%) - Ash _{pc}	2.5%	IAI 2006

As in the case of anode consumption, the use of Equation 4–13 and Equation 4–14 with actual plant-specific data is considered a Tier 3 type methodology. A Tier 2 type technique involves applying some measured data in combination with industry-typical values to these equations. Shown in Table 4–4 are Tier 2 industry-typical values that can be applied by facilities to estimate CO₂ emissions arising from anode baking.

According to a communication with representatives of the Canadian aluminium industry,¹⁰ one of the three aluminium companies has only relied on plant-specific values to develop its process CO₂ 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 earlier years of the time series.

It should be noted that the use of petroleum coke in anodes for the production of aluminium was also reported by Statistics Canada with all other non-energy uses of petroleum coke. To avoid double counting, the CO₂ emissions from the consumption of anodes in the aluminium smelting process were therefore subtracted from the total non-energy emissions associated with the consumption of petroleum coke.

Calculating PFC Emissions:

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

Equation 4–15: for Slope Method

$$PFC \text{ Emissions (tCO}_2\text{eq)} = \frac{\text{slope} \times AEF \times AED \times MP \times GWP}{1000}$$

where:

Slope	=	slope (for CF ₄ or C ₂ F ₆) of the emission relationship ([kg PFC/t Al]/[AE-minutes/cell-day])
AEF	=	number of anode effects per pot per day (AE/cell-day)
AED	=	anode effect duration (minutes)
MP	=	total aluminium production (t)
GWP	=	global warming potential for CF ₄ or C ₂ F ₆

¹⁰ Chaput P. and Dubois C. 2007. Personal communications (emails from Chaput P. and Dubois C. to A. Au, Greenhouse Gas Division, dated October 12, 2007). Aluminum Association of Canada and Alcoa.

Equation 4–16: for Pechiney Overvoltage Method

$$PFC \text{ Emissions (tCO}_2\text{eq)} = \frac{\text{overvoltage coefficient} \times AEO/CE \times GWP \times MP}{1000}$$

where:

overvoltage coefficient	=	([kg PFC/t Al]/[mV/cell-day])
AEO	=	anode effect overvoltage (mV/cell-day)
CE	=	aluminium production process current efficiency expressed as a fraction
GWP	=	global warming potential for CF ₄ or C ₂ F ₆
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 CF₄ using the slope or overvoltage coefficients as per Equation 4–15 and Equation 4–16. Emissions of C₂F₆ are then calculated by multiplying the CF₄ estimates by the CF₄/C₂F₆ 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,¹¹ 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 4–5 and Table 4–6 above for estimates of some earlier years of the time series.

Calculating SF₆ emissions:

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

¹¹ Chaput P. 2007. Personal communication (email from Chaput P. to A. Au, Greenhouse Gas Division, dated October 12, 2007). Aluminum Association of Canada.

Table 4–5 Tier 2 Default Slope and Overvoltage Coefficients (IAI 2006)

Type of Cell	Slope Coefficients for CF ₄ ([kg PFC/t Al]/ [AE-minutes/cell-day])	Overvoltage Coefficients for CF ₄ ([kg PFC/t Al]/ [mV/cell-day])	Weight Fraction CF ₄ / C ₂ F ₆
Centre Worked Pre-baked	0.143	1.16	0.121
Side Worked Pre-baked	0.272	3.65	0.252
Vertical Stud Søderberg	0.092	NA	0.053
Horizontal Stud Søderberg	0.099	NA	0.085

Note: NA = not applicable

Table 4–6 PFC Emission Factors

Type of Cell	Emission Factors (kg PFC/t Al)	
	CF ₄	C ₂ F ₆
Centre Worked Pre-Baked	0.4	0.04
Side Worked Pre-Baked	1.6	0.4
Vertical Stud Søderberg	0.8	0.04
Horizontal Stud Søderberg	0.4	0.03

4.17.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has been performed for the category of Aluminium Production (i.e. for the CO₂, PFC and SF₆ 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 for the CO₂, PFC and SF₆ estimates were ±7%, ±9% and ±3%, respectively. For the CO₂ and PFC estimates, it should be noted that the uncertainty assessment was done for only one year of the time series (2006 for CO₂ and 2007 for PFC). It is expected that emission estimates of more recent years would have similar uncertainties, while older estimates would have slightly higher uncertainties. For the SF₆ estimate, it was assumed that the uncertainty would be the same as that of the Magnesium Casting category, since the method used to develop SF₆ emission estimates is the same for both Aluminium Production and Magnesium Casting.

The AAC has consistently been used as the data source of estimates shown in this inventory over the time series. The methodology applied by smelters may be of the Tier 3, Tier 2, or Tier 1 type, depending on data availability. However, for recent years, a Tier 3 type technique has been applied by all smelters for estimating emissions.

4.17.4. Category-Specific QA/QC and Verification

CO₂ and PFC emissions from Aluminium Production were key categories that have undergone Tier 1 QC checks as elaborated in the QA/QC plan (see Annex 6). The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC 2000). No issues of importance were detected from the Tier 1 QC process.

4.17.5. Category-Specific Recalculations

There was no recalculation for the category of Aluminium Production.

4.17.6. 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.

4.18. Magnesium Metal Production and Casting (CRF Categories 2.C.5.1 & 2.C.4.2)

4.18.1. Source Category Description

SF₆ is emitted during magnesium production and casting, where it is used as a cover gas to prevent oxidation of the molten metals. Although emitted in relatively small quantities, SF₆ is an extremely potent GHG, with a 100-year GWP of 23 900. SF₆ is not manufactured in Canada. All SF₆ is imported.

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 SF₆ and eventually eliminating the use of SF₆ as cover gas at its plant.¹² This research, as well as the use of substitute gas mixtures, produced significant reductions in SF₆ emissions in the mid-1990s to late 1990s. For the years 2005–2007, Norsk Hydro's SF₆ 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 SF₆ every year during the entire period. Some casters started using SF₆ towards the mid- or late 1990s, whereas others replaced it with an alternative gas, such as SO₂. Two facilities have ceased their casting operations over the last few years. During the 2005–2008 period, only seven facilities were in operation and had used SF₆. Two companies shut down their magnesium casting operations in different times of 2009 (one in June and one in December).

4.18.2. Methodological Issues

For SF₆ 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/que-rysite/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 SF₆ value was estimated based on its 2007 data and number of months of operation in 2008 (i.e. 7 months). For 2009 onwards, since there have been no magnesium production plants operating in Canada, there has been no need to perform any data collection.

Representatives from both Norsk Hydro and Timminco were contacted in 2006, so that the methodology they had applied to estimate SF₆ emissions could be understood. Both companies reported that they used the IPCC default method (Emissions of SF₆ = Consumption of SF₆), as recommended in the IPCC Good Practice Guidance (IPCC 2000). However, they have used different ways for estimating their SF₆ consumption. Norsk Hydro confirmed the use of the weight difference method.¹³ This method is based on measuring the weight of gas cylinders used at the facility at the time when these were purchased and when these were returned to suppliers at the end of the usage. The accounting method was reported as being used by Timminco for estimating its SF₆ use.¹⁴ In this method, accounting of delivered purchases and inventory changes of SF₆ used are recorded. The purchases must be the actual volumes received in the calendar period; 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 SF₆ emissions from casters, the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997) provide one general equation that assumes that all SF₆ used as a cover

12 Laperrière J. 2004. Personal communication (email from Laperrière J. to A. Au, Greenhouse Gas Division, dated October 27, 2004). Norsk Hydro.

13 Laperrière J. 2006. Personal communication (email from Laperrière J. to A. Au, Greenhouse Gas Division, dated October 4, 2006). Norsk Hydro.

14 Katan R. 2006. Personal communication (emails from Katan R. to A. Au, Greenhouse Gas Division, dated March 16–22, 2006). Timminco.

gas is emitted to the atmosphere. To estimate SF₆ emissions for 1990–2004 using this equation, attempts had been made, through a study (Cheminfo Services 2005b) in 2005, to collect data on SF₆ consumption from casting facilities. A couple of facilities indicated that they did not hold any historical records of their past SF₆ consumption. Therefore, to estimate SF₆ use for the entire time series, results of a previous study (Cheminfo Services 2002) were used in combination with the data received from the Cheminfo Services (2005b) study and some assumptions. For casters that had SF₆ data for only a year, it was assumed that their SF₆ use stayed constant, during the other operating years, at the level of the year for which the actual SF₆ data were obtained. For casters that had data for more than one year, linear interpolation between two data points was applied to estimate SF₆ consumption for the other years.

For 2005–2007, consumption data were provided by all seven operating casting facilities through a voluntary data submission process. They were used for the calculation of emissions. For 2008, data were made available by six out of the seven casting facilities through the voluntary data submission process. For the remaining facility, it was assumed that its 2008 SF₆ use stayed at the 2007 level. For 2009, communication was established with all seven companies. Two of the companies, for which magnesium casting operations were shut down in 2009, were not able to report their 2009 SF₆ use data, but provided reasonable assumptions that could be used to estimate the 2009 SF₆ use. SF₆ use data for 2009 were provided by the other five facilities. No 2010 or 2011 data were obtained from these facilities. The reported 2009 SF₆ use data were taken to be the 2010 and 2011 use data.

The technique applied to estimate emissions from magnesium casting for 1990–2004 and 2008–2009 is considered to be a modified Tier 3 type method, as it is based on the reporting of facility-specific emission data and some assumptions. For 2005–2007, the method used is considered as a Tier 3 type.

4.18.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has been performed for the category of Magnesium Casting. It took into account the uncertainty associated with the SF₆ data reported by each facility. The uncertainty for the category as a whole

was estimated at $\pm 4.0\%$. It should be noted that the uncertainty assessment was done for only one year of the time series (2007). As such, it is expected that emission estimates of more recent years (2005 onwards) would have a similar uncertainty value, while older estimates would have a slightly higher uncertainty.

As the last magnesium production facility was closed in August 2008, it became difficult to gather the data needed for the Tier 1 uncertainty assessment of the Magnesium Production category. Hence, based on the fact that the same emission estimation method (i.e. emissions = consumption of SF₆) was applied to both categories of Magnesium Casting and Magnesium Production, it was assumed that the Magnesium Production category would have the same uncertainty ($\pm 4.0\%$) as the Magnesium Casting category.

The data source remains consistent over the time series. The methodology, which equates consumption of SF₆ as a cover gas by magnesium casters to emissions of SF₆, is applied over the time series with some assumptions for some historical years, as discussed in the methodology section.

4.18.4. Category-Specific QA/QC and Verification

Magnesium Production and Magnesium Casting have both undergone Tier 1 QC checks as elaborated in the QA/QC plan (see Annex 6). The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC 2000). No issues of importance were detected from the Tier 1 QC process.

4.18.5. Category-Specific Recalculations

There was no recalculation for the categories of Magnesium Production and Magnesium Casting.

4.18.6. Category-Specific Planned Improvements

Efforts will be made to obtain the up-to-date SF₆ use data from magnesium casting.

4.19. Production of Halocarbons (CRF Category 2.E)

4.19.1. Source Category Description

Chlorodifluoromethane (HCFC-22 or CHClF_2) is produced when reacting chloroform (CHCl_3) with hydrogen fluoride (HF), in the presence of antimony pentachloride (SbCl_5) as catalyst. During the manufacture of HCFC-22, trifluoromethane (HFC-23 or CHF_3) is generated as a byproduct (IPCC 2002).

The reaction is carried out in a continuous flow reactor, usually under high pressure (up to 500 psig) and temperatures in the order of 45 to 200°C. Although the reaction is exothermic, heat is added to increase the flow of vapours leaving the reactor. The vapour stream contains HCFC₂₂ (CHClF_2), HFCF-21 (CHCl_2F), HFC-23 (CHF_3), HCl, excess CHCl_3 , 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 1993.¹⁵

HCFC-22 can be used as refrigerant, as a blend component in foam blowing and as a chemical feedstock for manufacturing synthetic polymers (IPCC 2002). However, due to its ozone-depleting properties, developed countries have scheduled the phase-out of HCFC-22 for the coming

years. In Canada, there has been no more manufacturing or import of equipment containing HCFC-22 as of Jan. 1, 2010 (HRAI 2008).

4.19.2. Methodological Issues

To estimate HFC-23 emissions from HCFC-22 production, the total HCFC-22 production was multiplied by the IPCC Tier 1 default emission factor of 0.04 t HFC-23 / t HCFC-22 produced (IPCC/OECD/IEA 1997). It was assumed that destruction (through thermal oxidation) or transformation of HFC-23 was not practiced in Canada. The 1990–1992 production data were collected by the UPCIS from HCFC producers.¹⁶

4.19.3. Uncertainties and Time-Series Consistency

Uncertainty in the HFC-23 emission estimates has not been assessed. However, it was believed that the production data reported by HCFC-22 producers were reasonably accurate. The major source of uncertainty could be the Tier 1 default emission factor, because the correlation between the quantity of HFC-23 emitted and the HCFC-22 production rate can vary with plant infrastructure and operating conditions (IPCC 2002).

4.19.4. Category-Specific QA/QC and Verification

Informal checks (such as data transcription checks, calculation checks, and unit conversion checks) were done on the category of HCFC-22 Production. No issues of importance were detected.

4.19.5. Category-Specific Recalculations

There were no recalculations for this category.

4.19.6. Category-Specific Planned Improvements

There are currently no improvements planned for this category.

¹⁵ Bovet Y. 2007. Personal communication (email from Bovet Y. to A. Au, Greenhouse Gas Division, dated November 8, 2007). Environment Canada, UPCIS.

¹⁶ Bovet Y. and Y. Guilbault. 2004–2006. Personal communications (emails received from Bovet Y. and Guilbault Y. to A. Au, Greenhouse Gas Division, during the years 2004–2006). UPCIS.

4.20. Consumption of Halocarbons (CRF Category 2.F)

Hydrofluorocarbons (HFCs) and, to a very limited extent, perfluorocarbons (PFCs) are serving as alternatives to ozone-depleting substances being phased out under the Montreal Protocol. Application areas of HFCs and PFCs include refrigeration and air conditioning, fire suppression, aerosols, solvent cleaning, foam blowing, and other applications (such as semiconductor manufacturing in the case of PFCs).

Before the ban on the production and use of CFCs came into effect in 1996, as a result of the Montreal Protocol, very few HFCs were produced and used. The only HFCs produced were HFC152a, a component of the refrigerant blend R-500; and HFC-23, a by-product of HCFC-22 production (discussed in the previous section). As such, emissions from HFC consumption were considered negligible for the 1990–1994 period. HFC-134a began to be produced in 1991 and a variety of other HFCs are now also being produced (IPCC/OECD/IEA 1997). All HFCs consumed in Canada are imported in bulk or in products (e.g. refrigerators). There is no known production of HFCs in Canada.

PFCs have been primarily used as cooling/heating agents in specialized market segments and in electronic safety testing. However, emissions from the consumption of PFCs are minor relative to the by-product emissions of PFCs from aluminium production (discussed in the section on aluminium production). Like HFCs, all PFCs consumed in Canada are imported in bulk or in products. There is no known PFC manufacturing in Canada.

4.20.1. Methodological Issues

HFC emission estimates for 1995 were based on data gathered from an initial HFC survey conducted by the Use Patterns and Control Implementation Section (UPCIS) of Environment Canada in 1996. Environment Canada has revised subsequent surveys to obtain more detailed activity data. The 1998, 1999, 2001 and 2005 HFC surveys were the source of activity data for emission estimates for the years 1996–2000 and 2004 (2004–2006 emails from Y. Bovet and Y. Guilbault).¹⁷ In some cases, one survey was done to col-

lect 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 2005–2010¹⁸ were collected by the GHG Division through a voluntary data submission process. In this process, requests for data were sent to the main importers of bulk HFCs and to companies that import/export HFC-containing products. For 2009, the distribution list for data collection was expanded, as the Division became aware of other players (either importers of bulk HFCs or importers/exporters of items with HFCs) in the market by looking at HFC import data collected by the Canadian Border Services Agency (CBSA).¹⁹

In terms of data on imports of bulk HFCs, since the 2007 and 2008 data were not provided by one of the major importers, it was assumed that the company would have the same 2006–2007 and 2006–2008 growth rates (%) in its imports as the other reporting companies. The same company also did not respond to the voluntary data submission survey for 2009 and 2010 data. As such, its 2009 and 2010 HFC import was assumed to stay at the 2008 level. As mentioned above, there were other companies added to the distribution list of the 2009 data collection, and some of these companies that reported their data in 2009 decided not to participate in the 2010 voluntary data collection. For these companies it was assumed that their 2009 value would be applicable for 2010.

For 2011, there was no voluntary collection of HFC data arranged due to the expectation that such data would later on be acquired through a CEPA section 71 (mandatory environmental reporting) initiative. The initiative, currently underway, would collect import and distribution data on bulk HFCs, from 2005 to 2012. In respect of 2011 HFC emissions, the assumption has been to keep levels of consumption of HFCs the same as 2010.

In terms of data on import/export of HFC-containing products, in the cases where data were not available from

¹⁷ Bovet Y. and Y. Guilbault. 2004–2006. Personal communications (emails received from Bovet Y. and Guilbault Y. to A. Au, Greenhouse Gas Division, during the years 2004–2006). UPCIS.

¹⁸ Except for 2010, data collection by the GHG Division on bulk HFCs only covered “Sales.” However, with no Canadian production existing for HFCs, and an insignificant amount of exports, the import values should theoretically be close to the sales values. In fact import values were added to the 2010 data collection in order to verify the sales values.

¹⁹ It should be noted that HFC data from the CBSA cannot be used for GHG inventory purposes, as these HFC data are collected and categorized only under three types: HFC-134a, HFC-152a and others. Also, the data are not presented by use type. However, company-specific data from the CBSA are a useful tool for expanding the distribution list for the HFC data collection conducted by the GHG Division and for cross-checking the data submitted to the Division.

companies, it was assumed that the non-reported quantities stayed at the levels of the most recent years for which data were available, or data were linearly interpolated. For instance, 1995 data on the quantities of HFCs contained in imported and exported products, except imported and exported vehicles, were not available. As such, 1995 HFC quantities in imported and exported products were assumed to be zero. For 1999–2003, these quantities were linearly interpolated from the data available in 1998 and 2004. Similar to the situation for data on bulk HFCs, the distribution list for HFC item data collection has been expanded for 2009 data, and this list was used for the 2010 data collection.

Since detailed 1995 HFC data were not available, the IPCC Tier 2 method could not be applied. Instead, a modified Tier 1 methodology was used to obtain a representative estimate of the actual 1995 HFC emissions for the following groups: aerosols, foams, air conditioning original equipment manufacture (AC OEM), AC service, refrigeration, and total flooding systems. To estimate 1996–2008 HFC emissions at the national level, an IPCC Tier 2 methodology was applied. A more detailed description of the Tier 1 and Tier 2 methods used is provided in the following subsections.

Once the emission estimates at the national level were obtained, they were distributed by province/territory based on proxy variables, such as gross output of accommodation and food services for commercial refrigeration and number of households for residential refrigeration. The details of the proxy variables used and assumptions made can be made available upon request.

The IPCC Tier 2 methodology was used to estimate emissions from the consumption of PFCs for the years 1995–2011. Details of the method are found in the following subsections. The 1995–2000 activity data were obtained through the 1998 and 2001 PFC surveys conducted by Environment Canada. As 2001–2004 data were unavailable, emission estimates were developed, by and large, based on the assumption that the use quantities in various applications stayed constant since 2000. The GHG Division conducted a collection of 2003–2007 PFC use data from major distributors of PFCs in 2008 and 2009. The data from the major distributors were then integrated with existing PFC use data. The 2008 and 2009 PFC use data from major distributors were collected in 2009 and 2010. No collection

of 2010 and 2011 PFC use data occurred; instead, the 2010 PFC use data were extrapolated from the 2009 PFC use data using 2009 and 2010 GO (gross output) data of applicable economic sectors. These PFC use data were used in the emission estimation. The poor data collection responses from PFC use companies prompted to the switch to collect data from the major distributors of PFCs.

4.20.1.1. 1995 HFC Emission Estimates

The following subsections provide explanations on the emission factors used and the assumptions made to develop 1995 HFC emission estimates for AC OEM, AC service, refrigeration, foam blowing, aerosol products and total flooding systems.

Air Conditioning Original Equipment Manufacture (AC OEM)

To estimate emissions from AC OEM, the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997) suggest a 2–5% loss rate. For Canada, a rate of 4% was assumed.

AC Service

Since it was assumed that for AC systems, HFCs were mostly used to replace operating losses, a loss rate of 100% was applied.

Refrigeration

It was assumed that all refrigeration in Canada falls under the “commercial and industrial” category, since it was the dominant emission source. It was also assumed that the quantity of HFCs reported under “refrigeration” represented the amount used for initial and subsequent recharging of equipment. Therefore,

Equation 4-17:

$$HFC(refrig) = Charge + Operating Loss$$

The IPCC considers that operating loss is approximately 0.17(charge) (IPCC/OECD/IEA 1997). Therefore, assuming the total charge remains constant for the short term,

$$HFC(refrig) = Charge + 0.17 (Charge) = 1.17 (Charge)$$

or

$$Charge = \frac{HFC(refrig)}{1.17}$$

Assuming assembly leakage was minimal,

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

Thus,

Equation 4–18:

$$\text{Emissions} = 0.17 \times \left(\frac{\text{HFC(refrig)}}{1.17} \right)$$

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.

4.20.1.2. 1996–2011 HFC and 1995–2009 PFC Emission Estimates

The following subsections provide explanations on the emission factors used and the assumptions made to develop 1996–2011 HFC and 1995–2009 PFC emission estimates.

Refrigeration and AC System Assembly

The Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997) recommend the use of the following equation for the estimation of emissions from the assembly of residential refrigeration, commercial refrigeration, stationary AC, and mobile AC systems:

Equation 4–19:

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

where:

$E_{\text{assembly},t}$	=	emissions during system manufacture and assembly in year t
Charge_t	=	quantity of refrigerant charged into new systems in year t
k	=	assembly losses in percentage of the quantity charged

The k value was chosen from a range of values that were provided for each equipment category in the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997) (Table 4–7).

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:

Table 4–7 Percentage of Losses during Assembly (k) for Various Applications

For HFC estimates		For PFC estimates	
Application Type	k Values (%)	Application Type	k Values (%)
Residential Refrigeration	2.0	Refrigeration (including ultra low temperature refrigeration)	3.5
Commercial Refrigeration	3.5	Stationary AC	3.5
Stationary AC	3.5	Mobile	4.5
Mobile AC	4.5		

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		

Equation 4–20:

$$E_{operation,t} = Stock_t \times x$$

where:

- $E_{operation,t}$ = quantity of HFCs/PFCs emitted during system operations in year t
- $Stock_t$ = quantity of HFCs/PFCs stocked in existing systems in year t
- x = annual leakage rate in percentage of total HFC/PFC charge in the stock

The term “ $Stock_t$ ” 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 equipment. It was assumed that no leakage occurred in the year of manufacturing. The Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997) give a range of values for the annual leakage rate (x) for each of the different equipment categories. The annual leakage rate chosen for each category is shown in Table 4–8.

System Disposal

It was assumed that there were no HFC/PFC emissions from the disposal of refrigeration and stationary AC systems during 1995–2009, since these systems have a lifetime of 15 years (IPCC default value) and HFC use began only in 1995. For the disposal of mobile AC systems with a slightly shorter lifetime of 12 years (the IPCC default average value), it was assumed that there were no recovery and recycling technologies in place and, therefore, 100% of the quantities remaining in systems built in 1995 would be emitted in 2008. This is a conservative assumption because various regulatory requirements currently existing in Canada would prohibit release of HFCs.

Foam Blowing

The IPCC Tier 2 methodology presented in the revised 1996 IPCC guidelines (IPCC/OECD/IEA 1997) was used to estimate HFC (1996–2011) and PFC (1995–2009) emissions from foam blowing. Foams are grouped into two main categories: open cell and closed cell.

Open Cell Foam Blowing

In the production of open cell foam, 100% of the HFCs used are emitted (IPCC/OECD/IEA 1997). There has been no known PFC use in open cell foam blowing. Open cell foam production categories that release HFC emissions include the following:

- Cushioning—Automobiles;
- Cushioning—Others;
- Packaging—Food;
- Packaging—Others; and
- Other Foam Uses.

Closed Cell Foam Blowing

During the production of closed cell foam, approximately 10% of the HFCs/PFCs used are emitted (IPCC/OECD/IEA 1997). The remaining quantity of HFCs/PFCs is trapped in the foam and is emitted slowly over a period of approximately 20 years. The IPCC Tier 2 equation (as shown below) was used to calculate emissions from closed cell foam:

Equation 4–21:

$$E_{foam,t} = 10\% \times Qty_{manufacturing,t} + 4.5\% \times Orig. Charge$$

where:

- $E_{foam,t}$ = emissions from closed cell foam in year t
- $Qty_{manufacturing,t}$ = 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 fireextinguishing systems.

Aerosols/Metered Dose Inhalers

The IPCC Tier 2 methodology presented in the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997) was used to calculate HFC emissions from aerosols for 1996 onwards. The emission estimate for the current year is equal to half of the HFCs used in aerosols in the current year plus half of the HFCs used in aerosols in the previous year. The amount of HFCs used each year is equal to the amount of HFCs used to produce aerosols and the amount of HFCs in imported aerosol products and excludes the amount of HFCs in exported aerosol products.

Since no data on PFCs used in aerosols were gathered from Environment Canada's PFC surveys, it was assumed that PFC emissions coming from the use of PFCs in aerosols were negligible.

Solvents

The IPCC Tier 2 methodology presented in the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997) was used to estimate HFC and PFC emissions from solvents. The emission estimate for the current year is equal to half of the HFCs/PFCs used as solvents in the current year plus half of the HFCs/PFCs used as solvents in the previous year. The amount of HFCs/PFCs used each year is equal to the amount of HFCs/PFCs produced and imported as solvents and excludes the amount of HFCs/PFCs exported as solvents. HFCs/PFCs used as solvents include the following categories:

- electronics industries;
- laboratory solvents; and
- general cleaning.

Semiconductor Manufacture

There are two main uses of PFCs in the semiconductor manufacturing industry: plasma etching of silicon wafers and plasma cleaning of chemical vapour deposition chambers.

IPCC Tier 2b methodology, as shown below, was used to estimate PFC emissions from the semiconductor manufacturing industry:

Equation 4–22:

$$E_{SC} = E_{FC} + E_{CF4}$$

where:

E_{SC}	=	total PFC emissions from semiconductor
E_{FC}	=	emissions resulting from the use of PFCs (see Equation 4–23 below)
E_{CF4}	=	CF ₄ emitted as a by-product during the use of PFCs (see Equation 4–24 below)

Table 4–9 PFC Emission Rates¹

Process	IPCC Default Emission Fractions			
	CF ₄	C ₂ F ₆	C ₃ F ₈	c-C ₄ F ₈
(1-C) Plasma Etching	0.7	0.4	0.4	0.3
(1-C) Chemical Vapour Deposition Chamber	0.8	0.7	0.4	ND
B Plasma Etching	NA	0.1	ND	NA
B Chemical Vapour Deposition Chamber	NA	0.1	0.2	NA

Notes:

1. Tier 2b, from IPCC (2000) Table 3-15

NA = not applicable.

ND = no data.

Equation 4–23:

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

where:

- h = fraction of fluorocarbon remaining in shipping container (heel) after use
- p = process type (plasma etching or chemical vapour deposition chamber cleaning)
- FC_{i,p} = quantity of fluorocarbon i fed into the process type p
- C_{i,p} = use rate (fraction destroyed or transformed) for each fluorocarbon i and process type p
- a_{i,p} = fraction of gas volume i fed into the process p with emission control technologies
- d_{i,p} = fraction of fluorocarbon i destroyed in the process p by the emission control technologies

Equation 4–24:

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

where:

- B_{i,p} = fraction of gas i transformed into CF₄ 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 be equal to 0 and d_{i,p} to 1. Also, h was assumed to equal 0.1, as suggested in IPCC (2000).

Other Sources

Minor amounts of PFC emissions have been identified as related to PFC use in the electronics industry for emissive applications, including reliability testing (inert liquids), coolants (direct evaporative cooling for electric and electronic apparatuses and indirect coolants in closed-circuit electronic apparatuses), and precision cleaning (IPCC 2000). These emissions can be classified into two types of sources: *emissive* and *contained*.

Emissive sources include the following:

- electrical environmental testing;
- gross leak testing; and
- thermal shock testing.

Unidentified and miscellaneous PFC uses reported in the PFC survey were also considered as part of *emissive* sources. According to the IPCC Tier 2 methodology, 50% of PFCs used for the above purposes would be released during the first year and the remaining 50% released in the following year.

Contained sources consist of PFCs used as an electronic insulator and a dielectric coolant for heat transfer in the electronics industry. The IPCC Tier 2 emission factors (IPCC 2000) are applied to the PFC use data obtained from the PFC survey to estimate PFC emissions from contained sources, as follows:

Equation 4–25:

$$E_{\text{contained},t} = (k \times Qty_1) + (x \times Stock_t) + (d \times Qty_t)$$

where:

$E_{\text{contained},t}$	=	emissions from contained sources
Qty_t	=	quantity of PFC sale for use or manufacturing of contained sources in year t
$Stock_t$	=	quantity of PFCs in stock in year t
k	=	manufacturing emission rate (1% of annual sales)
x	=	leakage rate (2% of stock)
d	=	disposal emission factor (5% of annual sales)

4.20.2. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has been performed for the category of HFC Consumption. It took into account the uncertainties associated with all the subcategories, such as residential/commercial refrigeration, stationary/mobile AC, etc. To determine the uncertainty for a subcategory, the uncertainties related to activity data (Cheminfo 2005c) and emission factors (Japan's Ministry of the Environment 2009) were used. It should be noted that the category uncertainty can vary throughout the time series because it is dependent on the magnitude of each of the subcategory emission estimates, which changes from year to year. The uncertainty associated with the category as a whole for the time series ranged from $\pm 34\%$ to $\pm 50\%$.

Maintaining the consumption of HFCs constant between 2010 and 2011 is expected to increase the uncertainty of the category. Considering that 2010 was the year that brought with it the ban on the production and import of HCFC-containing equipment, it is expected that the surge seen in the use of HFCs (as replacements to HCFCs) would subside for 2011 and after.

A Tier 1 uncertainty assessment has also been performed for the category of PFC Consumption. Similar to HFC Consumption, the uncertainties related to activity data (IPCC 2006) and emission factors (Japan's Ministry of the Environment 2009) were taken into account in the assessment for PFC Consumption. The uncertainty associated with the category as a whole for the time series ranged from $\pm 10\%$ to $\pm 24\%$.

4.20.3. Category-Specific QA/QC and Verification

Consumption of Halocarbons resulting in HFC emissions was a key category that has undergone Tier 1 QC checks as developed in the QA/QC plan (see Annex 6). The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC 2000). Some transcription errors (for 1999–2008 estimates) were detected from the Tier 1 QC process.

4.20.4. Category-Specific Recalculations

No recalculations were performed for this source category.

4.20.5. Category-Specific Planned Improvements

Environment Canada, in the course of 2012 and early 2013, conducted a contract to research emission factors associated with Canadian refrigeration and AC equipment, for all the stages of its life cycle. This study is expected to produce more practical (and lower) EF values that will suit Canadian circumstances. The new EFs will be used in the next NIR's estimates.

As mentioned earlier, the inventory agency is also collaborating with EC's regulatory group for a comprehensive collection of HFC importation and distribution data from 2005 to 2012. It is expected that these data will allow updates to the 2011 estimates, as well as improvements to some of the historical data.

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

4.21.1. Source Category Description

In addition to magnesium production and casting, electrical equipment in electric utilities and semiconductor manufacturing are known sources of SF₆ emissions. In electric utilities, SF₆ is used as an insulating and arc-quenching medium in high-tension electrical equipment, such as

electrical switchgear, stand-alone circuit breakers and gas-insulated substations.

There is currently no production of SF₆ in Canada; therefore, all Canadian supply of SF₆ is obtained through imports. From 1990 to 1996, more than 95% of total SF₆ imports came from the United States; however, in recent years, this percentage has declined, with an increase in SF₆ imports from Germany (Cheminfo Services 2002).

4.21.2. Methodological Issues

SF₆ Emissions from Electrical Equipment

A modified Tier 3 method was used to estimate SF₆ emissions from electrical equipment in utilities for certain years (i.e. 2006–2011) of the time series, in place of the previous top-down approach (which assumed that all SF₆ purchased from gas distributors replaces SF₆ lost through leakage). The SF₆ emission estimates by province for 2006–2011 were provided by the Canadian Electricity Association (CEA)—which represents electricity companies across Canada, except for the province of Quebec—and Hydro Quebec (HQ). The emission data submitted by the CEA and HQ were prepared following the *SF₆ Emission Estimation and Reporting Protocol for Electric Utilities* (“the Protocol”) (Environment Canada and Canadian Electricity Association 2008). The national SF₆ estimate for each year of 2006–2011 was the sum of all provincial estimates. The *Protocol* is the result of a collaborative effort between the GHG Division, the CEA and HQ. It is also part of the memorandum of understanding between the GHG Division and the CEA, and of the voluntary data submission agreement of HQ.

In summary, the *Protocol* explains how the (country-specific) modified Tier 3 method was derived from the IPCC Tier 3 life cycle methodology. It also explains the different options available for estimating the equipment life cycle emissions. These are equal to the sum of SF₆ used to top up the equipment and the equipment disposal and failure emissions (which are equal to nameplate capacity less recovered quantity for disposal emissions or to simply nameplate capacity for failure emissions). The options for the tracking of SF₆ consumed for top-ups are mass flow meters, weigh scales and cylinder count. For further details on the methodology, data uncertainty, data quality control, data verification by third party, transfer of information and data to the GHG Division, documentation and archiving, new information or data updates, and protocol

reviews and amendments, please refer to the Protocol (available upon request at <http://www.ec.gc.ca/Publications/default.asp?lang=En&xml=5926D759-36A6-467C-AE05-077C5E6C12A2>). A more detailed description of the methodology is also provided in Annex 3.2.

Estimates were not available from the CEA and HQ for the years 1990–2005 because a systematic manner for taking inventory of the quantities of SF₆ used was only started in 2006. Hence, the application of the Protocol was not possible. Section 7.3.2.2 of the 2000 IPCC Good Practice Guidance suggests four approaches for such a situation: 1) overlap, 2) surrogate method, 3) interpolation, and 4) trend extrapolation. Each of these techniques has been evaluated for its applicability in this particular situation. The surrogate and trend extrapolation methods could not be used because, according to the 2000 IPCC Good Practice Guidance, it is NOT good practice to use these approaches for a long period. The interpolation approach could not be used because data for intermittent years were needed. The overlap approach was determined to be the most appropriate option in this case for the following reasons:

- The overlap between two or more sets of annual emission estimates could be assessed. (In this case, the overlap was assessed between four sets of annual estimates – 2006, 2007, 2008 and 2009.)
- There was a consistent and proportional relationship between the estimates developed using the “old” (i.e. used in the previous submission) and the modified Tier 3 methods. (In this case, the national estimates developed using the modified Tier 3 method were consistently around 10–20% of those developed using the old method.)

Emissions at provincial/territorial levels were estimated based on the national emission estimates (obtained from the use of the overlap approach) and the percent of provincial shares (based on the reported 2006–2009 data)

SF₆ Emissions from Semiconductor Manufacturing

The method applied to estimate SF₆ emissions from semiconductor manufacturing was similar to the one used for calculating PFC emissions. However, as there is no by-product CF₄ created during the use of SF₆ in the process, Equation 4–24 is not needed. Hence,

Equation 4–26:

$$SF_6 \text{ Emissions} = (1 - h) \times [FC \times (1 - C) \times (1 - a \times d)]$$

where:

h	=	fraction of SF ₆ remaining in shipping container (heel) after use (%)
FC	=	quantity of SF ₆ fed into the process (or sales) (t)
C	=	use rate (fraction destroyed or transformed) (%)
a	=	fraction of gas volume fed into the process with emission control technologies
d	=	fraction of SF ₆ destroyed in the process by the emission control technologies

The value of “h” provided and confirmed by two major SF₆ gas distributors, Air Liquide and Praxair, was 12%.²⁰ 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 SF₆ sales to semiconductor manufacturers in 2004–2009 were estimated by multiplying the SF₆ import (data purchased from Statistics Canada) by the sales distribution (in %) to semiconductor manufacturers. No SF₆ sales data were collected for the 2010 and 2011 data years. The 2009 SF₆ sales data were therefore used to determine the amount of SF₆ used by semiconductor manufacturers. As explained above, sales data by market segment provided by some of the major SF₆ gas distributors were used to establish the percentage of sales attributed to each user/market type. It is noteworthy to mention that attempts have been made to collect SF₆ use data directly from manufacturers, but the response rate for the data-gathering exercise was rather low and the small amount of collected data would

not bring in any improvement to the current estimation method.

4.21.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment was conducted for the category of SF₆ from Electrical Equipment. It should be noted, though, that the uncertainty assessment was done using 2007 data from the previous submission. Therefore, it is expected that emission estimates of this submission would have much lower uncertainty values. The uncertainty for the category as a whole was estimated at ±32.0%.

A Tier 1 uncertainty assessment has also been performed for the category of Semiconductor Manufacturing. Although the assessment took into account uncertainties associated with the parameters of Equation 4–24, it should be mentioned that the most of these uncertainties were assumed values due to data unavailability. The uncertainty for the category as a whole was estimated at ±45%. The uncertainty value is applicable to all years of the time series.

Depending on the years, the data source and methodology used for SF₆ from electrical equipment could vary, as explained in the section above. For SF₆ from semiconductor manufacturing, both data source and methodology used were consistent throughout the time series.

4.21.4. Category-Specific QA/QC and Verification

SF₆ Consumption in Electrical Equipment was a key category that has undergone Tier 1 QC checks as developed in the QA/QC plan (see Annex 6). The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC 2000). No issues of importance were detected.

Informal checks (such as data transcription checks, calculation checks and unit conversion checks) were done on the category of Semiconductor Manufacturing. No issues of importance were detected.

4.21.5. Category-Specific Recalculations

A transcription error resulted in the recalculation of 2010 SF₆ emissions from Semiconductor Manufacturing.

20 Rahal H. and Tardif A. 2006. Personal communications (emails from Rahal H. and Tardif A. to A. Au, Greenhouse Gas Division, dated November 22, 2006, and November 13, 2006, respectively). Praxair and Air Liquide, respectively.

4.21.6. Category-Specific Planned Improvements

As a planned improvement for the category of SF₆ from Electrical Equipment, an assessment of the uncertainty associated with the new emission data will be performed in collaboration with the Canadian electric utility companies.

Efforts will be made to obtain up-to-date SF₆ sales data.

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

4.22.1. 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 the Industrial Processes Sector. 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 CO₂ emissions. Also included in this category are emissions from use of hydrocarbons (such as coal) as reductants for base metal smelting.

The use of fossil fuels as feedstock or for other non-energy uses is reported in an aggregated manner by Statistics Canada (#57-003) under “Non-Energy Use” for each individual fuel. In the event that CO₂ emissions resulting from non-energy fuel use are allocated to another category of the Industrial Processes Sector (as is the case for ammonia production, iron and steel production, and aluminium production), those emissions are subtracted from the total non-energy emissions to avoid double counting.

4.22.2. Methodological Issues

Emission rates for non-energy use of fuels were developed based on the total potential CO₂ emission rates and the IPCC default percentages of carbon stored in products. The total potential CO₂ 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 RESD data for any given year are preliminary and subject to revisions in subsequent publications. These data were multiplied by the emission rates shown in Annex 3 to estimate CO₂ emissions for this subsector.

This technique is considered to be a Tier 1 type method, as it is based on the use of national consumption data and average national emission factors. Methodological issues for calculating CO₂ emissions from the non-energy use of fossil fuels are not addressed specifically in the IPCC Good Practice Guidance (IPCC 2000).

4.22.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has also been performed for the subsector of Other and Undifferentiated Production. The assessment took into account uncertainties associated with the activity data and emission factors (ICF Consulting 2004). The uncertainty for the category as a whole was estimated at ±21%. It should be noted that the uncertainty assessment was done for only one year of the time series (2007).

The methodology used is consistent over the time series. However, the updated activity data for 1996 to 2010—received in the latest RESD (dated January 2013)—resulted in a recalculation of emissions for 2004–2010. For 1996–2003, the older RESD values were kept, and therefore emissions were not recalculated. This category has thus been reported in two time series that are not consistent in the underlying data. The reasons behind this approach—as applied to both the non-energy and energy-related activity data—have been amply discussed in the NIR’s Executive Summary. It is intended that for the older time series, i.e., emissions between 1996 and 2003, the updated data be acquired and that new emission values be reported in the next NIR.

4.22.4. Category-Specific QA/QC and Verification

Other and Undifferentiated Production was a key category that has undergone Tier 1 QC checks as developed in the QA/QC plan (see Annex 6). The checks performed were consistent with the Tier 1 General Inventory Level QC

Procedures outlined in the IPCC Good Practice Guidance (IPCC 2000). No issues of importance were detected.

4

4.22.5. Category-Specific Recalculations

New values from RESD resulted in the recalculation of emissions from 2004 to 2010.

4.22.6. Category-Specific Planned Improvements

As mentioned in Section 4.22.3, it is intended that emission estimates for years 1996 to 2003 be recalculated, based on the latest RESD activity data, and that results be reported in NIR 2014.

Chapter 5

Solvent and Other Product Use (CRF Sector 3)

5.1. Overview

Although the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997) mentions that solvents and related compounds can be significant sources of emissions of non-methane volatile organic compounds (NMVOCs), the Solvent and Other Product Use Sector accounts only for direct greenhouse gas (GHG) emissions. Annex 10 of the NIR provides details on emissions of NMVOCs and other indirect GHG emissions.

This Sector specifically includes emissions that are related to the use of N₂O 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 CO₂ emissions associated with the production of solvents are included in the Industrial Processes Sector.

As shown in Table 5–1, the GHG emissions from the Solvent and Other Product Use Sector contributed 0.25 Mt CO₂ eq to the 2011 national GHG inventory, compared

with 0.18 Mt CO₂ eq in 1990. These emissions represented 0.04% of the total Canadian GHG emissions in 2011. The emission trends, either long term or short term, were driven mainly by the domestic demand for N₂O for anaesthetic or propellant purposes.

Most of the N₂O sold in Canada is used as an anaesthetic. The second major application of N₂O is as a propellant to generate pressure in aerosol products, with the largest application being pressure-packaged whipped cream. Demand for N₂O in Canada for manufacturing of this food product has been relatively stable since 1995 (Cheminfo Services 2006).

Although not a key category (KC), this category that forms a Sector underwent Tier 1 quality control checks like a KC to ensure correctness of estimates. Further details on quality assurance and quality control and uncertainty assessment can be found in sections 5.1.4 and 5.1.3, respectively.

5.1.1. Source Category Description

N₂O is a clear, colourless, oxidizing liquefied gas with a slightly sweet odour, and is stable and inert at room temperature. Steam (H₂O) and N₂O are formed in a low-pressure and low-temperature reaction that decomposes ammonium nitrate (NH₄NO₃). While the steam is condensed out, the “crude” N₂O 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 N₂O for commercial sales in Canada. It supplies N₂O to two of the three primary N₂O gas distributors that essentially account for the total commercial market in Canada. These companies sell cylinders of N₂O to a relatively large number of sub-distributors. It is estimated that there may be 9000 to 12 000 final end-use customers for N₂O in Canada, including dental offices, clinics, hospitals and laboratories (Cheminfo Services 2006).

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

GHG Source Category	GHG Emissions (kt CO ₂ eq)							
	1990	2000	2005	2007	2008	2009	2010	2011
Solvent and Other Product Use TOTAL	179	450	378	326	342	260	242	247
Use of N ₂ O as an anaesthetic	151	384	319	276	289	220	204	209
Use of N ₂ O as a propellant	27	66	59	51	53	40	38	38

Note: The sums of anaesthetic and propellant use may not add up to the solvent total due to rounding.

N₂O is used in a limited number of applications, with anaesthetic use representing the vast majority of consumption in Canada. Use as a propellant in food products is the second largest type of end use in Canada. Other areas where N₂O can be used include production of sodium azide¹ (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 N₂O 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 N₂O can be used, only the two major types are emissive. When N₂O is used as an anaesthetic, it is assumed that none of the N₂O is metabolized (IPCC 2006). In other words, the used N₂O quickly leaves the body in exhaled breath (i.e. is emitted) as a result of the poor solubility of N₂O in blood and tissues. When N₂O is used as a propellant, only emissions coming from N₂O used in whipped cream are estimated, because the amounts of N₂O 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 N₂O gas expands and whips the cream into foam. As none of the N₂O is reacted during the process, it is all emitted to the atmosphere (Cheminfo Services 2006).

5.1.2. Methodological Issues

Estimation of N₂O 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 N₂O producer and the three major N₂O 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. NOC provided its production, import, export and domestic sales data for 2011.

As a complete set of sales data covering 1990–2011 could not be gathered, the domestic sales of Canadian producer and N₂O import data purchased from Statistics Canada² were used to estimate the total domestic sales volumes (or consumption) of N₂O. 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 2006–2011 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 N₂O sold for anaesthetic and propellant purposes, the total domestic sales volume was multiplied by the percentage of each of these provided in the sales patterns.

To estimate emissions coming from usage of anaesthetic at the national level, it was assumed that 100% of the quantity used in anaesthetic applications was emitted, as explained previously in the source category description section. This is the recommended emission rate as per the 2006 IPCC guidelines.

To estimate emissions coming from N₂O 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 1990–2011 annual population statistics were obtained from Statistics Canada (2012).

¹ N₂O 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

² 1990–2005 data were downloaded from http://www.statcan.ca/trade/scripts/trade_search.cgi, but this URL is no longer functional. For 2006–2009 data: Bourgeois P. 2010. Personal communications (email from Bourgeois, to E. Renault, Greenhouse Gas Division, on December 2, 2010). Statistics Canada.

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 $\pm 19\%$. 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 as the data sources and methodology applied were the same.

5.1.4. Quality Assurance, Quality Control and Verification

This Sector was treated as a key category and has undergone Tier 1 quality control checks as developed in the quality assurance/quality control plan (see Annex 6). The checks performed were consistent with the Tier 1 general inventory level quality control procedures outlined in the IPCC good practice guidance (IPCC 2000). No issues of importance were detected from the Tier 1 quality control process.

5.1.5. Recalculations

No recalculations were performed on this category.

5.1.6. Planned Improvements

No improvement is currently planned for this category.

Chapter 6

Agriculture (CRF Sector 4)

6.1. Overview

Emission sources from the Agriculture Sector include enteric fermentation (CH_4) and manure management (N_2O and CH_4) categories from animal production and the agricultural soils (N_2O) and field burning of crop residues (CH_4 and N_2O) categories that occur during crop production. Carbon dioxide emissions from, and removals by, agricultural lands are reported in the Land Use, Land-use Change and Forestry (LULUCF) Sector under the Cropland category (see Chapter 7).

The largest sectors in Canadian agriculture are beef cattle (non dairy), swine, and cereal and oil seed crops production. There is also a large poultry industry and a large dairy industry. Sheep are raised, but production is highly localized and small compared to the beef, swine, dairy and poultry industries. Other animals are produced for commercial purposes, namely buffalo,¹ llamas, alpacas, horses and goats, but production is small.

Canadian agriculture is highly regionalized due to historic and climatic influences. Approximately 70% of beef cattle and more than 90% of wheat, barley and canola are produced on the Prairies in a semi-arid to subhumid ecozone. On the other hand, approximately 70% of dairy cattle, 60% of swine and poultry, 95% of corn and 90% of soybeans are produced on the humid mixedwood plains ecozone in Eastern Canada.

In 1990 there were 10.5 million non-dairy cattle in Canada, 1.4 million dairy cattle, 10 million swine and 100 million poultry. Beef cattle and swine populations peaked in 2005

at 15 million head each but have since decreased to 12 million head. Since 1990, poultry populations have increased to 140 million. Dairy cattle populations have decreased steadily from 1990 to 1 million head in 2011.

Since 1990, cropping practices have changed in Canada, with increasing canola production from 3 Mt to 14 Mt, corn production from 7 Mt to 16 Mt, and soybean production from 1.3 Mt to 5 Mt, and decreasing wheat production from 32 Mt to 25 Mt. Synthetic nitrogen consumption has increased from 1.2 Mt N in 1990 to 2 Mt N in 2011, while the area under summerfallow has decreased by 4.8 million hectares (Mha) and the regions using conservation tillage have increased by 12.9 Mha.

As a result of those changes, total greenhouse gas (GHG) emissions from the Canadian Agriculture Sector have increased from 47 Mt CO_2 eq in 1990, to 54 Mt CO_2 eq in 2011 (Table 6–1). This difference represents an increase of 15% from 1990, mainly due to higher populations of beef cattle and swine (16% and 17% increases, respectively), as well as an increase in the use of synthetic nitrogen fertilizers (68%).

Emissions of CH_4 from livestock accounted for 19 Mt CO_2 eq in 1990 and 21 Mt CO_2 eq in 2011, and mean estimates lie within an uncertainty range of -15 to +21%. Over the time series of 1990 to 2011, mean CH_4 emissions are estimated to have increased by 2.0 Mt CO_2 eq, an 11% increase. The observed increase in emissions falls within an uncertainty range of 7% to 15%. Emissions of N_2O from agricultural soils and livestock accounted for 28 Mt CO_2 eq in 1990 and 33 Mt CO_2 eq in 2011, an increase of 19%.

Emissions from the Agriculture Sector peaked in 2005; until 2008, there were no significant changes in total emissions, as increases in emissions due to increased use of nitrogen fertilizer and crop residue decomposition were offset by reductions in emissions from animal production as major livestock populations decreased (Table 6–1). Since 2008, fertilizer emissions have continued to increase; however, due to the continued decline in livestock populations and a decline in crop production in 2011 and the resulting lower residual emissions, total agricultural emissions were more than 4 Mt CO_2 eq lower in 2011 than peak levels in 2005 to 2008.

¹ The Intergovernmental Panel on Climate Change (IPCC) category “buffalo” is being used in Canada to represent the North American bison (*Bison bison*) that is raised for meat production using methods similar to beef cattle.

Table 6–1 Short- and Long-Term Changes in GHG Emissions from the Agriculture Sector¹

GHG Source Category		GHG Emissions (kt CO ₂ eq)							
		1990	2000	2005	2007	2008	2009	2010	2011
Agriculture TOTAL		47 000	56 000	58 000	58 000	59 000	56 000	56 000	54 000
Enteric Fermentation		16 000	20 000	22 000	21 000	20 000	19 000	19 000	18 000
—CH ₄	Dairy Cattle	3 100	2 800	2 700	2 600	2 600	2 600	2 600	2 600
	Beef Cattle ²	12 000	16 000	18 000	17 000	17 000	16 000	15 000	14 000
	Others ³	610	910	1 100	1 000	940	890	870	860
Manure Management		5 700	7 000	7 500	7 200	6 900	6 700	6 500	6 400
—CH ₄	Dairy Cattle	660	600	580	560	560	560	570	570
	Beef Cattle ²	670	760	840	790	770	740	710	690
	Swine	1 100	1 400	1 600	1 500	1 300	1 300	1 300	1 300
	Poultry	130	150	160	150	150	150	150	150
	Others ⁴	20	30	40	40	40	30	30	30
—N ₂ O	All Animal Types	3 200	4 000	4 300	4 200	4 100	3 900	3 800	3 700
Agricultural Soils		25 000	29 000	29 000	30 000	31 000	30 000	30 000	30 000
Direct Sources		14 000	15 000	15 000	16 000	17 000	16 000	16 000	16 000
	Synthetic Nitrogen Fertilizers	5 900	7 700	7 000	8 100	8 500	8 600	8 800	9 200
	Manure Applied as Fertilizers	1 800	2 100	2 200	2 100	2 000	1 900	1 900	1 900
	Crop Residue Decomposition	4 700	4 700	5 200	5 200	6 200	5 600	5 800	5 100
	Cultivation of Organic Soils	60	60	60	60	60	60	60	60
	Conservation Tillage ⁵	-300	-740	-890	-940	-1 200	-1 100	-1 100	-1 200
	Summerfallow	1 400	1 100	830	700	760	660	590	570
	Irrigation	280	340	350	350	390	360	390	410
Pasture, Range, and Paddock Manure		2 200	3 100	3 400	3 300	3 200	3 000	2 900	2 700
Indirect Sources		8 700	10 000	10 000	11 000	11 000	11 000	11 000	11 000
Crop Residue Burning (CH ₄ & N ₂ O)		210	120	40	40	50	40	30	30

Notes:

1. Totals may not add up due to rounding.

2. Beef Cattle includes dairy heifers.

3. Others, Enteric Fermentation, includes buffalo, goat, horse, lamb, llama/alpaca, sheep and swine.

4. Others, Manure Management, includes buffalo, goat, horse, lamb, llama/alpaca and sheep.

5. The negative values reflect a reduced N₂O emission due to the adoption of conservation tillage.

Recalculations were less than 1% in this submission, with an increase in emissions of less than 0.1 Mt CO₂ eq for 1990 and an increase of 0.1 Mt CO₂ eq in 2010, with no notable impact on the emission trend. A complete Tier 2 analysis of N₂O emissions estimation processes resulted in a number of corrections of minor errors in the calculation databases (Table 6–2).

Emissions from biological nitrogen fixation by the legume-rhizobium association are reported as not occurring. This decision is supported by Rochette and Janzen (2005), who concluded that there is no evidence that measurable amounts of N₂O are produced during the nitrogen fixation process. Rice is not produced in Canada and is not a source of CH₄ emissions. 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 Annex 3.3.

6.2. Enteric Fermentation (CRF Category 4.A)

6.2.1. Source Category Description

In Canada, animal production varies from region to region. In western Canada, beef production dominates, combin-

Table 6–2 Corrections and Improvements Carried Out for Canada's 2013 Submissions

Correction or Improvement	Years affected
1. Correction to quantity of N leached from fertilizer application	Complete time series
2. Correction of rounding issues, and input errors in crop residue burning	Complete time series
3. Correction to dairy heifer N-excretion rate	Complete time series
4. Refinement to calculations during the change in database platforms for N ₂ O calculations, including: (i) changes to distribution of fertilizers in the Maritime Provinces, (ii) application of AWMS at the animal subcategory level and (iii) rounding of proportions of AWMS to the nearest percentage point for some minor animal categories	Complete time series
5. Integration of 2011 <i>Census of Agriculture</i> population numbers for minor animal categories, with linear interpolation between census years	2007 to 2010

ing both intensive production systems with high animal densities finished in feedlots, and low-density, ranch-style, pasturing systems for cow-calf operations. Most dairy production occurs in eastern Canada in high-production, high-density facilities. Eastern Canada also has traditionally produced swine in high-density, intensive production facilities. Over the past 20 years, some swine production has shifted to western Canada. Other animals that produce CH₄ by enteric fermentation are raised as livestock, such as buffalo, goats, horses, llamas/alpacas and sheep; however, populations of these animals have traditionally been low.

Methane (CH₄) 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 CH₄ is produced as a by-product. This process results in an accumulation of CH₄ in the rumen that is emitted by eructation and exhalation. Some CH₄ is released later in the digestive process by flatulence, but this accounts for less than 5% of total emissions. Ruminant animals, such as cattle, generate the most CH₄.

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, CH₄ emissions are calculated, by province, by multiplying the animal population of a given category/subcategory by its corresponding emission factor.

For cattle, CH₄ emission factors are estimated using the Intergovernmental Panel on Climate Change (IPCC) Tier 2 methodology, based on the equations provided by IPCC Good Practice Guidance (IPCC 2000). A national study by

Boadi et al. (2004) broke down cattle subcategories, by province, into subannual production stages and defined their physiological status, diet, age class, sex, weight, growth rate, activity level and production environment. These data were integrated into IPCC Tier 2 equations to produce annual emission factors for each individual animal subcategory that take into account provincial production practices. The data describing each production stage were obtained by surveying beef and dairy cattle specialists across the country.

Increased milk production in dairy cattle herds over the 1990–2011 time period are reflected in a 17% increase in CH₄ emission factors from this animal category. Increased milk production increases the requirement of energy for lactation (NE_l) and requires greater food consumption. In beef cattle, changes in mature body weight influence maintenance and growth energy (NE_m and NE_g) requirements and as a consequence feed consumption. From 1990 to 2003 large breeds were popular and emission factors increased from 1990 to 2003 by 7%, but have since decreased from their peak by 5% (see Table A3-17, Annex 3.3).

For non-cattle animal categories, CH₄ emissions from enteric fermentation continue to be estimated using the IPCC Tier 1 methodology. Poultry are excluded from enteric fermentation estimates, since no emission factors are available.

Activity data consist of domestic animal populations for each animal category/subcategory, by province, and are obtained from Statistics Canada (Annex 3.3, Table A3-11). The data are based on the *Census of Agriculture*, conducted every five years and updated annually by semi-annual or quarterly surveys for cattle, swine and sheep.

6.2.3. Uncertainties and Time-Series Consistency

An uncertainty analysis using the Monte Carlo technique was carried out on the methodology used to estimate emissions of methane from agricultural sources. The analysis considered the uncertainty in the parameters defined in Boadi et al. (2004) as they are used within the IPCC Tier 2 methodology equations. Details of this analysis can be found in Annex 3.3, Section A3.3.3.3. Uncertainty distributions for parameters were taken from Karimi-Zindashty et al. (2012), though some additional parameters and updates were included in this analysis.

The uncertainty ranges for CH₄ emissions from enteric fermentation were similar in 1990 and in 2011, and mean estimates lie within an uncertainty range of -17 to +23% (Table 6–3). Over the time series of 1990 to 2011, mean emissions are estimated to have increased by 1.9 Mt CO₂ eq, a 12% increase. The observed increase falls within an uncertainty range of 8% to 16%.

The uncertainty in emissions was mainly associated with the calculation of the emission factor. The range of uncertainty around the calculation of the Tier 2 emission factors was the highest (43%) in the case of beef cattle. Calcula-

tions of uncertainty in emissions and emission factors were the most sensitive to the use of IPCC default parameters in the Tier 2 calculation methodology, in particular the methane conversion rate (Y_m) and the factor associated with the estimation of the net energy of maintenance (C_f) (Karimi-Zindashty et al. 2012). The uncertainty in the estimate of average national livestock populations for major livestock categories, was low (under 6%), and the population of minor livestock categories, though their uncertainty was greater (up to 11%), contributed little to the overall uncertainty of the total emissions due to their small numbers.

The methodology and parameter data used in the calculation of emission factors are consistent throughout the entire time series (1990–2011) with the exception of milk production for dairy cattle. The time series of milk production from 1990 to 1998 is estimated. Two milk production data sets exist in Canada: (i) publishable records that represent production data for genetically elite animals within the Canadian herd from 1990 to present, and (ii) management records that provide a more accurate estimate of production from the entire Canadian dairy herd from 1999 to present. An estimate of real milk production for the entire Canadian herd from 1990 to 1998 was calculated based on the average ratio between the publishable and the management data from 1999 to 2007.

Table 6–3 Uncertainty in Estimates of Emissions of CH₄ from Enteric Fermentation

Animal Category	Uncertainty Source	Mean Value ¹	2.5% Prob ^{2,3}	97.5% Prob
Dairy Cattle	Population (1000 head)	983	929 (-5.4%)	1036 (+5.4%)
	Tier 2 Emission Factor (kg/head/year)	127.6	107.2 (-16%)	154.4 (+21%)
	Emissions (Mt CO ₂ eq)	2.6	2.1 (-18%)	3.2 (22%)
Non-dairy Cattle	Population (1000 head)	12 181	12 229 (-1.8%)	12 689 (+1.8%)
	Tier 2 Emission Factor (kg/head/year)	56.7	46.1 (-19%)	70.1 (+24%)
	Emissions (Mt CO ₂ eq)	14.5	11.9 (-18%)	18.3 (+26%)
Other Animals	Emissions (Mt CO ₂ eq)	0.96	0.78 (-18%)	1.1 (+17%)
Total Emissions	Emissions (Mt CO ₂ eq)	1990	16.1	13.4 (-17%)
		2011	18.0	15.0 (-17%)
	Trend	1990–2011	1.9 (12%)	2.6 (+16%)

Notes:

1. Mean value reported from database, with the exception of Trend, which is the difference between 1990 and 2011.

2. Values in parentheses represent the uncertain percentage of the mean, with the exception of the Trend, where values in parentheses represent the percentage change between 1990 and 2011.

3. Values for confidence intervals are calculated from percentages derived for an analysis of uncertainty in 2010.

6.2.4. QA/QC and Verification

Enteric Fermentation, as a key category, has undergone Tier 1-level QC checks as elaborated in the QA/QC plan (Annex 6) in a manner consistent with IPCC (2000) Good Practice Guidance. The activity data, methodologies and changes are documented and archived in both paper and electronic forms. The IPCC Tier 2 emission factors for cattle, derived from Boadi et al. (2004), have been reviewed by independent experts (McAllister and Basarab 2004).

Internal Tier 2-level QC checks carried out in 2010–2011 included a complete review and rebuild of calculation methodology, input data, and a review and compilation of Canadian research on enteric fermentation (MacDonald and Liang 2011). The literature review suggested that no specific bias can be clearly identified in the enteric emission estimate. Based on the sensitivity analyses carried out in the uncertainty analysis and the review of literature, improvements to the cattle model require the development of country-specific parameters that take into account specific regional management influences on emissions, replacing IPCC defaults currently used in the emission model. Details of this review can be found in Annex 3.3.

6.2.5. Recalculations

The integration of 2011 *Census of Agriculture* (Statistics Canada 2012) population numbers for minor animal categories—buffalo, goats, horses, llamas and alpacas—and poultry with a linear interpolation between 2006 and 2011, resulted in a decrease in emissions from this source after the last census year of 20 kt CO₂ eq in 2007 up to an 80-kt CO₂ eq decrease in 2010. Emissions decreased because populations of large animals such as buffalo and horses decreased by 36 and 14%, respectively, though the populations of goats and broiler chickens did increase.

6.2.6. Planned Improvements

In general, the enteric fermentation methodology is robust; improvements are mainly dependent on the ability to collect more complete data on diet composition fed to livestock that will facilitate the development of parameters specific to animal subcategories within different regions of Canada. At present, data have been collected to develop a time series that accounts for changes in feed ration digestibility. Regional data will be submitted to animal nutrition experts for review in 2013. Implementation of new data and methodologies will occur over the medium term.

A study has begun with Canadian experts in the beef industry to update and improve the beef production model, but is in its initial stages.

6.3. Manure Management (CRF Category 4.B)

In Canada, the animal waste management systems (AWMS) typically used in animal production include 1) liquid storage, 2) solid storage and drylot, and 3) pasture and paddock. To a lesser extent, AWMS also include other systems such as composting and biodigestors. No manure is burned as fuel.

Both CH₄ and N₂O 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 CH₄ emissions but relatively low N₂O emissions, whereas well-aerated systems generate high N₂O emissions but relatively low CH₄ emissions.

Manure management practices vary regionally and also by animal category. Dairy, poultry and swine production occur in modern high-density production facilities. Dairy and swine produce large volumes of liquid manure while poultry produces solid manure, both of which are spread on a limited landbase. Feedlot beef production results in large volumes of drylot and solid manure, whereas low-density pasturing systems for beef result in widely dispersed manure in pastures and paddocks. Production systems for other animals, such as buffalo, goats, horses, llamas/alpacas and sheep are generally in pastured or medium-density production facilities producing mainly solid manure.

6.3.1. CH₄ 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 CO₂; however, if little oxygen is present, carbon is reduced, resulting in the production of CH₄. The quantity of CH₄ produced depends on manure characteristics and on the type of manure man-

agement system. Manure characteristics are in turn linked to animal category and animal nutrition.

6.3.1.2. Methodological Issues

Methane emissions from manure management are calculated for each animal category/subcategory by multiplying its population by the corresponding emission factor (see Annex 3.3 for detailed methodology). The animal population data are the same as those used for the enteric fermentation emission estimates (Section 6.2.2). Methane emission factors for manure management are estimated using the IPCC Tier 2 methodology (IPCC 2006).

All Tier 2 parameters were taken from expert consultations described in Boadi et al. (2004) and Marinier et al. (2004, 2005) or from the IPCC (2006) Guidelines. For dairy and beef cattle, the Boadi et al. (2004) Tier 2 animal production model was used to derive gross energy of consumption (GE) from which volatile solids (VS) were estimated using Equation 4.16 of the Good Practice Guidance and manure ash contents from Marinier et al. (2004). All other livestock used VS taken from Marinier et al. (2004) based on ash content and digestible energy derived from expert consultations. For swine, sheep and poultry, different parameters were used for subcategories based on size class for swine and sheep as well as for turkeys, broilers and layers in the poultry category.

Emission factors were derived using the CH₄ producing potential (B₀) and CH₄ conversion factors (MCF) taken from the IPCC (2006) Guidelines. Manure management systems (AWMS) for each animal category were taken from Marinier et al. (2005) for each province, taking into account regional differences in production practices and manure storage systems. A more complete description of the derivation of the distribution factor for manure management systems is contained in Annex 3.3, Section A3.3.4.4.

An increase in emission factors over the period of 1990 to 2011 (see Table A3-14 in Annex 3.3) reflects higher gross energy intake for dairy cattle due to increased milk productivity and for beef cattle due to changes in live body weights (see Section 6.2.2).

6.3.1.3. Uncertainties and Time-Series Consistency

The uncertainty analysis of emissions of methane from agricultural sources using the Monte Carlo technique included methane emissions from manure management.

The analysis used parameter estimates and uncertainty distributions from Marinier et al. (2004) supplemented with information from Karimi-Zindashty et al. (2012) and additional and updated parameters specific to this analysis. Details of this analysis can be found in Annex 3.3, Section A3.3.4.8.

The estimate of 2.7 Mt CO₂ eq from manure management CH₄ emissions from Canadian livestock in 2011 lies within an uncertainty range of -29% to +33% (Table 6-4). The emission estimate from manure management in 1990, 2.6 Mt CO₂ eq, has a slightly larger uncertainty range, -33% to +38%, due to greater uncertainty associated with the type of manure management systems in 1990. The estimate of a +6% increase in mean emissions between 1990 and 2011 lies within an uncertainty range of a possible decrease of -7% to a maximum increase of +9%.

As was the case with enteric fermentation, most uncertainty in the emission estimate was associated with the calculation of the emission factor. The uncertainty range around the mean emission factor was as high as 124% in the case of dairy cattle. The uncertainty in emissions was most sensitive to the use of IPCC default parameters in the Tier 2 calculation methodology, in particular the methane conversion factor (MCF) that was applied to all regions of Canada and all animal types and the maximum methane production capacity (B₀) (Karimi-Zindashty et al. 2012).

The methodology and parameter data used in the calculation of emission factors are consistent for the entire time series (1990–2011) with the exception of milk production for dairy. Milk production from 1990 to 1999 in Ontario and the western provinces is estimated as described in Section 6.2.3.

6.3.1.4. QA/QC and Verification

Methane emissions from manure management have undergone Tier 1-level QC checks as elaborated in the QA/QC plan (Annex 6) in a manner consistent with IPCC good practice. The activity data and methodologies are documented and archived in both paper and electronic forms. The IPCC Tier 2 CH₄ emission factors for manure management practices by all animal categories derived from Marinier et al. (2004) have been reviewed by independent experts (Patni and Desjardins 2004). These documents have been archived in both paper and electronic form.

Internal Tier 2-level QC checks carried out in 2010–2011 included a complete review and rebuild of calculation

Table 6–4 Uncertainty in Estimates of Emissions of CH₄ from Manure Management³

Animal Category	Uncertainty Source		Mean Value ¹	2.5% Prob. ²	97.5% Prob
Dairy Cattle	Population (1000 head)		983	929 (-5.4%)	1036 (+5.4%)
	Tier 2 Emission Factor (kg/head/year)		27.7	12.5 (-53%)	45.6 (+70%)
	Emissions (Mt CO ₂ eq)		0.57	0.26 (-54%)	0.96 (70%)
Non-dairy Cattle	Population (1000 head)		12 181	12 229 (-1.8%)	12 689 (+1.8%)
	Tier 2 Emission Factor (kg/head/year)		2.7	1.8 (-34%)	4.6 (+69%)
	Emissions (Mt CO ₂ eq)		0.69	0.48 (-32%)	1.2 (+71%)
Swine	Population (1000 head)		11 926	11 499 (-2.7%)	12 130 (+2.7%)
	Tier 2 Emission Factor (kg/head/year)		5.0	2.5 (-47%)	7.3 (+55%)
	Emissions (Mt CO ₂ eq)		1.3	0.6 (-51%)	1.8 (+46%)
Other Animals	Emissions (Mt CO ₂ eq)		0.18	0.12 (-35%)	0.22 (+19%)
Total Emissions	Emissions (Mt CO ₂ eq)	1990	2.6	1.7 (- 33%)	3.5 (+38%)
		2011	2.7	1.9 (- 29%)	3.6 (+33%)
	Trend	1990-2011	0.16 (6%)	-0.18 (-7%)	0.23 (+9%)

Notes:

1. Mean value reported from database, with the exception of Trend, which is the difference between 1990 and 2011.
2. Values in parentheses represent the uncertain percentage of the mean, with the exception of the Trend, where values in parentheses represent the percentage change between 1990 and 2011.
3. Values for confidence intervals are calculated from percentages derived for an analysis of uncertainty in 2010.

methodology, input data and review and compilation of Canadian research on manure management (MacDonald and Liang 2011). No specific bias can be clearly identified in the IPCC Tier 2 model parameters due to the high variability in research results and the lack of supporting information for research carried out on manure storage installations. There is no clear standard to evaluate if IPCC parameters are appropriate for estimating emissions from manure management systems in the Canadian context. More standardized and detailed research is required in Canada to improve upon the current Tier 2 methodology. Details of this review can be found in Annex 3.3, Section A3.3.4.7.

6.3.1.5. Recalculations

The integration of 2011 *Census of Agriculture* (Statistics Canada 2012) population numbers noted in Section 6.2.5 resulted in a decrease in emissions from this source after the last census year of 2 kt CO₂ eq in 2007 up to a decrease

of 7 kt CO₂ eq decrease in 2010. The large decrease in emissions from large animals such as buffalo and horses due to their declining populations was offset slightly by the increase in poultry populations.

6.3.1.6. Planned Improvements

Analysis of the manure management model suggested that improvements could be made to the values used for the distribution of manure management systems (AWMS) based on Statistics Canada farm environmental management surveys. Plans are in place to analyze whether this data source can be used for inventory purposes.

As noted in Section 6.2.6, data have been collected to develop a time series that accounts for changes in feed ration digestibility. Methodology will be developed to incorporate a time series for digestible energy used in the calculation of volatile solids for certain animal categories and will be incorporated over the medium term.

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

6.3.2.1. Source Category Description

The production of N₂O during storage and treatment of animal waste occurs during nitrification and denitrification of nitrogen contained in the manure. Nitrification is the oxidation of ammonium (NH₄⁺) to nitrate (NO₃⁻), and denitrification is the reduction of NO₃⁻ to N₂O or N₂. 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 N₂O. Nitrous oxide emissions from manure excreted on pasture, range and paddock by grazing animals are reported separately (see Section 6.4.2, Manure on Pasture, Range and Paddock).

6.3.2.2. Methodological Issues

Emissions of N₂O 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 CH₄ 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 NH₃ and NO_x during storage 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 N₂O 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 N₂O for each type of AWMS.

6.3.2.3. Uncertainties and Time-Series Consistency

Uncertainties for populations of major animal categories are low due to the biannual and quarterly surveys carried out on a provincial basis. Non-dairy cattle populations have the lowest uncertainty ($\pm 1.8\%$ of the mean) with slightly higher uncertainty for swine ($\pm 2.6\%$ of the mean), dairy cattle ($\pm 5.4\%$ of the mean) and sheep ($\pm 6.0\%$ of the mean). For other animals whose population estimates are only renewed through the *Census of Agriculture*, uncertainty is higher, ranging from $\pm 6\%$ for horses to $\pm 12\%$ for buffalo. Uncertainties associated with rates of nitrogen excretion are $\pm 20\%$ (IPCC 2006), types of AWMS are $\pm 20\%$ (Marinier et al. 2004), and with the emission factors are $\pm 20\%$ (IPCC 2006). The overall level and trend uncertainties associated with this source of emission were estimated to be $\pm 25\%$ and $\pm 21\%$, respectively (Hutchinson et al. 2007).

The same methodology, emission factors and data sources are used for the entire time series (1990–2011).

6.3.2.4. QA/QC and Verification

This category has undergone Tier 1-level QC checks as elaborated in the QA/QC plan (Annex 6) in a manner consistent with IPCC Good Practice Guidance. The activity data, methodology and changes to methodologies are documented and archived in both paper and electronic form. A complete Tier 2 QC was carried out on all calculation processes and parameters during the rebuilding of the Agricultural N₂O emission database.

There have been very few published data on N₂O emissions from manure management storage in Canada or in regions with practices and climatic conditions comparable to those of Canada. More standardized and detailed research is required in Canada to improve upon the current methodology.

6.3.2.5. Recalculations

Recalculations have been carried out for this source due to a correction to the dairy heifer N excretion rate, due to the use of 2011 *Census of Agriculture* (Statistics Canada 2012) population numbers for minor animal categories (see Section 6.2.5) and refinements to calculations during the development of the new N₂O database. Refinements to the database included the application of AWMS at the animal subcategory level and the rounding of proportions of AWMS to the nearest percentage point for some

Table 6–5 Recalculations of Estimates of Emissions from AWMS and Impact on Emission Trend

Year	Submissions Year	Category Emissions (Mt CO ₂ eq)	Change in Emissions (kt CO ₂ eq)	Category Emissions (%)	Change Emissions Total (%)	Trend Category Emissions ¹
1990	2012	3.1	40	1.2%	0.08%	21%
	2013	3.2				(2012)
2010	2012	3.8	50	1.2%	0.08%	21%
	2013	3.8				(2013)

Notes:

1. Numbers in parentheses indicate submission year in which the change in trend is calculated.

minor animal categories. These changes modified the distribution of manure N among manure storage types, but had very little overall impact on emissions (less than 0.1 kt CO₂ eq). The application of Tier 2 quality control checks during the rebuilding of the N₂O emission estimate database did, however, identify an error in the N excretion rate used for dairy heifers. The N excretion rate for dairy heifers in the database used for prior submissions was reduced by the same factor as non-dairy slaughter heifers, whereas a portion of dairy heifers are maintained for replacement of the milking herd and therefore are not slaughtered in their second year. Emissions from this category increased by as much as 1.2% over the whole time series but had an impact of less than 0.1% on total agricultural emissions (Table 6–5). An increase in poultry and goat populations between 2006 and 2011 drove an increase in total N excretion estimates for 2007 to 2010. This increase resulted in an additional increase in emissions of 20 kt CO₂ eq in 2010 above the correction to dairy heifer N excretion. The recalculation did not influence emission trends. Dairy heifer populations were greater in 1990 than they are at present, and the increase in minor animal N excretion compensated for the lower increase in emissions in 2010 associated with the dairy heifer N excretion correction.

6.3.2.6. Planned Improvements

Data from direct measurements of N₂O emissions from manure management in Canada are scarce. Recent scientific advances in analytical techniques allow direct measurements of N₂O emissions from point sources. However, it will likely take several years before N₂O emissions can be reliably measured and verified for various manure management systems in Canada.

As noted in Section 6.3.1.6, plans are in place to analyze whether improvements could be made to the values

used for the distribution of manure management systems (AWMS) based on Statistics Canada farm environmental management surveys.

As noted in Section 6.2.6, data have been collected to develop a time series that accounts for changes in animal nutrition, and country-specific nitrogen excretion rates will be calculated. Methodology will be developed to incorporate a time series for digestible energy used in the calculation of volatile solids for certain animal categories and will be incorporated over the medium term.

6.4. N₂O Emissions from Agricultural Soils (CRF Category 4.D)

Emissions of N₂O 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 N₂O 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 NH₃ and NO_x 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 N₂O emissions by altering mineralization of organic nitrogen, nitrification and denitrification.

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

Direct sources of N₂O from soils include the application of synthetic nitrogen fertilizers and animal manure, crop resi-

due decomposition, and cultivation of histosols. In addition, Canada also reports three country-specific sources of emissions/removals driven by soil organic matter decay from tillage practices, summerfallow and irrigation. Emissions/removals from these sources are estimated similarly based on nitrogen inputs from the application of synthetic nitrogen fertilizers and animal manure and crop residue nitrogen.

6.4.1.1. Synthetic Nitrogen Fertilizers

6.4.1.1.1. Source Category Description

Synthetic fertilizers add large quantities of nitrogen to agricultural soils. This added nitrogen undergoes transformations, such as nitrification and denitrification, which can release N_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).

6.4.1.1.2. Methodological Issues

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 and are scaled up at provincial and national levels. The amount of nitrogen applied is obtained from yearly fertilizer sales, which are available from regional fertilizer associations and compiled at the national level. All synthetic nitrogen fertilizers sold by retailers are assumed to be applied for crop production in Canada; the quantity of fertilizers applied to forests is deemed negligible. More details on the inventory method can be found in Annex 3.3.

6.4.1.1.3. Uncertainties and Time-Series Consistency

Uncertainties associated with N_2O emission estimates from synthetic nitrogen fertilizer applications result from the uncertainty in estimates of nitrogen fertilizer application ($\pm 20\%$); 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 Annex 3.3. The overall level and trend uncertainties associated with this source of emissions 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 (1990–2011).

6.4.1.1.4. QA/QC and Verification

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

While Statistics Canada conducts QC checks before the release of synthetic nitrogen fertilizer consumption data, the Pollutant Inventories and Reporting Division of Environment Canada carries out its own Tier 2 QC checks through historical records and consultations with regional and provincial agricultural industries.

Emissions of N_2O associated with synthetic fertilizer nitrogen applications on agricultural soils in Canada vary on a site-by-site basis, but there is a close agreement between the IPCC default emission factor of 1% (IPCC 2006) and the measured emission factor of 1.2% in eastern Canada, excluding emissions during the spring thaw period (Gregorich et al. 2005).

6.4.1.1.5. Recalculations

In this submission, emission estimates have been recalculated due to a correction in N excretion rates for dairy heifers, a modification in the distribution of fertilizers in the Maritime Provinces and changes to minor animal populations for the years 2007 to 2010. These changes resulted in a change in the redistribution of synthetic nitrogen fertilizers among ecodistricts, and led to recalculations in the range of 0.1–0.15 kt CO_2 eq for the entire time series.

6.4.1.1.6. Planned Improvements

There is no immediate plan in place aimed at improving emission estimates for this source; in the mid term, research efforts will be made to differentiate between N_2O emission factors from organic and inorganic N sources.

6.4.1.2. Manure Applied as Fertilizer

6.4.1.2.1. Source Category Description

The application of animal manure as fertilizer to agricultural soils can increase the rate of nitrification and denitri-

fication and result in enhanced N₂O emissions. Emissions from this category include all the manure managed by drylot, liquid and other animal waste management systems. Manure deposited on pasture by grazing animals is accounted for in Section 6.4.2.

6.4.1.2.2. Methodological Issues

Similar to the methodology used to estimate emissions from synthetic nitrogen fertilizers, the method used to estimate N₂O emissions from animal manure applied to agricultural soils is a country-specific IPCC Tier 2 method that takes into account moisture regimes (long-term growing season precipitation and potential evapotranspiration) and topographic conditions. Emissions are calculated by multiplying the amount of manure nitrogen applied to agricultural soils by an emission factor for each ecodistrict, and summed at the provincial and national levels. All manure that is handled by AWMS, except for the manure deposited on pasture, range and paddock from grazing animals, is assumed to be subsequently applied to agricultural soils (see Section 6.4.2).

6.4.1.2.3. Uncertainties and Time-Series Consistency

Uncertainties associated with N₂O emission estimates from animal manure applied as fertilizers result from uncertainties associated with estimates of manure nitrogen for each animal type ($\pm 1\% \sim \pm 15\%$), average animal manure nitrogen excretion rate ($\pm 20\%$), manure nitrogen loss ($\pm 20\%$), RF_{TEXTURE} ($\pm 30\%$), and EF_{BASE} ($\pm 25\%$). The overall level and trend uncertainties associated with this source of emission estimates from 1990 to 2011 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 (1990–2011).

6.4.1.2.4. QA/QC and Verification

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

6.4.1.2.5. Recalculations

Recalculations have been carried out for this source due to the correction to the dairy heifer N excretion rate and refinements to the N₂O database as noted in Section 6.3.2.5 as well as the use of 2011 *Census of Agriculture* (Statistics Canada 2012) population values for minor animal categories. Emissions from this category increased by 1.7% in 1990 and 1.5% in 2010, but had an impact of less than 0.1% on total agricultural emissions (Table 6–6). Increases in N excretion from minor animal categories alone were responsible for an increase emissions in 2010 of 7 kt CO₂ eq of the total increase of 29 kt CO₂ eq. The recalculation had little influence on the emission trend of this source. As noted in Section 6.3.2.5, decreases in the proportion of dairy heifer N excretion in 2010 were offset by the increase in N excretion from poultry and goats.

6.4.1.2.6. Planned Improvements

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

6.4.1.3. Biological Nitrogen Fixation

6.4.1.3.1. Source Category Description

Biological nitrogen fixation by the legume-rhizobium association is not considered a source of N₂O emissions by

Table 6–6 Recalculations of Estimates of Emissions from Application of Manure on Agricultural soils and Impact on Emission Trend

Year	Submission Year	Category Emissions (Mt CO ₂ eq)	Change in Emissions (kt CO ₂ eq)	Category Emissions (%)	Change Emissions Total (%)	Trend Category Emissions ¹
1990	2012	1.75	30	1.7%	0.06%	6.9%
	2013	1.78				(2012)
2010	2012	1.87	29	1.5%	0.05%	6.7%
	2013	1.90				(2013)

Notes:

1. Numbers in parentheses indicate submission year in which the change in trend is calculated.

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 N₂O are produced during the nitrogen fixation process. Canada reports this source as “not occurring.” However, the contribution of legume nitrogen to N₂O emissions from crop residue decomposition is still included (see Section 6.4.1.4).

6.4.1.4. Crop Residue Decomposition (CRF Category 4.D.4)

6.4.1.4.1. Source Category Description

When a crop is harvested, a portion of the crop is left on the field to decompose. The remaining plant matter is a nitrogen source for nitrification and denitrification and thus can contribute to N₂O production.

6.4.1.4.2. Methodological Issues

Emissions are estimated using an IPCC Tier 2 approach based on the amount of nitrogen contained in crop residue multiplied by the emission factor at the ecodistrict level and scaled up to the provincial and national levels. The amount of nitrogen contained in crop residues from both nitrogen-fixing and non-nitrogen-fixing crops is estimated using country-specific crop characteristics (Janzen et al. 2003). Emission factors are determined using the same approach as for synthetic fertilizer nitrogen application, using moisture regimes and topographic conditions.

6.4.1.4.3. Uncertainties and Time-Series Consistency

Uncertainties associated with N₂O emission estimates from crop residue decomposition result from uncertainties associated with estimates of crop residue nitrogen returned to the soil based on crop production data ($\pm 15\%$), above- and below-ground crop residue nitrogen concentration ($\pm 15\%$), RF_{TEXTURE} ($\pm 30\%$), and EF_{BASE} ($\pm 25\%$). The overall level and trend uncertainties associated with this source of emission estimates from 1990 to 2011 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 (1990–2011).

6.4.1.4.4. QA/QC and Verification

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

6.4.1.4.5. Recalculations

There were no recalculations in this category for this submission.

6.4.1.4.6. Planned Improvements

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

6.4.1.5. Cultivation of Organic Soils (Histosols)

6.4.1.5.1. Source Category Description

Cultivation of organic soils (histosols) for crop production usually involves drainage, lowering the water table and increasing aeration, which enhance the decomposition of organic matter and nitrogen mineralization. The enhancement of decomposition upon the cultivation of histosols can result in greater denitrification and nitrification, and thus higher N₂O production (Mosier et al. 1998).

6.4.1.5.2. Methodological Issues

The IPCC Tier 1 methodology (IPCC 2000) is used to estimate N₂O emissions from cultivated organic soils. Emissions of N₂O are calculated by multiplying the area of cultivated histosols by the IPCC default emission factor.

Areas of cultivated histosols at a provincial level are not surveyed in the *Census of Agriculture*. Consultations with numerous soil and crop specialists across Canada have resulted in an estimated area of 16 kha of cultivated organic soils in Canada, a constant level for the period 1990–2011 (Liang et al. 2004a).

6.4.1.5.3. Uncertainties and Time Series Consistency

Uncertainties associated with N₂O 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 2011 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 (1990–2011).

6.4.1.5.4. QA/QC and Verification

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

6.4.1.5.5. Recalculations

There were no recalculations in this source of emission estimates over the last two years.

6.4.1.5.6. Planned Improvements

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

6.4.1.6. Changes in N₂O Emissions from Adoption of No-Till and Reduced Tillage

6.4.1.6.1. Source Category Description

This category is not derived from additional nitrogen inputs (i.e. fertilizer, manure or crop residue); rather, it is implemented as modifications to N₂O emission factors due to the change from conventional to conservation tillage practices—namely, reduced tillage (RT) and no-tillage (NT).

6.4.1.6.2. Methodological Issues

Compared with conventional or intensive tillage (IT), direct seeding or NT as well as RT change several factors that influence N₂O 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 N₂O emissions for the Prairies (Malhi and Lemke 2007), but increases N₂O emissions for the non-

Prairie regions of Canada (Rochette et al. 2008a). The net result across the country amounts to a small reduction in emissions. This reduction is reported separately, as a negative estimate (Table 6–1).

Changes in N₂O emissions resulting from the adoption of NT and RT are estimated through modifications of emission factors for synthetic fertilizers, manure nitrogen applied to cropland, and crop residue nitrogen decomposition. This subcategory is kept separate from the fertilizer and crop residue decomposition source categories to preserve the transparency in reporting; however, this separation causes negative emissions to be reported. An empirically derived tillage factor (F_{TILL}), defined as the ratio of mean N₂O fluxes on NT or RT to mean N₂O fluxes on IT ($N_{2O_{NT}}/N_{2O_{IT}}$), represents the effect of NT or RT on N₂O emissions (see Annex 3.3).

6.4.1.6.3. Uncertainties and Time-Series Consistency

Uncertainties associated with changes in N₂O 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 2011 have not been assessed.

The same methodology and emission factors are used for the entire time series (1990–2011).

6.4.1.6.4. QA/QC and Verification

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

6.4.1.6.5. Recalculations

There was no change in the area of conservation tillage, but small recalculations have occurred in this category as a result of changes in nitrogen inputs from manure (see Section 6.3.2.5). These recalculations have increased avoided emissions slightly by 0.49 kt CO₂ eq in 1990 and 2.3 kt CO₂ eq in 2010. The increase in poultry and goat populations in the 2011 census contributed approximately 1 kt CO₂ eq to the total increase in avoided emissions in 2010.

6.4.1.6.6. Planned Improvements

There is no immediate plan in place aimed at improving emission estimates from this source. However, work is ongoing to develop level and trend uncertainty estimates using the IPCC Tier 2 method.

6.4.1.7. N₂O Emissions Resulting from Summerfallowing

6.4.1.7.1. Source Category Description

This category is not derived from additional nitrogen input but reflects changes in soil conditions that affect N₂O 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 N₂O emissions relative to a cropped situation, such as higher soil water content, higher soil temperature, and greater availability of soil carbon and nitrogen (Campbell et al. 1990, 2005).

6.4.1.7.2. Methodological Issues

Experimental studies have shown that N₂O 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 N₂O emissions because no crops are grown or fertilizer applied could lead to underestimating total N₂O emissions. The emissions from SF land are therefore calculated through a country-specific method by summing emissions from fertilizer nitrogen, manure nitrogen application to annual crops and crop residue nitrogen for a given ecodistrict and multiplying the sum by the proportion of that ecodistrict area under SF (Rochette et al. 2008b). A more detailed description of the approach is provided in Annex 3.3. This subcategory is reported separately from the Synthetic Nitrogen Fertilizers, Animal Manure Applied as Fertilizers and Crop Residue Decomposition source categories to enhance the transparency of the reporting process.

6.4.1.7.3. Uncertainties and Time-Series Consistency

Uncertainties associated with N₂O emission estimates from summerfallow result from uncertainties associated with area estimates of summerfallow from the *Census of Agriculture* (cropland area: up to $\pm 10\%$; the fraction of cropland that is under summerfallow (FRAC_{FALLOW}): up to

$\pm 10\%$) and EF_{BASE}: $\pm 25\%$. The overall level and trend uncertainties associated with this source of emission estimates from 1990 to 2011 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 (1990–2011).

6.4.1.7.4. QA/QC and Verification

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

6.4.1.7.5. Recalculations

There is no change in the area of summerfallow, but recalculations have occurred in this category as a result of changes in nitrogen inputs from manure nitrogen as well as changes in the redistribution of synthetic nitrogen fertilizers among ecodistricts and in the Maritime Provinces (see Section 6.3.2.5). These recalculations resulted in a change in the emission estimate in the range of -0.2~0.3 kt CO₂ eq annually for the entire time series.

6.4.1.7.6. Planned Improvements

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

6.4.1.8. N₂O Emissions from Irrigation

6.4.1.8.1. Source Category Description

Similar to tillage practices and summerfallow, the effect of irrigation on N₂O emissions is not derived from additional nitrogen input but reflects changes in soil conditions that affect N₂O emissions. Higher soil water content under irrigation increases the potential for N₂O emissions through increased biological activity, reducing soil aeration (Jambert et al. 1997) and thus enhancing denitrification.

6.4.1.8.2. Methodological Issues

The methodology is country specific and is based on the assumptions that 1) irrigation water stimulates N₂O 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 N₂O emissions from agricultural soils was estimated using an EF_{BASE} estimated at a P/PE = 1 (precipitation/potential evapotranspiration, EF_{BASE} = 0.017 N₂O-N/kg N) for the irrigated areas of a given ecodistrict. To improve the transparency, the effect of irrigation on soil N₂O emissions is also reported separately from other source categories.

6.4.1.8.3. Uncertainties and Time-Series Consistency

Uncertainties associated with N₂O emission estimates from irrigation result from uncertainties associated with synthetic 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* (up to $\pm 10\%$), as well as EF_{BASE} ($\pm 25\%$). 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 (1990–2011).

6.4.1.8.4. QA/QC and Verification

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

6.4.1.8.5. Recalculations

Recalculations have occurred in this category because of changes in nitrogen inputs from dairy manure as well as changes in the redistribution of synthetic nitrogen fertilizers among ecodistricts and in the Maritime Provinces (see Section 6.3.2.5). These recalculations resulted in a change in the emission estimate in the range of $-0.1 \sim 0.2$ kt CO₂ eq annually for the entire time series.

6.4.1.8.6. 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 by grazing animals, nitrogen in the manure undergoes transformations, such as ammonification, nitrification and denitrification. During these transformation processes, N₂O can be emitted.

6.4.2.2. Methodological Issues

The emissions from manure excreted by grazing animals are calculated using the IPCC Tier 1 methodology (IPCC/OECD/IEA 1997). Emissions are calculated for each animal category by multiplying the number of grazing animals for that category by the appropriate nitrogen excretion rate and by the fraction of manure nitrogen available for conversion to N₂O.

The animal population data are the same as those used in the Enteric Fermentation category (see Section 6.2). The number of grazing animals for each category or subcategory is calculated using the total population multiplied by the fraction of animals grazed on pasture, range and paddock. The nitrogen excretion rates are based on the IPCC (2006) defaults. The fraction of manure nitrogen available for conversion to N₂O 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 N₂O-N/kg N for cattle and swine, and 0.01 kg N₂O-N/kg N for sheep/lamb, goat and horse.

6.4.2.3. Uncertainties and Time-Series Consistency

Uncertainties associated with N₂O emission estimates from animal manure on pasture, range and paddock result from uncertainty in the number of grazing animals ($\pm 1\%$ 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 2011 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 (1990–2011).

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 N₂O 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

Recalculations have been carried out for this source due to the correction to the dairy heifer N excretion rate, refinements to calculations in the new N₂O database and the integration of new animal population numbers from the most recent census, as noted in Section 6.3.2.5. In 1990, emissions from this category increased by 0.9% but had an impact of less than 0.1% on total agricultural emissions (Table 6–7). A decrease in emissions from buffalo and horses due to their decreasing population numbers between 2006 and 2011 entirely compensated for the increase in dairy heifer N excretion, and as a result there was almost no change in emissions in 2010. The recalculated increase in emissions in 1990 and the constant emissions in 2010 decreased the emission trend from this source by 1%.

6.4.2.6. Planned Improvements

Emissions of N₂O from the Manure Deposited on Pasture, Range and Paddock by grazing animals for Canada are a key source category according to the level assessment. Because of its importance, Canada has initiated a three-year research project, starting in September 2009, to quantify N₂O 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 N₂O emissions for this source using country-specific emission factors. This improvement will also trigger an update of the uncertainty analysis.

6.4.3. Indirect Emissions of N₂O from Soils (CRF Category 4.D.3)

A fraction of the nitrogen from both synthetic fertilizer and manure that are applied to agricultural fields is transported off-site through volatilization in the form of NH₃ and NO_x 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 N₂O.

6.4.3.1. Volatilization and Redeposition of Nitrogen

6.4.3.1.1. Source Category Description

When synthetic fertilizer or manure is applied to cropland, a portion of the nitrogen is lost through volatilization in the form of NH₃ or NO_x, which can be redeposited elsewhere and undergo further transformation, resulting in N₂O emissions off-site. The quantity of this volatilized nitrogen depends on a number of factors, such as rates of fertilizer and manure nitrogen application, fertilizer types, methods and time of nitrogen application, soil texture, rainfall, temperature, and soil pH.

6.4.3.1.2. Methodological Issues

There are few published scientific data that actually determine N₂O emissions from volatilization and redeposition of

Table 6–7 Recalculations of Estimates of Emissions from Application of Manure on Pasture, Range and Paddock with the Impact on Emission Trend

Year	Submission Year	Category Emissions (Mt CO ₂ eq)	Change in Emissions (kt CO ₂ eq)	Category Emissions (%)	Change Emissions Total (%)	Trend Category Emissions ¹
1990	2012	2.19	19	0.9%	0.04%	32%
	2013	2.21				(2012)
2010	2012	2.89	0	0.0%	0.00%	31%
	2013	2.89				(2013)

Notes:

1. Numbers in parentheses indicate submission year in which the change in trend is calculated.

NH₃ and NO_x. Leached or volatilized N may not be available for the process of nitrification and denitrification for many years, particularly in the case of N leaching into groundwater. Even though Indirect Soil N₂O 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 N₂O emissions due to volatilization and redeposition of nitrogen from synthetic N fertilizers and animal manure. The amount of synthetic fertilizer and manure nitrogen is multiplied by the fraction of N that is volatilized as NH₃-N and NO_x-N and then by an emission factor. The amount of nitrogen applied is obtained from yearly fertilizer sales data, which are available from Statistics Canada, and from the amounts of manure nitrogen excreted by animals (see Annex 3.3). The amount of nitrogen that volatilizes is assumed to be 10% of the total amount of synthetic fertilizer applied, 20% of the applied manure nitrogen to cropland, and from 12% to 48% of excreted manure nitrogen during handling and storage (IPCC 2006). The default IPCC emission factor, 0.01 kg N₂O-N/kg N, is used to derive the N₂O emission estimate (IPCC/OECD/IEA 1997).

6.4.3.1.3. Uncertainties and Time-Series Consistency

Uncertainties associated with N₂O emission estimates from volatilization of NH₃ and NO_x due to applications of synthetic and manure nitrogen result from uncertainty in estimates of synthetic fertilizer nitrogen consumption ($\pm 20\%$), fraction of volatilized NH₃ and NO_x from synthetic nitrogen fertilizers ($\pm 20\%$), animal populations and categories ($\pm 1\%$ to $\pm 15\%$), manure nitrogen excretion rate ($\pm 20\%$), fraction of volatilized NH₃ + NO_x from animal manure ($\pm 20\%$), as well as emission factors (-50% to $+300\%$). Indirect

N₂O Emissions are among the source categories with the highest uncertainty in the inventory, with little prospect for short-term improvements. The overall level and trend uncertainties associated with this source of emission estimates from 1990 to 2011 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 (1990–2011).

6.4.3.1.4. QA/QC and Verification

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

6.4.3.1.5. Recalculations

Recalculations have been carried out for this source due to the correction to the dairy heifer N excretion rate as noted in Section 6.3.2.5, the refinements to the N₂O emission database and the use of 2011 *Census of Agriculture* (Statistics Canada 2012) population values for minor animal categories. Emissions from this category increased 0.9% in 1990 and 0.6% in 2010, but had an impact of less than 0.1% on total agricultural emissions (Table 6–8). Increases in N excretion from minor animal categories increased emissions in 2010 by 4 kt CO₂ eq of the total 17 kt CO₂ eq increase. As noted in Section 6.3.2.5, decreases in the proportion of dairy heifer N excretion in 2010 was mostly offset by the increase in N excretion from poultry and goats.

6.4.3.1.6. Planned Improvements

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

Table 6–8 Recalculations of Estimates of Emissions from Volatilisation of NH₃ and Impact on Emission Trend

Year	Submission Year	Category Emissions (Mt CO ₂ eq)	Change in Emissions (kt CO ₂ eq)	Category Emissions (%)	Change Emissions Total (%)	Trend Category Emissions ¹
1990	2012	1.99	18	0.9%	0.04%	30%
	2013	2.01				(2012)
2010	2012	2.58	17	0.6%	0.03%	29%
	2013	2.60				(2013)

Notes:

1. Numbers in parentheses indicate submission year in which the change in trend is calculated.

6.4.3.2. Leaching, Erosion, and Runoff

6.4.3.2.1. Source Category Description

When synthetic fertilizer, manure and crop residue are added to cropland, a portion of the nitrogen from these sources is lost through leaching, erosion and runoff. The magnitude of this loss depends on a number of factors, such as application rate and method, crop type, soil texture, rainfall and landscape. This portion of lost nitrogen can further undergo transformations, such as nitrification and denitrification, and can produce N_2O emissions off-site.

6.4.3.2.2. Methodological Issues

There are few published scientific data that determine N_2O emissions from leaching, erosion and runoff in Canada. Similar to N_2O emissions from volatilization and redeposition of NH_3 and NO_x , 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_2O emissions from leaching, runoff and erosion of fertilizers, manure and crop residue nitrogen from agricultural soils. Indirect N_2O emissions from runoff and leaching of nitrogen at the ecodistrict level are estimated using $FRAC_{LEACH}$ multiplied by the amount of synthetic fertilizer nitrogen, non-volatilized manure nitrogen and crop residue nitrogen and by an emission factor of 0.025 kg N_2O -N/kg N (IPCC 2000).

The default value for the fraction of nitrogen that is lost through leaching and runoff ($FRAC_{LEACH}$) in the Revised 1996 Guidelines is 0.3; however, $FRAC_{LEACH}$ can reach values as low as 0.05 in regions where rainfall is much lower than potential evapotranspiration (IPCC 2006), such as in the Prairie region of Canada. Accordingly, it is assumed that $FRAC_{LEACH}$ would vary among ecodistricts from a low of 0.05 to a high of 0.3. For ecodistricts with no moisture deficit during the growing season (May through October), the maximum $FRAC_{LEACH}$ value of 0.3 recommended by the IPCC (2006) Guidelines is assigned. The minimum $FRAC_{LEACH}$ value of 0.05 is assigned to ecodistricts with the greatest moisture deficit. For the remaining ecodistricts, $FRAC_{LEACH}$ is estimated by the linear extrapolation of the two end-points described above.

6.4.3.2.3. Uncertainties and Time-Series Consistency

Uncertainties associated with N_2O estimates from leaching, runoff and erosion of nitrogen from synthetic nitrogen fertilizers, animal 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 ($\pm 15\%$), $FRAC_{LEACH}$ ($\pm 50\%$), as well as the leaching/runoff emission factor EF_{LEACH} ($-48\% \sim +200\%$). The overall level and trend uncertainties associated with this source of emission estimates from 1990 to 2011 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 (1990–2011).

6.4.3.2.4. QA/QC and Verification

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

6.4.3.2.5. Recalculations

Recalculations have been carried out for this source due to the correction to the dairy heifer N excretion rate as noted in Section 6.3.2.5, the integration of new census population numbers, and a correction in the source of nitrogen used in calculating leached N from fertilizer application. The leached N was linked in the previous database to recommended N and had not been corrected for fertilizer sales. The correction to dairy heifer manure resulted in a small increase of 0.3% and 0.2% in 1990 and 2010, respectively (roughly 19 and 16 kt CO_2 eq). However, the change from recommended N corrected for fertilizer sales had a larger impact, decreasing emissions by 1.4% in 1990 (95 kt CO_2 eq) and increasing emissions by 0.7% in 2010 (61 kt CO_2 eq). The implementation of 2011 *Census of Agriculture* (Statistics Canada 2012) numbers decreased leaching emissions by 2.6 kt CO_2 eq. As a result of these changes, the trend in emissions for this category was increased from 25% to 28%.

Table 6–9 Recalculations of Estimates of Emissions from Leaching and Erosion with their Impact on Emission Trend

Year	Submission Year	Category Emissions (Mt CO ₂ eq)	Change in Emissions (kt CO ₂ eq)	Category Emissions (%)	Change Emissions Total (%)	Trend Category Emissions ¹
1990	2012	6.74	-76	-1.1%	-0.16%	25%
	2013	6.67				(2012)
2010	2012	8.44	74	0.9%	0.13%	28%
	2013	8.52				(2013)

Notes:

1. Numbers in parentheses indicate submission year in which the change in trend is calculated.

6.4.3.2.6. Planned Improvements

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

6.5. CH₄ and N₂O Emissions from Field Burning of Agricultural Residues (CRF Category 4.F)

6.5.1. Source Category Description

Crop residues are sometimes burned in Canada, as a matter of convenience and disease control through residue removals, even though this practice has declined in recent years because of concerns over soil quality and environmental issues. Crop residue burning is a net source of CH₄, CO, NO_x and N₂O (IPCC/OECD/IEA 1997).

6.5.2. Methodological Issues

There are no published data on emissions of N₂O and CH₄ from field burning of agricultural residues in Canada. Thus, the IPCC default emission factors and parameters from the Good Practice Guidance (IPCC 2000) were used for estimating emissions.

A complete time series of activity data on the type and the percent of each crop residue subject to field burning was developed based on Statistics Canada's *Farm Environmental Management Survey* (FEMS)² and on expert consultations (Coote et al. 2008).

Crop-specific parameters, such as moisture content of the crop product and ratio of above-ground crop residue to crop product, required for estimating the amount of crop residue burned, were obtained from Janzen et al. (2003), and are consistent with the values used to estimate emissions from crop residue decomposition.

6.5.3. Uncertainties and Time-Series Consistency

The uncertainties associated with CH₄ and N₂O emissions from field burning of agricultural residues were determined using an IPCC Tier 1 method (IPCC 2006).

The uncertain quantities associated with CH₄ and N₂O emissions from field burning of agricultural residues are the amount of field crop residues burned and emission factors. The uncertainty in the amount of crop residues burned is estimated, based on the area of specific seeded crop, to be ±50% (Coote et al. 2008). The uncertainties associated with the emission factors are not reported in the 2006 IPCC Guidelines but are assumed to be similar to those associated with burning of Savanna and grassland: ±40% for CH₄ and ±48% for N₂O (IPCC 2006). The level and trend uncertainties for CH₄ emission estimates from 1990 to 2011 were estimated to be ±29% and ±23%, respectively. The level and trend uncertainties for N₂O emission estimates were estimated to be ±29% and ±23%, respectively.

6.5.4. QA/QC and Verification

CH₄ and N₂O emissions from field burning of agricultural residues have undergone Tier 1-level QC checks as elaborated in the QA/QC plan (Annex 6) in a manner consistent with IPCC Good Practice Guidance. The activity data and methodologies are documented and archived in both paper and electronic forms.

2 <http://www.statcan.gc.ca/cgi-bin/imdb/p2SV.pl?Function=getSurvey&SDDS=5044&lang=en&db=imdb&adm=8&dis=2#a4>

6.5.5. Recalculations

In this submission, emission estimates have been recalculated due to a correction of rounding and data entry errors of crop areas. These corrections resulted in a change in the total crop biomass burnt and led to recalculations in the range of -0.06~-0.84 kt CO₂ eq for the entire time series. A data entry error in the year 2001 was corrected that resulted in an increase of 5.5 kt CO₂ eq in that year.

6.5.6. 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 change. The assessment includes emissions and removals of CO₂, additional emissions of CH₄, N₂O and CO due to wildfires and controlled burning,

and N₂O released following land conversion to cropland. All emissions from and removals by the LULUCF Sector are excluded from the national totals.

In 2011, the estimated net GHG flux in the LULUCF Sector, calculated as the sum of CO₂¹ emissions and removals and non-CO₂ emissions, amounted to emissions of 87 Mt. If these were included in the national totals, they would increase the total Canadian GHG emissions by about 12%. 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.

1 Unless otherwise indicated, all emissions and removals are in CO₂ equivalents.

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

Sectoral Category	Net GHG Flux (kt CO ₂ eq) ⁴							
	1990	2000	2005	2007	2008	2009	2010	2011
Land Use, Land-Use Change and Forestry TOTAL ¹	-62 000	-52 000	63 000	52 000	-11 000	-10 000	103 000	87 000
a. Forest Land	-88 000	-64 000	54 000	45 000	-18 000	-15 000	99 000	83 000
Forest Land Remaining Forest Land	-87 000	-63 000	55 000	46 000	-17 000	-14 000	99 000	84 000
Land Converted to Forest Land	-1 000	-1 000	-900	-900	-800	-800	-700	-700
b. Cropland	12 000	40	-4 100	-5 700	-6 500	-6 900	-7 600	-8 000
Cropland Remaining Cropland	-2 000	-7 000	-10 000	-11 000	-12 000	-12 000	-13 000	-13 000
Land Converted to Cropland	13 000	7 000	6 000	5 700	5 300	5 500	5 300	5 300
c. Grassland	NE, NO	NE, NO	NE, NO	NE, NO	NE, NO	NE, NO	NE, NO	NE, NO
Grassland Remaining Grassland	NE	NE	NE	NE	NE	NE	NE	NE
Land Converted to Grassland	NO	NO	NO	NO	NO	NO	NO	NO
d. Wetlands	5 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000
Wetlands Remaining Wetlands	1 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000
Land Converted to Wetlands	4 000	800	1 000	700	800	800	700	700
e. Settlements	9 000	8 000	9 000	10 000	10 000	9 000	9 000	9 000
Settlements Remaining Settlements	-100	-200	-200	-200	-200	-200	-200	-200
Land Converted to Settlements	9 000	9 000	10 000	10 000	10 000	10 000	10 000	10 000
Forest conversion (memo item) ²	26 000	20 000	20 000	20 000	20 000	19 000	19 000	19 000
Grassland conversion (memo item) ^{2,3}	300	200	200	200	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 net removals of CO₂ from the atmosphere.

NE = Not estimated, NO=Not Occurring

The Forest Land category has the largest influence on sectoral totals. The net fluxes are negative (removals) in 11 of the 22 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 –110 Mt (1992) and 180 Mt (1995) (see Figure 2-13). 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, with removals every year since 2001—up to 8.0 Mt in 2011. The 61% decline of emissions from land converted to cropland and growing removals by cropland remaining cropland equally contribute to the 20-Mt reduction in net emissions over the 1990–2011 period.

Over the 1990–2011 period, net fluxes in the Wetlands category (managed peatlands and flooded lands) fluctuate between 2.7 Mt and 5.5 Mt. Emissions from land converted to wetlands declined from 4 Mt to 0.7 Mt during the period. Current emissions from flooded lands account for 56% of all emissions in the Wetlands category, compared to a share of 83% in 1990.

The LULUCF Sector continues to draw on the best Canadian expertise within Canada's national multidisciplinary

framework for monitoring, accounting and reporting emissions and removals in managed lands. The Monitoring, Accounting and Reporting System (MARS) framework² 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.

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 crosscategory estimates of forest conversion to other lands.

This submission does not incorporate any change in response to the recommendations of the expert review team (ERT) that reviewed Canada's 2012 submission, as the review report was not yet available at the time this submission was prepared. Changes in this year's submission include updates in forest-related activity—harvest statistics and wildfire areas, error corrections in the forest

² First described in the NIR of the 2004 submission and implemented in the 2006 submission.

Table 7-2 Summary of Changes in the LULUCF Sector

List of Changes	Years Affected
Forest Land	
Revisions to official harvest activity data	Complete time series
Wildfire area updates	2009, 2010
Error corrections	Complete time series
Forest Conversion	
Forest conversion revisions	Complete time series
New mapping activity	Complete time series
Cropland	
Processing system update	Complete time series
Wetland	
Updated peat extraction statistics	Complete time series
New reservoir activity data	2006–2010

modelling system, new mapping and revisions to forest conversion, cropland processing system updates, new flooded land activity data, and updated peat harvest statistics (Table 7–2).

7.2. Land Category Definition and Representation of Managed Lands

In order to harmonize all land-based estimates, a common definitional framework was elaborated and adopted by all groups involved in estimate preparation. Definitions are consistent with the IPCC (2003) land categories, while remaining relevant to land management practices, prevailing environmental conditions and available data sources in Canada. This framework applies to all LULUCF estimates reported under the Convention.

Forest land includes all areas of 1 ha or more where tree formations can reach 25% crown cover and 5 m in height *in-situ*. Not all Canadian forests are under the direct influence of human activities, prompting the non-trivial question of what areas properly embody the “managed forests.” For the purpose of the GHG inventory, managed forests are those managed for timber and non-timber resources (including parks) or subject to fire protection. Annex 3.4 provides more detail on the implementation of the “managed forests” definition.

Agricultural land comprises both cropland and agricultural grassland. Cropland includes all lands in annual crops, summerfallow and perennial crops (mostly forage, but also including berries, grapes, nursery crops, vegetables, and fruit trees and orchards). Agricultural grassland is defined as “unimproved” pasture or rangeland that is used only for grazing domestic livestock. It occurs only in geographical areas where the grassland would not naturally regrow to forest if abandoned: the natural shortgrass prairie in southern Saskatchewan and Alberta and the dry, interior mountain valleys of British Columbia. All agricultural land that is not grassland is *de facto* classified as cropland, including unimproved pastures where natural vegetation would be forest (eastern Canada and most of British Columbia).

Vegetated areas that do not meet the definition of forest land or cropland are generally classified as grassland: extensive areas of tundra in the Canadian north are considered un-managed grassland.

Wetlands are areas where permanent or recurrent saturated conditions allow the establishment of vegetation and soil development typical of these conditions and that are not already in forest land, cropland or agricultural grasslands. Managed wetlands are those where human interventions have altered the water table—for example, peatlands drained for peat extraction or flooded lands (IPCC 2003).

Settlements include all built-up land: urban, rural residential, land devoted to industrial and recreational use; roads, rights-of-way and other transportation infrastructure; and resource exploration, extraction and distribution (mining, oil and gas). The diversity of this category has so far precluded an assessment of its extent in the Canadian landscape; however, it is often involved in land conversion, and the impact of forest land conversion to settlements is assessed in this GHG inventory.

Other land comprises areas of rock, ice or bare soil, and all land areas that do not fall into any of the other five categories. Currently, only emissions from the conversion of other land to reservoirs 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 2011. Cumulative land-use change areas are the total land areas converted over the past 20 years (10 years for reservoirs). The grassland diagonal cell refers to the total area of agricultural grassland, whereas grassland converted to settlements refers to land conversion of un-managed tundra to settlements in northern Canada. Column totals equal the total land area as reported in the CRF for each category.

The MARS land monitoring system includes the conversion of un-managed forests and grassland to other land categories. Un-managed land converted to any use always becomes “managed”; once land has become managed, it does not revert to “un-managed” status, even if manage-

Table 7-3 Land Use and Land-use Change Matrix for the 2011 Inventory Year (Areas in kha)¹

Initial Land Use	Final Land Use					
	Forest	Cropland	Grassland	Wetlands	Settlements	Other
Forest	229 266	430	NO	74	503	NO
Cropland	80	47 081	NO	NE	NE	NO
Grassland	NO	3	NE	NE	1	NE
Wetlands	NO	NE	NO	413 ²	NE	NE
Settlements	NO	NE	NO	NO	NE	NO
Other	NO	NO	NO	54	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.

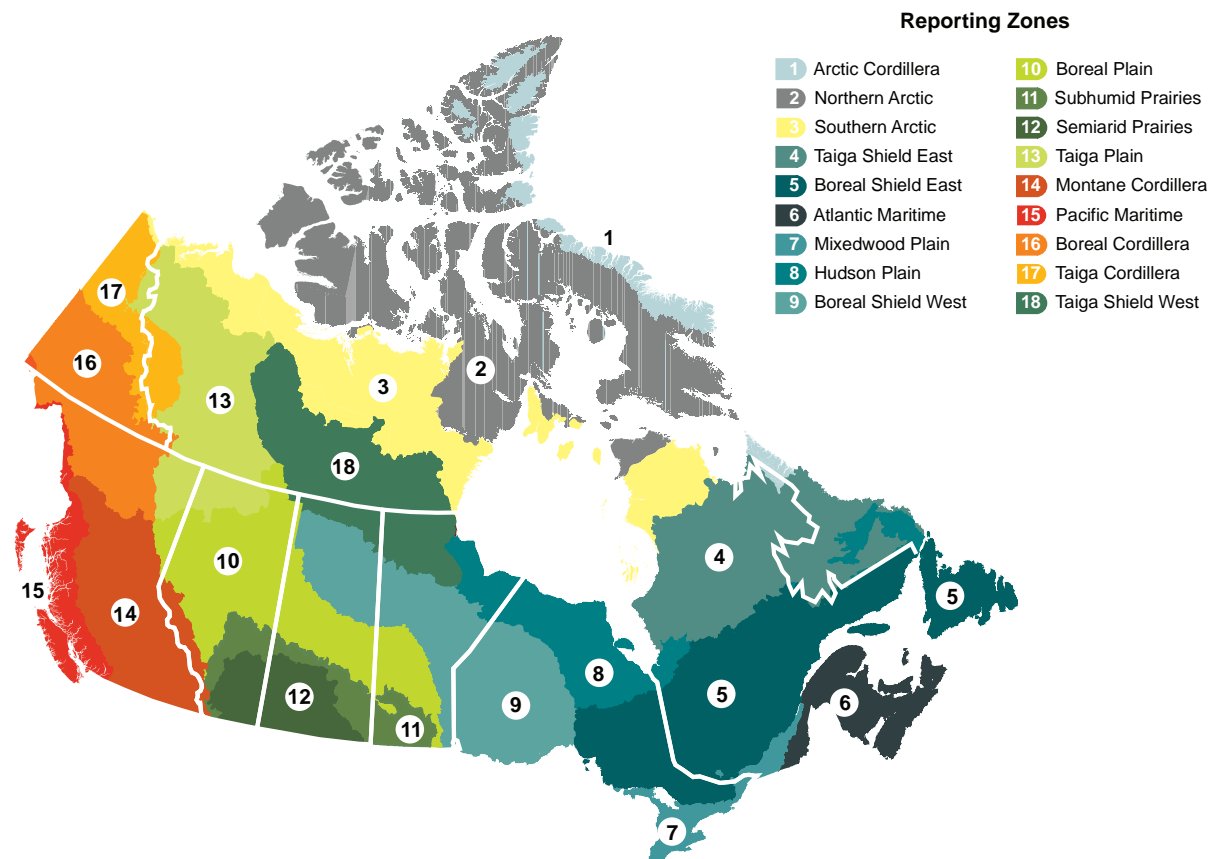
NO = Not occurring.

ment practices are discontinued. Parks and protected areas are included in managed lands.

With a few exceptions (e.g. emissions due to liming), the LULUCF estimates as reported in the CRF tables are spatially attached to “reporting zones” (Figure 7-1). These reporting zones are essentially the same as Canada’s terrestrial

ecozones (Marshall and Shut 1999), with three exceptions: the Boreal Shield and Taiga Shield ecozones are split into their east and west components to form four reporting zones; and the Prairies ecozone is divided into a semi-arid and a subhumid component. Estimates are reported for 17 of the 18 reporting zones, leaving out the northernmost ecozone of Canada: the Arctic Cordillera, where no direct

Figure 7-1 Reporting Zones for LULUCF Estimates



human-induced LULUCF GHG emissions and removals are detected for this sector. More details on the spatial estimation and reporting framework can be found in Annex 3.4.

The areas reported in the CRF tables represent those used for annual estimate development, but not always the total land area under a land category or subcategory in a specific inventory year. Hence areas of land converted to wetlands (reservoirs) represent a fraction of total reservoir areas (those flooded for 10 years or less), not the total area of reservoirs in Canada.

Similarly, the areas of land conversion reported in the CRF tables refer to the cumulative total land area converted over the last 20 years (10 years for reservoirs) and should not be confused with annual rates of land-use change. The trends observed in the land conversion categories of the CRF (e.g. land converted to forest land, land converted to cropland) result from the balance between land area newly converted to a category and the transfer of lands converted more than 20 years ago (10 years for reservoirs) into the “land remaining land” categories.

7.3. Forest Land

Forest and other wooded lands cover 389 million hectares (Mha) of Canadian territory; forest lands alone occupy 348 Mha (NRCan 2010). Managed forests, those under direct human influence, extend over 229 Mha, or 66% 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 2011, the net GHG balance of managed forest land amounted to emissions of 83 Mt (Table 7–1 and CRF Table 5). This estimate includes net emissions and removals of CO₂, as well as N₂O, CO and CH₄ 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 emissions of 84 Mt) and land converted to forest land (0.08 Mha, net removals of 0.7 Mt) in 2011.

The managed forest GHG balance is not spatially homogeneous. In 2011, managed forests in the Boreal Plains, Montane Cordillera and Boreal Shield West reporting zones are three large net sources of GHG, while those in the Taiga Plains, Boreal Shield East and Boreal Cordillera are net sinks (Table 7–4). Note that the spatial distribution of emissions

Table 7–4 GHG Balance of Managed Forests by Reporting Zone, 2011¹

Reporting Zone Number	Reporting Zone Name	Managed Forest Area (kha)	Net GHG Balance (Mt CO ₂ eq)
1	Arctic Cordillera	–	NA
2	Northern Arctic	–	NA
3	Southern Arctic	–	NA
4	Taiga Shield East	1 100	2
5	Boreal Shield East	55 600	- 39
6	Atlantic Maritime	15 400	- 5
7	Mixedwood Plains	2 700	- 8
8	Hudson Plains	302	- 1
9	Boreal Shield West	28 800	28
10	Boreal Plains	36 000	76
11	Subhumid Prairies	1 820	- 2
12	Semiarid Prairies	18	- 0.01
13	Taiga Plains	20 000	- 27
14	Montane Cordillera	35 400	69
15	Pacific Maritime	13 200	10
16	Boreal Cordillera	16 600	- 23
17	Taiga Cordillera	412	- 0.22
18	Taiga Shield West	1 830	4

Notes:

1. Negative sign indicates removal of CO₂ from the atmosphere.

NA = Not applicable.

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 CO₂ from the atmosphere through photosynthesis, and some of this carbon is sequestered in standing vegetation (biomass), dead organic matter and soils. CO₂ is returned to the atmosphere by vegetation respiration and the decay, through heterotrophic respiration, of organic matter. The natural CO₂ exchanges between the atmosphere and biota are large fluxes, globally recycling on the order of one seventh of the total atmospheric CO₂ content annually. These large gross fluxes result from the accumulation of minute processes dispersed over vast land areas. Only a small fraction of the carbon (C) taken up by photosynthesis accumulates in ecosystem C pools after all respiratory and disturbance C losses (Stinson et al. 2011).

Human interactions with the land can directly alter the size and rate of these natural exchanges of GHGs, in both the immediate and long term. Land-use change and land-use practices in the past still affect current GHG fluxes to and from the terrestrial biosphere. This long-term effect is a unique characteristic of the LULUCF Sector, which makes it very distinct from other sectors, such as Energy.

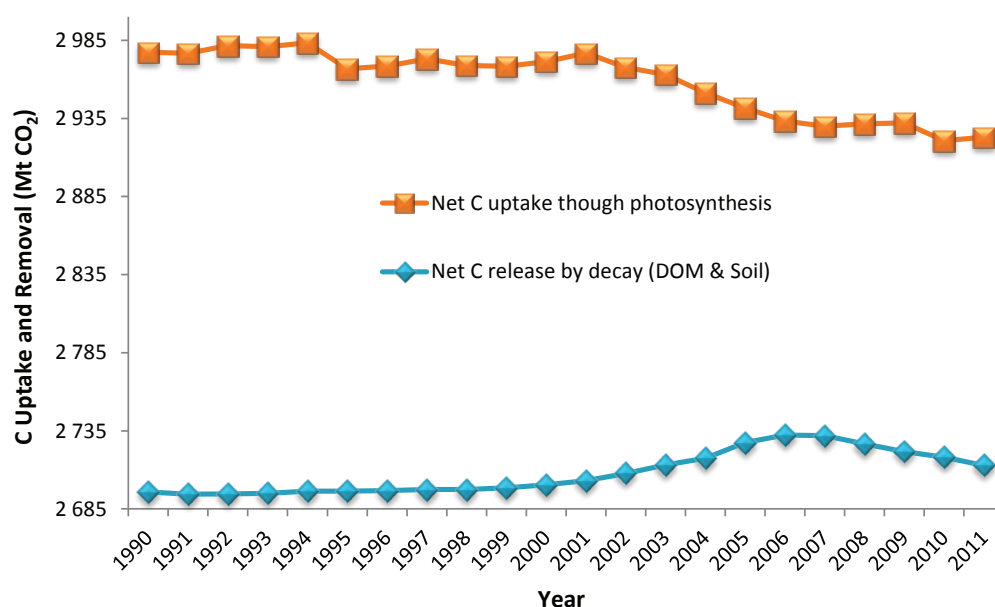
While the intended focus is on anthropogenic impacts on the GHG balance, it is recognized that separating human from natural effects in the LULUCF Sector poses a unique challenge. Humans manipulate biological processes in a myriad of ways and intensities. What we observe is typically the outcome of these various manipulations and their combined interactions with an equally varied biophysical environment, including natural disturbances. Untangling the various cause-and-effect relationships in the long term and short term is still the object of complex scientific inquiries.

Canada emphasizes that while all efforts are made to provide IPCC-compliant GHG estimates, such estimates may not truly account for direct human effects or accurately reflect where and when emissions occur (Stinson et al. 2011).

Canada applies a Tier 3 methodology for estimating GHG emissions and removals in managed forests. Canada's National Forest Carbon Monitoring, Accounting and Reporting System (NFCMARS – Kurz and Apps 2006) includes a model-based approach (Carbon Budget Model of the Canadian Forest Sector, CBM-CFS3 – Kull et al. 2011; Kurz et al. 2009). This model integrates forest inventory data and yield curves with spatially referenced activity data on forest management and natural disturbances (fires, insect infestations) to estimate forest carbon stocks, stock changes and CO₂ 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 CO₂ uptake by growing trees and emissions from forest management activities (harvesting), heterotrophic respiration and natural disturbances. The interested reader will find additional information on estimation methodology in Annex 3.4.

Carbon stock changes in managed forests are reported in CRF Table 5A, by reporting zone. For any given pool, carbon stock changes include not only exchanges of GHG with the atmosphere, but also the carbon transfers to and from pools, for example its transfer from living biomass to dead organic matter upon stand mortality. Therefore individual carbon stock changes give no indication of the net fluxes between carbon pools in managed forests and the atmosphere. The largest carbon fluxes to and from managed forests consist of net carbon uptake by growing trees and its release due to the decay of organic matter (–2900 and 2700 Mt, respectively, in 2011; see Figure 7–2). The upward trend in dead organic matter (DOM) decay over the years 2000–2006 reflects the long-term, growing effect of past disturbances, especially insect epidemics that have left substantial quantities of decaying DOM. Over the last decade, insect epidemics have affected a total of over 57 Mha³ of managed forests, with 72% being located in the Montane Cordillera reporting zone and corresponding to the epidemics of Mountain Pine Beetle. The gradual decline in Mountain Pine Beetle epidemics explains the decreasing emission trend post-2006. In contrast, much of the interannual variability of the GHG budget of managed forests hinges on the occurrence, location and severity of fires. During the 1990–2011 period, annual wildfire emis-

3 May include areas repeatedly infested, e.g., a hectare infested in three successive years is counted as three hectares towards the 57 Mha.

Figure 7–2 Large Annual Carbon Fluxes to and from the Atmosphere in Managed Forests, 1990–2011: Net Carbon Uptake (or Net Primary Production) and Release Due to Decay (from Heterotrophic Respiration)

sions fluctuated between 11 and 264 Mt. The consumption of dead organic matter by fires accounts for 76% 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 CO₂ equivalents are in the form of CO, 7% as CH₄, and 4% in the form of N₂O.

In order to avoid double counting, estimates of C stock changes in CRF Table 5A exclude carbon emissions emitted as CO₂, CH₄ and CO due to biomass burning, which are reported in Table 5(V). Emissions and removals are automatically tallied in CRF Table 5.

In keeping with the IPCC default methodology (IPCC 2003), forest land estimates reflect the assumption that all carbon transferred out of forests in the form of wood products is deemed an immediate emission. Under this assumption, in 2011 the transfer of carbon from forests to harvested wood products (HWP) from forest management activities amounts to emissions of 130 Mt, a decrease of 14% compared to 1990 and of 33% from the peak of 2004. However, this assumption introduces significant temporal inaccuracies in emission patterns, as it omits the long-term C storage in HWP in use and subsequently in landfills, followed by its eventual release (IPCC 2006). This section presents

preliminary estimates of the impact of incorporating the long-term C storage in HWP in use.

Estimates presented here were developed using the general framework of the “Production” approach, one of the four approaches to incorporate long-term C storage in HWPs (IPCC 2006). A country-specific model, the Carbon Budget Model Framework for Harvest Wood Products (CBM-FHWP) was developed to monitor and quantify the fate of carbon off-site from the point of harvest. The CBM-FHWP tracks HWP sub-pools and carbon flows between sub-pools through the action of events (e.g. manufacturing, use, trade and disposal). More information on Canada’s application of the production approach and the CBM-FHWP is available in Annex 3.4.

Emissions associated with HWP using both the default and production approach are presented in Table 7–5. The column “Net GHG Flux excluding C removed off-site” shows the net forest flux excluding carbon taken off-site in harvested material (but including the on-site decay of harvest residues). The next two sets of columns contrast emissions from HWP under two different approaches, and the resulting net emissions or removals in Forest land remaining forest land (FLFL).

In general, incorporating the delay in emissions from HWP due to C storage in commodities increases the net sink

Table 7–5 Net GHG Flux in Forest Land Remaining Forest Land with Two Harvested Wood Products (HWP) Estimation Approaches (Mt CO₂ equivalent¹)

Inventory Year	Net GHG Flux excluding C removed off-site	Instant Oxidation Approach ²		Production Approach ³	
		Emissions from HWP	Total Net GHG Flux ⁴	Emissions from HWP	Total Net GHG Flux ⁵
1990	-238.6	152.0	-86.6	58.1	-180.5
1991	-210.2	150.3	-59.9	69.9	-140.3
1992	-265.3	159.0	-106.2	87.0	-178.3
1993	-196.3	164.7	-31.6	96.2	-100.1
1994	-205.5	171.9	-33.6	105.1	-100.4
1995	1.8	177.0	178.9	113.8	115.6
1996	-208.3	172.1	-36.2	110.8	-97.5
1997	-252.5	177.5	-75.0	113.8	-138.7
1998	-59.1	166.7	107.7	105.6	46.5
1999	-181.0	186.5	5.5	114.1	-66.9
2000	-252.4	189.6	-62.9	122.6	-129.8
2001	-233.7	174.6	-59.1	107.1	-126.7
2002	-92.3	184.1	91.8	113.8	21.5
2003	-129.2	170.3	41.1	101.6	-27.6
2004	-95.9	195.1	99.2	123.4	27.4
2005	-135.2	190.5	55.2	121.1	-14.1
2006	-106.5	172.3	65.8	109.2	2.8
2007	-108.5	154.0	45.6	101.9	-6.6
2008	-147.1	130.3	-16.8	100.6	-46.5
2009	-123.4	109.0	-14.4	99.1	-24.3
2010	-33.7	133.0	99.3	101.7	68.0
2011	-46.3	130.2	83.9	100.2	54.0

Notes:

1. Negative sign indicates net removals from the atmosphere.
2. Instant oxidation is the default approach in IPCC (2003) to estimate emissions from HWP.
3. The production approach accounts for the HWP from domestically harvested wood, both within and outside Canada; imported HWP are excluded (IPCC 2006).
4. Values should match total estimates reported under Forest land remaining forest land in CRF Table 5 and NIR Table 7–1.
5. Total emissions and removals in Forest land remaining forest land, using the production approach for HWP.

or reduces the net source in forest land remaining forest land. It does not remove the interannual variability created by natural disturbances. Under the instant oxidation approach, emissions from HWP simply equal the quantity of C harvested. In contrast, the temporal pattern of emissions under the production approach results from historical commodity production combined with the duration of the economic lives of various commodities. The impact of any significant changes in harvest levels, or in the mix of products, is therefore spread out over several subsequent years and decades as commodities are gradually retired from use. A portion of harvested carbon nevertheless continues to be emitted in the harvest year. In any one year, between 18% and 38% of C in domestically harvested fibre is not stored in commodities and is presumed lost in the processing stream, for simplicity identified as “milling waste.” These emissions can fluctuate with harvest levels,

variations in product mix and changes in processing technologies.

The difference in FLFL estimates due to changing the HWP estimation approach is not constant over time; the impact is larger at the beginning of the time series, and decreases over time. This is to be expected, since the HWP pool starts in 1990 and at that time contains no C from historically produced commodities. Over time, C accumulates in the pool of HWP in use, and so emissions from the pool increase (from 58 Mt CO₂ in 1990 to about 100 Mt CO₂ in 2011).

7.3.1.2. Uncertainties and Time-Series Consistency

Uncertainty Estimates

Conducting uncertainty analysis is a significant challenge in complex modelling frameworks such as the one used for modelling forest carbon dynamics, with multiple interactions and dependencies between current and historical events, and among the very large number of model inputs and parameters, required to simulate carbon dynamics.

Numerical techniques are used to quantify uncertainties about the outputs of the CBM-CFS3 (Metsaranta et al. 2013). Careful consideration is given to the identification and representation of uncertainty sources in the analysis (see Annex A3.4.2.4 for additional information). Modelling of the entire managed forests of Canada is not done as a single run, but in separate “project runs” whose output is subsequently assembled. For each “project,” 100 Monte Carlo runs are conducted using the base input data for the 2013 submission (covering the entire 1990–2011 time series). Confidence intervals are obtained for each inventory year, by randomly sampling 10 000 combinations of all the project runs for that year. Separate uncertainty estimates are produced for each gas.

Throughout the entire time series the uncertainties about annual estimates are expressed as a 95% confidence interval, bound by 2.5th and 97.5th percentiles of the Monte Carlo run outputs (see Table 7–6 for CO₂ fluxes, and Table 7–7 and Table 7–8 for CH₄ and N₂O emissions, respectively).

Over the entire time series, the range of the 95% confidence interval about the median CO₂ estimates averaged 74 Mt. Expressing this range in relative terms (as % of the estimate) can be misleading, as the relative uncertainty will be largest when the net CO₂ 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-CO₂ 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

Table 7–6 Estimates of the Net Annual CO₂ Fluxes for Forest Land Remaining Forest Land, 1990–2011, with 2.5th and 97.5th Percentiles

Inventory Year	Net CO ₂ Flux (Gg)	2.5 th Percentile (Gg)	97.5 th Percentile (Gg)
1990	-91 000	-230 000	-92 000
1991	-68 000	-215 000	-63 000
1992	-109 000	-256 000	-108 000
1993	-42 000	-189 000	-36 000
1994	-43 000	-184 000	-35 000
1995	149 000	23 000	183 000
1996	-43 000	-193 000	-34 000
1997	-78 000	-230 000	-74 000
1998	84 000	-42 000	261 000
1999	-4 000	-133 000	7 000
2000	-65 000	-214 000	-59 000
2001	-64 000	-195 000	-48 000
2002	73 000	-53 000	168 000
2003	28 000	-72 000	49 000
2004	84 000	-27 000	96 000
2005	46 000	-93 000	48 000
2006	55 000	-48 000	56 000
2007	36 000	-83 000	47 000
2008	-23 000	-154 000	-15 000
2009	-24 000	-111 000	-14 000
2010	80 000	-2 000	86 000
2011	66 000	-48 000	93 000

Table 7–7 Estimates of the Annual CH₄ Emissions from Forest Land Remaining Forest Land, 1990–2011, with 2.5th and 97.5th Percentiles

Inventory Year	Net CH ₄ Flux (Gg CO ₂ eq)	2.5 th Percentile (Gg)	97.5 th Percentile (Gg)
1990	3 000	2 600	4 000
1991	5 000	3 900	6 300
1992	1 500	1 300	1 900
1993	6 200	5 000	7 500
1994	5 600	4 900	7 300
1995	19 000	17 000	24 000
1996	4 400	3 700	5 400
1997	1 600	1 300	2 100
1998	15 000	13 000	21 000
1999	6 000	5 700	8 200
2000	1 300	1 000	1 800
2001	2 700	2 400	4 500
2002	11 000	9 700	16 000
2003	8 300	7 700	12 000
2004	9 500	8 300	13 000
2005	5 400	4 500	7 100
2006	6 500	6 000	10 000
2007	6 000	5 800	9 300
2008	4 000	3 400	5 400
2009	6 000	5 200	9 500
2010	12 000	9 800	16 000
2011	11 000	8 900	18 000

Table 7–8 Estimates of the Annual N₂O Emissions from Forest Land Remaining Forest land, 1990–2011, with 2.5th and 97.5th Percentiles

Inventory Year	Net N ₂ O Flux (Gg CO ₂ eq)	2.5 th Percentile (Gg)	97.5 th Percentile (Gg)
1990	1 800	1 600	2 500
1991	3 100	2 400	3 800
1992	920	790	1 200
1993	3 800	3 100	4 700
1994	3 500	3 000	4 500
1995	12 000	10 000	15 000
1996	2 700	2 300	3 400
1997	990	820	1 300
1998	9 000	7 900	13 000
1999	3 800	3 500	5 100
2000	790	680	1 100
2001	1 700	1 500	2 700
2002	7 100	6 100	10 000
2003	5 100	4 800	7 600
2004	5 900	5 000	8 000
2005	3 400	2 800	4 400
2006	4 000	3 600	6 100
2007	3 800	3 500	5 700
2008	2 500	2 100	3 300
2009	3 700	3 200	5 700
2010	7 200	5 900	9 700
2011	7 000	5 500	11 000

of these sources, the results of the uncertainty analysis are better understood as expressions of precision than estimates of accuracy. These results will be used, among other factors, to analyze and prioritize improvements in the estimation of anthropogenic emissions and removals in this category.

Time-Series Consistency

All estimates have been developed in a consistent manner, but some sources of activity data do not provide full coverage for the reporting period. Estimates for wildfire areas in 2004–2011 were derived from a composite of real-time, remotely sensed imagery and monitoring data collected by provincial resource management agencies produced by the Canadian Wildland Fire Information System.⁴ Estimates for 1990–2003 were derived solely 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 all collected in the same year across the country;

Annex 3.4 explains how forest inventory data from various sources were processed to provide complete, coherent and consistent forest data for 1990.

7.3.1.3. QA/QC and Verification

Tier 2 quality control (QC) checks (White and Dymond 2008; Dymond 2008) specifically address estimate development in the Forest Land category. Systematic and documented quality assurance / quality control (QA/QC) procedures are performed in four areas: workflow checks (manual), model checks (automated), benchmark checks (manual) and external reviews. Check results are systematically documented; an issue logging system identifies each issue and facilitates tracking and managing its resolution.

Environment Canada, while maintaining its own QA/QC procedures for estimates developed internally (refer to Annex 6), has implemented category-specific Tier 2 checks for estimates obtained from partners, as well as for all estimates and activity data contained in the LULUCF geodatabase and entered into the CRF reporter. These procedures and their outcome are fully documented in the centralized archives.

7.3.1.4. Recalculations

Recalculations can be grouped into the following three categories:

Harvest and Wildfire Activity Data Updates: A detailed review of forest management information identified revisions to official harvest data throughout the time series, which were incorporated for this submission. The largest recalculation was for the 2010 inventory year, where official data replaced preliminary harvest estimates. Updated wildfire area data that utilized more detailed mapping of areas affected by fires for 2009 and 2010 caused upward recalculations for these years.

Forest Conversion Updates: Updated forest land conversion estimates were provided based on digital remote sensing analysis for the entire time series. Forest conversion rates and corresponding emissions decreased for the 1990–1999 time period, while both increased in the 2000–2009 time period. More detailed information on Forest Conversion recalculations is presented in Section 7.8.4.

Error Corrections: Errors identified in the implementation of various methodological changes introduced in past submissions were corrected, namely those related to harvest

⁴ http://cwffis.cfs.nrcan.gc.ca/en_CA/index

activities. The error correction that had the largest influence on total recalculations was related to the reduced Ontario harvest discount factor, which affected all years prior to 2008. In brief, forest inventory data for Ontario do not contain sufficient information on un-even aged hardwood forests. Therefore these areas were excluded from Ontario forest inventory estimates by using a 25% discount factor on total harvest for the province. Through consultation with provincial experts this discount factor was reduced to 5%, which led to an increase in reported harvest activity and a corresponding increase in emissions from harvesting.

Recalculations in any one year or spatial unit are due to the combined effects of activity data updates and error corrections. Upward recalculations across the time series can be mainly attributed to harvest recalculations in the Boreal Shield East and Boreal Shield West reporting zones. However, in 2007 decreased wildfire emissions cancelled out the increased emissions from harvesting, resulting in an overall downward recalculation for that year. During the 1990–2007 time period, harvest area increased by on average 14 and 21 kha (5 and 30%) in the Boreal Shield East and Boreal Shield West, respectively, resulting in a collective average increase of 4.7 Mt CO₂ eq for these reporting zones. The significant upward recalculation in 2010 of 30 Mt CO₂ eq is largely due to updated harvest statistics for that year.

Recalculations in other forest disturbance categories such as wildfire and insects are an indirect consequence of updates to disturbances such as harvesting and forest conversion. Changes to activity data for one disturbance type alter the pool of candidate forest inventory records available for subsequent disturbances. This results in recalculations to emissions estimates of other disturbance categories.

7.3.1.5. Planned Improvements

Long-term planned improvements include enhancing the quality of forest inventory data and greater focus on drivers of anthropogenic emissions and removals. A more systematic approach for implementing improvements will reduce the frequency of recalculations.

Although already more realistic spatially and temporally than the official estimates, the HWP estimates provided in this submission should be considered as preliminary. Further elaboration of the production approach for HWP is

planned for future submissions, including an examination of the appropriateness of IPCC default half-lives to Canadian circumstances, the feasibility of including pre-1990 HWP production, incorporating long-term storage at solid waste disposal sites (SWDS), and representing the use of milling waste and end-of-life products as bioenergy feedstocks.

7.3.2. Land Converted to Forest Land

7.3.2.1. Category Description

This category includes all lands converted to forest land through direct human activity. Post-harvest tree planting is not included, nor is abandoned farmland where natural vegetation is allowed to establish; hence, the category more precisely refers to forest establishment where the previous land use was not forest (typically, abandoned farmland).

The total cumulative area of land converted to forest land declined from 174 kha in 1990 to 80 kha in 2011. The trend reflects the gradual transfer of lands afforested more than 20 years ago to the forest land remaining forest land category, and a dearth of recent data on current rates of forest establishment. Eighty-six percent of all farmland converted to forest land over the last 20 years is in eastern Canada (Atlantic Maritime, Mixedwood Plains and Boreal Shield East reporting zones) and only 8% in the Prairies (Boreal Shield West, Boreal Plains and Subhumid Prairies reporting zones). However, caution must be exerted in regard to analysis of afforestation trends due to the absence of a reliable and comprehensive data source.

Net removals consequently declined throughout the period, from 1.0 Mt in 1990 to 0.7 Mt in 2011. Net carbon accumulation largely occurs in biomass (166 Gg C in 2011 – CRF table 5A); soil carbon sequestration is negligible and will remain so because this category is restricted to plantations that are younger than 20 years. For the same reason, and considering the relatively low net increment of planted trees in the early years, the subcategory as a whole is not expected to contribute significantly to the net greenhouse gas balance of forest lands.

7.3.2.2. Methodological Issues

The Feasibility Assessment of Afforestation for Carbon Sequestration (FAACS) initiative collected and compiled

afforestation records for 1990–2002 (NRCan 2005a). In this period, softwood plantations, especially spruce and pine, accounted for 90% of the area planted. Activities for 1970–1989 and 2003–2008 were estimated based on activity rates observed in the FAACS data, complemented with information from the Forest 2020 Plantation Demonstration Assessment (NRCan 2005b). No new afforestation activity data were collected for the 2009–2011 inventory years.

GHG emissions and removals on lands newly converted to forests were estimated using CBM-CFS3, as described in Annex 3.4. Changes in soil carbon stocks are highly uncertain because of difficulties in locating data about the carbon stocks prior to plantation. It was assumed that the ecosystem would generally accumulate soil carbon at a slow rate; the limited time frame of this analysis and the scale of the activity relative to other land use and land-use change activities suggest that the impact of this uncertainty, if any, is minimal.

7.3.2.3. Uncertainties and Time-Series Consistency

It was not possible, owing to data and resource limitations, to develop formal uncertainty estimates for this category.

7.3.2.4. QA/QC and Verification

Tier 2 QC checks (Dymond 2008) specifically address estimate development in the Forest Land category. Environment Canada, while maintaining its own QA/QC procedures for estimates developed internally (refer to Annex 6), has implemented specific ones for estimates obtained from partners, as well as for all estimates and activity data contained in the LULUCF geodatabase and entered into the CRF reporter.

7.3.2.5. Recalculations

There were no recalculations in this category.

7.3.2.6. Planned Improvements

There is currently limited access to information on afforestation activity. Efforts are underway to obtain data on afforestation activities in recent years from provincial and territorial resource management agencies and to develop uncertainty estimates for areas of afforestation.

7.4. Cropland

Cropland covers approximately 48 Mha of the Canadian territory. In 2011, the net GHG balance in the Cropland category amounted to removals of 8.0 Mt CO₂ eq (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 13 Mt CO₂ eq in 2011) and land, either forest or grassland, converted to cropland (net emissions of 5.3 Mt CO₂ eq and 0.006 Mt CO₂ eq, respectively, in 2011). The estimates in land “converted to cropland” include net emissions and removals of CO₂, as well as N₂O and CH₄ emissions.

7.4.1. Cropland Remaining Cropland

Cultivated agricultural land in Canada includes areas of field crops, summerfallow, hayland, and tame or seeded pasture. Cropland is found mainly in the nine southernmost reporting zones. About 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 CO₂ emissions/removals in mineral soils, CO₂ emissions from agricultural lime application and cultivation of organic soils, and CO₂ emissions/removals resulting from changes in woody biomass from specialty crops. An enhanced Tier 2 approach is used for estimating CO₂ emissions from and removals by mineral soils triggered by changes in land management practices. Table 7–9 summarizes the trend in emissions and removals for these categories.

7.4.1.1. CO₂ 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 CO₂ emission to or removal from the atmosphere.

In 1990, changes in mineral soil management amounted to a net CO₂ removal of about 2.1 Mt CO₂ eq (Table 7–9). This net sink steadily increased to about 14 Mt CO₂ eq in 2011, reflecting continuous efforts in reducing summerfallow

Table 7–9 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 ₂) ¹							
		1990	2000	2005	2007	2008	2009	2010	2011
Total Cropland Remaining Cropland		-1 600	-7 000	-10 000	-11 000	-12 000	-12 000	-13 000	-13 000
<i>Cultivation of Histosols</i>		300	300	300	300	300	300	300	300
<i>Liming</i>		200	270	290	290	290	290	290	290
<i>Perennial Woody Crops</i>		50	80	30	- 10	- 20	- 30	- 40	- 40
<i>Total Mineral Soils</i>		-2 100	-7 600	-11 000	-12 000	-12 000	-13 000	-13 000	-14 000
Change in Crop Mixture	Increase in Perennial	-1 300	-3 100	-4 600	-5 200	-5 500	-5 700	-6 000	-6 300
	Increase in Annual	3 500	3 700	3 600	3 600	3 500	3 500	3 500	3 500
Change in Tillage	Conventional to Reduced Tillage	- 860	-1 000	- 900	- 850	- 820	- 790	- 760	- 730
	Conventional to No-till	- 540	-2 600	-3 600	-3 900	-4 100	-4 200	-4 300	-4 300
	Other	- 0.4	- 230	- 580	- 710	- 760	- 820	- 870	- 920
Change in Summerfallow (SF)	Increase in SF	1 700	1 400	1 300	1 200	1 200	1 200	1 200	1 200
	Decrease in SF	-4 800	-7 000	-7 600	-7 700	-7 800	-7 900	-7 900	-8 000
<i>Land Conversion—Residual Emissions</i> ²		190	1 300	1 600	1 700	1 800	1 800	1 800	1 800

Notes:

1. Negative sign indicates removal of CO₂ from the atmosphere.2. Net residual CO₂ 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

and increasing conservation tillage (Campbell et al. 1996; Janzen et al. 1998; McConkey et al. 2003). The area of summerfallow declined by 68% over the 1990–2011 period, resulting in a net sink that increased from 3.1 Mt CO₂ eq in 1990 to 6.8 Mt CO₂ eq in 2011. The increase in net sink due to the adoption of conservation tillage practices (from 1.4 Mt CO₂ eq in 1990 to 5.0 Mt CO₂ eq in 2011) is substantiated by a net increase of 13 Mha in areas under no-till and reduced tillage over the 1990–2011 period. The net change in crop mixture resulted in a change from a source of 2.2 Mt CO₂ eq in 1990 to a sink of 2.8 Mt CO₂ eq in 2011.

The net increase in sink from changes in management practices over time was partially offset by an increase since 1990 in net residual CO₂ emissions from the decay of dead organic matter and SOC on land converted to cropland more than 20 years prior to the inventory year. Emissions from land converted for less than 20 years are included under land converted to cropland. The increase since 1990 in these residual emissions is due to a methodological artefact. Since forest conversion monitoring goes back only to 1970, post-20-year residual emissions in 1990 only accounted for the land converted in 1970. Residual emissions display an apparent increase because the temporal coverage increases with each inventory year. In the CRF

tables, these emissions are split among the dead organic matter and soil pools.

Methodological Issues

Following the IPCC Good Practice Guidance for LULUCF (IPCC 2003), the premise is that the changes in SOC are driven by changes in soil management practices. Where no change in 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 yieldpromoting practices and reestablishment 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 CO₂ changes in mineral soils were derived from the following LMCs:

- change in the proportion of annual and perennial crops;
- change in tillage practices; and
- change in area of summerfallow.

Carbon emissions and removals were estimated by applying country-specific carbon emission and removal factors multiplied by the relevant area of land that underwent a management change. Calculations were performed at a high degree of spatial disaggregation, namely by Soil Landscapes of Canada (SLC) polygons (see Annex 3.4.1). The carbon emission/removal factors represent the rate of SOC change per year and per unit area that underwent an LMC. The annual CO₂ emissions/removals by mineral soils undergoing a specific LMC are expressed as:

Equation 7-1:

$$\Delta C = F \times A$$

where:

ΔC	=	change in soil carbon stock, Mg C
F	=	average change in SOC subject to LMC, Mg C/ha
A	=	area of LMC, ha

In reality, the impact of LMC on SOC varies with initial conditions. The most accurate estimate of soil carbon stock change would therefore be derived by individually considering the cumulative effects of the long-term management history of each piece of land or farm field. Limits are imposed by the availability of activity data within the modelling framework. At this point, the inventory relies extensively on the *Census of Agriculture* for estimates of areas of LMC (i.e. changes in tillage, types of crop and fallow). The area of LMC was determined individually for 3264 SLC polygons having agricultural activities, each one having an agricultural area in the order of 1000–1 000 000 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.

Uncertainties and Time-Series Consistency

Uncertainty was estimated analytically with a Tier 1 approach. The uncertainties associated with estimates of CO₂ emissions or removals involve estimates of uncertainties for area and carbon factors of management changes for fallow, tillage and annual/perennial crops (McConkey et al. 2007).

The uncertainty about the area in a management practice for an ecodistrict varied inversely with the relative proportion it occupied of the total area of agricultural land in that ecodistrict. The relative uncertainty of the area of management practice (expressed as standard deviation of an assumed normal population) decreased from 10% to 1.25% of the area as the relative area of that practice increased.⁵

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

⁵ T. Huffman, Agriculture and Agri-Food Canada, personal communication to Brian McConkey, 2007.

change due to variation in the location or timing of the management practice. More details about estimating process and situational uncertainties are presented in Annex 3.4. Uncertainty estimates associated with emissions/removals of CO₂ from mineral soils were developed by McConkey et al. (2007), who reported uncertainty values at $\pm 19\%$ for the level and $\pm 27\%$ for the trend. These uncertainty estimates have not been updated since the 2011 annual submission, but should still be applicable because there has been no change in the inventory method over the last two submissions.

Consistency in the CO₂ estimates is ensured through the use of the same methodology for the entire time series of estimates (1990–2011).

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 Vandenberg et al. (2008). The comparison showed that empirical data on changes in SOC in response to no tillage were highly variable, particularly for eastern Canada. Nonetheless, the modelled factors were still within the range derived from the empirical data. For the switch from annual to perennial cropping, the mean empirical factor was 0.59 Mg C/ha per year, and this compared favourably with the range of 0.46–0.56 Mg C/ha per year in the modelled factors in western Canadian soil zones. For eastern Canada, only two empirical change factors were available, but they fell within 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 ± 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

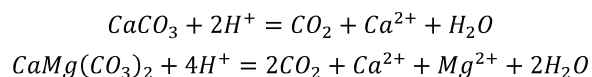
There were small changes in area statistics resulting from a more complete Tier-2 QC: 1) shifting to an annual time step increased processing iterations, contributing to differences in the reporting of areas and 2) updating areas of forest land conversion for the entire time series impacted area statistics for cropland remaining cropland. As a result of these changes, recalculations were carried out with an increase in removals of 89 kt CO₂ eq, for 1990 and a decrease in removals of 150 kt CO₂ eq in 2010, with no notable impact on the emission trend.

Planned Improvements

Improvements to the CENTURY model and the use of alternative models such as DAYCENT and RothC are also being explored, to improve the simulation of Canadian agricultural conditions. The quality of area statistics collected through the *Census of Agriculture* will be improved using land cover information.

7.4.1.2. CO₂ 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, CO₂ 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 CO₂ 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 ± 0.25 Mt CO₂ eq for the level uncertainty and 0.09 ± 0.30 Mt CO₂ eq for the trend uncertainty (McConkey et al. 2007).

The same methodology is used for the entire time series of emission estimates (1990–2011).

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. CO₂ Emissions from Cultivation of Organic Soils

Category Description

In Canada, cultivated organic soils are defined as the conversion of organic soils to agriculture for annual crop production, normally accompanied by artificial drainage, cultivation and liming. Organic soils used for agricultural production in Canada include the Peaty Phase of Gleysolic soils, Fibrisols over 60 cm thick, and Mesisols and Humisols over 40 cm thick (AAFC 1998).

Methodological Issues

The emissions from the cultivation of organic soils were calculated by multiplying the total area of cultivated histosols by the default emission factor of 5 Mg C/ha per year (IPCC 2006).

Areas of cultivated histosols are not provided by the *Census of Agriculture*; area estimates were based on the expert opinion of soil and crop specialists across Canada (Liang et al. 2004). The total area of cultivated organic soils in Canada (constant for the period 1990–2011) was estimated to be 16 kha, or 0.03% of the cropland area. The area of cultivated histosols is mainly located in Atlantic Maritime, Mixedwood Plains and Pacific Maritime reporting zones.

Uncertainties and Time-Series Consistency

The uncertainty associated with emissions from this source is due to the uncertainties from the area estimates for the cultivated histosols and the emission factor. The 95% confidence limits associated with the area estimate of cultivated histosols are assessed to be $\pm 50\%$ (Hutchinson et al. 2007). The 95% confidence limits of the default emission factor are $\pm 90\%$ (IPCC 2006). The overall mean and uncertainties associated with this source of emissions were estimated to be 0.3 ± 0.09 Mt CO₂ eq for the level uncertainty and 0 ± 0.13 Mt CO₂ eq for the trend uncertainty (McConkey et al. 2007).

The same methodology and emission factors are used for the entire time series of emission estimates (1990–2011).

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. CO₂ Emissions and Removals in Woody Biomass

Category Description

Perennial woody biomass is found on cropland planted with vineyards, fruit orchards and Christmas trees. It also accumulates on abandoned cropland allowed to revert to natural vegetation. In the definitional framework adopted in Canada for LULUCF reporting, abandoned cropland is still considered “cropland” until there is evidence of a new land use; however, there is little information on the dynamics of cropland abandonment or recultivation. Owing to these data limitations, only vineyards, fruit orchards and Christmas trees are considered; for the time being changes in woody biomass from “abandoned cropland” on cropland remaining cropland are excluded.

Methodological Issues

Vineyards, fruit orchards and Christmas tree farms are intensively managed for sustained yields. Vineyards and fruit trees are pruned annually, and old plants are replaced on a rotating basis for disease prevention, stock improvement or introduction of new varieties. For all three crops, it is assumed that, because of rotating practices and the requirements for sustained yield, a uniform age-class distribution is generally found on production farms. Hence, there would be no net increase or decrease in biomass carbon within existing farms, as carbon lost from harvest or replacement would be balanced by gains due to new plant growth. The approach therefore was limited to detecting changes in areas under vineyards, fruit orchards and Christmas tree plantations and estimating the corresponding carbon stock changes in total biomass. More information on assumptions and parameters can be found in Annex 3.4.

Uncertainties and Time-Series Consistency

Upon a loss of area with perennial woody crops, all carbon in woody biomass is assumed to be immediately released. It is assumed that the uncertainty for carbon loss equals

the uncertainty about mass of woody biomass carbon. The default uncertainty of $\pm 75\%$ (i.e. 95% confidence limits) for woody biomass on cropland from the IPCC Good Practice Guidance (IPCC 2003) was used.

If the loss in area of fruit trees, vineyards or Christmas trees is estimated to have gone to annual crops, there is also a deemed perennial to annual crop conversion with associated uncertainty that contributes to carbon change uncertainty. For area of gain in fruit trees, vineyards or Christmas trees, the uncertainty in annual carbon change was also assumed to be the default uncertainty of $\pm 75\%$ (i.e. 95% confidence limits) (IPCC 2003).

The overall mean and uncertainties associated with emissions or removals of CO₂ from woody specialty crops were estimated to be -43 ± 4.3 kt CO₂ eq for the level uncertainty and -92 ± 138 kt CO₂ eq for the trend uncertainty (McConkey et al. 2007).

The same methodology was used for the entire time series of emission estimates (1990–2011).

QA/QC and Verification

This category has undergone Tier 1 QC checks (see Annex 6) in a manner consistent with IPCC Good Practice Guidance (IPCC 2000). The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

Recalculations

There were small changes in area statistics resulting from a more complete Tier 2 QC as noticed in Section 7.4.1.1. This was mainly due to a shift to an annual time step in system processing that allowed for more comprehensive checks to ensure that land management changes do not exceed the limits or capacity for changes within the analysis unit (SLC polygons). As a result, recalculations were carried out with no change in estimates for 1990 and an increase in removals of 36 kt CO₂ eq in 2010.

Planned Improvements

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

7.4.2. Land Converted to Cropland

This subcategory includes the conversion of forest land and grassland to cropland. Emissions from the conversion of forest land to cropland account for nearly 100% of the total emissions in this category, which have decreased from 13 Mt CO₂ eq in 1990 to 5.3 Mt CO₂ eq in 2011. Emissions from the conversion of grassland are relatively insignificant.

7.4.2.1. Forest Land Converted to Cropland

Clearing forest for use as agricultural land is an ongoing but declining practice in Canada, although agriculture remains an important cause of forest conversion (accounting for 37% of forest area conversion in 2011). The cumulative area of forest land converted to cropland since 1971 was 1286 kha in 1990; in 2011, the cumulative area converted since 1992 was 430 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 2011, immediate emissions from this year’s forest conversion accounted for 3.0 Mt CO₂ eq, or 58% of all emissions from forest land converted to cropland, while residual emissions from events that occurred in the last 20 years accounted for the remaining 2.2 Mt CO₂ eq. Ninety-five percent of emissions originate from the biomass and dead organic matter pools during and after conversion, with the remainder being attributed to the soil pool.

Methodological Issues – Dead Organic Matter and Biomass Pools

As stated above, emissions from the dead organic matter (DOM) and biomass pools account for almost all emissions due to the conversion of forests to cropland. Their estimation is performed in the same modelling environment as that used for forest land remaining forest land. A general description of this modelling environment was provided in Section 7.3.1.1; more information is provided in Annex 3.4.

Methodological Issues – Soils

Emissions from soils in this category include the net C stock change due to the actual conversion, a very small net CO₂ source from change in management practices in the 20 years following conversion, and the N₂O emissions from the decay of soil organic matter. The soil emissions

from forest land conversion to cropland were calculated by multiplying the total area of conversion by the empirically derived emission factor along with modelling-based SOC dynamics (see Annex 3.4). As explained below, patterns of change in SOC after the conversion of forest to cropland clearly differ between eastern and western Canada.

Eastern Canada

All agricultural land in the eastern part of the country was forested before its conversion to agriculture. Many observations, either in the scientific literature or the Canadian Soil Information System, of forest SOC comparisons with adjacent agricultural land in eastern Canada show a mean loss of carbon of 20% at depths to approximately 20–40 cm (see Annex 3.4). Average nitrogen change was –5.2%, equivalent to a loss of approximately 0.4 Mg N/ha. For those comparisons where both nitrogen and carbon losses were determined, the corresponding carbon loss was 19.9 Mg C/ha. Therefore, it was assumed that nitrogen loss was a constant 2% of carbon loss.

The CENTURY model (Version 4.0) is used to estimate the SOC dynamics from conversion of forest land to cropland in eastern Canada. More details of methodologies for determining the maximal carbon loss and its rate constant associated with the conversion of forest land can be found in Annex 3.4.

Following a Tier 2-type methodology, as was done for direct N₂O emissions from agricultural soils (see Agriculture Sector, Chapter 6), emissions of N₂O from forest conversion to cropland were estimated by multiplying the amount of carbon loss by the fraction of nitrogen loss per unit of carbon and by an emission factor (EF_{BASE}). EF_{BASE} was determined for each ecodistrict based on topographic and climate conditions (see Annex 3.3).

Western Canada

Much of the current agricultural land in western Canada (Prairies and British Columbia) was grassland in the native condition. Hence, forest land converted to cropland has been primarily of forest that lies on the fringe of former grassland areas.

The Canadian Soil Information System (CanSIS) represents the best available data source for SOC under forest and agriculture. On average, these data suggest that there is no loss of SOC from forest conversion and that, in the long term, the balance between carbon input and SOC mineralization under agriculture remains similar to what it was

under forest. It is important to recognize that along the northern fringe of western Canadian agriculture, where most forest conversion is occurring, the land is marginal for arable agriculture; pasture and forage crops are the dominant management practices.

For western Canada, no loss of SOC over the long term was assumed from forest land converted to cropland managed exclusively for seeded pastures and hayland. The carbon loss from forest conversion in western Canada results from the loss of above- and below-ground tree biomass and from loss or decay of other above- and below-ground coarse woody DOM that existed in the forest at the time of forest conversion. The average nitrogen change in western Canada for sites at least 50 years from breaking was +52% (see Annex 3.4), reflecting substantial added nitrogen in agricultural systems compared with forest management practices. However, recognizing the uncertainty about actual carbon-nitrogen dynamics for forest conversion, loss of forest land to cropland in western Canada was assumed not to be a source of N₂O.

Uncertainties and Time-Series Consistency

Greenhouse gas fluxes from forest land converted to cropland result from the combination of (i) burning or harvesting—immediate emissions from biomass and dead organic matter or transfers to HWP accounted for as immediate emissions, respectively; (ii) the organic matter decay and subsequent CO₂ emissions in the DOM pool; and (iii) the net carbon losses from SOC. Note that immediate CO₂ emissions always refer to area converted in the inventory year; residual emissions, while also occurring on land converted during the inventory year, mostly come from land converted over the last 20 years. Non-CO₂ emissions are produced only by burning, and occur during the conversion process.

Immediate and residual CO₂ emissions from the biomass and DOM pools represent the largest components of this category, and contribute the most to the category uncertainty. In all cases, uncertainty values are presented as the 95% confidence interval (immediate emissions – ±23%, residual emissions from the DOM pool – ±36%, and residual emissions from the soil pool – ±59%). Uncertainty values associated with non-CO₂ emissions were estimated to be ±23% for the immediate emissions and ±37% for the residual emissions from the DOM pool.

Reflecting the estimation approach and procedures, uncertainty estimates were derived independently for the bio-

mass and dead organic matter pools, and for soil organic matter. The uncertainty about activity data described in Section 7.8.2 was incorporated in all analyses.

The fate of biomass and DOM upon forest conversion and the ensuing emissions are modelled in the same framework as that used for forest land; the corresponding uncertainty estimates were therefore also developed within this framework and with the same Monte Carlo runs that generated uncertainty estimates in the Forest Land category. The analysis was only carried out for the time series 1990–2009 of the 2011 submission. A description of the general approach is provided in Section 7.3.1.2; more information can be found in Section 3.4.2.4 of Annex 3.4.

The uncertainty about the net CO₂ flux from the soil pool was estimated analytically (McConkey et al. 2007). More information is provided in Annex 3.4.2.4 on the general approach used to conduct this analysis.

QA/QC and Verification

This category has undergone Tier 1 QC checks (see Annex 6) in a manner consistent with IPCC Good Practice Guidance (IPCC 2000). Quality checks were also performed externally by Agriculture and AgriFood Canada, which derived the estimates of SOC change. The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

To address the question raised by the expert review team during the 2009 annual inventory review, Canada has provided additional materials in Annex 3.4 to support the methodology.

Recalculations

Recalculations were carried out, with an increase in emissions of 579 kt CO₂ eq in 1990 and a decrease of 296 kt CO₂ eq in 2010 because of updates in forest conversion activity for the entire time series (see Section 7.8).

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 CO₂ and N₂O 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 2011 from soils amounted to 6 kt CO₂ eq, including carbon losses and N₂O 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 N₂O emissions in forest converted to cropland, emissions of N₂O in grassland converted to cropland were estimated by a Tier 2 methodology, multiplying the amount of carbon loss by the fraction of nitrogen loss per unit of carbon by a base emission factor (EF_{BASE}). EF_{BASE} is determined for each ecodistrict based on climate and topographic characteristics (see Annex 3.3.3).

Uncertainty and Time-Series Consistency

The conversion from agricultural grassland to cropland occurs, but within the land definitional framework the conversion in the other direction is not occurring (see Section 7.2). Therefore, the uncertainty in absolute value of the area of this conversion cannot be larger than the uncertainty about the area of cropland or grassland. Hence, the uncertainty of the area of conversion was set to the lower of the uncertainties of the area of either cropland or grassland in each ecodistrict. The uncertainty of SOC change was estimated as in forest land conversion to cropland. The overall mean and uncertainty associated with emissions due to SOC losses on grassland conversion to cropland were estimated to be 6 ± 7 kt CO₂ eq for the level uncertainty, and -72 ± 48 kt CO₂ eq for the trend uncertainty.

The same methodology and emission factors are used for the entire time series of emission estimates (1990–2011).

QA/QC and Verification

This category has undergone Tier 1 QC checks (see Annex 6) in a manner consistent with IPCC Good Practice Guidance (IPCC 2000). The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

Recalculations

There were small changes in area statistics resulting from a more complete Tier 2 QC as noted in Section 7.4.1.1. As a result, recalculations were carried out, with an increase in emissions of 6 kt CO₂ eq in 1990 and a decrease of 2 kt CO₂ eq in 2010.

Planned Improvements

Canada plans to validate the modelled soil carbon change factors with the measured and published soil carbon change factors from grassland conversion as these become available.

7.5. Grassland

Agricultural grassland is defined under the Canadian LULUCF framework as pasture or rangeland on which the only agricultural land management activity has been the grazing of domestic livestock (i.e. the land has never been cultivated). It occurs only in geographical areas where the grassland would not naturally grow into forest if abandoned: the natural shortgrass prairie in southern Saskatchewan and Alberta and the dry, interior mountain valleys of British Columbia. Agricultural grassland is found in three reporting zones: Semi-arid Prairies (5600 kha), Montane Cordillera (200 kha), and Pacific Maritime (4 kha). As with cropland, the change in management triggers a change in carbon stocks (IPCC 2003). Very little information is available on management practices on Canadian agricultural grassland, and it is unknown whether grazed land is improving or degrading. Therefore, Canada reports this grassland remaining grassland category using the IPCC Tier 1 method based on no change in management practices since 1990. More details on the method are provided in Annex 3.4. Canada also collects data on prescribed burning and wildfires from grassland remaining grassland by expert consultations, and will report emissions of CH₄ and N₂O from this source in future submissions. 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 7–3).

7.6. Wetlands

In Canada, a wetland is land that is saturated with water long enough to promote anaerobic processes, as indicated by poorly drained soils, hydrophytic vegetation and various kinds of biological activity that are adapted to a wet environment—in other words, any land area that can keep water long enough to let wetland plants and soils develop. As such, wetlands cover about 14% of the land area of Canada (Environment Canada 2003). The Canadian Wetland Classification System groups wetlands into five broad categories: bogs, fens, marshes, swamps and shallow water (National Wetlands Working Group 1997).

However, for the purpose of this report and in compliance with land categories as defined in IPCC (2003), the Wetlands category should be restricted to those wetlands that are not already in the Forest, Cropland or Grassland categories. There is no corresponding area estimate for these wetlands in Canada.

In accordance with IPCC guidance (IPCC 2003), two types of managed wetlands are considered, where human intervention has directly altered the water table level and thereby the dynamics of GHG emissions/removals: peatlands drained for peat harvesting; and flooded land (namely, the creation of reservoirs). Owing to their differences in nature, GHG dynamics and the general approaches to estimating emissions and removals, these two types of managed wetlands are considered separately.

7.6.1. Managed Peatlands

7.6.1.1. Source Category Description

Of the estimated 123 Mha of peatlands in Canada,⁶ approximately 25 kha are, or were at some point in the past, drained for peat extraction. Some 14 kha are currently being actively managed. The other 11 kha consist of peatlands that are no longer under production. In the Canadian context, generally only bog peatlands with a peat thickness of 2 m or greater and an area of 50 ha or greater are of commercial value for peat extraction (Keys 1992). Peat production is concentrated in the provinces of

New Brunswick, Quebec, Alberta and Manitoba. Canada produces only horticultural peat.

Since the 1980s, virtually all peat extraction in Canada has relied on vacuum harvest technology; approximately 100 t/ha (wet basis) of horticultural peat is extracted with this technology (Cleary 2003). A drawback of the technology, as opposed to the traditional cut-block method, is poor natural vegetation regrowth in the post-production phase. Since the 1990s, peatland restoration activities have been pursued with greater interest.

Peat extraction activities expanded during the 1990–2000 period, with a 47% increase in the land area under active peat extraction, from 9.5 kha in 1990 to 14 kha at the turn of the century. Owing to this expansion and to the significant contribution of vegetation clearing and decay to the overall GHG budget, emissions from managed peatlands show a significant increase over the first half of the assessment period. Since then, emissions have declined (Figure 7–3), from 1.5 Mt in 2000 to 1.2 Mt in 2011. Emissions from managed peatlands are reported under land converted to wetlands for the first 20 years after conversion and under wetlands remaining wetlands thereafter.

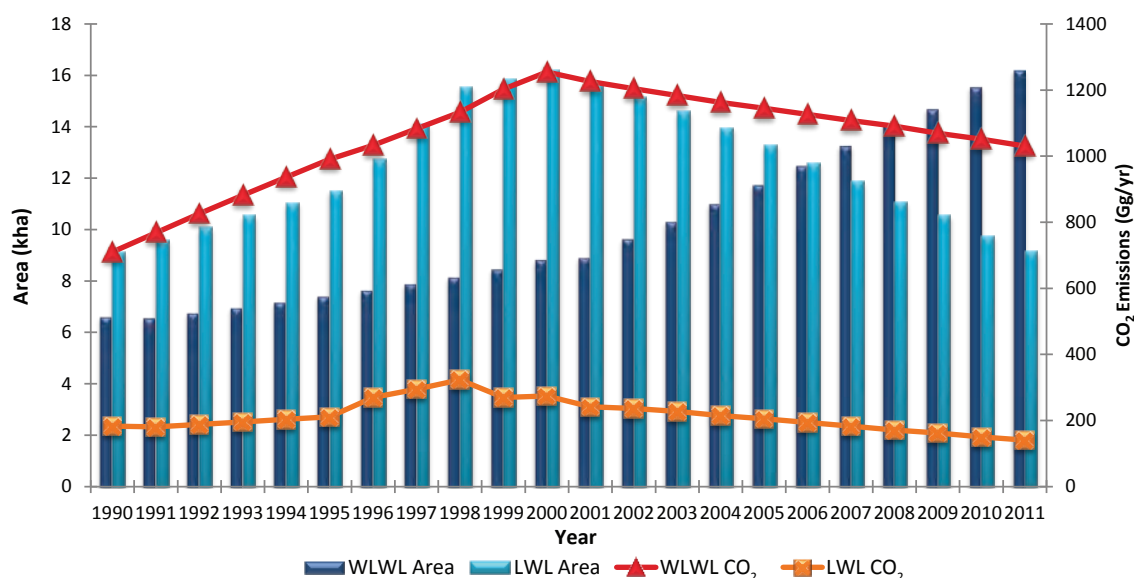
7.6.1.2. Methodological Issues

The general phases of peat extraction are 1) drainage, 2) vegetation clearing, 3) extraction, 4) stockpiling, 5) abandonment and 6) peatland restoration and establishment of natural vegetation. Due to drainage, CO₂ is the dominant GHG emitted from commercial peatlands and the only gas reported under this category. The main sources of emissions are vegetation clearing upon conversion, the continuing decay of dead organic matter and the rapid oxidation of exposed peat, resulting in a threefold increase in CO₂ emission rates compared to natural peatlands (Waddington and Warner 2001). Estimates were developed using a Tier 2 methodology, based on domestic emission factors. They include emissions and removals during all five phases. More information on estimation methodology can be found in Annex 3.4.

Note that the methodology does not include carbon losses from the peat transported off-site; should these be included, total emissions from managed peatlands would significantly increase.

⁶ This area includes peatlands that would be classified as Forest, Cropland and Grassland in the IPCC land classification.

Figure 7-3 Areas of Managed Peatlands and CO₂ Emissions from These Lands, 1990–2011 (LWL: Land Converted to Wetlands; WLWL: Wetlands Remaining Wetlands)



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.⁷ This introduces significant uncertainty about activity data. In addition, the fate of abandoned peatlands is not monitored in Canada; there is no information on older peat fields that could have been converted to other uses. Therefore, the area estimate of abandoned peatlands is probably conservative.

7.6.1.4. QA/QC and Verification

Annex 6 describes the general QA/QC procedures being implemented for Canada's GHG inventory; they apply to this category as well. Areas were derived in collaboration with the Canadian Sphagnum Peat Moss Association.

7.6.1.5. Recalculations

Updated 2009 peat production data and new 2010 data from Natural Resources Canada were incorporated into the managed peatland area model, leading to recalculations across the time series.⁸ From 1990 to 2004, recalculations are on average 0.6 kt, with larger recalculations from 2005 to 2010 (on average 12 kt).

7.6.1.6. Planned Improvements

Work is underway to decrease the uncertainty of the estimate of preconversion aboveground biomass (or biomass removal due to peat extraction) by analyzing geospatial information related to peatlands. Visual air photo interpretation will be used to identify areas of activity along with the pre- and post-disturbance conditions of peat extraction sites. In addition, activity is underway to develop improved estimates of activity area for peatland conversion, drainage and extraction, and restoration. Efforts are

⁷ Gerry Hood, Canadian Sphagnum Peat Moss Association, personal communication to D. Blain, Environment Canada, 2006.

⁸ <http://mmsd.mms.nrcan.gc.ca/stat-stat/prod-prod/ann-ann-eng.aspx>

also being made to develop an appropriate methodology to estimate the emissions associated with the decay of offsite harvested peat as recommended in the 2006 IPCC guidelines.

7.6.2. Flooded Lands (Reservoirs)

This category includes in theory all lands that have been flooded regardless of purpose. Owing to methodological limitations, this submission includes only large hydroelectric reservoirs created by land flooding. Existing water bodies dammed for water control or energy generation were not considered if flooding was minimal (e.g. Manitoba's Lake Winnipeg, the Great Lakes).

Since 1970, land conversion to flooded lands occurred in reporting zones 4, 5, 7, 8, 10 and 14. The total land area flooded for 10 years or less declined from 900 kha in 1990 to 120 kha in 2011. In 2011, 55% of the 120 kha of reservoirs flooded for 10 years or less were previously forested (mostly un-managed forests).

Total emissions from reservoirs declined from 4.4 Mt in 1990 to 1.5 Mt CO₂ in 2011.

7.6.2.1. Methodological Issues

Two concurrent estimation methodologies were used to account for GHG fluxes from flooded lands—one for forest clearing and the other for flooding. When there was evidence of forest biomass clearing and removal prior to flooding, the corresponding carbon stock changes for all non-flooded carbon pools were estimated as in all forest conversion events, using the CBM-CFS3 (refer to Section 7.8 below and Annex 3.4). Emissions from the burning and decay of all non-flooded dead organic matter are reported under land converted to wetlands for the first 10 years post-clearing and in wetlands remaining wetlands beyond this period. The construction of large reservoirs in northern Quebec (Touloustuc, Eastmain1, Peribonka), whose impoundments were completed in 2005, 2006 and 2008, respectively, resulted in this type of forest clearing prior to flooding. Note that emissions from forest clearing in the general area surrounding future reservoirs (e.g. for infrastructure development) are reported under forest conversion to settlements.

The second methodology is applied to estimate CO₂ emissions from the surface of reservoirs whose flooding has

been completed. The default approach to estimate emissions from flooding assumes that all forest biomass carbon is emitted immediately (IPCC 2003). In the Canadian context, this approach would overestimate emissions from reservoir creation, since the largest proportion of any submerged vegetation does not decay for an extended period. A domestic approach was developed and used to estimate emissions from reservoirs based on measured CO₂ fluxes above reservoir surfaces, consistent with the descriptions of IPCC Tier 2 methodology (IPCC 2003, 2006) and following the guidance in Appendix 3a.3 of IPCC (2003). Annex 3.4 of this National Inventory Report contains more detail on this estimation methodology. The assessment includes CO₂ emissions only. Emissions from the surface of flooded lands are reported for a period of 10 years after flooding, in an attempt to minimize the potential double counting of dissolved organic carbon lost from the watershed and subsequently emitted from reservoirs. Therefore, only CO₂ emissions are calculated for hydroelectric reservoirs where flooding had been completed between 1981 and 2011.

For each reservoir, the proportion of pre-flooding area that was forest is used to apportion the resulting emissions to the subcategories forest land converted to wetlands and other land converted to wetlands.

It is important to note that fluctuations in the area of lands converted to wetlands (reservoirs) reported in the CRF tables are not indicative of changes in current conversion rates, but reflect the difference between land areas recently flooded (less than 10 years before the inventory year) and older reservoirs (more than 10 years before the inventory year), whose areas are thus transferred out of the inventory. The reporting system does not encompass all the reservoir areas in Canada.

7.6.2.2. Uncertainties and Time-Series Consistency

For forest land converted to wetlands, refer to the corresponding subheading in Section 7.8, Forest Conversion. Annex 3.4 discusses the uncertainty associated with the Tier 2 estimation methodology.

Owing to current limitations in LULUCF estimation methodologies, it is not possible to fully monitor the fate of dissolved organic carbon (DOC) and ensure that it is accounted for under the appropriate land category. The possibility of double counting in the Wetlands category is, however, limited to watersheds containing managed lands, which

would exclude several large reservoirs in reporting zones 4 and 5. Much of the DOC in these zones originate from unmanaged lands, and are not a reporting requirement.

7.6.2.3. QA/QC and Verification

Annex 6 describes the general QA/QC procedures being implemented for Canada's GHG inventory; they apply to this category as well.

Additional Tier 2 QC checks were performed on activity data, emission factors and methodology (for further explanation see Section 7.6.2.4, Recalculations).

For forest land converted to wetlands, also refer to the corresponding subheading in Section 7.8, Forest Conversion.

Canada's approach to estimating emissions from forest flooding is more realistic temporally than the default approach (IPCC 2003), which assumes that all biomass carbon on flooded forests is immediately emitted. Canada's method is more refined in that it distinguishes forest clearing and flooding; emissions from the former are estimated as in all forest clearing associated with land-use change. Further, in Canada's approach, emissions from the surface of reservoirs are derived from measurements, rather than from an assumption (immediate decay of all submerged biomass) that clearly is not verified.

7.6.2.4. Recalculations

Recalculations in the flooded lands category are due to both the indirect effects of changes in other forest conversion categories and from new activity data in the later part of the time series. Recalculations from 1990 to 2005 (averaging 138 kt CO₂ eq) are an indirect consequence of updates to forest conversion to settlement in the same regions where forest conversion to flooded lands occurs. Although activity data for flooded lands before 2006 have not changed, the changes to activity data for one disturbance type (e.g. forest conversion to settlement) alter the pool of candidate forest inventory records available for subsequent simulation of disturbances in the CBM-CFS. New flooding events associated with hydroelectric reservoir development (Chute Allard/Rapides des Coeurs and Rupert Diversion) were included in this submission. The combined impacts of new activity data and indirect modelling effects leads to an average recalculation of 230 kt CO₂ eq from 2006 to 2010.

7.6.2.5. Planned Improvements

Further refining estimates of CO₂ emissions from the surface of reservoirs partly rests upon the quantification of lateral transfers of dissolved carbon from the watershed. The monitoring of dissolved organic carbon as it travels through the landscape to the point of emission or long-term storage is beyond current scientific capabilities, and will require long-term investments in research. Efforts to ensure activity data are updated and validated will continue on an ongoing basis.

7.7. Settlements

The Settlements category is very diverse, and includes all roads and transportation infrastructure; rights-of-way for power transmission and pipeline corridors; residential, recreational, commercial and industrial lands in urban and rural settings; and land used for resource extraction other than forestry (oil and gas, mining).

In settlements remaining settlements, urban trees contribute very little to the national GHG budget. Estimates for 2011 indicate modest removals of less than 0.2 Mt CO₂ eq.

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 2011, 504 kha of lands converted to settlements accounted for emissions of a little less than 10 Mt CO₂ eq. Forest land conversion to settlements represents 98% of these emissions. The conversion of cropland to settlements is known to occur in Canada; an approach to developing activity data and an estimation methodology is under development.

7.7.1. Settlements Remaining Settlements

This category includes estimates of carbon sequestration in urban trees. No modification has been made in activity data or methods since the last submission. The current approach considers only the removal activity of urban trees on the non-built-up portion of urban areas. This component, although approximate, makes a very minor contribution to the LULUCF Sector and represents a low priority for improvement.

7.7.1.1. QA/QC and Verification

Annex 6 describes the general QA/QC procedures being implemented for Canada's GHG Inventory; they apply to this category as well.

7.7.2. Land Converted to Settlements

7.7.2.1. Source Category Description

In 2011, emissions from land conversion to settlements amounted to a little less than 10 Mt CO₂ eq. While there are potentially several land categories, including forests that have been converted to settlements, there are currently insufficient data to quantify areas or associated emissions for all types of land-use change. Significant efforts were invested in quantifying the areas of forest land converted to settlements; this is the leading forest conversion type. On average, during the 1990–2011 period, 25 kha of forest land are converted annually to settlements, predominantly in the Boreal Plains, Boreal Shield East, Atlantic Maritime and Mixedwood Plains reporting zones. Forest land conversion accounts for nearly 100% of emissions reported under this category. A consistent methodology was developed for all forest conversion, which is outlined in Section 7.8.

The remainder of this section covers non-forest land conversion to settlements in the Canadian north, primarily the Arctic and Sub-Arctic regions and reporting zones 4 and 8. In 2011, the conversion of nonforest land to settlements in the Canadian north accounted for emissions of 150 kt CO₂ eq; this value is very similar in the entire trend from 1990. The major source of emissions in this category is associated with conversion of grassland to settlement land in reporting zone 13, the Taiga Plains.

7.7.2.2. Methodological Issues (Non-forest Land Converted to Settlements)

Resource development in Canada's vast northern ecumene is the dominant driver of land-use change. An accurate estimation of this direct human impact in northern Canada requires that activities be geographically located and the preconversion vegetation known—a significant challenge, considering that the area of interest extends over 557 Mha, intersecting with eight reporting zones (2, 3, 4, 8, 10, 13, 17 and 18). For all reporting zones except 4 and 8, various

information sources and geographic data sets were used to identify areas of high land-use change potential and narrow down the geographical domain of interest. These areas were targeted for change detection analysis using 23 Worldwide Reference System Landsat frames from circa 1985, 1990 and 2000. The scenes cover more than 8.7 Mha, or 56% of the area with high potential for land-use change. Lack of available imagery prevented the implementation of the system beyond 2000.

For reporting zones 4 and 8, a change enhancement and manual delineation approach was implemented for the 1975–2000 time period for the entire area.

Emissions include only the carbon in preconversion above-ground biomass. In spite of the existing relevant literature, the estimation of actual or average biomass density over such a large area is challenging and remains fraught with uncertainty.

7.7.2.3. Uncertainties and Time-Series Consistency

For forest land converted to settlements, refer to the corresponding subheading in Section 7.8, Forest Conversion.

The uncertainty about the area of non-forest land converted to settlements in the Canadian north is estimated at 20%; the uncertainty about the preconversion standing biomass varies between 35% and 50%. Annex 3.4 provides more information.

7.7.2.4. QA/QC and Verification

Annex 6 describes the general QA/QC procedures being implemented for Canada's GHG inventory; they apply to this category as well.

For forest land converted to settlements, refer to the corresponding subheading in Section 7.8, Forest Conversion.

7.7.2.5. Planned Improvement

Future efforts to improve estimates for this category will focus on improving estimates of above-ground biomass for pre-conversion condition for land-use change events in the Arctic and Sub-Arctic region; updating estimates of activity data for land-use change in the Arctic and Sub-Arctic region for the post-2000 time period; and improving the data and estimation approach used for removals associated with urban forests.

In addition, planned improvements described under Section 7.8, Forest Conversion, will also affect this category (see Section 7.8.5, Planned Improvements).

7.8. Forest Conversion

Forest conversion is not a reporting category, since it overlaps with the subcategories of land converted to cropland, land converted to wetlands and land converted to settlements; it is nevertheless reported as a memo item. This section will briefly discuss methodological issues specific to this type of land-use change and outline the general approach taken to estimate its extent, location and impact. A consistent approach was applied for all types of forest conversion, minimizing omissions and overlaps, while maintaining spatial consistency as much as possible.

In 2011, forest conversion to cropland, wetlands and settlements amounted to total emissions of 19 Mt CO₂ eq, down from 26 Mt CO₂ eq in 1990. This decline includes a 6.5 Mt CO₂ eq decrease in immediate and residual emissions due to forest conversion to cropland and a 1.3 Mt CO₂ eq decrease in emissions from forest conversion to reservoirs. There was, however, a slight increase of 0.5 Mt CO₂ eq in immediate and residual emissions due to forest conversion to settlement lands. Note that the above values include residual emissions more than 20 years after conversion (10 years for reservoirs) that are included in the “land remaining...” categories.

Care should be taken to distinguish annual forest conversion rates (65 kha in 1990 and 50 kha in 2011) from the total area of forest land converted to other uses as reported in the CRF tables for each inventory year. The CRF figures encompass all forest land conversion for 20 years including the current inventory year (10 years for reservoirs) and hence are significantly higher than the annual rates of forest conversion to other land use.

It is also important to note that immediate emissions from forest conversion, which occur upon the conversion event, are only a fraction of the total emissions due to current and previous forest conversion activities reported in any inventory year; some of these “immediate” emissions are carbon transferred to forest products. In 2011, immediate emissions (7.2 Mt CO₂ eq) represented only 39% 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 27 kha, forest conversion to settlements accounts for the largest share of forest losses to other land categories, 53% in 2011. Conversion to cropland (19 kha), meanwhile, is the second most important cause of forest conversion, representing 37% of all forest area lost. The occasional impoundment of large reservoirs (e.g. La Forge 1 in 1993 and Eastman 1 in 2006) may also convert large forest areas to wetlands (flooded land); because much of the pre-conversion C stocks are flooded, these punctual events may not release commensurate quantities of greenhouse gases.

Geographically, the highest rates of forest conversion occur in the Boreal Plains (reporting zone 10), which accounts for 46% of the total forest area lost in 2011.

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 forest conversion on samples from remotely sensed Landsat images dated circa 1975, 1990, 2000 and 2008. For implementation purposes, all permanent forest removal wider than 20 m from tree

base to tree base and at least 1 ha in area was considered forest conversion. This convention was adopted as a guide to consistently label linear patterns in the landscape. The other main information sources consist of databases or other documentation on forest roads, power lines, oil and gas infrastructure, and hydroelectric reservoirs. Expert opinion was called upon when the remote sensing sample was insufficient, to resolve differences among records and remote sensing information, and to resolve apparent discrepancies across the 1975–1990, 1990–2000 and 2000–2008 area estimates. A more detailed description of the approach and data sources is provided in Annex 3.4.

All estimates of emissions from biomass and dead organic matter pools due to forest conversion were generated using the CBM-CFS3 (Section 7.3.1.1), except when forests were flooded without prior clearing. Emissions from the soil pool were estimated in different modelling frameworks, except for land conversion to settlements where CBM-CFS3 decay rates were used. Hence, methods are in general consistent with those used in the forest land remaining forest land subcategory. Annex 3.4 summarizes the estimation procedures.

7.8.2. Uncertainties and Time-Series Consistency

An overall uncertainty estimate of $\pm 30\%$ bounds the estimate of the total forest area converted annually in Canada (Leckie 2011), placing with 95% confidence the true value of this area for 2011 between 35 kha and 66 kha. Care should be taken not to apply the 30% 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

7.8.3. QA/QC and Verification

Annex 6 describes the general QA/QC procedures being implemented for Canada's GHG inventory; they apply to this category as well. In addition, detailed Tier 2 QA/QC procedures were carried out during estimate development procedures, involving documented QC of imagery interpretation, field validation, cross-calculations and detailed examination of results (Dyk et al. 2011). The calculations, use of records data, and expert judgement are traceable through the compilation system and documented. More information is available in Annex 3.4.

7.8.4. Recalculations

Recalculations occurred throughout the entire forest conversion estimation time period (1970–2011). These recalculations were the result of a combination of corrections to processing errors that omitted some mapped events; the use of complete area mapping for some particular post-conversion classes to avoid misrepresentation in scaling up processes; and revisions based on QC activity. Complexities in the processing and estimation development system currently do not enable a complete breakdown of each of these recalculation components.

New mapping activity added a total of 9.7 kha of forest conversion activity, which was related to two new reservoir developments occurring in the Boreal Shield East reporting zone (RZ 5).

This has resulted in an average recalculation of total area of 1.3 kha/yr for the entire 1970–2010 period. For the 1990 to 2010 period, the impact on area rates shows a different trend between the two decades: a decrease of less than 1 kha/yr in average with no notable trend before 2002, and a growing increase over the second decade that goes from 1.4 kha/yr in 2002 up to 3.5 kha/yr in 2010. Conversely, in terms of the resulting emissions, the recalculations show a similar pattern: an average decrease of 120 kt CO₂ eq per year over the 1990–2001 period and a growing increase for the rest of the years, going from 240 kt CO₂ eq in 2002 up to 670 kt CO₂ eq in 2010.

7.8.5. Planned Improvements

Planned improvements emphasize extension of the time period of mapping, QA/QC review and assessments, increased mapping coverage in areas with high uncertainty, field validation, use of additional records, and efforts to enhance the efficiency in the data compilation process.

Chapter 8

Waste (CRF Sector 6)

8.1. Overview

This Sector includes emissions from the treatment and disposal of wastes. Sources include solid waste disposal on land (landfills), wastewater treatment and waste incineration. The categories evaluated are CH₄ emissions from solid waste disposal on land, CH₄ and N₂O emissions from wastewater treatment, and CO₂, CH₄ and N₂O emissions from waste incineration.

Much of the waste treated or disposed of is biomass or biomass-based. CO₂ emissions attributable to such wastes are not included in inventory totals but are reported in the inventory as a memo item. CO₂ emissions of biogenic origin are not reported if they are reported elsewhere in the inventory or if the corresponding CO₂ 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 CO₂ by the harvested vegetation is not estimated by the Agriculture Sector and, thus, the inclusion of these emissions in the Waste Sector would result in an imbalance. Also, CO₂ emissions from wood and wood products are not included, because these emissions are accounted for in the Land Use, Land-use Change and Forestry (LULUCF) Sector at the time of tree harvesting. In contrast, CH₄ emissions from anaerobic decomposition of wastes are included in inventory totals as part of the Waste Sector.

If carbon is lost from forests at an unsustainable rate (i.e. faster than annual re-growth), the carbon budget for forest lands will be negative for net emissions.

In 2011, the greenhouse gas (GHG) emissions from the Waste Sector contributed 22 Mt to the national inventory, compared with 19 Mt for 1990—an increase of 14%. The national total emissions increased by 19% over the same time interval. The emissions from this sector represented 3.2% and 3.1% of the overall Canadian GHG emissions in 1990 and 2011, 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 92% of the emissions from this sector in 2011. The chief contributor to the Waste Sector emissions is the CH₄ released from MSW landfills, which for 2011 amounted to 18 Mt (0.84 Mt CH₄). This net emission value is determined by subtracting the amount of CH₄ captured from the total estimated CH₄ generated within the landfill by the Scholl Canyon model, then adding the quantity of the captured CH₄ that was not combusted by the flaring operation, where applicable. From our biennial survey of Canadian landfills, which collected 2008 and 2009 year data, approximately 29% of the CH₄ generated in Canadian MSW landfills in 2009 was captured and combusted (either for energy recovery, or flared). The landfill gas survey was delayed this year; therefore, the landfill gas collection and utilization data for 2010 and 2011 were assumed constant from 2009.

Overall, the increase in the CH₄ generation rate from MSW landfills is primarily dependent on population growth and on average household disposable income, which has been steadily increasing since the 1980s. Other factors, such as types and patterns of consumption (which influence volume of packaging materials) and rates of urbanization also play a part. This upward influence is mitigated by

Table 8–1 Waste Sector GHG Emission Summary, Selected Years

GHG Source Category	GHG Emissions (kt CO ₂ eq)							
	1990	2000	2005	2007	2008	2009	2010	2011
Waste Sector	19 000	20 000	21 000	21 000	21 000	21 000	22 000	22 000
Solid Waste Disposal on Land	17 000	18 000	20 000	20 000	20 000	20 000	20 000	20 000
Wastewater Handling	800	900	900	1 000	1 000	1 000	1 000	1 000
Waste Incineration	740	750	700	660	710	680	690	690

Note: Totals may not add up due to rounding.

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 2008, over 33 Mt of nonhazardous waste (residential, institutional, commercial, industrial, construction and demolition) were generated. Waste diversion initiatives began in the early 1990s and, based upon the national figures for 2008, approximately 25% of the waste generated is diverted from disposal (landfill or incineration) (Statistics Canada 2010b).

Table 8–1 summarizes the Waste Sector and subsector GHG contributions for the following inventory years: 1990, 2000, 2005, 2007, 2008, 2009, 2010 and 2011.

8.2. Solid Waste Disposal on Land (CRF Category 6.A)

8.2.1. Source Category Description

Emissions are estimated from two types of landfills in Canada:

- MSW landfills; and
- wood waste landfills.

In Canada, most waste disposal on land occurs in managed municipal or privately owned landfills. Very few, if any, unmanaged waste disposal sites exist. Therefore, it has been assumed that all waste is disposed of in managed facilities. Residential, institutional, commercial and industrial wastes are disposed of in MSW landfills. Over the past 15 years, dedicated construction and demolition (C & D) landfills were established. Typically, these landfills do not require CH₄ collection systems, as the CH₄ generation rate is very low due to the minimal organic content in the waste stream. However, for completeness of this emission source and accuracy of emissions from MSW landfills, the waste quantities now include C & D wastes.

Wood waste landfills are mostly privately owned and operated by forest industries, such as saw mills and pulp and paper mills. These industries use the landfills to dispose of surplus wood residue, such as sawdust, wood shavings,

bark and sludges. Some industries have shown increasing interest in waste-to-energy projects that produce steam and/or electricity by combusting these wastes. In recent years, residual wood previously regarded as a waste is now being processed as a value-added product—e.g., wood pellets for residential and commercial pellet stoves and furnaces, and hardboard, fibreboard and particle board. Wood waste landfills have been identified as a source of CH₄ emissions; however, there is a great deal of uncertainty in the estimates. These landfills are a minor source of CH₄ 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 CH₄ emissions from landfills, has been validated independently through a study conducted by the University of Manitoba (Thompson et al. 2006).

Landfill gas, which is composed mainly of CH₄ and CO₂, is produced by the anaerobic decomposition of organic wastes. The first phase of this process typically begins after waste has been in a landfill for 10 to 50 days. Although the majority of the CH₄ and CO₂ gases are generated within 20 years of landfilling, emissions can continue for 100 years or more (Levelton 1991).

A number of important site-specific factors contribute to the generation of gases within a landfill, including the following:

Waste composition: Waste composition is probably the most important factor affecting landfill gas generation rates and quantities. The amount of landfill gas produced is dependent on the amount of organic matter landfilled.

The rate at which gas is generated is dependent on the distribution and type of organic matter in the landfill.

Moisture content: Water is required for anaerobic degradation of organic matter; therefore, moisture content within a landfill significantly affects gas generation rates.

Temperature: Anaerobic digestion is an exothermic process. The growth rates of bacteria tend to increase with temperature until an optimum is reached. Therefore, landfill temperatures may be higher than ambient air temperatures. The extent to which ambient air temperatures influence the temperature of the landfill and gas generation rates depends mainly on the depth of the landfill. Temperature variations can affect microbial activity, subsequently affecting their ability to decompose matter (Maurice and Lagerkvist 2003).

pH and buffer capacity: The generation of CH₄ in landfills is greatest when neutral pH conditions exist. The activity of methanogenic bacteria is inhibited in acidic environments.

Availability of nutrients: Certain nutrients are required for anaerobic digestion. These include carbon, hydrogen, nitrogen and phosphorus. In general, MSW contains the necessary nutrients to support the required bacterial populations.

Waste density and particle size: The particle size and density of the waste also 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

CH₄ produced from the decomposition of waste in landfills is calculated using the Scholl Canyon model, which is a first-order decay model. This reflects the fact that waste degrades in landfills over many years. Data pertaining to landfill gas capture were obtained directly from the owners/operators of specific landfills with landfill gas collection systems.

CH₄ emissions are determined by calculating the amount of CH₄ generated from landfill waste decomposition through the Scholl Canyon model, subtracting the CH₄ captured through landfill gas recovery systems, then add-

ing the quantity of uncombusted CH₄ emitted by the flares for those locations where a portion or all of the recovered landfill gas is burned without energy recovery. The GHG emissions associated with the combustion of that portion of the landfill gas that is captured and utilized for energy generation purposes are accounted for in the Energy Sector. A more detailed discussion of the methodologies is presented in Annex 3.5.

8.2.2.1. CH₄ Generation

The Scholl Canyon model was used to estimate the quantity of CH₄ generated. The model is based upon the following first-order decay equation (IPCC/OECD/IEA 1997):

Equation 8-1:

$$Q_{T,x} = kM_xL_0e^{-k(T-x)}$$

where:

$Q_{T,x}$	=	amount of CH ₄ generated in the current year (T) by the waste M _x , kt CH ₄ /year
x	=	the year of waste input
M _x	=	the amount of waste disposed of in year x, Mt
k	=	CH ₄ generation rate constant, year ⁻¹
L ₀	=	CH ₄ generation potential, kg CH ₄ /t waste
T	=	current year

Equation 8-2:

$$Q_T = \sum Q_{T,x}$$

where:

Q_T	=	amount of CH ₄ generated in the current year (T), kt CH ₄ /year
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In order to estimate CH₄ emissions from landfills, information on several of the factors described above is needed. To calculate the net emissions for each year, the sum of $Q_{T,x}$ for every section of waste landfilled in past years was obtained (Equation 8-2), from which the captured gas was subtracted for each province. A computerized model has been developed to estimate aggregate emissions on a regional basis (by province and territory) in Canada. The national CH₄ emission value is the summation of emissions from all regions.

Waste Disposed of Each Year or the Mass of Refuse (M_x)

MSW Landfills

For the purposes of the inventory, MSW includes residential; institutional, commercial and industrial; and construction and demolition wastes. Two primary sources were used in obtaining waste generation and landfill data for the GHG inventory. The amounts of MSW landfilled in the years 1941 through to 1990 were estimated by B.H. Levelton (1991). For the years 1998, 2000, 2002, 2004, 2006 and 2008, MSW disposal data were obtained from the *Waste Management Industry Survey* that is conducted by Statistics Canada on a biennial basis (Canada 2000, 2003, 2004, 2007a, 2008a, 2010b). For the intervening odd years (1999, 2001, 2003, 2005, 2007), 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 from 2009 to 2011 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 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, 2010b) MSW landfill values. MSW landfill values for Prince Edward Island, the Northwest Territories, Nunavut and Yukon for the period 1991–2011 are obtained by trending historical landfill data with the provincial populations for 1971–2011 (Statistics Canada 2006, 2012). Waste quantities imported into Canada are accounted for within the Statistics Canada *Waste Management Industry Survey* since the facilities report all wastes being disposed of in their facility, whether of domestic or international origin.

Wood Waste Landfills

British Columbia, Quebec, Alberta and Ontario together landfill 93% of the wood waste in Canada (NRCan 1997). The amount of wood waste landfilled in the years 1970 through to 1992 has been estimated at a national level based on the National Wood Residue Data Base (NRCan 1997). Data for the years 1998 and 2004 were provided by subsequent publications (NRCan 1999, 2005). A linear regression trend analysis was conducted to interpolate the

amount of wood residue landfilled in the years 1991–1997 and 1999–2011.

CH₄ Generation Rate Constant (k)

The CH₄ kinetic rate constant (k) represents the first-order rate at which CH₄ is generated after waste has been landfilled. The value of k is affected by four major factors: moisture content, temperature, availability of nutrients and pH. It is assumed that, in a typical MSW landfill, the nutrient and pH conditions are attained and that, therefore, these factors are not limiting. In many parts of Canada, subzero conditions exist for up to seven months of the year, with temperatures dropping below –30°C (Thompson et al. 2006); however, evidence suggests that ambient temperature does not affect landfill decay rates (Maurice and Lagerkvist 2003; Thompson and Tanapat 2005). In addition, seasonal temperature variations in the waste are minimal when compared with atmospheric temperature variations (Maurice and Lagerkvist 2003). At depths exceeding 2 m, the landfill temperature is independent of the ambient temperature. It has been shown in Canadian field experiments that an insignificant amount of variation in landfill CH₄ production occurs between the winter and summer seasons (Bingemer and Crutzen 1987; Thompson and Tanapat 2005). Therefore, of all these factors, moisture content is the most influential parameter for Canadian landfills and is largely determined by the annual precipitation received at the landfills.

MSW Landfills

The k values used to estimate emissions from MSW landfills were obtained from a study conducted by Environment Canada's Greenhouse Gas Division that employed provincial precipitation data from 1941 to 2007 (Environment Canada 1941–2007). The provincial locations at which the average annual precipitations were calculated were those indicated in the Levelton study where major landfills were located over the 1941–1990 period (Levelton 1991). Since the k values are related to precipitation, and assuming that the moisture content of a landfill is a direct function of the annual precipitation, from these precipitation values, the associated k values were determined using a relationship prepared by the Research Triangle Institute (RTI) for the U.S. EPA (RTI 2004). The RTI assigns default decay values of less than 0.02/year, 0.038/year and 0.057/year to areas with an annual precipitation of less than 20 inches/year (< 500 mm), between 20 and 40 inches/year (500 to 1000 [average 750 mm]) and greater than 40 inches/

Table 8–2 MSW Landfill k Value Estimates for Each Province/Territory

Time Series	Provinces and Territories											
	N.L.	P.E.I.	N.S.	N.B.	Que.	Ont.	Man.	Sask.	Alta.	B.C.	N.W.T & Nvt	Yk.
1941–1975	0.075	0.056	0.076	0.06	0.053	0.041	0.020	0.01	0.012	0.082	0.001	0.001
1976–1989	0.080	0.062	0.079	0.063	0.057	0.047	0.017	0.009	0.012	0.082	0.002	0.001
1990–2011	0.078	0.061	0.075	0.059	0.059	0.046	0.019	0.012	0.012	0.083	0.003	0.002

year (> 1000 mm), respectively. The plot of these decay values and precipitation data showed a linear relationship. Using this relationship and Environment Canada's average provincial precipitation data for 1941–2007, average provincial landfill decay rates were calculated for three time periods that match those used to derive the methane generation potentials (L_0), i.e., 1941–1975, 1976–1989 and 1990–2007 (Environment Canada 1941–2007). It is assumed that the provincial k values determined for 1990–2007 are also applicable from 2008 to 2011.

These values are provided in Table 8–2.

Wood Waste Landfills

Based upon the default value for estimating wood products industry landfill CH_4 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_4 generation rate constant k for all of the wood waste landfills in Canada (NCASI 2003).

CH_4 Generation Potential (L_0)

MSW Landfills

The values of theoretical and measured L_0 range from 4.4 to 194 kg CH_4 /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 2011, three different L_0 s were used to represent discrete time periods where studies showed significant changes in waste composition from one period to the next. L_0 is a function of degradable organic carbon (DOC), which is in turn determined from the composition of the waste, as described below. For consistency with the quantities of MSW used in the Scholl Canyon model, the calculation of the L_0 accounted for the characteristics of the three MSW sources: residential; institutional, commercial and industrial; and construction and demolition wastes.

The provincial and territorial DOC values were calculated from waste disposal composition values for three distinct time periods: 1941–1975, 1976–1989 and 1990–2011.

These time intervals coincide with those employed for the calculation of the CH_4 generation rate constant k . Using waste composition data obtained from a Natural Resources Canada (NRCAN) study, which was based on the 2002 data year (NRCAN 2006), DOC values were derived and assumed to be constant over the period 1990–2011. Since waste diversion programs were not significant prior to 1990, a second set of DOC values was developed to represent the waste composition at disposal from 1976 to 1989 by adding the NRCAN landfill to the 2004 Statistics Canada recycled waste composition data (Statistics Canada 2007a). A third set of DOC values was developed from a 1967 national study to cover the period from 1941 to 1975 (CRC Press 1973). A summary of the L_0 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_0 values will be adjusted accordingly.

L_0 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:

Table 8–3 CH₄ Generation Potential (L₀) from 1941 to Present

Province/Territory	2002 Organic Waste Diversion (%)	1941 to 1975		1976 to 1989		1990 to Present	
		DOC	L ₀ (kg CH ₄ /t waste)	DOC	L ₀ (kg CH ₄ /t waste)	DOC	L ₀ (kg CH ₄ /t waste)
Newfoundland	N/A	0.30	121.01	0.18	71.60	0.18	71.50
Prince Edward Island	N/A	0.28	111.20	0.16	63.82	0.15	60.34
Nova Scotia	29.7	0.26	105.92	0.15	60.24	0.15	60.56
New Brunswick	19.8	0.24	97.53	0.16	63.23	0.15	59.98
Quebec	13.7	0.38	153.06	0.20	79.71	0.19	77.43
Ontario	16.4	0.37	147.61	0.20	79.19	0.20	78.34
Manitoba	4.9	0.34	137.60	0.19	74.28	0.18	73.41
Saskatchewan	4.3	0.37	149.93	0.21	82.63	0.21	82.33
Alberta	16.7	0.28	111.53	0.17	69.25	0.17	67.95
British Columbia	23.3	0.27	109.62	0.17	66.34	0.15	59.58
Territories (Yk., N.W.T. and Nvt.)	N/A	0.23	91.70	0.14	56.68	0.16	62.36

Sources: All values are derived from data obtained from NRCAN (2006), Statistics Canada (2007a) and CRC Press (1973), with the exception of the 2002 Organic Waste Diversion figures, which were obtained from Thompson et al. (2006).

N/A = Unavailable categorical information.

Equation 8–3:

$$L_o = MCF \times DOC \times DOC_F \times F \times \frac{16}{12} \times \frac{1000 \text{ kg CH}_4}{t \text{ CH}_4}$$

where:

L ₀	=	CH ₄ generation potential (kg CH ₄ /t waste)
MCF	=	CH ₄ methane correction factor (fraction)
DOC	=	degradable organic carbon (t C/t waste)
DOC _F	=	fraction DOC dissimilated
F	=	fraction of CH ₄ in landfill gas
16/12	=	stoichiometric factor

According to the 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 CH₄ 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_F value of 0.6 was selected from a default range of 0.5 to 0.6. This DOC_F value best reflects the lower concentration of lignin in the MSW waste, since the majority of wood wastes from pulp and paper industries and saw mills are disposed of in dedicated wood waste landfills.

The DOC calculation is derived from the biodegradable portion of the MSW (Equation 8–4):

Equation 8–4:

$$DOC = (0.4 \times A) + (0.17 \times B) + (0.15 \times C) + (0.3 \times D)$$

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 L₀ value of 80 kg CH₄/t of wood waste, which was used to estimate emissions from wood waste landfills by the Scholl Canyon model. IPCC defaults were used for MCF in unmanaged deep landfills (MCF = 0.8); the fraction of CH₄ in the landfill gas (F = 0.5); and the fraction of DOC dissimilated (DOC_F = 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 CH₄ 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 CH₄ to CO₂, thus reducing the CH₄ emissions. To calculate the net CH₄ emissions from landfills, the amount of CH₄ captured, as provided by the landfill facilities, is subtracted from the quantity of CH₄ 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 CH₄ 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 CH₄ in landfill gas of 99.7% was used to determine the quantity of CH₄ that circumvented the flare. This value was obtained from Table 2.4-3 of Chapter 2.4 of 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.¹ Data for the 1997 to 2003 period were collected directly from individual landfill operators biennially by Environment Canada's National Office of Pollution Prevention (Environment Canada 1997, 1999b, 2001, 2003a). As of 2006, beginning with the 2005 data year, this survey is now being conducted by Environment Canada's Pollutant Inventories and Reporting Division (Environment Canada 2007, 2009, 2011a). Landfill gas capture data are collected every odd year; therefore, for the purposes of the national GHG inventory, the landfill gas capture data for the subsequent even years are averaged from adjacent odd years starting from 1997. However, since the 2008 survey, the Division has been collecting two years' data biennially, i.e., 2006–2007 data and 2008–2009 data from the 2008 and 2010 facility surveys, respectively (Environment Canada 2009, 2011a). The 2009 captured landfill gas data were assumed constant for 2010 and 2011.

8.2.3. Uncertainties and Time-Series Consistency

The following discussion on uncertainty for the categories within this sector is based upon the results as reported in an uncertainty quantification study of the NIR by ICF

Consulting (2004). This Tier 2 evaluation of uncertainty employed values from the 2001 inventory year (Environment Canada 2003b). However, there have been modifications made to the methodology, emission factors and sources of information as a consequence of the findings of this uncertainty study. Therefore, the results of this study may not be an accurate representation of the current uncertainty around the emissions from this subsector and the model inputs. However, in the absence of a follow-up Tier 2 study, it is expected that the improvements made would result in a reduction of the uncertainty for this subsector.

The CH₄ emissions from this key category include CH₄ emissions from MSW landfills and wood waste landfills. The level of uncertainty associated with the CH₄ emissions from the combined subsectors was estimated to be in the range of –35% to +40%, which closely resembles the uncertainty range of –40% to +35% estimated in this study for the CH₄ emissions from MSW landfills. The level uncertainty range provided by the ICF Consulting study (2004) is only slightly larger than the ± 30% span estimated with a 90% confidence level by a previous study, which used a Tier 1 approach based upon 1990 data (McCann 1994). However, it should be noted that the 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 CH₄ emissions from this key category in 2001 (Environment Canada 2003b). The uncertainty estimates for CH₄ emissions from MSW landfills seem to have been largely influenced by the uncertainty in the inventory values for L₀ for 1941–1989 and 1990–2001 and the CH₄ generation rate constant k, where the uncertainty for both k and L₀ were based upon an estimate from one expert elicitation. A simplified model of the Scholl Canyon method was used for the Monte Carlo simulation, which may have had a bearing on relevancy of the uncertainty values. An error was introduced in the calculation of the MSW landfill CH₄ emission uncertainty by the use of the year 2000 value (instead of the 2001 value) for the total CH₄ captured in Canada, resulting in an uncertainty range of +20% to +24% for these activity data. The actual uncertainty for this activity data entry should have been ±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

¹ Personal communication with ME Perkin of Environment Canada's National Office of Pollution Prevention in 1998.

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 CH₄ generation rate, carbon content of the waste landfilled, and the biodegradable fraction of the waste, where the uncertainties were assumed by ICF Consulting (2004) based upon the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997) and/or the *IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000), where available.

The estimates are calculated in a consistent manner over time.

8.2.4. QA/QC and Verification

A linkage error in the Waste Sector model was identified; however, it was only identified after the emission values were confirmed for the present submission. The error only affects emissions from the provinces of Quebec and British Columbia and results in an overestimation of roughly 1.7% of the national emissions from Solid Waste Disposal on Land. This error will be corrected in the 2014 submission.

8.2.5. Recalculations

Managed Waste Disposal on Land: Recalculations were made over the entire 1990–2010 time series for emissions from MSW landfills to account for new provincial waste export data over the 1998–2010 time series. Slight recalculations were conducted for Prince Edward Island and the three territories from 2007 to 2010 to account for population revisions by Statistics Canada. Overall, these recalculations resulted in a slight reduction over the 1990–1997 time series of about 1% and a reduction ranging from 2% to 6% over the 1998–2010 time series for the 2012 submission.

8.2.6. Planned Improvements

A study is being considered to provide a current review of recent MSW waste composition values for all provinces and territories for urban and rural areas to update L₀.

Statistics Canada data from the 2012 *Waste Management Industry Survey* were not available in time for inclusion in the present submission; therefore, the updated 2010

disposed waste quantities are expected to be incorporated in the 2014 submission.

8.3. Wastewater Handling (CRF Category 6.B)

8.3.1. Source Category Description

Emissions from municipal and industrial wastewater treatment were estimated. Both municipal and industrial wastewater can be aerobically or anaerobically treated. When wastewater is treated anaerobically, CH₄ is produced; however, it is typical that systems with anaerobic digestion in Canada contain and combust the produced CH₄. CH₄ emissions from aerobic systems are assumed to be negligible. Both types of treatment system generate N₂O through the nitrification and denitrification of sewage nitrogen (IPCC/OECD/IEA 1997).

CO₂ is also a product of aerobic and anaerobic wastewater treatment. However, as detailed in Section 8.1, CO₂ emissions originating from the decomposition of organic matter are not included with the national total estimates, in accordance with 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: CH₄ from anaerobic wastewater treatment and N₂O from human sewage.

8.3.2. Methodological Issues

A more detailed discussion of the methodologies is presented in Annex 3.5.

8.3.2.1. CH₄ Emissions

Municipal Wastewater Treatment

The IPCC default method was not used because the required data were not available. A method developed for Environment Canada (AECOM Canada 2010) was used to calculate an emission factor. This country-specific methodology provides for the accurate estimation of provincial methane emissions that best suits the available related activity data. Based on the amount of organic matter generated per person in Canada and the conversion of organic

matter to CH₄, it was estimated that 1.97 kg CH₄/person per year could potentially be emitted from anaerobically treated wastewater. Additional information on the incorporated methodology is provided in Annex 3.5.

CH₄ emissions were calculated by multiplying the emission factor by the population of the respective province (Statistics Canada 2006, 2012) and by the fraction of wastewater that is treated anaerobically.

Industrial Wastewater Treatment

A survey was conducted by the Greenhouse Gas Division to obtain methane emissions from facilities that treated their effluent anaerobically on-site over the 1990–2009 time series. Where actual measured facility data were not provided, design specifications particular to that site were used to estimate maximum emissions expected. In the absence of current data, the values for 2010 and 2011 are assumed constant from 2009. A complete description of the methodology is provided in Annex 3.5.

8.3.2.2. N₂O Emissions

Municipal Wastewater Treatment

The N₂O emissions from municipal wastewater treatment facilities were calculated using the IPCC default method (IPCC/OECD/IEA 1997). This method estimates the N₂O emission factor as the product of the annual per capita protein consumption, the assumed protein nitrogen content (16%), the quantity of N₂O-N produced per unit of sewage nitrogen (0.01 kg N₂O-N/kg sewage nitrogen) and the N₂O/N₂O-N conversion factor (1.57). Protein consumption estimates, in kg/person per year, were obtained from an annual Food Statistics report published by Statistics Canada (2007b, 2008b, 2010a). Data are provided for the years 1991, 1996 and 2001 to 2009. Protein consumption data for missing years are estimated by applying a multiple linear regression application to the Statistics Canada data. Protein consumption values for 2010 and 2011 were assumed constant from 2009 in the absence of current data due to the discontinuation by Statistics Canada of the Food Statistics publication. Emissions were calculated by multiplying the emission factor by the population of the respective provinces (Statistics Canada 2006, 2012). A summary of the values for these two parameters over the time series is given in Table 8–4.

Industrial Wastewater Treatment

The *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997) do not address the methodology for the estimation of N₂O emissions from industrial wastewater treatment. Owing to a lack of activity data, the N₂O emissions from this category have not been evaluated.

8.3.3. Uncertainties and Time-Series Consistency

Municipal Wastewater Treatment

The following discussion on uncertainty for the categories within this sector is based upon the results as reported in an uncertainty quantification study of the NIR (ICF Consulting 2004). This Tier 2 evaluation of uncertainty employed values from the 2001 inventory year (Environment Canada 2003b). However, there have been modifications made to

Table 8–4 N₂O Emission Factors

Year	Annual Per Capita Protein Consumption (kg protein/person per year)	N ₂ O Emission Factor (kg N ₂ 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 ^a	25.01	0.063
1996 ^a	25.04	0.063
1997 ^a	25.50	0.064
1998 ^a	25.75	0.065
1999 ^a	26.01	0.065
2000 ^a	26.26	0.066
2001 ^b	26.63	0.067
2002 ^b	26.57	0.067
2003 ^b	26.19	0.066
2004 ^b	26.35	0.066
2005 ^c	25.96	0.065
2006 ^c	25.93	0.065
2007 ^c	26.20	0.066
2008 ^c	25.64	0.064
2009 ^c	25.50	0.064
2010 ^c	25.50	0.064
2011 ^c	25.50	0.064

Sources: ^aStatistics Canada (2007b), ^bStatistics Canada (2008b) and ^cStatistics Canada (2010a). The data have been adjusted to account for retail, household, cooking and plate loss.

the methodology, emission factors and sources of information as a consequence of the findings of this uncertainty study. Therefore, the results of this study may not be an accurate representation of the current uncertainty around the emissions from this subsector and the model inputs. However, in the absence of a follow-up Tier 2 study, it is expected that the improvements made would result in a reduction of the uncertainty for this subsector.

The overall level uncertainty associated with the wastewater treatment subsector was estimated to be in the range of –40% to +55%. The level uncertainty range provided by the ICF Consulting (2004) study is less than the $\pm 60\%$ span estimated with a 90% confidence level by a previous study, which used a Tier 1 approach based on 1990 data (McCann 1994). This is an improvement to the uncertainty as assessed for this category, since the uncertainty range quoted by ICF Consulting (2004) for a 95% confidence interval should typically show a larger value than that quoted for a 90% confidence interval. Based on 2001 data, the trend uncertainty associated with the total GHG emissions (comprising CH₄ and N₂O) from the wastewater treatment systems was estimated to be in the range of about +12% to +13%. The extrapolation of trend uncertainty in 2001 to the 2011 inventory should be made with caution, as trend uncertainty is more sensitive than level uncertainty to the changes in the inventory estimate values for the more recent years.

Since the methods and data sources have remained unchanged over the time series, the estimates for this category are consistent over time.

Industrial Wastewater Treatment

The IPCC *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000) provide for default uncertainties ranging from –25% to +25%. Since these data were for the most part obtained directly from the facility operators, based upon expert opinion, the uncertainty is estimated to be in the range of –15% to +15% or less.

8.3.4. QA/QC and Verification

No significant anomalies were identified.

8.3.5. Recalculations

After a review of the 2011 Submission, the ERT identified errors in the emission estimates for Wastewater Handling –

Human Sewage (6.B.2) and recommended an adjustment in the Waste Sector for 2008 and 2009. In accordance with the guidance for adjustments under Article 5, paragraph 2, of the Kyoto Protocol (decision 20/CMP.1), the adjustments to the Waste Sector were prepared by the expert review team (ERT) in consultation with Canada. Also, in accordance with the guidelines for review under Article 8 of the Kyoto Protocol (decision 22/CMP.1), the ERT officially notified Canada of the calculated adjustment.

The ERT determined that the inclusion of food wastage at the retail, household, cooking and place level resulted in an underestimation of the emissions from this source category. The 2012 submission evaluated the emissions based on protein consumption that excluded food wastage at these retail and consumer levels, which resulted in recalculations across the complete 1990–2009 time series to exclude plate losses from the protein consumption parameter in the calculation of N₂O emissions from human sewage.

In the interim period following the adjustment, Environment Canada commissioned a study to investigate the validity of the inclusion of wastage at these levels (AECOM 2012). As a result of this study, conducted by AECOM Canada Inc., Canada determined that inclusion of food wastage at the retail and consumer level was justifiable, and therefore emissions from this source category were recalculated for the 1990–2010 time series to include retail, household, cooking and plate protein losses. Recalculations were also necessary to correct an error in the fraction of the provincial population that treated municipal wastewater by anaerobic means. These recalculations affected the category CH₄ Emissions from Municipal Wastewater Treatment.

The combined recalculations resulted in a reduction of emissions from this subsector ranging from 19% to 25% over the 1990–2000 time series and approximately 26% from 2001 to 2010.

8.3.6. Planned Improvements

The biennial industrial wastewater treatment facility survey was to be completed for this present submission; however, this will now be completed for inclusion in the 2014 submission.

8.4. Waste Incineration (CRF Category 6.C)

8.4.1. Source Category Description

Emissions from MSW, hazardous wastes and sewage sludge incineration are included in the inventory. Some municipalities in Canada utilize incinerators to reduce the quantity of MSW sent to landfills and to reduce the amount of sewage sludge requiring land application.

GHG emissions from incinerators vary, depending on factors such as the amount of waste incinerated, the composition of the waste, the carbon content of the non-biomass waste and the facilities' operating conditions.

8.4.1.1. MSW Incineration

A combustion chamber of a typical mass-burn MSW incinerator is composed of a grate system on which waste is burned and is either water-walled (if the energy is recovered) or refractory-lined (if it is not). GHGs that are emitted from MSW incinerators include CO₂, CH₄ and N₂O.

As per the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997), CO₂ emissions from biomass waste combustion are not included in the inventory totals. The only CO₂ emissions detailed in this section are from fossil fuel-based carbon waste, such as plastics and rubber.

CH₄ emissions from Canadian MSW incinerators are negligible, based on the findings from a recent report commissioned by Environment Canada (CRA 2011).

8.4.1.2. Hazardous Waste Incineration

There are five hazardous waste incinerators in Canada located in Quebec, Ontario and Alberta. CO₂, N₂O and CH₄ are the greenhouse gases emitted from this source. The emissions are derived from the quantities of hazardous wastes incinerated that were provided directly by the facilities in a series of surveys summarized in a report (Environment Canada 2011b). A preliminary survey was conducted in 2006, which was followed by surveys in 2008 and 2010 to improve completeness of the coverage and data accuracy.

8.4.1.3. Sewage Sludge Incineration

Two different types of sewage sludge incinerators are used in Canada: multiple hearth and fluidized bed. In both types of incinerators, the sewage sludge is partially de-watered prior to incineration. The de-watering is typically done in a centrifuge or using a filter press. Currently, municipalities in Ontario and Quebec operate sewage sludge incinerators. GHGs emitted from the incineration of sewage sludge include CO₂, CH₄, and N₂O, as in the case of MSW incinerators; however, since the carbon present in the wastewater sewage sludge is of biological origin, the CO₂ emissions are not accounted 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. CO₂ Emissions

MSW Incineration

The *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997) do not specify a method to calculate CO₂ emissions from the incineration of fossil fuel-based waste (such as plastics and rubber). Therefore, the following three-step method was developed for MSW incineration:

- *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 CO₂ emission factors are founded on the assumption that the carbon contained in waste undergoes complete oxidation to CO₂. The amount of fossil fuel-based carbon available in the waste incinerated has been determined using typical percent weight carbon content values (Tchobanoglous et al. 1993). The amount of carbon per tonne of waste is estimated and converted to tonnes of CO₂ per tonne of waste by multiplying by the ratio of the molecular mass of CO₂ to that of carbon.

Calculating CO₂ emissions: Emissions were calculated on a provincial level by multiplying the amount of waste incinerated by the appropriate emission factor.

Hazardous Waste Incineration

CO₂ emissions were estimated from the quantities of hazardous wastes combusted over the 1990–2011 time series, where the emissions for 2010 and 2011 were assumed to be constant from 2009 since they were not included within the last survey. The emission estimation method used the IPCC default carbon content and fossil carbon percent of total carbon of 50% and 90%, respectively, for hazardous waste as presented in Table 5.6 of the IPCC Good Practice Guidance (IPCC 2000).

Sewage Sludge Incineration

CO₂ generated from the incineration of sewage sludge is not reported in the inventory emission totals, since the sludge consists solely of biogenic matter.

8.4.2.2. N₂O and CH₄ Emissions

MSW Incineration

Emissions of N₂O from MSW incineration were estimated using the IPCC default method (IPCC/OECD/IEA 1997). An average emission factor was calculated assuming that the IPCC five-stoker facility factors were most representative. To estimate emissions, the calculated emission factor was multiplied by the amount of waste incinerated by each province. CH₄ emissions from Canadian MSW incinerators are negligible, based on the findings from a recent report commissioned by Environment Canada (CRA 2011).

Hazardous Waste Incineration

N₂O and CH₄ emissions were estimated from emission factors derived from site-specific data provided by a facility rather than from IPCC defaults because of the relatively small emission contribution of these two gases, the availability of country-specific data, and the number of sites involved in this process. Site-specific data consisted of the quantities of hazardous waste processed at the facility and the cumulative measured N₂O and CH₄ emissions for 2009 (Environment Canada 2011b). The resulting emission factors were 3.16×10^{-3} kt N₂O/kt waste and 1.69×10^{-4} kt CH₄/kt of waste.

Sewage Sludge Incineration

Emissions generated from the incineration of sewage sludge are dependent on the amount of dried solids incinerated. To calculate the CH₄ emissions, the amount of dried solids incinerated is multiplied by an appropriate emission factor. Estimates of the amount of dried solids

in the sewage sludge incinerated in the years 1990–1992 are based on a study completed in 1994, 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 2002–2011, a regression analysis was completed using the Chandler and Compass Environmental Inc. incineration values.

CH₄ emissions are estimated based on emission factors obtained from the U.S. EPA publication *Compilation of Air Pollutant Emission Factors* (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 CH₄/kt of total dried solids for fluidized bed sewage incinerators equipped with venture scrubbers. To estimate emissions, the emission factor was multiplied by the amount of waste incinerated by each province. The national emissions were then determined as the summation of these emissions for all provinces.

Emissions of N₂O from sewage sludge incineration were estimated using the IPCC default emission factor for fluidized beds, 0.8 kg N₂O/t of dried sewage sludge incinerated (IPCC 2000). To estimate emissions, the emission factor was multiplied by the amount of waste incinerated by each province. The national emissions were then determined as the summation of these emissions for all provinces.

8.4.3. Uncertainties and Time-Series Consistency

The following discussion on uncertainty for the categories within this subsector is based upon the results as reported in an uncertainty quantification study of the Canadian NIR (ICF Consulting 2004). This Tier 2 evaluation of uncertainty employed values from the 2001 inventory year (Environment Canada 2003b). However, there have been modifications made to the methodology, emission factors and sources of information as a consequence of the findings of this uncertainty study. Therefore, the results of this study

may not be an accurate representation of the current uncertainty around the emissions from this subsector and the model inputs. However, in the absence of a follow-up Tier 2 study, it is expected that the improvements made would result in a reduction of the uncertainty for this subsector.

The overall level uncertainty associated with the waste incineration source category was estimated to be in the range of -12% to +65%. For 2001 inventory estimates, the overall trend uncertainty associated with the total GHG emissions (comprising CO₂, CH₄ and N₂O) from incineration of wastes (comprising MSW and sewage sludge) was estimated to be in the range of about +10% to +11%. The inventory trend uncertainty was estimated at +10%. The extrapolation of trend uncertainty in 2001 to the 2011 inventory should be made with caution, as the trend uncertainty is more sensitive than level uncertainty to the changes in the inventory estimate values for the more recent years.

8.4.4. QA/QC and Verification

No significant anomalies were identified.

8.4.5. Recalculations

From 2007 to 2010, minor recalculations were conducted for MSW incineration to account for revised Statistics Canada population data.

8.4.6. Planned Improvements

Facility-level incineration surveys had been conducted in 2008 and in 2010. The data from these preliminary surveys were to be reviewed for completeness and accuracy with the results from the 2012 biennial incineration survey, before they were considered for incorporation into the Waste Sector model, and into the Energy Sector methodologies (where energy recovery systems are in place), and for reporting in the 2013 submission. However, due to delays in the survey, these data were not available to update the values and allow for transfer of Energy Sector-related emissions to that sector as recommended by the ERT in past reviews. The consideration for inclusion of these data is now planned for the 2014 submission.

Chapter 9

Recalculations and Improvements

This chapter summarizes the recalculations implemented in Canada's national greenhouse gas (GHG) inventory since its 2012 submission in order to facilitate an integrated view of changes in, and impacts on, emission levels and trends. Improvements to the 2013 submission due to methodological changes or refinements are presented in Section 9.1, while a description of planned improvements for future inventories can be found in Section 9.2.

Although the quantification of uncertainty for the emission estimates (Annex 7) helps prioritize improvements of future inventories, uncertainty is not an indicator of potential future changes resulting from continual improvement activities.

9.1. Explanations and Justifications for Recalculations

The United Nations Framework Convention on Climate Change (UNFCCC) requires all Annex I Parties to continually improve their national greenhouse gas inventories. As new information and data become available and more accurate methods are developed, previous estimates are updated to provide a consistent and comparable trend in emissions and removals. As such, recalculations are expected to occur annually, reflecting the principle of continuous improvement. The nature, rationale and impact of these recalculations are documented in this national inventory report and associated data tables. Recalculations can result for any number of reasons, including the following:

- i. Correction of errors detected by quality control procedures;
- ii. Incorporation of updates to activity data including changes in data sources;
- iii. Reallocation of activities to different categories

- (although this will only affect sub-totals);
- iv. Refinements of methodologies and emission factors;
- v. Inclusion of categories previously not estimated (which improves inventory completeness); and
- vi. Due to recommendations from UNFCCC reviews.

On a continuous basis, Environment Canada consults and works jointly with key federal and provincial partners along with industry stakeholders, research centres and consultants to improve the quality of the underlying variables and scientific information for use in the compilation of the national inventory. Where necessary, Environment Canada revises and recalculates the emission and removal estimates for all years in the inventory, as good inventory preparation practice requires that methodological improvements and updates be applied to the entire time series of annual estimates (i.e. from 1990 to the most recent year reported). A consistent time series is required to avoid confounding a methodological change with an actual change in GHG emissions or removals.

In response to the findings of the Expert Review Team (ERT) during the course of the centralized review of Canada's 2012 submission, revised estimates of GHG emissions were required for CH₄ and N₂O emissions from the burning of waste tires for category 1.A.2.f.i Other Manufacturing – Cement to ensure completeness.¹

Table 9–1 provides a summary of all recalculations that occurred due to methodological changes or refinements since the previous submission, with a brief description, justification and summary of individual impacts on emissions and trends. In addition to the changes listed in Table 9–1, further recalculations may have occurred due to updates in activity data, reallocations of emissions, the correction of errors discovered since the previous submission, or minor incremental enhancements. Further details on sectoral recalculations may also be found within the individual chapters for each sector. Estimated impacts on levels and trends at a national level are presented in Sections 9.1.1 and 9.1.2.

¹ The report of the individual review of the annual submission of Canada submitted in 2012, which presents findings of the ERT, was not available as of the drafting of this report.

Table 9-1 Summary of Recalculations Due to Methodological Change or Refinement

CRF#	Category	Description	Justification	Impact on Emissions
1.A.1, 1.A.2 and 1.A.4: CO ₂ , CH ₄ , N ₂ O	Energy - Fuel Combustion	Updates and corrections to emissions factors for coal, landfill gas, natural gas, petroleum coke, propane, waste fuels and coke oven gas. Refer to Section 3.2.1.5 for specific details.	Increase accuracy and transparency	Emission factor and activity data updates to the overall fuel combustion (1.A) resulted in an increase of 1.41% for CO ₂ (6.86 Mt), 11.85% for CH ₄ (506.65 kt CO ₂ eq), and 2.68% for N ₂ O (279.91 kt CO ₂ eq) for the 2010 data year.
1.A.1, 1.A.2, 1.A.3 and 1.A.4: CO ₂ , CH ₄ , N ₂ O	Energy - Fuel Combustion	Revised energy consumption data from 2004 to 2010. Refer to Section 3.2.1.5 for specific details.	Increase accuracy of emissions at the sub-sectorial level	See above
1.A.2.f.i; CO ₂ , CH ₄ , N ₂ O	Other Manufacturing - Cement	Estimated CH ₄ and N ₂ O emissions from the use of waste fuels. Applied IPCC default CH ₄ , N ₂ O waste fuels emission factors. Revised CO ₂ emission factor based on data from the Cement Association of Canada and emission factors from the WBCSD Cement Sustainability Initiative. Refer to Section 3.2.1.5 for specific details.	Ensure completeness and accuracy	Emission factor updates contributed to a range of -30 kt to +15 kt over the time period.
1.B.2 CH ₄	Oil - Petroleum Refining	Revised energy consumption data from 2004 to 2010. Refer to Section 3.3.2.5 for specific details.	Increase accuracy	The contribution of revised energy data to the petroleum refining and oil and gas industry resulted in a decrease of 0.24% (-35.2 kt) for CO ₂ and a decrease of 0.04% (-16.15 kt CO ₂ eq) for CH ₄ .
1.B.2 CH ₄	Oil and Gas	Revised activity data from Statistics Canada, provincial agencies and industries. Refer to Section 3.3.2 and 3.3.2.5 for specific details.	Increase accuracy	See above
2.A.3 CO ₂	Limestone and Dolomite Use	Revised activity data for 2010.	NRCan provided revised value for consumption of limestone and dolomite in 2010.	Recalculation resulted in 48% reduction in 2010 emission.
2.A.7.2 CO ₂	Magnesite Use	Revised activity data for 2010.	Updates to activity data for 2010 resulted in the recalculation of emissions for the year.	Recalculation resulted in 4% increase in 2010 emission.
2.B.1 CO ₂	Ammonia Production	Revised activity data for 2009 and 2010.	Updates to activity data for 2009 and 2010 resulted in the recalculation of emissions for these years.	Recalculations resulted in 2.5% and 0.3% for years 2009 and 2010, respectively.
2.C.1 CO ₂	Iron and Steel Production	Revised activity data for 2004 to 2010.	The revision of Statistics Canada's coke use data for the years 2004-2010 resulted in the recalculation of emissions for these years.	Recalculations resulted in a range of increases and decreases with the maximum of change values being 4.2% for 2010 and -2.7% for 2007.
2.F.7 SF ₆	Semiconductor Manufacture	Revised activity data for 2010.	A transcription error resulted in the recalculation of 2010 SF ₆ emissions from Semiconductor Manufacture.	Recalculation resulted in 77% reduction in 2010 emission.

Table 9-1 Summary of Recalculations Due to Methodological Change or Refinement (cont'd)

CRF#	Category	Description	Justification	Impact on Emissions
2.G CO ₂	Other and Undifferentiated Production	Revised activity data for 2004 to 2010.	New values from the RESD resulted in the recalculation of emissions from 2004 to 2010.	Recalculations resulted in a range of increases and decreases with the maximum of change values being 9.8% for 2010 and -1.3% for 2007.
4.A. CH ₄	Enteric Fermentation	Incorporation of new 2011 <i>Census of Agriculture</i> numbers for minor animals.	Availability of new data	A decrease in emissions after the last census year of 20 kt CO ₂ eq in 2007 up to an 80-kt CO ₂ eq decrease in 2010.
4.B. (a) CH ₄	Manure Management	Incorporation of new 2011 <i>Census of Agriculture</i> numbers for minor animals.	Availability of new data	The integration of 2011 <i>Census of Agriculture</i> resulted in changes in minor livestock populations and, in turn, to changes in emissions from this source of -2 kt CO ₂ eq in 2007 and -7 kt CO ₂ eq in 2010.
4.B. (b) N ₂ O	Manure Management	Incorporation of new 2011 <i>Census of Agriculture</i> numbers for minor animals and a correction to the dairy heifer N excretion rate.	Availability of new data and an error correction	These changes resulted in an increase in emissions - by 40 kt CO ₂ eq in 1990, and 50 kt CO ₂ eq in 2010.
4.D.1. N ₂ O	Agricultural Soils - Direct Emissions	Incorporation of new 2011 <i>Census of Agriculture</i> numbers for minor animals and a correction to the dairy heifer N excretion rate along with the refinement of the database.	Availability of new data and an error correction	These changes resulted in an increase of emissions by 29 kt CO ₂ eq in 1990, and 26 kt CO ₂ eq in 2010.
4.D.2. N ₂ O	Agricultural Soils - Pasture, Range and Paddock	Incorporation of new 2011 <i>Census of Agriculture</i> numbers for minor animals and a correction to the dairy heifer N excretion rate.	Availability of new data and an error correction.	These changes resulted in an increase in emissions - by 19 kt CO ₂ eq in 1990, and no change in 2010.
4.D.3. N ₂ O	Agricultural Soils - Indirect Emissions	Incorporation of new 2011 <i>Census of Agriculture</i> numbers for minor animals and a correction to the dairy heifer N excretion rate along with the refinement of the database.	Availability of new data and minor error corrections	The recalculations resulted in a decrease in emissions of 58 kt CO ₂ eq in 1990, and an increase in emissions of 91 kt CO ₂ eq in 2010.
4.F. CH ₄ & N ₂ O	Crop Residue Burning	Corrections of errors in rounding and data entry of crop areas	These errors were discovered through the Tier-2 QC.	The recalculations resulted in a change in the total crop biomass burnt and led to a decrease in emissions in the range of -0.06~-0.84 kt CO ₂ eq for the entire time series. A data entry error in the year 2001 was corrected that resulted in an increase of 5.5 kt CO ₂ eq in that year.

Table 9-1 Summary of Recalculations Due to Methodological Change or Refinement (cont'd)

CRF#	Category	Description	Justification	Impact on Emissions
5.A	LULUCF-Forest Land	Updates of harvest, wildfire and revision of forest conversion activity data in addition to several error corrections in system modelling were implemented.	Harvest activity data were revised to reflect updates in provincial harvest statistics. Wildfire activity was revised based on utilization of detailed mapping of areas affected by fires in recent years. Forest conversion activity was revised as part of ongoing efforts to improve estimate quality. Error corrections result from ongoing quality control activity.	Recalculations in any one year or spatial unit are due to the combined effects of activity data updates and error corrections. There were upward total recalculations across the time series for all years except 2007, where decreased wildfire emissions cancelled out the increased emissions from harvesting. The significant upward recalculation in 2010 (30 Mt CO ₂ eq) is largely due to updated harvest statistics and wildfire activity data.
5.B.1	LULUCF- Cropland remaining Cropland (CLCL)	Processing system revisions and updates	Refined processing was implemented to improve annualization approach and reduce assumptions associated with land management practices. Revisions of forest land conversion impacted area statistics for Cropland remaining Cropland (CLCL).	Recalculations resulted in increased removals of 89 kt CO ₂ eq for 1990 and a decrease in removals of 150 kt CO ₂ eq in 2010, with no notable impact on the emission trend.
5.B.2	LULUCF - Forest Land converted to Cropland (FLCL)	Revised activity data for Forest Conversion	Estimates for the entire time series were revised to reflect improved mapping and sampling activity and quality control activity.	Recalculations resulted in an increase of emissions of 579 kt CO ₂ eq in 1990 and a decrease of 296 kt CO ₂ eq in 2010.
5.B.2, 5.D.2, 5.E.2	LULUCF - Forest Land Conversion LCL, LWL, LSL	Revised activity data for Forest Conversion	Estimates for entire time series (1970-2008) were revised based on additional sampling, quality control activity and revision of spatial boundary layers. These estimates are developed by the Canadian Forest Service for the Monitoring Accounting and Reporting System (MARS).	Due to their cross-cutting nature, the recalculations of forest area converted to other land use affect estimates for several LULUCF sub-categories (FLCL, FLWL and FLSL). The impacts of these changes are not readily discernible unless spatially disaggregated or considered in each end-use class. For example, there is a reduction of FLSL emissions by 285 kt in 1990 and an increase of 653 kt in 2010.
5.D.2	Wetlands - Reservoirs - Emissions from Reservoirs	Revised activity data for land converted to reservoirs	Revisions of forest land conversion estimates indirectly caused recalculations in forest land converted for hydroelectric reservoir development. New flooding events were included in the later part of the time series for this submission.	Recalculations from 1990 to 2005 (averaging 138 kt CO ₂ eq) are an indirect consequence of updates in other forest conversion categories, which alters the model simulation for forest disturbance and corresponding emission estimates. From 2006 to 2010, recalculations, averaging 230 kt CO ₂ eq, are due to the combined effects of utilizing new activity data and updates in other forest conversion categories.

Table 9-1 Summary of Recalculations Due to Methodological Change or Refinement (cont'd)

CRF#	Category	Description	Justification	Impact on Emissions
5.D.2	Wetlands - Peatland peat extraction	Revised activity data for peat extraction	Peat production data update for entire time series (1990-2010).	Updated 2009 peat production data and new 2010 data from Natural Resources Canada were incorporated into the managed peatland area model, leading to recalculations across the time series. From 1990 to 2004, recalculations are on average 0.6 kt (decrease), with larger recalculations from 2005 to 2010 (on average 12-kt increase).
6.A.1 CH ₄	Waste, Solid Waste Disposal on Land	Updated waste quantities exported to the U.S.	Prior to this submission, waste exports were provided only by Ontario. Ontario monitors its waste exports due to the Ontario/Michigan agreement. No other province tracks the quantities of non-hazardous wastes. Therefore, to provide a more complete and accurate database, and due to a recommendation for more transparency from the ERT on waste exports, bordering states were solicited for information.	The recalculations decreased CH ₄ emission estimates from this category by 2.6 % (530 kt CO ₂ eq) for 2010.
6.B.2 CH ₄	Waste, Municipal Wastewater Handling	Correction of errors in percentage of population served by anaerobic systems for all provinces over the complete time series.	Error found by internal review of the model and rectified for estimate accuracy.	The recalculation resulted in a reduction of 30 kt CO ₂ eq in 2010 and a reduction ranging from 19 to 26% across the time series.
6.B.2 N ₂ O	Waste, Human Sewage	Reinstatement of protein consumption adjusted for retail, preparation and plate losses across the complete time series.	A report commissioned by Environment Canada provided sufficient support to justify the use of protein consumption adjusted for retail, preparation and plate losses.	In 2010 this recalculation resulted in a reduction of 32% or 320 kt CO ₂ eq

9.1.1. Implications for Emission Levels

Overall GHG emissions (excluding the Land Use, Land-use Change and Forestry [LULUCF] Sector) were revised by relatively small amounts for all years. Recalculations had the largest implications for 2010, 2004 and 2005, which showed changes of +1.32% (692 Mt to 701Mt), -0.92% (751Mt to 744 Mt), and -0.32% (740 Mt to 737 Mt), respectively. See Table 9–2 for additional details. These changes include revisions to the underlying 2003–2010 historical energy data by Canada's statistics agency, Statistics Canada (see notes on recalculations in Chapter 3). In comparison,

recalculations performed in last year's NIR (2012), adjusted emission totals for the years 1992, 2004 and 2005 by 1.39%, 1.18% and 1.14%, respectively relative to the original 2011 submission. Significant recalculations occurred in the LULUCF Sector (Table 9–2) due mainly to updates in forest and forest land conversion activity data. Chapter 7 provides more information on recalculations and improvements associated with the LULUCF Sector.

It should be noted that the ERT required Canada to provide estimates of GHG emissions for CH₄ and N₂O emissions from the burning of waste tires in the cement sector during the centralized review, and subsequently required

Table 9–2 Summary of Recalculations

	GHG Emissions per Year									
	1990	2000	2004	2005	2006	2007	2008	2009	2010	2011
National Total										
Current (Mt CO ₂ eq)	591	718	744	737	727	749	731	689	701	702
2012 submission (Mt CO ₂ eq)	589	718	751	740	726	751	731	690	692	-
Change (%)	0.30%	0.00%	-0.92%	-0.32%	0.23%	-0.30%	0.04%	-0.14%	1.32%	-
LULUCF										
Current (Mt CO ₂ eq)	-62	-52	107	63	73	52	-11	-10	103	87
2012 submission (Mt CO ₂ eq)	-67	-62	97	54	65	51	-17	-12	72	-
Change (%)	-8.7%	-16.0%	10.5%	17.1%	12.5%	0.5%	-34.7%	-18.6%	43.4%	-

a complete resubmission of Canada's 2012 CRF tables on October 24, 2012. These changes were minor and resulted in a slight revision upwards of 3.2 kt CO₂eq. This change was not significant and did not impact the GHG emissions total.

9.1.2. Implications for Emission Trends

Overall, the recalculations of the total GHG estimates (excluding the LULUCF Sector) had an upward effect on the trend between 1990 and 2010, now reported as an 18.6% increase in total GHG emissions since 1990 instead of the previously reported 17.1% increase. The trend between 1990 and 2011 shows an 18.7% increase in GHG emissions.

9.2. Planned Improvements

Canada has identified planned improvements in Table 9–4 that, when implemented, will impact the inven-

tory time series from 1990 onwards. Further details on sectoral improvement plans may also be found within the individual chapters for each sector. Annual improvements to the national inventory must be applied to all estimation years in order to maintain time series consistency.

The planned improvement activities are based on recommendations from both internal sources and external review processes such as the UNFCCC expert reviews, and collaborative work between inventory sector experts and industry, other government departments, and academia. As part of Canada's National System, improvement activities and work plans are developed on a continuous basis to further refine and increase the transparency, completeness, accuracy, consistency and comparability of the Canadian GHG inventory. Improvement activities are developed by sector experts and prioritized by a prioritization and planning committee (P&PC) using key category contributions, quality assurance/quality control (QA/QC) activities, uncertainty assessments, resource availability and potential impacts as primary considerations.

Table 9–3 Principal Planned Improvements

CRF#	Category	Description	Basis of Planned Improvement
1.A.3.B	Energy – Road Transportation	The development of better on-road activity data	Based on a UNFCCC Expert Review Team recommendation
1.A.3.d	Marine Transport	Development of an improved model to estimate marine emissions	Based on a UNFCCC Expert Review Team recommendation
2.F.	Industrial Processes – Consumption of HFCs	Development and use of country-specific EFs	Continuous improvement
2.G	Industrial Processes – Other & Undifferentiated Production	Allocation of CO ₂ emissions from petrochemical industry to the category Petrochemical Production	Continuous improvement

Table 9–4 Principal Planned Improvements

CRF#	Category	Description	Basis of Planned Improvement
4.A/4B	Enteric Fermentation/Manure Management	Integration of time series of nutrition data for certain animal categories	Improve capacity to capture change in farm practices in emission estimates
4B	Manure Management	Integrate new information on manure management systems	Improve capacity to capture change in farm practices in emission estimates
4D	Agricultural Soils	Update Tier 2 uncertainty analyses based on improved methods and integrated data management. Implement a country-specific method (Tier 2) for estimating N ₂ O emissions from grazing animals on pasture, range and paddock.	Based on a UNFCCC Expert Review Team recommendation
5.B.2, 5.D.2, 5.E.2	LULUCF - Forest Land Conversion LCL, LWL, LSL	Ongoing efforts to improve estimates of forest conversion and reduce uncertainty of estimates	Addition of new mapping time period (circa 2012) will reduce uncertainties associated with extrapolation of activity data. Ongoing quality control activity, addition of new sampling and enhanced mapping.
5.C.1	LULUCF - Burning of Grassland Remaining Grassland (GLGL)	Burning of managed grassland occurs in Canada by either prescribed burning or wildfires	Canada is working on collecting activity data on grassland burning for the entire time series based on a UNFCCC Expert Review Team recommendation. Activity data on managed grassland burning have been collected through expert consultations. It is expected that Canada will develop inventory methods for estimating emissions from burning of managed grasslands in the 2014 or 2015 NIR.
5. D	Wetlands	Improve estimates from peatland conversion, drainage and extraction, and restoration.	Improve estimates of the impacts of peatland extraction
5. D	Wetlands	Analyze geospatial information related to peatlands under extraction to improve the preconversion above-ground biomass estimate (biomass loss).	Decrease uncertainty of land-use change impact
5. D	Wetlands	Scoping of horticultural peatland emission methodology (2006 GLs)	To comply with future reporting obligations
5. D/E	Wetlands & Settlements	Completion of uncertainty assessments	Based on a UNFCCC Expert Review Team recommendation
5.G	Other: Harvested Wood Products	Further elaboration of the production approach to incorporate the delayed carbon emissions due to long-term storage in harvested wood products (HWP)	To comply with future reporting obligations through implementation of the 2006 IPCC guidelines
6.A.1	Waste - Solid Waste Disposal on Land	Examining the possibility of a study to update provincial waste composition data.	Based on a UNFCCC Expert Review Team recommendation

References

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Canada. 1999. Canadian Environmental Protection Act, 1999. S.C., 1999, c. 33. Canada Gazette. Part III, vol. 22, no. 3. Ottawa (ON): Queens Printer. Available online at <http://www.gazette.gc.ca/archives/p3/1999/index-eng.html>

[CAIT] Climate Analysis Indicators Tool. 2012. Version 9.0. Washington (DC): World Resources Institute. Available online at <http://cait.wri.org/cait.php?page=yearly&mode=view>

[EIA] Energy Information Agency. 2004. World Energy Use and Carbon Dioxide Emissions, 1980–2001. Washington (DC): Energy Information Agency.

Environment Canada. 2012. Canada's Emissions Trends 2012. Available online at <http://www.ec.gc.ca/Publications/default.asp?lang=En&xml=253AE6E6-5E73-4AFC-81B7-9CF440D5D2C5>

[NRCan] Natural Resources Canada. 2009. Energy Efficiency Trends in Canada, 1990 to 2007. Ottawa (ON): Office of Energy Efficiency, Natural Resources Canada. #M141-1/2007.

Statistics Canada. 2011a. Energy Statistics Handbook – First quarter 2011. Catalogue No. 57-601. [cited 2012 February 22]. Available online at <http://www.statcan.gc.ca/bsolc/olc-cel/olc-cel?catno=57-601-X&lang=eng>

Statistics Canada. 2011b. Report on Energy Supply–Demand in Canada (Annual). 1991–2010. #57-003-XIB.

Statistics Canada. 2012. CANSIM Table 051-0001: Estimates of population, by age group and sex for July 1, Canada, provinces and territories, annual. CANSIM (database). Available online at <http://www5.statcan.gc.ca/cansim/a26?lang=eng&retrLang=eng&id=0510001&paSer=&pattern=&stByVal=1&p1=1&p2=-1&tabMode=dataTable&csid>

Statistics Canada. 2013a. CANSIM Table 403-0001: For-hire trucking survey, commodity origin and destination. CANSIM (database).

Statistics Canada. 2013b. CANSIM Table 403-0004: Trucking commodity origin and destination survey (TCOD), trucking industry, annual. CANSIM (database).

Chapter 1, Introduction

Canada. 1999. Canadian Environmental Protection Act, 1999. S.C., 1999, c. 33. Canada Gazette. Part III, vol. 22, no. 3. Ottawa: Queens Printer. Available online at <http://www.gazette.gc.ca/archives/p3/1999/g3-02203.pdf>

[CAIT] Climate Analysis Indicators Tool. 2012. Version 9.0. Washington (DC): World Resources Institute. Available online at <http://cait.wri.org/cait.php?page=yearly&mode=view>

Environment Canada. 2012. Climate Trends and Variations Bulletin: Annual 2011. Environment Canada. Available online at <http://ec.gc.ca/adsc-cmda/default.asp?lang=En&n=77842065-1>

Environment Canada. 2013. Facility Greenhouse Gas Emissions Reporting Program - Overview of Reported 2011 Emissions. Environment Canada. Available online at <http://www.ec.gc.ca/ges-ghg/default.asp?lang=En&n=8044859A-1>

Hengeveld H, Whitewood B, Ferguson A. 2005. An Introduction to Climate Change – A Canadian Perspective. Ottawa (ON): Environment Canada.

[IPCC] Intergovernmental Panel on Climate Change. 1995. Climate Change 1995: The Science of Climate Change. Summary for Policymakers and Technical Summary of the Working Group I Report. p. 22. Cambridge (UK): Cambridge University Press.

[IPCC] Intergovernmental Panel on Climate Change. 2000. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at www.ipcc-nggip.iges.or.jp/public/gp/english/

[IPCC] Intergovernmental Panel on Climate Change. 2003. Good Practice Guidance for Land Use, Land-Use Change and Forestry. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf.htm

[IPCC] Intergovernmental Panel on Climate Change. 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at www.ipcc-nggip.iges.or.jp/public/2006gl

[IPCC] Intergovernmental Panel on Climate Change. 2007a. Climate Change 2007: Synthesis Report Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Core Writing Team. Pachauri RK, Reisinger A, editors. Geneva (CH): IPCC. Available online at www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf

[IPCC] Intergovernmental Panel on Climate Change. 2007b. Climate Change 2007: The Physical Science Basis, Contribution of Working Group 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Solomon S, Qin D, Manning M, Chen Z, Marquis M,

Averyt KB, Tignor M, Miller HL, editors. Cambridge (UK): Cambridge University Press. Available online at www.ipcc.ch/ipccreports/ar4-wg1.htm

[IPCC/OECD/IEA] Intergovernmental Panel on Climate Change / Organisation for Economic Co-operation and Development / International Energy Agency. 1997. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change, Organisation for Economic Co-operation and Development, and International Energy Agency. Available online at www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm

Statistics Canada. 2012. CANSIM Table 051-0001: Estimates of population, by age group and sex for July 1, Canada, provinces and territories, annual. CANSIM (database). Available online at <http://www5.statcan.gc.ca/cansim/a26?lang=eng&retrLang=eng&id=0510001&paSer=&patte rn=&stByVal=1&p1=1&p2=-1&tabMode=dataTable&csid>

[UNFCCC] United Nations Framework Convention on Climate Change. 2008. Report of the review of the initial report of Canada. April. FCCC/IRR/2007/CAN. Available online at <http://unfccc.int/resource/docs/2008/irr/can.pdf>

[UNFCCC] United Nations Framework Convention on Climate Change. 2012. National Greenhouse Gas Inventory Data for the Period 1990–2010. 2012 November. FCCC/SBI/2012/31. Available online at http://unfccc.int/ghg_data/ghg_data_unfccc/items/4146.php

[WMO] World Meteorological Organization. 2012. WMO Greenhouse Gas Bulletin: The State of Greenhouse Gases in the Atmosphere Based on Global Observations through 2011. 19 November 2012. No. 8. Available online at <http://www.wmo.int/pages/prog/arep/gaw/ghg/GHGbulletin.html>.

Chapter 2, Greenhouse Gas Emission Trends, 1990–2011

AMEC. 2006. Identifying and Updating Industrial Process Activity Data in the Minerals Sector for the Canadian Greenhouse Gas Inventory. Unpublished report. Mississauga (ON): AMEC Earth & Environmental, a division of AMEC Americas Ltd. March.

Baymag. 2011. Company website. [cited 2012 February 16]. Available online at <http://www.baymag.com/applications/index.php>

[CAPP] Canadian Association of Petroleum Producers. 2011. 2011 CAPP Crude Oil Forecast, Markets & Pipeline – Production and Supply Data. June 2011. Available online at <http://www.capp.ca/forecast>

[CAPP] Canadian Association of Petroleum Producers. 2012. Statistical Handbook for Canada's Upstream Petroleum Industry. Table 5.5g Reference Crude Oil Prices and Foreign Exchange Rates – Bow River @ Hardisty. [updated 2013 January; accessed 2013 February]. Available online at <http://www.capp.ca/library/statistics/handbook>

[Cheminfo] Cheminfo. 2006. Improvements and Updates to Certain Industrial Process and Solvent Use-Related Sections in Canada's Greenhouse Gas Inventory. Cheminfo Services Inc.

Environment Canada. 2011. An Inventory of Landfill Gas Recovery and Utilization in Canada 2009. Report prepared by the Greenhouse Gas Division of Environment Canada.

[ERCB] Energy Resources Conservation Board. 2012. Alberta's Energy Reserves 2011 and Supply/Demand Outlook 2012–2021: ST98-2012. Available online at <http://www.ercb.ca/sts/ST98/ST98-2012.pdf>

[IPCC] Intergovernmental Panel on Climate Change. 2003. Good Practice Guidance for Land Use, Land-Use Change and Forestry. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at <http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf.htm>

[IPCC/OECD/IEA] Intergovernmental Panel on Climate Change / Organisation for Economic Co-operation and Development / International Energy Agency. 1997. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Available online at <http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm>

[NEB] National Energy Board. 2006. Canada's Oil Sands – Opportunities and Challenges to 2015: An Update. [updated 2006 June; accessed 2010 March]. Available online at <http://www.neb.gc.ca/clf-nsi/rnrgynfmrtn/nrgyrprt/lrnd/lrnd-eng.html>

[NRCAN] Natural Resources Canada. 2007. Canadian Minerals Yearbook – Silica / Quartz. Minerals and Metals Sector, Natural Resources Canada. Available online at <http://www.nrcan-nrcan.gc.ca/mms-smm/busi-indu/cmy-amc/com-eng.htm>

[NRCAN] Natural Resources Canada. 2012a. Comprehensive Energy Use Database. Ottawa (ON): Office of Energy Efficiency. [revised 2012 August; cited 2013 February 14]. Available online at http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/trends_res_ca.cfm

[NRCAN] Natural Resources Canada 2013b. Energy Efficiency Trends Analysis Tables. Ottawa (ON): Office of Energy Efficiency [revised 2013 January 17; cited 2013 February 14]. Available online at http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/analysis_ca.cfm

Nyboer J, Tu J. 2010. GHG Emission Trend Analysis in the Fossil Fuel Production Industries. 2010 update. MK Jaccard and Associates Inc. February 2010 (Draft).

Ontario Ministry of the Environment. 2006. Back-grounder: The Ontario/Michigan Waste Issue. Available online at <http://www.ene.gov.on.ca/envision/news/2006/083101mb.pdf>

Statistics Canada. 1990–2004. Cement. Catalogue #44-001-X.

Statistics Canada. 2004–2010. Cement. CANSIM tables 303-0060 and 303-0061.

Statistics Canada. 2000, 2003, 2004, 2007, 2008, 2010. Waste Management Industry Survey: Business and Government Sectors. System of National Accounts, Statistics Canada. #16F0023XIE. Available online at <http://www.statcan.ca/bsolc/english/bsolc?catno=16F0023X&CHROPG=1>

Statistics Canada. 2009. Farm product price index. #21-007-XIB. Available online at <http://www.statcan.gc.ca/bsolc/olc-cel/olc-cel?catno=21-007-X&lang=eng>

Statistics Canada. 2012. Energy Statistics Handbook. Statistics Canada Catalogue no. 57-601-X, Table 4.2-2 Crude oil and equivalent – Production – Domestic, by type. Ottawa (ON). Available online at <http://www5.statcan.gc.ca/bsolc/olc-cel/olc-cel?catno=57-601-X&CHROPG=1&lang=eng>

Statistics Canada. 2011. CANSIM Database Table 129-0001: Operating statistics of Canadian natural gas carriers. Available online at <http://www5.statcan.gc.ca/cansim/a33?RT=TABLE&themelD=3475&spMode=tables&lang=eng>

Statistics Canada. Report on Energy Supply–Demand in Canada (Annual). #57-003-XIB.

Chapter 3, Energy

BioMer. 2005. Biodiesel Demonstration and Assessment for Tour Boats in the Old Port of Montreal and Lachine Canal National Historic Site. Final Report.

[CAPP] Canadian Association of Petroleum Producers. 1999. CH₄ and VOC Emissions from the Canadian Upstream Oil and Gas Industry, Vols. 1 and 2. Prepared for the Canadian Association of Petroleum Producers. Calgary (AB): Clearstone Engineering Ltd. Canada. Publication No. 1999-0010.

[CAPP] Canadian Association of Petroleum Producers. 2005a. A National Inventory of Greenhouse Gas (GHG), Criteria Air Contaminant (CAC) and Hydrogen Sulphide (H₂S) Emissions by the Upstream Oil and Gas Industry, Vols. 1–5. Calgary (AB): Clearstone Engineering Ltd. January.

[CAPP] Canadian Association of Petroleum Producers. 2005b. Extrapolation of the 2000 UOG Emission Inventory to 2001, 2002 and 2003. Prepared for the Canadian Association of Petroleum Producers. Calgary (AB): Clearstone Engineering Ltd.

[CAPP] Canadian Association of Petroleum Producers. 2006. An Inventory of GHGs, CACs, and H₂S Emissions by the Canadian Bitumen Industry: 1990 to 2003. Prepared for the Canadian Association of Petroleum Producers. Calgary (AB): Clearstone Engineering Ltd.

[CGA] Canadian Gas Association. 1997. 1995 Air Inventory of the Canadian Natural Gas Industry. Calgary (AB): Radian International LLC.

[CPPI] Canadian Petroleum Products Institute. 2004. Economic and Environmental Impacts of Removing Sulphur from Canadian Gasoline and Distillate Production. Prepared for the Canadian Petroleum Products Institute. Calgary (AB): Levelton Consultants Ltd. in association with Purvin & Gertz Inc. August.

Environment Canada. 2007. Bitumen-Oil Sands Extrapolation Model – Rev 3. Calgary (AB): Clearstone Engineering Ltd.

[ERCB] Energy Resources Conservation Board. 2012. Alberta Mineable Oil Sands Plant Statistics, Monthly Supplement December 2011: ST39-2011. Available online at <http://www.ercb.ca/sts/ST39-2011.pdf>

[GRI] Gas Research Institute. 2000. Vented Emissions from Maintenance at Natural Gas Distribution Stations in Canada. Austin (TX): Radian International LLC.

ICF Consulting. 2004. Quantitative Assessment of Uncertainty in Canada's National GHG Inventory Estimates for 2001. Final report submitted to the Greenhouse Gas Division, Environment Canada by ICF Consulting. September.

[IPCC] Intergovernmental Panel on Climate Change. 2000. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at <http://www.ipcc-nggip.iges.or.jp/public/gp/english/>

[IPCC/OECD/IEA] Intergovernmental Panel on Climate Change / Organisation for Economic Co-operation and Development / International Energy Agency. 1997. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Available online at <http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm>

King B. 1994. Management of Methane Emissions from Coal Mines: Environmental, Engineering, Economic and Institutional Implications of Options. Report prepared by Neill and Gunter Ltd. for Environment Canada.

McCann TJ. 1997. Fossil Fuel Energy Trade & Greenhouse Gas Emissions. Unpublished report. Prepared by T.J. McCann and Associates for Environment Canada.

McCann TJ. 2000. 1998 Fossil Fuel and Derivative Factors. Report prepared by T.J. McCann and Associates for Environment Canada.

Mourits F. 2008. Overview of the IEA GHG Weyburn-Midale CO₂ Monitoring and Storage Project: Presentation to Interdepartmental CCS Coordinating Committee. Natural Resources Canada. May 2008.

[NEB] National Energy Board. 1998–2011. Estimated Production of Canadian Crude Oil and Equivalent. Available online at <http://www.neb.gc.ca/clf-nsi/rnrgynfmrtn/sttstc/crdlndptrlmprdct/stmtdprdctn-eng.html>

Nyboer J, Tu K. 2006. GHG Emission Trend Analysis in the Fossil Fuel Production Industries. Burnaby (BC): Canadian Industrial Energy End-Use Data and Analysis Centre, Simon Fraser University (Draft).

[PTRC] Petroleum Technology Research Centre. 2004. IEA GHG Weyburn CO₂ Monitoring & Storage Project Summary Report 2000–2004. Regina, Saskatchewan. Available online at http://www.ptrc.ca/siteimages/Summary_Report_2000_2004.pdf

[PTRC] Petroleum Technology Research Centre. 2011. IEA GHG Weyburn-Midale CO₂ Monitoring and Storage Project Received Achievement Award from the Carbon Sequestration Leadership Forum in China. Available online at http://www.ptrc.ca/siteimages/CSLF_Release_Final.pdf

SGA Energy Ltd. 2000. Emission Factors and Uncertainties for CH₄ & N₂O from Fuel Combustion. Unpublished report prepared by SGA Energy Ltd for the Greenhouse Gas Division, Environment Canada.

Smyth S. 2010. Fossil Fuel Import and Export models. Greenhouse Gas Division, Environment Canada 2010.

Statistics Canada. Electric Power Generation Transmission Distribution (Annual). #57-202-X.

Statistics Canada. Report on Energy Supply–Demand in Canada (Annual). #57-003-X.

TFIS Inc. 2011. Canadian Liquid Biofuels Production and Consumption Information. Unpublished report prepared by TFIS Inc for the Greenhouse Gas Section, Environment Canada.

[UNFCCC] United Nations Framework Convention on Climate Change. 2012. FCCC/ARR/2011/CAN. Report of the individual review of the annual submission of Canada submitted in 2011, April 2012. Available online at <http://unfccc.int/resource/docs/2012/arr/can.pdf>

[U.S. EPA] United States Environmental Protection Agency. 1995a. Compilation of Air Pollutant Emission Factors. Vol. I: Stationary Point and Area Sources, AP 42. 5th Edition. Available through National Technical Information Services, Springfield, Virginia, U.S.A. Publication No. PB95-196028.

[U.S. EPA] United States Environmental Protection Agency. 1995b. Protocol for Equipment Leak Emission Estimates, Emission Standards Division. Washington (DC): U.S. Environmental Protection Agency. Report No. EPA-453-/R-95-017.

[WBCSD] World Business Council for Sustainable Development. 2011. Cement CO₂ and Energy Protocol. Version 3.04. Cement Sustainability Initiative.

Chapter 4, Industrial Processes

[AAC] Aluminum Association of Canada. 2002a. Framework Agreement on Voluntary Greenhouse Gas Reductions in Québec entered into between the Government of Québec and the Aluminium Association of Canada. Montréal (QC): Government of Québec and AAC. January.

[AAC] Aluminum Association of Canada. 2002b. Calculating Direct GHG Emissions from Primary Aluminium Metal Production. Prepared by Alcan, obtained from Aluminum Association of Canada (AAC), Montréal (QC).

[AIA] Association de l'Industrie d'Aluminium du Québec. 1993. The Aluminium Industry Today for the Needs of Tomorrow. Québec, Montréal (QC).

AMEC. 2006. Identifying and Updating Industrial Process Activity Data in the Minerals Sector for the Canadian Greenhouse Gas Inventory. Unpublished report. Mississauga (ON): AMEC Earth & Environmental, a division of AMEC Americas Ltd. March.

Cheminfo Services. 2002. Review of Canadian SF₆ Emissions Inventory. Unpublished report. Markham (ON): Cheminfo Services Inc. September.

Cheminfo Services. 2005a. Improving and Updating Industrial Process-Related Activity Data and Methodologies in Canada's Greenhouse Gas Inventory, Sulphur Hexafluoride (SF₆) from Electrical Equipment. Unpublished report. Markham (ON): Cheminfo Services Inc. March.

Cheminfo Services. 2005b. Improving and Updating Industrial Process-Related Activity Data and Methodologies Used in Canada's Greenhouse Gas Inventory, Sulphur Hexafluoride Emissions from the Magnesium Casting Sector. Unpublished report. Markham (ON): Cheminfo Services Inc. March.

Cheminfo Services. 2005c. Improving and Updating Industrial Process-Related Activity Data and

Methodologies Used in Canada's Greenhouse Gas Inventory, Hydrofluorocarbons (HFCs). Unpublished report. Markham (ON): Cheminfo Services Inc. March.

Cheminfo Services. 2006. Improvements and Updates to Certain Industrial Process and Solvent Use-Related Sections in Canada's Greenhouse Gas Inventory. Final Report. Markham (ON): Cheminfo Services Inc. September.

Cheminfo Services. 2010. Study of Potential Additions and Updates to the Industrial Process Sources of GHGs in the Canadian GHG Inventory, and Development of Canadian-Specific Methodologies and Emission Estimates for such Sources. Final Report. Markham (ON): Cheminfo Services Inc. December.

[CIEEDAC] Canadian Industrial Energy End-Use Data and Analysis Centre. 2006. A Review of Energy Consumption in Canadian Oil Refineries 1990, 1994 to 2004. Burnaby (BC): Simon Fraser University. March.

[CIEEDAC] Canadian Industrial Energy End-Use Data and Analysis Centre. 2010. A Review of Energy Consumption and Related Data: Canadian Cement Manufacturing Industry, 1990 to 2008. Burnaby (BC): Simon Fraser University. January.

Environment Canada (GHG Division) and Canadian Electricity Association. 2008. SF6 Emission Estimation and Reporting Protocol for Electric Utilities.

[GTIS] Global Trade Information Services Inc. Canadian Soda Ash Import and Export Data. 1995–2006 trade data retrieved on October 1, 2007; 2007–2009 data retrieved on June 21, 2010. Available online at <http://www.gtis.com>

[HRAI] Heating, Refrigeration and Air Conditioning Institute of Canada. 2008. HCFC Phase-Out Awareness. Available online at <http://www.hrai.ca/hcfcphaseout/index.html>

[IAI] International Aluminium Institute. 2006. The Aluminium Sector Greenhouse Gas Protocol (Addendum to the WRI/WBCSD Greenhouse Gas Protocol), October. Available online at <http://www.world-aluminium.org/?pg=/Downloads/Publications/Full%20Publication&path=344>

ICF Consulting. 2004. Quantitative Assessment of Uncertainty in Canada's National GHG Inventory Estimates for 2001. Final report submitted to the Greenhouse Gas Division. Environment Canada, by ICF Consulting. September.

[IPCC] Intergovernmental Panel on Climate Change. 2000. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at <http://www.ipcc-nggip.iges.or.jp/public/gp/english/>

[IPCC] Intergovernmental Panel on Climate Change. 2002. Background Papers – IPCC Expert Meetings on Good

Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (section on HFC-23 Emissions from HCFC-22 Production). Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at <http://www.ipcc-nggip.iges.or.jp/public/gp/gpg-bgp.htm>

[IPCC] Intergovernmental Panel on Climate Change. 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol. 3, Industrial Processes and Product Use. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at <http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol3.htm>

[IPCC/OECD/IEA] Intergovernmental Panel on Climate Change / Organisation for Economic Co-operation and Development / International Energy Agency. 1997. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Available online at <http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm>

Japan's Ministry of the Environment. 2009. National Greenhouse Gas Inventory Report of Japan. Greenhouse Gas Inventory Office of Japan's Ministry of the Environment.

Jaques AP. 1992. Canada's Greenhouse Gas Emissions: Estimates for 1990. Environmental Protection, Conservation and Protection, Environment Canada. Report EPS 5/AP/4.

Laval University. 1994. Polyfluorocarbons and the Environment (Their Effect on Atmospheric Equilibrium). Study prepared by the Analytical Chemistry Group for Environment Canada. Québec (QC): Laval University. March.

McCann TJ. 2000. 1998 Fossil Fuel and Derivative Factors. Unpublished report. Prepared by TJ McCann and Associates for Environment Canada. March.

Ministry of Energy, Mines & Petroleum Resources. 2006–2011. MINFILE Production Detail Report, 2006–2011. BC Geological Survey.

Ministry of Northern Development and Mines. 1989. Limestone Industries and Resources of Central and Southwestern Ontario – Vol. III. Report prepared for the Aggregate Resources Section, Land Management Branch, Ontario Ministry of Natural Resources.

[NRCAN] Natural Resources Canada. 1990–2006. (Annual). Canadian Minerals Yearbook. Minerals and Metals Sector, Natural Resources Canada. Available online at http://www.nrcan.gc.ca/mms/cmy/pref_e.htm

Øye HP, Huglen R. 1990. Managing aluminium reduction technology—Extracting the most from Hall-Héroult. *Journal of the Minerals, Metals & Materials Society (JOM)* 42(11):23–28.

SIDEX. 2004. 5th Strategic Diversification Newsletter: Exploration Outlook in Québec for a Neglected

Commodity. Société d'investissement dans la diversification de l'exploration. March. Available online at <http://www.sidex.ca/Vpub/magnesite/Magnesite-presentation.pdf>

Statistics Canada. Cement, 1990–2004 (Monthly). Catalogue #44-001-XIB.

Statistics Canada. Industrial Chemicals and Synthetic Resins, 1990–2007 (Monthly). Catalogue #46-002-XIE.

Statistics Canada. Non-Metallic Mineral Products Industries (Annual). Catalogue #44-250-XIE (discontinued).

Statistics Canada. Primary Iron and Steel, 1990–2003 (Monthly). Catalogue #41-001-XIB.

Statistics Canada. Report on Energy Supply–Demand in Canada, 1990–2011 (Annual). Catalogue #57-003-XIB.

Statistics Canada. Steel, Tubular Products and Steel Wire, 2004–2008, 2010 (Monthly). Catalogue #41-019-X.

Statistics Canada. 2008–2011. Micro data of Production of industrial chemicals and synthetic resins, annual (tonnes) 2008–2011.

Statistics Canada. 2005–2009. CANSIM Database Table 303-0060: Production, Shipments and Stocks of Cement, Monthly (Metric Tonnes). Available online at <http://cansim2.statcan.ca>

Statistics Canada. 2011. CANSIM Database Table 303-0061: Production, Shipments and Stocks of Cement, Monthly (Metric Tonnes). Available online at <http://cansim2.statcan.ca>

Statistics Canada. 2010–2011. Catalogue # 65C-0003: Canadian International Merchandise Trade Database.

Chapter 5, Solvent and Other Product Use

Cheminfo Services. 2006. Improvements and Updates to Certain Industrial Process and Solvent Use-Related Sections in Canada's Greenhouse Gas Inventory. Unpublished report. Markham (ON): Cheminfo Services Inc. September.

[IPCC] Intergovernmental Panel on Climate Change. 2000. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at <http://www.ipcc-nggip.iges.or.jp/public/gp/english/>

[IPCC] Intergovernmental Panel on Climate Change. 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol. 3, Industrial Processes and Product Use. Inter-

governmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at <http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol3.htm>

[IPCC/OECD/IEA] Intergovernmental Panel on Climate Change / Organisation for Economic Co-operation and Development / International Energy Agency. 1997. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Available online at <http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm>

Statistics Canada. 2012. Annual Demographic Estimates: Canada, Provinces and Territories. Catalogue no. 91-215-X.

Chapter 6, Agriculture

Boadi DA, Ominski KH, Fulawka DL, Wittenberg KM. 2004. Improving Estimates of Methane Emissions Associated with Enteric Fermentation of Cattle in Canada by Adopting an IPCC (Intergovernmental Panel on Climate Change) Tier-2 Methodology. Final report submitted to the Greenhouse Gas Division, Environment Canada. Winnipeg (MB): Department of Animal Science, University of Manitoba.

Campbell CA, Zentner RP, Janzen HH, Bowren KE. 1990. Crop Rotation Studies on the Canadian Prairie. Ottawa (ON): Canadian Government Publishing Centre.

Campbell CA, Janzen HH, Paustian K, Gregorich EG, Sherrod L, Liang BC, Zentner RP. 2005. Carbon storage in soils of the North American Great Plains: effect of cropping frequency. *Agronomy Journal* 97:349–363.

Coote DR, Liang BC, Huffman EC. 2008. Crop residue burning in Canada. Gatineau (QC): Greenhouse Gas Division, Environment Canada.

Gregorich EG, Rochette P, VandenBygaart AJ, Angers DA. 2005. Greenhouse gas contributions of agricultural soils and potential mitigation practices in eastern Canada. *Soil & Tillage Research* 83:53–72.

Hutchinson JJ, Rochette P, Vergé X, Worth D, Desjardins R. 2007. Uncertainties in Methane and Nitrous Oxide Emissions Estimates from Canadian Agroecosystems Using Crystal Ball. Preliminary report submitted to the Greenhouse Gas Division, Environment Canada, by the Research Branch, Agriculture and Agri-Food Canada.

[IPCC] Intergovernmental Program on Climate Change. 2000. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at <http://www.ipcc-nggip.iges.or.jp/public/gp/english/>

[IPCC] Intergovernmental Panel on Climate Change. 2006. 2006 IPCC Guidelines for National Greenhouse Gas

Inventories, Vol. 4: Agriculture, Forestry and Other Land Use. Intergovernmental Panel on Climate Change. Available online at <http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.htm>

[IPCC/OECD/IEA] Intergovernmental Panel on Climate Change / Organisation for Economic Co-operation and Development / International Energy Agency. 1997. Revised 1996 IPCC Guidelines for Greenhouse Gas Inventories. Available online at <http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm>

Jambert C, Delmas R, Serça D, Thouron L, Labroue L, Delprat L. 1997. N₂O and CH₄ emissions from fertilized agricultural soils in southwest France. *Nutrient Cycling in Agroecosystems* 48:105–114.

Janzen HH, Beauchemin KA, Bruinsma Y, Campbell CA, Desjardins RL, Ellert BH, Smith EG. 2003. The fate of nitrogen in agroecosystems: an illustration using Canadian estimates. *Nutrient Cycling in Agroecosystems* 67:85–102.

Karimi-Zindashty Y, Macdonald JD, Desjardins RL, Worth D, Hutchinson JJ, Vergé XPC. 2012. Sources of uncertainty in the IPCC Tier 2 Canadian livestock model. *The Journal of Agricultural Science*. 150:556–559.

Liang BC, Padbury G, Patterson G. 2004a. Cultivated organic soils in Canada. Gatineau (QC): Greenhouse Gas Division, Environment Canada.

Liang BC, McConkey BG, Campbell CA, Curtin D, Lafond GP, Brandt SA, Lafond AP. 2004b. Total and labile soil organic nitrogen as influenced by crop rotations and tillage in Canadian prairie soils. *Biology and Fertility of Soils* 39:249–257.

MacDonald JD, Liang BC. 2011. Analysis of Canadian Quantification Methodologies of Greenhouse Gas emissions from Livestock: IPCC Tier 2 Quality Control Documentation 2011 submission. Gatineau (QC): Greenhouse Gas Division, Environment Canada. Internal report.

Malhi SS, Lemke R. 2007. Tillage, crop residue and N fertilizer effects on crop yield, nutrient uptake, soil quality and nitrous oxide gas emissions in a second 4-yr rotation cycle. *Soil Tillage Research* 96:269–283.

Marinier M, Clark K, Wagner-Riddle C. 2004. Improving Estimates of Methane Emissions Associated with Animal Waste Management Systems in Canada by Adopting an IPCC Tier 2 Methodology. Final report submitted to the Greenhouse Gas Division, Environment Canada, by the Department of Land Resource Science. Guelph (ON): University of Guelph.

Marinier M, Clark K, Wagner-Riddle C. 2005. Determining manure management practices for major domestic animals in Canada. Final report submitted to the Greenhouse Gas Division, Environment Canada, by the Department of

Land Resource Science. Guelph (ON): University of Guelph.

McAllister TA, Basarab J. 2004. A review of the report “Improving Estimates of Methane Emissions Associated with Enteric Fermentation of Cattle in Canada by Adopting an IPCC (Intergovernmental Panel on Climate Change) Tier-2 Methodology”. Report submitted to the Greenhouse Gas Division, Environment Canada, by Agriculture and Agri-Food Canada, Lethbridge (AB) and Alberta Agriculture, Lacombe (AB).

McConkey BG, Campbell CA, Zentner RP, Dyck FB, Selles F. 1996. Long-term tillage effects on spring wheat production on three soil textures in the Brown soil zone. *Canadian Journal of Plant Science* 76:747–756.

McConkey BG, Liang BC, Campbell CA, Curtin D, Moulin A, Brandt SA, Lafond GP. 2003. Crop rotation and tillage impact on carbon sequestration in Canadian prairie soils. *Soil & Tillage Research* 74:81–90.

Mosier A, Kroeze C, Nevison C, Oenema O, Seitzinger S, van Cleemput O. 1998. Closing the global N₂O budget: nitrous oxide emissions through the agricultural nitrogen cycle. *Nutrient Cycling in Agroecosystems* 52:225–248.

Patni N, Desjardins R. 2004. Comments on “Determining Manure Management Practices for Major Domestic Animals in Canada” by Marinier et al. (2004). Report submitted to the Greenhouse Gas Division, Environment Canada, by Agriculture and Agri-Food Canada, Ottawa (ON).

Rochette P, Janzen HH. 2005. Towards a revised coefficient for estimating N₂O emissions from legumes. *Nutrient Cycling in Agroecosystems* 73:171–179.

Rochette P, Angers DA, Chantigny MH, Bertrand N. 2008a. Nitrous oxide emissions respond differently in a loam and a heavy clay soil. *Soil Science Society of America Journal* 72:1363–1369.

Rochette P, Worth DE, Lemke RL, McConkey BG, Pennock DJ, Wagner-Riddle C, Desjardins RL. 2008b. Estimation of N₂O emissions from agricultural soils in Canada. I. Development of a country-specific methodology. *Canadian Journal of Soil Science* 88:641–654.

Statistics Canada. 2012. Table 95-640-XWE - 2011 Farm and farm operator data (database). [accessed 2012 Dec. 20]. Available online at <http://www29.statcan.gc.ca/ceag-web/eng/data-type-selection-type-donnees?geold=0>.

Chapter 7, Land Use, Land-use Change and Forestry

[AAFC] Agriculture and Agri-Food Canada. 1998. The Canadian System of Soil Classification. Soil Classification Working Group. Research Branch, Agriculture and Agri-Food Canada. Publication 1646, Third Edition 1998, NRC Research Press.

- Bruce JP, Frome M, Haites E, Janzen H, Lal R, Paustian K. 1999. Carbon sequestration in soils. *Journal of Soil Water Conservation* 54:382–389.
- Campbell CA, McConkey BG, Zentner RP, Selles F, Curtin D. 1996. Long-term effects of tillage and crop rotations on soil organic C and total N in a clay soil in southwestern Saskatchewan. *Canadian Journal of Soil Science* 76:395–401.
- Cleary J. 2003. Greenhouse Gas Emissions from Peat Extraction in Canada: A Life Cycle Perspective. Montréal (QC): M.Sc. Thesis, McGill University. C2GCR Report No. 2003-1.
- Dymond C. 2008. Overview QAQC Procedures for NIR 2009. Internal Report. Victoria (BC): Natural Resources Canada, Canadian Forest Service.
- Dyk A, Tinis S, Leckie D. 2011. Deforestation Area Estimation for Canada: Quality Control Overview. Internal Report DRS-N-031. Canadian Forest Service, Natural Resources Canada.
- Environment Canada. 2003. Wetlands in Canada. Available online at <http://www.ec.gc.ca/default.asp?lang=en&n=540B1882-1>
- Hutchinson JJ, Rochette P, Verge X, Desjardins R, Worth D. 2007. Uncertainties in Methane and Nitrous Oxide Emissions Estimates from Canadian Agroecosystems Using Crystal Ball. Preliminary report submitted to the Greenhouse Gas Division, Environment Canada, by the Research Branch, Agriculture and Agri-Food Canada.
- [IPCC] Intergovernmental Panel on Climate Change. 2000. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at <http://www.ipcc-nggip.iges.or.jp/public/gp/english/>
- [IPCC] Intergovernmental Panel on Climate Change. 2003. Good Practice Guidance for Land Use, Land-Use Change and Forestry. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at <http://www.ipcc-nggip.iges.or.jp/public/gp/gluglucf/gpuglucf.htm>
- [IPCC] Intergovernmental Panel on Climate Change. 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol. 4: Agriculture, Forestry and Other Land Use. Intergovernmental Panel on Climate Change. Available online at <http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.htm>
- Janzen HH, Campbell CA, Gregorich EG, Ellert BH. 1997. Soil carbon dynamics in Canadian agroecosystems, in: Lal R, Kimble JM, Follett RF, Stewart BA, editors. *Soil Processes and Carbon Cycles*. Boca Raton (FL): CRC Press. p. 57–80.
- Janzen HH, Campbell CA, Izaurrealde RC, Ellert BH, Juma N, McGill WB, Zentner RP. 1998. Management effects on soil C storage on the Canadian prairies. *Soil & Tillage Research* 47:181–195.
- Keys D. 1992. Canadian Peat Moss and the Environment. Issues Paper, no. 1992-3. North American Wetlands Conservation Council, (Canada).
- Kull SJ, Rampley GJ, Morken S, Metsaranta J, Neilson ET, Kurz WA. 2011. Operational-Scale Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3) Version 1.2: User's Guide. Edmonton (AB): Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre.
- Kurz WA, Apps MJ. 2006. Developing Canada's National Forest Carbon Monitoring, Accounting and Reporting System to Meet the Reporting Requirements of the Kyoto Protocol. Mitigation and Adaptation Strategies for Global Change 11:33–43.
- Kurz WA, Dymond CC, White TM, Stinson G, Shaw CH, Rampley GJ, Smyth C, Simpson BN, Neilson ET, Trofymow JA, et al. 2009. CBM-CFS3: A model of carbon-dynamics in forestry and land-use change implementing IPCC standards. *Ecological Modelling* 220:480–504.
- Leckie D. 2011. Deforestation Area Estimation Uncertainty for Canada's National Inventory Report Greenhouse Gas Sources and Sinks 2011. Internal Report DRS-N-0XX, Canadian Forest Service, Natural Resources Canada.
- Liang BC, Padbury G, Patterson G. 2004. Cultivated organic soils in Canada. Gatineau (QC): Greenhouse Gas Division, Environment Canada.
- Marshall IB, Shut P. 1999. A National Ecological Framework for Canada. Ecosystems Science Directorate, Environment Canada; and Research Branch, Agriculture and Agri-Food Canada. Available online at <http://sis.agr.gc.ca/cansis/nsdb/ecostat/intro.html#ecological%20framework>
- McConkey B, Liang BC, Campbell CA, Curtin D, Moulin A, Brandt SA, Lafond GP. 2003. Crop rotation and tillage impact on carbon sequestration in Canadian prairie soils. *Soil & Tillage Research* 74:81–90.
- McConkey BG, VandenBygaart AJ, Hutchinson J, Huffman T, Martin T. 2007. Uncertainty Analysis for Carbon Change—Cropland Remaining Cropland. Report submitted to Environment Canada by the Research Branch, Agriculture and Agri-Food Canada.
- Metsaranta J, Shaw C, Smyth C, Hilger A, Hafer M, Stinson G, Neilson E, Morken S, Kurz WA. 2011. Uncertainty Estimates: National Forest GHG Inventory Reporting for the 2011 National Inventory Report. Unpublished Manuscript.
- National Wetlands Working Group. 1997. The Canadian Wetland Classification System. 2nd Edition. Warner BG,

Rubec CDA, editors. Waterloo (ON): Wetlands Research Centre, University of Waterloo. Available online at <http://www.portofentry.com/Wetlands.pdf>

[NRCan] Natural Resources Canada. 2005a. Feasibility Assessment of Afforestation for Carbon Sequestration (FAACS) Initiative: Afforestation Policy Analysis. Canadian Forest Service. Available online at <http://cfs.nrcan.gc.ca/subsite/afforestation/feasibilityafforestation>

[NRCan] Natural Resources Canada. 2005b. Forest 2020 Plantation Demonstration Assessment (PDA): Afforestation Policy Analysis. Canadian Forest Service. Available online at <http://cfs.nrcan.gc.ca/subsite/afforestation/forest2020pda>

[NRCan] Natural Resources Canada. 2010. Canada's National Forest Inventory. Natural Resources Canada. Available online at <http://canadaforests.nrcan.gc.ca/statsprofile/inventory/canada>

Stinson G, Kurz W, Smyth CE, Neilson ET, Dymond CC, Metzaranta JM, Boisvenue C, Rampley GJ, Li Q, White TM, Blain D. 2011. An inventory-based analysis of Canada's managed forest carbon dynamics, 1990 to 2008. *Global Change Biology*. doi:10.1111/j.1365-2486.2010.02369.x

VandenBygaart AJ, Gregorich EG, Angers DA. 2003. Influence of agricultural management on soil organic carbon: A compendium and assessment of Canadian studies. *Canadian Journal of Soil Science* 83:363–380.

VandenBygaart AJ, McConkey BG, Angers DA, Smith W, De Gooijer H, Benthall M, Martin T. 2008. Soil carbon change factors for the Canadian agriculture national greenhouse gas inventory. *Canadian Journal of Soil Science* 88:671–680.

Waddington JM, Warner KD. 2001. Restoring the carbon sink function of cut-over peatlands. *Écoscience* 8(3):359–368.

White T, Dymond C. 2008. NIR 2007 QAQC report. Internal report. Ottawa(ON): Environment Canada.

Chapter 8, Waste

AECOM Canada. 2010. Improved Methodology for the Estimation of Greenhouse Gases from Canadian Municipal Wastewater Treatment Facilities. March 29, 2010.

AECOM Canada. 2012. Evaluation of Canada's Estimation Methodology of Nitrous Oxide Emissions from Human Sewage. November 2012.

Bingemer HG, Crutzen PJ. 1987. The production of methane from solid wastes. *Journal of Geophysical Research* 92:2181–2187.

CRA 2011. Estimation of Greenhouse Gas (GHG) Emissions from Canadian Unmanaged Municipal Solid Waste (MSW) Landfills and MSW Incinerators and Validation of MSW Landfill Model Methane Generation Rate Constant. Prepared by Conestoga-Rovers & Associates. June.

CRC Press. 1973. National Waste Composition (1967). Table 1.1-9: Summary of International Refuse Composition, of the Handbook of Environmental Control. Volume II: Solid Waste. CRC Press. 1973.

Environment Canada. 1996. Perspectives on Solid Waste Management in Canada, an Assessment of the Physical Economic and Energy Dimensions of Solid Waste Management in Canada. Vol. I. Prepared by Resource Integration Systems for Environment Canada. March.

Environment Canada. 1997, 1999b, 2001, 2003a. Inventory of Landfill Gas Recovery and Utilization in Canada. National Office of Pollution Prevention.

Environment Canada. 1999a. Municipal Solid Waste Incineration in Canada: An Update on Operations 1997–1998. Prepared by Compass Environmental Inc for Environment Canada and Federal Panel on Energy Research Development.

Environment Canada. 2003b. Canada's Greenhouse Gas Inventory, 1990–2001. Greenhouse Gas Division.

Environment Canada. 2003c. Municipal Solid Waste Incineration in Canada: An Update on Operations 1999–2001. Prepared by A.J. Chandler & Associates in conjunction with Compass Environmental Inc for Environment Canada.

Environment Canada. 2007. An Inventory of Landfill Gas Recovery and Utilization in Canada 2005. A report prepared by the Greenhouse Gas Division of Environment Canada with the support of the University of Manitoba.

Environment Canada. 2009. An Inventory of Landfill Gas Recovery and Utilization in Canada 2006 and 2007. A report prepared by the Greenhouse Gas Division of Environment Canada.

Environment Canada. 2011a. An Inventory of Landfill Gas Recovery and Utilization in Canada 2008 and 2009. A report prepared by the Greenhouse Gas Division of Environment Canada.

Environment Canada. 2011b. Waste Incineration in Canada – a summary of facility level survey data 1990–2009. Unpublished report prepared by the Pollutant Inventory Greenhouse Gas Division of Environment Canada.

Environment Canada. 1941–2007. Historical Precipitation Data. Retrieved June–July 2008; available online at www.climate.weatheroffice.ec.gc.ca/climateData/canada_e.html

ICF Consulting. 2004. Quantitative Assessment of Uncertainty in Canada's National GHG Inventory Estimates for 2001. Final report submitted to the Greenhouse Gas Division. Environment Canada, by ICF Consulting. September.

[IPCC] Intergovernmental Panel on Climate Change. 2000. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at www.ipcc-nggip.iges.or.jp/public/gp/english/

[IPCC/OECD/IEA] Intergovernmental Panel on Climate Change / Organisation for Economic Co-operation and Development / International Energy Agency. 1997. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Available online at www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm

Levelton BH. 1991. Inventory of Methane Emissions from Landfills in Canada. Unpublished report prepared for Environment Canada by B.H. Levelton & Associates.

Maurice C, Lagerkvist A. 2003. LFG emission measurements in cold climatic conditions: season variations and methane emissions mitigation. *Cold Regions Science and Technology* 36:37–46.

McCann TJ. 1994. Uncertainties in Canada's 1990 Greenhouse Gas Emission Estimates: A Quantitative Assessment. Prepared by TJ McCann and Associates for Environment Canada. March.

[NCASI] National Council for Air and Stream Improvement. 2003. Calculation Tools for Estimating Greenhouse Gas Emissions from Wood Products Manufacturing Facilities. Report prepared by National Council for Air and Stream Improvement, Inc.

[NRCan] Natural Resources Canada. 1997. National Wood Residue Data Base. Natural Resources Canada. (Printouts from J. Roberts).

[NRCan] Natural Resources Canada. 1999. Canada's Wood Residues: A Profile of Current Surplus and Regional Concentrations. Prepared for National Climate Change Process Forest Sector Table by the Industry. Economics and Programs Branch, Canadian Forest Service. Natural Resources Canada. March.

[NRCan] Natural Resources Canada. 2005. Estimated Production, Consumption and Surplus Mill Wood Residues in Canada—2004. Report prepared for Natural Resources Canada by the Forest Products Association of Canada.

[NRCan] Natural Resources Canada. 2006. An Analysis of Resource Recovery Opportunities in Canada and the Projection of Greenhouse Gas Emission Implications. Natural Resources Canada. March.

Pelt R, Bass RL, Heaton RE, White C, Blackard A, Burklin C, Reisdorph A. 1998. User's Manual Landfill Gas Emissions Model. Version 2.0. Report prepared for the Control Technology Centre. Office of Research and Development. U.S. Environmental Protection Agency. Radian International and the Eastern Research Group.

[RTI] Research Triangle Institute. 2004. Documentation for Changes to the Methodology for the Inventory of Methane Emissions from Landfills. September 2004.

Statistics Canada. 2000, 2003, 2004, 2007a, 2008a, 2010b. Waste Management Industry Survey: Business and Government Sectors. System of National Accounts. Statistics Canada. #16F0023XIE.

Statistics Canada. 2006. Annual Demographic Statistics. #91-213-XIB.

Statistics Canada. 2007b, 2008b, 2010a. Food Statistics. #21-020-XIE. .

Statistics Canada. 2012. Annual Demographic Estimates: Canada, Provinces and Territories. Catalogue no. 91-215-X.

Tchobanoglous GH, Theisen, Vigil S. 1993. Integrated Solid Waste Management. New York (NY): McGraw Hill, Engineering Principles and Management Issues.

Thompson S, Tanapat S. 2005. Waste management options for greenhouse gas reduction. *Journal of Environmental Informatics* 6(1):16–24.

Thompson S, Sawyer J, Bonam RK, Smith S. 2006. Recommendations for Improving the Canadian Methane Generation Model for Landfills. Winnipeg (MB): Natural Resources Institute. University of Manitoba.

[U.S. EPA] U.S. Environmental Protection Agency. 1995. Compilation of Air Pollutant Emission Factors. Vol. I. Stationary Point and Area Sources. Chapter 2: Solid Waste Disposal. 5th Edition. Available online at www.epa.gov/ttn/chief/ap42/ch02

