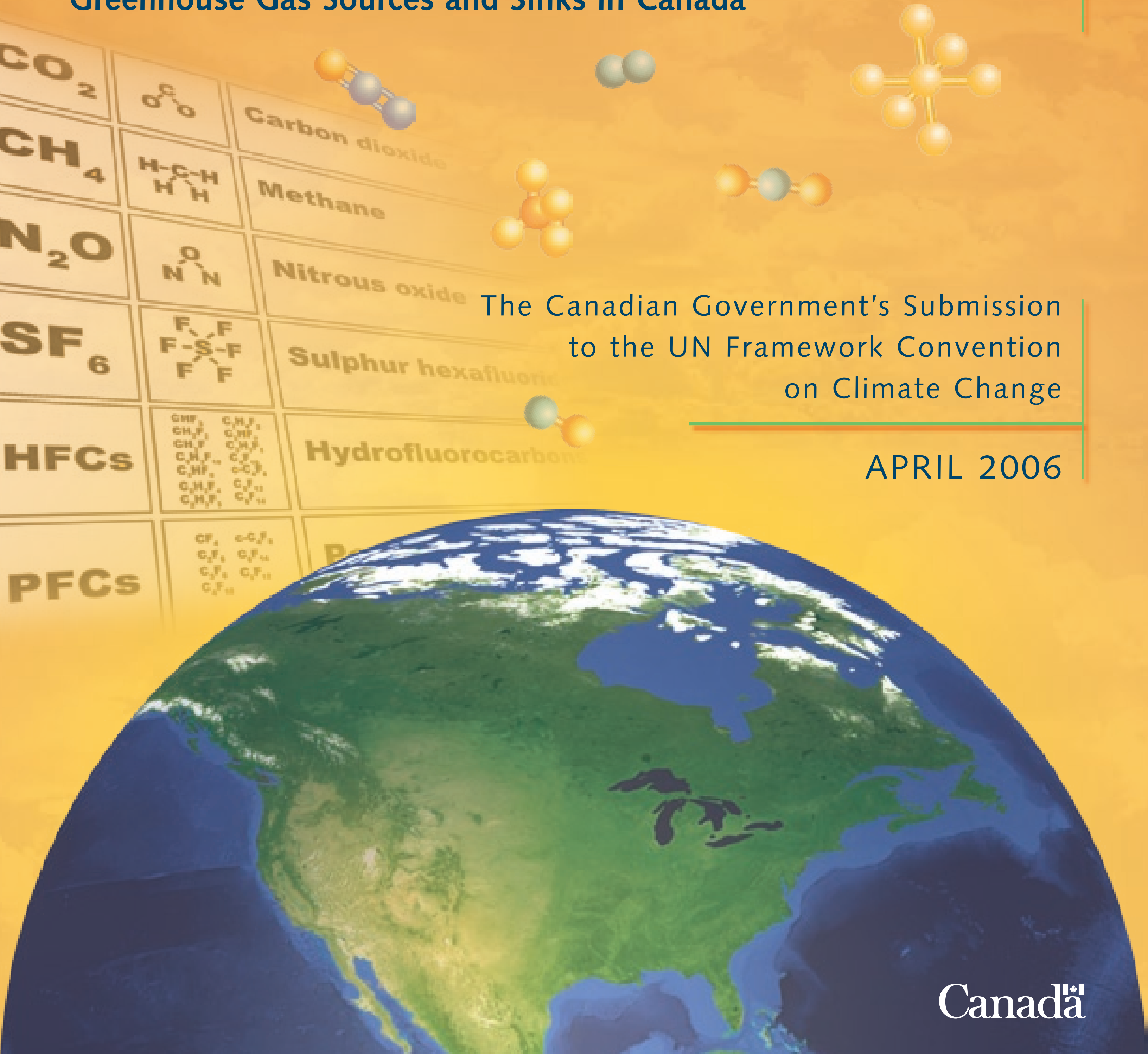
Environment Canada Environnement Canada

National Inventory Report

1990–2004

Greenhouse Gas Sources and Sinks in Canada



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

APRIL 2006

Canada

Library and Archives Canada Cataloguing in Publication

Canada.

Main entry under title:
National Inventory Report: 1990–2004, Greenhouse Gas Sources and Sinks in Canada

Annual
1990/2004-
Issued by Greenhouse Gas Division.

Issues also in French under title: Le rapport d'inventaire national : 1990–2004, Sources et puits de gaz à effet de serre au Canada

Continues: Canada's greenhouse gas inventory.
Available also on the Internet and on CD-ROM.

ISSN: 1910-7048
ISBN: 0-662-43576-1
Cat. no.: En81-4/2004E
EPS #5/AP/12 E

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

TD885.5 363.738'74'097105 C2006-980262-9

Copies of this document are available from:

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National Inventory Report

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ACKNOWLEDGEMENTS

The Greenhouse Gas Division of Environment Canada wishes to acknowledge the many individuals and organizations that contributed to the 2006 National Inventory Report. Although the list of all researchers, government employees, and consultants who provided technical support is too long to include here, Environment Canada's Greenhouse Gas Division would like to thank the authors and contributors as well as the reviewers whose work helped to improve this year's report.

Development of the overall report was directed by Frank Neitzert in concert with Pascale Collas and Afshin Matin. Frank Neitzert led the development of and authored the Executive Summary, Chapter 2 (Trends), Chapter 3 (Energy), and portions of Annex 10 (Industrial Sector Analysis), as well as contributing to Annex 1 (Key Categories) and Annex 4 (Comparison of Sectoral and Reference Approaches). Pascale Collas led the development of Chapter 6 (Agriculture), Chapter 7 (Land Use, Land-Use Change and Forestry, or LULUCF), and the corresponding sections of Annex 3 (Additional Methodologies) and authored Annex 6 (Quality Assurance and Quality Control). Afshin Matin managed the production of Chapter 4 (Industrial Processes), Chapter 5 (Solvents), Chapter 8 (Waste), and Chapter 9 (Recalculations and Improvements), as well as Annex 5 (Completeness) and Annex 7 (Uncertainty). Chia Ha together with Sara Ednie compiled the Common Reporting Format and summary tables for Annex 1 (Key Categories), Annex 8 (National Trends), Annex 9 (Electricity Intensity), and Annex 12 (Provincial/Territorial Emissions). Chia Ha also authored major portions of Chapter 2 (Trends), Chapter 3 (Energy), Annex 1 (Key Categories), Annex 4 (Comparison of Sectoral and Reference Approaches), and Annex 10 (Industrial Sector Analysis). Sara Ednie also developed Annex 9 (Electricity Intensity), Annex 13 (Emission Factors), and Annex 14 (Rounding Protocol). Kerry Rhoades managed the compilation of the National Inventory Report and authored Chapter 1 (Introduction). Scott McKibbon authored Annex 11 (Provincial/Territorial Analysis), with contributions from Rock Radovan. Scott McKibbon also authored portions of Chapter 2 (Trends) and Chapter 3 (Energy), with contributions from Pascal Bellavance, Ryan Gallant, and Rock Radovan. Chang Liang authored Chapter 6 (Agriculture) and Section A3.4 of Annex 3 (Methodology for Agriculture). Dominique Blain authored Chapter 7 (LULUCF) and the related methodological annex (Section A3.5 of Annex 3), to which Chang Liang, Ana Morales, Mark McGovern, and Evan Seed also contributed. Craig Palmer was the author of Chapter 8 (Waste) and the related methodological annex (Section A3.6 of Annex 3). He also performed quality control on portions of the Industrial Processes estimates and contributed to Chapter 2 (Trends). Alice Au provided significant assistance in the authoring of Chapter 4 (Industrial Processes), Chapter 5 (Solvents), and the methodological annex related to Industrial Processes (Section A3.2 of Annex 3) and performed quality control on one Waste Sector emission category. Ana Morales together with Savvas Farassoglou compiled LULUCF estimates and performed quality control on the Agriculture Sector and LULUCF Sector estimates. Renata Zaremba contributed to various sections and annexes related to the Industrial Processes Sector and to Chapter 9 (Recalculations and Improvements). Renata Zaremba also coordinated the quality control work on the key and non-key categories of the Industrial Processes and Waste sectors. Paula Critchley assisted in the authoring of Chapter 8 (Waste) and the related methodological annex (Section A3.6 of Annex 3) and in quality control on Industrial Processes Sector estimates. Michel Sirois made significant contributions to the authoring of Annex 7 (Uncertainty) and provided quality control checks on estimates related to the Industrial Processes Sector. Samantha Boardley provided invaluable support throughout the drafting and compilation of the National Inventory Report.

We would also like to acknowledge the efforts of our colleagues at Statistics Canada, Justin Lacroix and Gary Smalldridge, for their help in analyzing and interpreting Canada's energy supply and demand data. We are also grateful to our federal colleagues from the national LULUCF Monitoring, Accounting and Reporting System, who contributed estimates for the LULUCF and Agriculture sectors. In particular, we would like to thank Jim Wood, Werner Kurz, Thomas White, Don Leckie, Dennis Paradine, and Tony Lemprière of the Canadian Forest Service of

Natural Resources Canada, Marie Boehm, Tim Martin, Brian McConkey, Murray Bentham, and Philippe Rochette of Agriculture and Agri-Food Canada, and Wenjun Chen of the Canadian Centre for Remote Sensing. Of the many people and organizations that provided support and information, we are especially indebted to the many individuals in various industries, industry associations, engineering consulting firms, and universities who provided engineering and scientific support.

READERS' COMMENTS

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FOREWORD

On December 4, 1992, Canada ratified the United Nations Framework Convention on Climate Change (UNFCCC), which subsequently entered into force in March of 1994. Under Decision 3/CP.5 of the UNFCCC, national inventories for UNFCCC Annex I Parties should be submitted to the UNFCCC Secretariat each year by April 15.

The UNFCCC reporting guidelines for national inventories, agreed to at the Eighth and Ninth Conferences of the Parties, incorporate the methodological Good Practice Guidance that has been developed by the Intergovernmental Panel on Climate Change. These guidelines stipulate how emission estimates are to be prepared and what is to be included in the annual inventory report. By including additional information, the inventory report serves as a much better tool from which to generate indicators to compare Parties' performance under the UNFCCC. The Framework Convention also commits Parties to improve the quality of national and regional emissions data and to provide support to developing countries.

Environment Canada, in consultation with a range of stakeholders, is responsible for preparing Canada's official national inventory. This National Inventory Report, prepared by staff of the Greenhouse Gas Division of Environment Canada, complies with the UNFCCC reporting guidelines on annual inventories. It represents the efforts of many years of work and builds upon the results of previous reports, published in 1992, 1994, 1996, 1997, and yearly from 1999 to 2005. In addition to the inventory data, the inventory report contains relevant supplementary information and an analysis of recent trends in emissions and removals.

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

Since the publication of the 1990 emissions inventory,[1] an ever-increasing number of people have become interested in climate change and, more specifically, greenhouse gas emissions. While this interest has sparked a number of research activities, only a limited number have focused on measuring emissions and developing better emission estimates. There will always be uncertainties associated with emission inventories; however, ongoing work, both in Canada and elsewhere, will continue to improve the estimates and reduce uncertainties associated with them. Priority areas for improvement include both the quality of input data and the methodologies utilized to develop emission and removal estimates. A number of areas have undergone improvements over the last few years as we improve the quality of the inventory. These improvements are described within the report.

Art Jaques, P. Eng.
April 12, 2006

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[1] Jaques, A.P. (1992), *Canada's Greenhouse Gas Emissions: Estimates for 1990*, Environmental Protection, Conservation and Protection, Environment Canada, EPS 5/AP/4, December.

LIST OF ACRONYMS, ABBREVIATIONS, AND UNITS

AAC	Aluminum Association of Canada
AAFC	Agriculture and Agri-Food Canada
AC	air conditioning
AC OEM	air conditioning original equipment manufacture
Al	aluminium
Al_2O_3	alumina
ASH	manure ash content
ATV	all-terrain vehicle
AWMS	animal waste management system
B_0	maximum methane production potential
BOD_5	five-day biochemical oxygen demand
C	carbon
CAC	Criteria Air Contaminant
$CaCO_3$	calcium carbonate
$CaMg(CO_3)_2$	dolomite
CanFI	Canada Forest Inventory
CanSIS	Canadian Soil Information System
CaO	lime
CAPP	Canadian Association of Petroleum Producers
CBM	Carbon Budget Model
CBM-CFS	Carbon Budget Model of the Canadian Forest Sector
CEA	Canadian Electricity Association
CEPA 1999	*Canadian Environmental Protection Act, 1999*
CF_4	carbon tetrafluoride
C_2F_6	carbon hexafluoride
CFC	chlorofluorocarbon
CFS	Canadian Forest Service
CH_4	methane
CIEEDAC	Canadian Industrial Energy End-Use Data Analysis Centre
CKD	cement kiln dust
CO	carbon monoxide
CO_2	carbon dioxide
COD	chemical oxygen demand
CPPI	Canadian Petroleum Products Institute
CRF	Common Reporting Format
CTS	crop-and-tillage system
CVS	Canadian Vehicle Survey
DE	digestible energy
DHI	Dairy Herd Improvement
DM	dry matter
DMI	dry matter intake
DOC	degradable organic carbon
DOM	dead organic matter
EAF	electric arc furnace
EF	emission factor
EF_{BASE}	a weighted average of emission factors
EPA	Environmental Protection Agency (United States)
EPWG	Emissions and Projections Working Group
eq	equivalent
ERT	Expert Review Team
FAACS	Feasibility Assessment of Afforestation for Carbon Sequestration
FCR	fuel consumption ratio
FEMS	Farm Environmental Management Survey
$Frac_{FALLOW}$	fraction of cropland that is under summerfallow
$Frac_{GASM}$	fraction of manure nitrogen that volatilizes as NH_3-N and NO_x-N
$Frac_{LEACH}$	fraction of nitrogen that is lost through leaching and runoff
F_{TILL}	tillage ratio factor
F_{TOPO}	fraction of the ecodistrict area in the lower section of the toposequence
g	gram
GCV	gross calorific value
GDP	gross domestic product
GE	gross energy
Gg	gigagram
GHG	greenhouse gas
GHV	gross heating value
GIS	geographic information system
GL	gigalitre
Gt	gigatonne
GWP	global warming potential
ha	hectare
HCFC	hydrochlorofluorocarbon
HDD	heating degree-day
HDDT	heavy-duty diesel truck
HDDV	heavy-duty diesel vehicle
HDGV	heavy-duty gasoline vehicle
HFC	hydrofluorocarbon
HHV	higher heating value
HM	heavy metal
HNO_3	nitric acid
HWP	harvested wood product
HWP-C	carbon stored in harvested wood products
IE	included elsewhere
IPCC	Intergovernmental Panel on Climate Change
IT	intensive tillage
k	methane generation rate constant
kg	kilogram
kha	kilohectare
kPa	kilopascal
kt	kilotonne
kWh	kilowatt-hour
L	litre
lb.	pound

LDDT	light-duty diesel truck
LDDV	light-duty diesel vehicle
LDGT	light-duty gasoline truck
LDGV	light-duty gasoline vehicle
LDV	light-duty vehicle
LHV	lower heating value
LMC	land management change
LPG	liquefied petroleum gas
LTO	landing and takeoff
LULUCF	Land Use, Land-Use Change and Forestry
m	metre
m^3	cubic metre
MAI	mean annual increment
MARS	Monitoring, Accounting and Reporting System
MC	motorcycle
MCF	methane conversion factor
Mg	magnesium
$MgCO_3$	magnesite, magnesium carbonate
M-GEM	Mobile Greenhouse Gas Emission Model
MgO	magnesia
Mha	megahectare
ML	megalitre
mol	mole
MS	manure system distribution factor
MSW	municipal solid waste
Mt	megatonne
mV	millivolt
MW	megawatt
N	nitrogen
N_2	nitrogen gas
Na_2CO_3	sodium carbonate
Na_3AlF_6	cryolite
NAICS	North American Industrial Classification System
NBI	net biomass increment
NE	not estimated
NFI	National Forest Inventory
NGL	natural gas liquid
NH_3	ammonia
NH_4^+	ammonium
NIR	National Inventory Report
NMVOC	non-methane volatile organic compound
NO	not occurring
NO_3^-	nitrate
NO_x	nitrogen oxides
N_2O	nitrous oxide
NPRI	National Pollutant Release Inventory
NRCan	Natural Resources Canada
NT	no-tillage
ODS	ozone-depleting substance
OECD	Organisation for Economic Co-operation and Development
OEM	original equipment manufacturer
PFC	perfluorocarbon
PJ	petajoule
POP	persistent organic pollutant
ppb	part per billion
ppbv	part per billion by volume
P/PE	precipitation to potential evapotranspiration ratio
ppm	part per million
QA	quality assurance
QC	quality control
RESD	*Report on Energy Supply–Demand in Canada*
RF_{THAW}	a ratio factor adjusting EF_{BASE} for emissions during spring thaw
RT	reduced tillage
SF_6	sulphur hexafluoride
SIC	Standard Industrial Classification
SLC	Soil Landscapes of Canada
SO_2	sulphur dioxide
SO_x	sulphur oxides
SOC	soil organic carbon
STP	standard temperature and pressure
SUV	sport utility vehicle
t	tonne
t-km	tonne-kilometre
TJ	terajoule
TWh	terrawatt-hour
UN	United Nations
UNECE	United Nations Economic Commission for the Environment
UNFCCC	United Nations Framework Convention on Climate Change
VIO	vehicle in operation
Vkmt	vehicle kilometres travelled
VOC	volatile organic compound
VS	volatile solids
wt	weight

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EXECUTIVE SUMMARY

ES.1 GREENHOUSE GAS INVENTORIES AND CLIMATE CHANGE

The United Nations Framework Convention on Climate Change (UNFCCC) — Article 4(1)(a), Article 12(1)(a), and Decision 3/CP.5 — requires Annex I Parties to submit an annual greenhouse gas (GHG) inventory report using UNFCCC reporting guidelines. The year 2006 marks the publication of Canada's 12th National Inventory Report (NIR). It is also the second inventory since the Kyoto Protocol to the UNFCCC, which Canada ratified in 2002, came into force. Underpinning the UNFCCC is the national GHG inventory, composed of the NIR and Common Reporting Format (CRF) tables. It is the key tool for monitoring and reporting on emissions from sources and removals by sinks and, with respect to the Kyoto Protocol, is the ultimate measure for assessing compliance with the national emissions target.

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

The national inventory system includes all institutional, legal, and procedural arrangements made within a Party for estimating emissions and removals of GHGs according to the above methodologies, as well as for reporting and archiving the inventory information. This requires that a number of key inventory planning, preparation, and management functions be performed. The current report provides a short discussion (in Chapter 1) on the system that Canada has developed. A full description of the national system in accordance with guidelines under Article 5.1 of the Protocol is to be included, among other things, in Canada's initial report, due January 1, 2007, to the UNFCCC, a report that is also to facilitate the calculation of the assigned amount (emissions target) under Article 7.4.

This year's GHG inventory incorporates a number of improvements in the estimation methodologies, including the results of detailed studies on fugitive emissions from oil and gas industries. The Land Use, Land-Use Change and Forestry (LULUCF) methodologies have been entirely upgraded, and new estimation methods have been incorporated in the Industrial Processes and Waste sectors and the Agricultural Soils category. In developing the inventory, Tier 1 quality assurance/quality control (QA/QC) procedures continue to be used to formally ensure and document the quality of the estimates. In addition, some Tier 2 QA/QC has been conducted as time and resources permit.

The current report includes an inventory of anthropogenic (human-induced) emissions by sources, and removals by sinks, of the six main GHGs not controlled by the Montreal Protocol. This Executive Summary highlights some of the latest developments in the inventory, discusses underlying trends in the emissions, provides some international context, and presents provincial and territorial emissions for the period 1990–2004. Chapter 1, the Introduction, provides an overview of the most recent climate and GHG concentration trends, as well as Canada's legal, institutional, and procedural arrangements for producing the inventory (i.e., the national inventory system), a brief description of estimation methodologies and QA/QC procedures, and explanations of major changes to this year's inventory and assessments of completeness and uncertainty. Chapter 2 provides an in-depth analysis of Canada's GHG emission trends in accordance with the UNFCCC reporting guidelines.

Chapters 3–8 provide descriptions and additional analysis for each broad emissions and removals category according to UNFCCC CRF requirements. Chapter 9 presents a summary of recalculations and planned improvements. Annexes 1–7 provide a key category analysis, detailed explanations of estimation methodologies, a comparison of the sectoral and reference approaches, a more complete description of QA/QC procedures, completeness assessments, and a discussion of inventory uncertainty. Summary tables of GHG emissions tabulated by jurisdiction, sector, and gas are presented in Annexes 8 and 12. Annexes 9, 10, and 11 present additional details on the GHG intensity of electricity generation and trend analyses by industrial sector and by province/territory, respectively. Emission factors are provided in Annex 13, and a description of rounding procedures is found in Annex 14. Finally, brief summary tables showing emissions of ozone and aerosol precursors are provided in Annex 15.

ES.1.1 DEVELOPING CANADA'S NATIONAL GREENHOUSE GAS INVENTORY

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

- carbon dioxide (CO_2);
- methane (CH_4);
- nitrous oxide (N_2O);
- sulphur hexafluoride (SF_6);
- perfluorocarbons (PFCs); and
- hydrofluorocarbons (HFCs).

The inventory reporting format is based on international reporting methods agreed to by the Parties to the UNFCCC, using the procedures of the Intergovernmental Panel on Climate Change (IPCC) (see above). The inventory uses an internationally agreed upon reporting format that groups emissions into the following six sectors: Energy, Industrial Processes, Solvent and Other Product Use, Agriculture, LULUCF, and Waste. Each of these sectors is further subdivided within the inventory and follows, as closely as possible, the UNFCCC category and subsector divisions.[2] Detailed descriptions of the methodologies used to estimate the sector emissions and removals and their respective trends are provided in Chapters 3 through 8 and Annexes 2 and 3. In keeping with UNFCCC reporting requirements for Annex I Parties, this report also contains information on the ozone precursors nitrogen oxides (NO_x), carbon monoxide (CO), and non-methane volatile organic compounds (NMVOCs), as well as on sulphur dioxide (SO_2).

ES.2 SUMMARY OF NATIONAL TRENDS IN GREENHOUSE GAS EMISSIONS AND REMOVALS

In 2004, Canadians contributed about 758 megatonnes of CO_2 equivalent (Mt CO_2 eq)[3] of GHGs to the atmosphere (Figure S-1),[4] an increase of 0.6% over the 754 Mt recorded for the year 2003. This is considerably less than the 3.9% increase that occurred between 2002 and 2003. Canada's economic GHG intensity — the amount of GHGs emitted per unit of economic activity — was 2.6% lower in 2004 than in 2003. Since 1990, emissions have increased by about 27%.

Table S-1 depicts Canada's total GHG emissions from 1990 to 2004, along with several primary indicators: gross domestic product (GDP), population, energy use, energy production, and energy export. From the table, it is evident that the 27% increase in GHG emissions during the 14-year period outpaced increases in population (which totalled 15%) and approximately equalled the increase in energy use (which was 26%). However, the growth in total emissions was well short of the 47% growth in GDP between 1990 and 2004 (Statistics Canada, #13-213: millions of chained 1997 dollars).

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[2] Minor differences exist between the UNFCCC and Canada's national inventory sector designations. These are explained in footnotes throughout this report. More details can be found in Chapters 3–8, where the methodology used in Canada's inventory is described.

[3] Each of the GHGs has a unique average atmospheric lifetime over which it is an effective climate-forcing agent. The concept of global warming potential (GWP) has been introduced to equate this climate forcing for different GHGs to that of CO_2. A more detailed explanation is provided in Section 1.1.5 of this document.

[4] Unless explicitly stated otherwise, all emission estimates given in Mt represent emissions of GHGs in Mt CO_2 equivalent.

The result is that economic GHG intensity has decreased by a total of 14% over the period, an average of 1% per year. More goods were manufactured, more commercial activity occurred, and more travel took place per unit of GHG emissions. These trends are summarized graphically in Figure S-2. The indexed curves clearly show that GHG emissions per energy used remained static over the period, while economic GHG intensity decreased. This is to some extent related to energy efficiency improvements that have taken place in the Canadian economy since 1990 (NRCan, 2005).

Another trend worth noting is the much larger growth in energy *production* than energy *use* between 1990 and 2004. This is a consequence of Canada's large fossil fuel resources and an economy geared to take advantage of them, with increasing quantities of energy being delivered to the international market. The resultant sharp growth in energy exports over the period has had a significant impact on the emission trend. (See Section ES.4.1 for more details.)

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

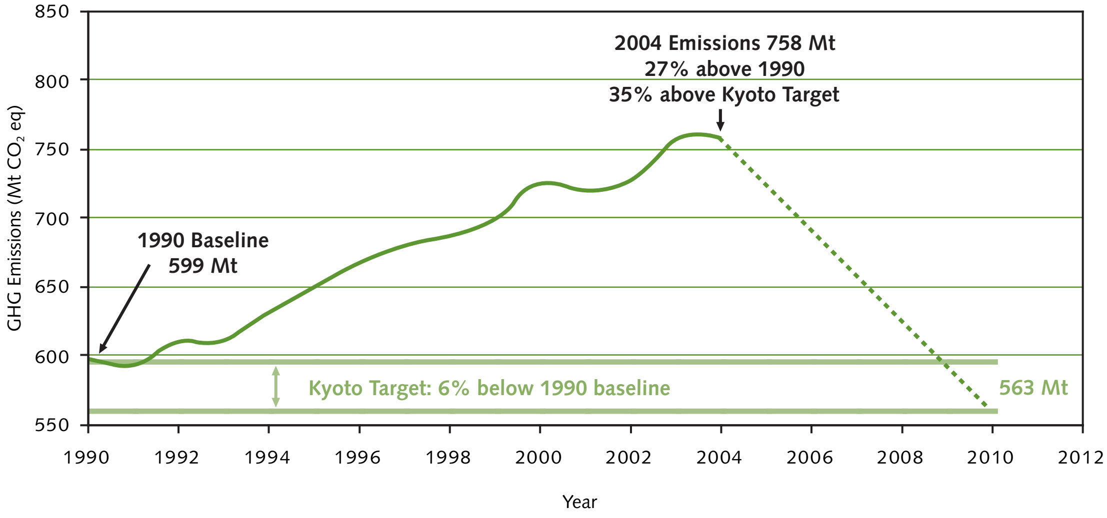

FIGURE S-2: Trends in GHG Emissions per Capita and per Unit GDP, 1990–2004

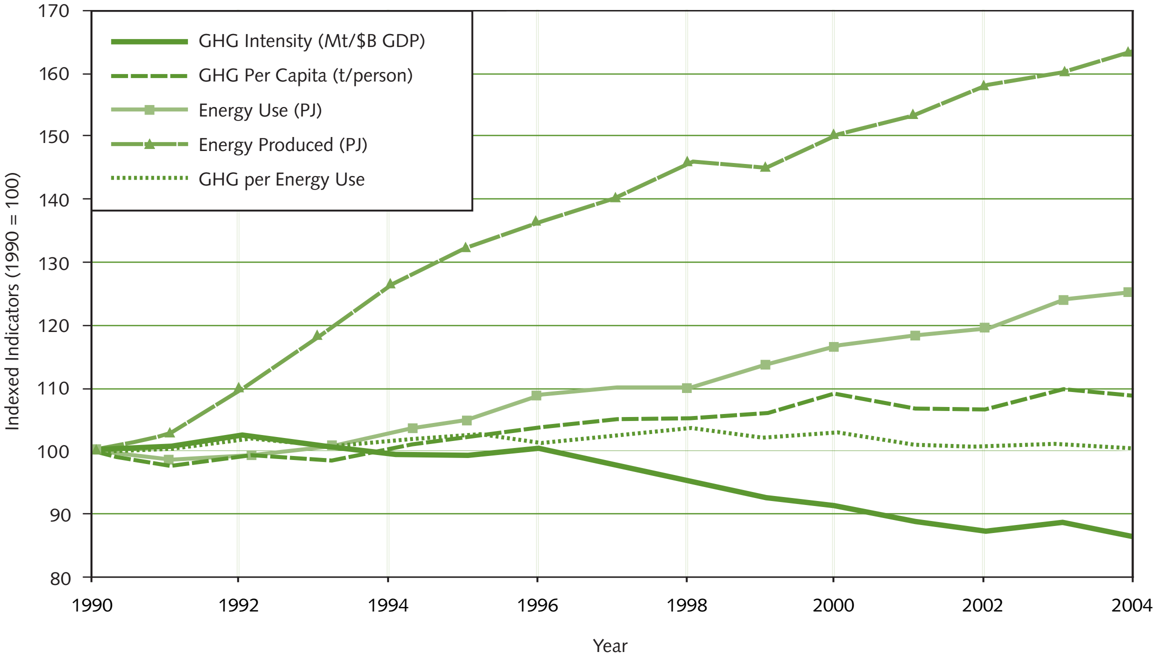

TABLE S-1: Canada's GHG Emissions and Accompanying Variables, 1990–2004

	1990	1995	2000	2003	2004
Total GHG Emissions (Mt)	**599**	**649**	**725**	**754**	**758**
Growth Since 1990	N/A	8.3%	21.1%	25.9%	26.6%
Annual Change	N/A	2.8%	3.8%	3.9%	0.6%
Average Annual Change	N/A	1.7%	2.1%	2.0%	1.9%
GDP — Expense[1]	**712 019**	**773 355**	**946 014**	**1 012 635**	**1 045 643**
Growth Since 1990	N/A	8.6%	32.9%	42.2%	46.9%
Annual Change	N/A	2.7%	5.5%	2.4%	3.3%
Average Annual Change	N/A	1.7%	3.3%	3.2%	3.3%
Economic GHG Intensity (Mt/$B GDP)	**0.84**	**0.84**	**0.77**	**0.744**	**0.725**
Growth Since 1990	N/A	–0.3%	–8.9%	–11.5%	–13.8%
Annual Change	N/A	0.1%	–1.6%	1.5%	–2.6%
Average Annual Change	N/A	–0.1%	–0.9%	–0.9%	–1.0%
GHG Efficiency ($GDP/kt GHG)	**1.19**	**1.19**	**1.30**	**1.343**	**1.379**
Growth Since 1990	N/A	0.3%	9.7%	13.0%	16.0%
Annual Change	N/A	–0.1%	1.6%	–1.5%	2.7%
Average Annual Change	N/A	0.1%	1.0%	1.0%	1.1%
Population (000s)[2]	**27 698**	**29 302**	**30 689**	**31 660**	**31 946**
Growth Since 1990	N/A	5.8%	10.8%	14.3%	15.3%
Annual Change	N/A	1.0%	0.9%	0.9%	0.9%
Average Annual Change	N/A	1.2%	1.1%	1.1%	1.1%
GHG per Capita (t/person)	**21.6**	**22.1**	**23.6**	**23.81**	**23.73**
Growth Since 1990	N/A	2.4%	9.3%	10.1%	9.7%
Annual Change	N/A	1.8%	2.9%	2.9%	–0.3%
Average Annual Change	N/A	0.5%	0.9%	0.8%	0.7%
Energy Use (PJ)[3]	**9 230**	**9 695**	**10 830**	**11 479**	**11 618**
Growth Since 1990	N/A	5.0%	17.3%	24.4%	25.9%
Annual Change	N/A	1.4%	3.0%	3.6%	1.2%
Average Annual Change	N/A	1.0%	1.7%	1.9%	1.8%
Energy Produced (PJ)[4]	**7 746**	**10 299**	**11 729**	**12 492**	**12 784**
Growth Since 1990	N/A	33.0%	51.4%	61.3%	65.0%
Annual Change	N/A	4.6%	3.8%	1.3%	2.3%
Average Annual Change	N/A	6.6%	5.1%	4.7%	4.6%
Net Energy Exported (PJ)[4]	**1 769**	**4 056**	**4 851**	**4 958**	**5 172**
Growth Since 1990	N/A	129.2%	174.2%	180.2%	192.3%
Annual Change	N/A	14.8%	6.1%	–6.3%	4.3%
Average Annual Change	N/A	25.8%	17.4%	13.9%	13.7%
Emissions Associated with Net Exports (Mt)[4]	**21.5**	**42.9**	**47.5**	**46.2**	**47.8**
Growth Since 1990	N/A	99.5%	121.0%	115.1%	122.6%
Annual Change	N/A	17.9%	4.7%	–9.6%	3.5%
Average Annual Change	N/A	19.9%	12.1%	8.9%	8.8%

Notes:

1 GDP, expenditure-based (million 1997 chained dollars), Informetrica, January 11, 2006.

2 Statistics Canada, *Demographic Statistics 2003*, Catalogue No. 91-213-XPB.

3 Statistics Canada (2004), Catalogue No. 57-003-XIB, Table S, Line 2 - Availability, Total Primary.

4 Natural gas and crude oil only.

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

N/A = not available

Changes from the Previous NIR

As a result of a number of significant changes and improvements to the inventory, Canada's 1990–2004 GHG estimates have been revised since last year's report. Results of detailed studies on emissions from facilities in the upstream oil and gas and oil refining industries have been incorporated into the Energy Sector's GHG estimates. In addition, Statistics Canada's underlying energy data for 2003 were updated, primarily affecting the estimates for electricity emissions. A major revision of the estimation model for emissions from landfills has been performed to incorporate better, Canada-specific parameters in the GHG estimates for the Waste Sector. Finally, agricultural soil N_2O emission estimates have been modified through the adoption of improved, country-specific methodologies and factors. Taken together, these changes are the primary contributors to the revised national GHG estimates.

As a result, total GHG emissions (without LULUCF) previously reported for 1990 have been revised upward from 596 to 599 Mt, while emission estimates previously reported for 2003 have been revised upward from 740 Mt to 754 Mt. The overall impact of these changes is that emission growth over the period 1990–2003, previously reported to be 24%, is now estimated to be 26%.

ES.3 EMISSIONS AND REMOVALS ESTIMATES AND TRENDS

ES.3.1 2004 EMISSIONS AND REMOVALS

Table S-2 details Canada's emissions and removals for 2004. On an individual GHG basis, CO_2 contributed 78% of the total emissions, while CH_4 accounted for 15%. N_2O accounted for 6% of the emissions, while PFCs, SF_6, and HFCs constituted the remaining 1%.

Approximately 73% of total GHG emissions in 2004 resulted from the combustion of fossil fuels. Another 9% were from fugitive sources, with the result that 82% of emissions were from the Energy Sector. A sectoral breakdown of Canada's total emissions for 2004 is shown in Figure S-3.

As per reporting requirements, the LULUCF Sector estimates are not included in the national totals. This sector displays net overall emissions of 81 Mt for 2004. This would, if included, increase the total Canadian GHG emissions by 11%.

ES.3.2 SECTOR TRENDS

ES.3.2.1 Year-to-Year Changes

Table S-3 outlines changes in Canada's GHG emissions and removals, by sector, between 1990 and 2004.

As indicated above, emissions in 2004 are estimated at 758 Mt, up 4 Mt (0.6%) from 754 Mt in 2003. Between 2003 and 2004, there were increases in some sectors (notably Industrial Processes and Agriculture), but the overall growth was minor, owing mainly to significantly reduced emissions from electricity production (less coal and more nuclear generation) and, to a lesser extent, a reduced demand for heating fuel because of a warmer winter.

FIGURE S-3: Sectoral Breakdown of Canada's GHG Emissions, 2004

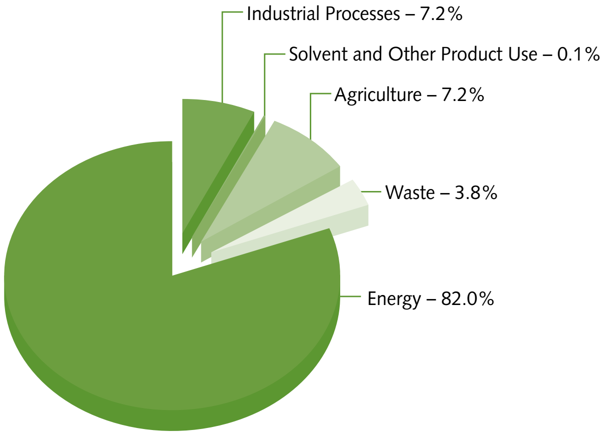

TABLE S-2: Canada's GHG Emissions by Gas and Sector, 2004

GHG Source/Sink Categories	Greenhouse Gases								
	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	TOTAL
Global Warming Potential			21		310				
Unit	*kt*	*kt*	*kt CO_2 eq*	*kt*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*
TOTAL[1]	593 000	5 200	110 000	140	44 000	4 700	3 060	3 000	758 000
ENERGY	553 000	3 000	60 000	30	10 000	–	–	–	620 000
a. Stationary Combustion Sources	352 000	200	5 000	9	3 000	–	–	–	360 000
Electricity and Heat Generation	129 000	4.7	99	2	700	–	–	–	130 000
Fossil Fuel Industries	75 000	100	3 000	2	500	–	–	–	79 000
Petroleum Refining and Upgrading	29 000	0.6	10	0.5	200	–	–	–	29 000
Fossil Fuel Production	46 200	100	3 000	1	400	–	–	–	49 000
Mining	15 300	0.3	6	0.3	100	–	–	–	15 400
Manufacturing Industries	50 300	3	60	2	500	–	–	–	50 900
Iron and Steel	6 480	0.3	5	0.2	60	–	–	–	6 550
Non-Ferrous Metals	3 220	0.07	2	0.05	20	–	–	–	3 230
Chemical	6 250	0.13	2.7	0.1	30	–	–	–	6 290
Pulp and Paper	8 990	2	40	0.9	300	–	–	–	9 310
Cement	4 310	0.09	2	0.05	20	–	–	–	4 330
Other Manufacturing	21 100	0.4	9	0.4	100	–	–	–	21 200
Construction	1 340	0.02	0.5	0.03	9	–	–	–	1 350
Commercial & Institutional	37 700	0.7	10	0.8	200	–	–	–	37 900
Residential	40 700	90	2 000	2	500	–	–	–	43 000
Agriculture & Forestry	2 080	0.04	0.7	0.06	20	–	–	–	2 100
b. Transportation[2]	185 000	30	600	30	8 000	–	–	–	190 000
Domestic Aviation	7 590	0.4	9	0.7	200	–	–	–	7 800
Road Transportation	140 000	12	260	16	5 100	–	–	–	145 000
Light-Duty Gasoline Vehicles	47 800	3.5	74	6.0	1 900	–	–	–	49 800
Light-Duty Gasoline Trucks	41 000	4.5	95	8.3	2 600	–	–	–	43 600
Heavy-Duty Gasoline Vehicles	4 010	0.57	12	0.60	190	–	–	–	4 210
Motorcycles	214	0.17	3.6	0.00	1.3	–	–	–	219
Light-Duty Diesel Vehicles	750	0.02	0.4	0.05	20	–	–	–	768
Light-Duty Diesel Trucks	873	0.02	0.5	0.06	20	–	–	–	893
Heavy-Duty Diesel Vehicles	44 400	2	50	1	400	–	–	–	44 900
Propane & Natural Gas Vehicles	837	1	30	0.02	5	–	–	–	870
Railways	5 350	0.3	6	2	700	–	–	–	6 000
Domestic Marine	6 260	0.5	10	1	400	–	–	–	6 600
Others	26 000	10	300	6	2 000	–	–	–	30 000
Off-Road Gasoline	4 000	4	90	0.08	20	–	–	–	4 000
Off-Road Diesel	14 000	0.7	10	5	2 000	–	–	–	20 000
Pipelines	8 280	8.3	170	0.2	70	–	–	–	8 520
c. Fugitive Sources	16 000	2 400	50 000	0.1	40	–	–	–	66 500
Coal Mining	–	50	1 000	–	–	–	–	–	1 000
Oil and Natural Gas	16 000	2 300	49 000	0	40	–	–	–	65 500
Oil	3 650	300	6 300	–	–	–	–	–	9 900
Natural Gas	7 200	1 000	21 000	–	–	–	–	–	28 000
Venting	160	1 000	22 000	0.1	40	–	–	–	22 000
Flaring	5 350	3.91	82.2	0.00	0.06	–	–	–	5 400
INDUSTRIAL PROCESSES	39 600	–	–	12.7	3 920	4 700	3 060	3 020	54 300
a. Mineral Production	9 500	–	–	–	–	–	–	–	9 500
Cement Production	7 100	–	–	–	–	–	–	–	7 100
Lime Production	2 000	–	–	–	–	–	–	–	2 000
Mineral Product Use[3]	630	–	–	–	–	–	–	–	630
b. Chemical Industry	5 700	–	–	12.7	3 920	–	–	–	9 600
Ammonia Production	5 700	–	–	–	–	–	–	–	5 700
Nitric Acid Production	–	–	–	2.7	830	–	–	–	830
Adipic Acid Production	–	–	–	9.98	3 090	–	–	–	3 090
c. Metal Production	12 000	–	–	–	–	–	3 030	2 220	17 600
Iron and Steel Production	8 160	–	–	–	–	–	–	–	8 160
Aluminium Production	4 200	–	–	–	–	–	3 030	–	7 280
SF_6 Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	2 190	2 190
d. Consumption of Halocarbons and SF_6	–	–	–	–	–	4 700	30	800	5 500
e. Other & Undifferentiated Production	12 000	–	–	–	–	–	–	–	12 000
SOLVENT & OTHER PRODUCT USE	–	–	–	1.6	480	–	–	–	480
AGRICULTURE	–	1 290	27 200	89	28 000	–	–	–	55 000
a. Enteric Fermentation	–	1 140	24 000	–	–	–	–	–	24 000
b. Manure Management	–	150	3 200	17	5 300	–	–	–	8 400
c. Agricultural Soils	–	–	–	72	22 000	–	–	–	22 000
Direct Sources	–	–	–	37	12 000	–	–	–	12 000
Pasture, Range, and Paddock Manure	–	–	–	14	4 300	–	–	–	4 300
Indirect Sources	–	–	–	20	7 000	–	–	–	7 000
WASTE	200	1 300	28 000	3	1 000	–	–	–	29 000
a. Solid Waste Disposal on Land	–	1 300	27 000	–	–	–	–	–	27 000
b. Wastewater Handling	–	12	250	3	1 000	–	–	–	1 200
c. Waste Incineration	200	0.06	1	0.2	50	–	–	–	250
LAND USE, LAND-USE CHANGE AND FORESTRY	59 000	640	14 000	27	8 400	–	–	–	81 000
a. Forest Land	51 000	640	13 000	27	8 300	–	–	–	73 000
b. Cropland	–140	5	100	0.3	100	–	–	–	58
c. Grassland	–	–	–	–	–	–	–	–	–
d. Wetlands	1 000	0.1	3	0.01	2	–	–	–	1 000
e. Settlements	7 000	3	60	0	30	–	–	–	7 000

Notes:

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

2 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

3 The category mineral product use includes CO_2 emissions from the use of limestone & dolomite, soda ash, and magnesite.

Totals may not add due to rounding.

TABLE S-3: Canada's GHG Emission Trends by Sector, 1990–2004

GHG Source/Sink Categories	GHG Emissions				
	kt CO_2 eq				
	1990	1995	2000	2003	2004
TOTAL[1]	**599 000**	**649 000**	**725 000**	**754 000**	**758 000**
ENERGY	**475 000**	**517 000**	**596 000**	**622 000**	**620 000**
a. Stationary Combustion Sources	**283 000**	**296 000**	**347 000**	**368 000**	**360 000**
Electricity and Heat Generation	95 300	101 000	132 000	139 000	130 000
Fossil Fuel Industries	53 000	56 000	70 000	77 000	79 000
Petroleum Refining and Upgrading	23 000	25 000	24 000	30 000	29 000
Fossil Fuel Production	30 000	32 000	45 000	47 000	49 000
Mining	6 200	7 860	10 400	15 700	15 400
Manufacturing Industries	54 900	53 100	53 200	49 500	50 900
Iron and Steel	6 490	7 040	7 190	6 370	6 550
Non-Ferrous Metals	3 230	3 110	3 190	3 200	3 230
Chemical	7 100	8 460	7 860	5 820	6 290
Pulp and Paper	13 600	11 700	11 000	9 010	9 310
Cement	3 590	3 420	3 970	4 180	4 330
Other Manufacturing	20 900	19 400	20 000	20 900	21 200
Construction	1 880	1 180	1 080	1 300	1 350
Commercial & Institutional	25 800	29 000	33 200	37 900	37 900
Residential	44 000	45 000	45 000	45 000	43 000
Agriculture & Forestry	2 420	2 790	2 570	2 210	2 100
b. Transportation[2]	**150 000**	**160 000**	**180 000**	**190 000**	**190 000**
Domestic Aviation	6 400	5 900	6 600	7 300	7 800
Road Transportation	107 000	119 000	131 000	140 000	145 000
Light-Duty Gasoline Vehicles	53 800	51 400	48 300	49 400	49 800
Light-Duty Gasoline Trucks	21 700	28 400	37 600	41 900	43 600
Heavy-Duty Gasoline Vehicles	3 140	4 760	4 370	4 140	4 210
Motorcycles	230	214	238	226	219
Light-Duty Diesel Vehicles	672	594	604	722	768
Light-Duty Diesel Trucks	591	417	645	796	893
Heavy-Duty Diesel Vehicles	24 500	30 800	38 700	42 300	44 900
Propane & Natural Gas Vehicles	2 200	2 100	1 100	820	870
Railways	7 000	6 000	7 000	6 000	6 000
Domestic Marine	5 000	4 400	5 100	6 100	6 600
Others	20 000	30 000	30 000	30 000	30 000
Off-Road Gasoline	5 000	4 000	6 000	4 000	4 000
Off-Road Diesel	10 000	10 000	20 000	10 000	20 000
Pipelines	6 900	12 000	11 300	9 110	8 520
c. Fugitive Sources	**43 300**	**57 000**	**64 900**	**66 200**	**66 500**
Coal Mining	2 000	2 000	900	1 000	1 000
Oil and Natural Gas	41 400	55 300	64 000	65 200	65 500
Oil	6 700	8 400	9 400	10 000	9 900
Natural Gas	18 000	23 000	27 000	28 000	28 000
Venting	13 000	18 000	22 000	22 000	22 000
Flaring	4 400	5 400	5 500	5 700	5 400
INDUSTRIAL PROCESSES	**53 300**	**55 500**	**49 800**	**50 100**	**54 300**
a. Mineral Production	**8 300**	**8 800**	**9 600**	**9 100**	**9 500**
Cement Production	5 400	6 100	6 700	6 800	7 100
Lime Production	2 000	2 000	2 000	2 000	2 000
Mineral Product Use[3]	1 100	880	1 000	610	630
b. Chemical Industry	**15 000**	**17 000**	**7 100**	**7 000**	**9 600**
Ammonia Production	3 900	5 300	5 400	5 100	5 700
Nitric Acid Production	780	780	800	810	830
Adipic Acid Production	10 700	10 700	900	1 090	3 090
c. Metal Production	**19 500**	**19 200**	**18 900**	**17 200**	**17 600**
Iron and Steel Production	7 060	7 880	7 890	7 040	8 160
Aluminium Production	9 310	9 160	8 220	7 660	7 280
SF_6 Used in Magnesium Smelters and Casters	3 110	2 110	2 770	2 490	2 190
d. Consumption of Halocarbons and SF_6	**1 800**	**2 100**	**4 500**	**6 000**	**5 500**
e. Other & Undifferentiated Production	**8 300**	**8 700**	**9 700**	**11 000**	**12 000**
SOLVENT & OTHER PRODUCT USE	**420**	**440**	**460**	**480**	**480**
AGRICULTURE	**45 000**	**49 000**	**51 000**	**53 000**	**55 000**
a. Enteric Fermentation	**18 400**	**21 100**	**21 700**	**22 600**	**24 000**
b. Manure Management	**6 700**	**7 400**	**7 800**	**8 100**	**8 400**
c. Agricultural Soils	**20 000**	**21 000**	**22 000**	**22 000**	**22 000**
Direct Sources	11 000	11 000	11 000	11 000	12 000
Pasture, Range, and Paddock Manure	3 200	3 700	3 900	4 000	4 300
Indirect Sources	6 000	6 000	6 000	6 000	7 000
WASTE	**25 000**	**26 000**	**28 000**	**29 000**	**29 000**
a. Solid Waste Disposal on Land	**23 000**	**25 000**	**27 000**	**27 000**	**27 000**
b. Wastewater Handling	**1 100**	**1 100**	**1 200**	**1 200**	**1 200**
c. Waste Incineration	**400**	**330**	**250**	**240**	**250**
LAND USE, LAND-USE CHANGE AND FORESTRY	**–82 000**	**190 000**	**–130 000**	**–11 000**	**81 000**
a. Forest Land	**–110 000**	**180 000**	**–140 000**	**–20 000**	**73 000**
b. Cropland	**14 000**	**7 000**	**3 100**	**830**	**58**
c. Grassland	**–**	**–**	**–**	**–**	**–**
d. Wetlands	**6 000**	**3 000**	**2 000**	**1 000**	**1 000**
e. Settlements	**8 000**	**7 000**	**7 000**	**7 000**	**7 000**

Notes:

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

2 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

3 The category mineral product use includes CO_2 emissions from the use of limestone & dolomite, soda ash, and magnesite.

Totals may not add due to rounding.

Energy Sector emissions actually showed a net decrease (of about 2 Mt), the first year-to-year reduction since 1991. In 2004, although electricity demand increased, GHG emissions from electricity generation decreased by 9 Mt. This was due to a reduction in coal-fired generation. In 2003, coal supplied 18.4% of electricity generation; this was reduced to 16.5% in 2004. To fill the electricity generation gap, nuclear sources grew from 12.4% of supply to 14.8% in 2004. This trend is the result of ongoing efforts in Ontario to close that province's coal generation plants (Nyboer *et al.*, 2006).

On average, Canadian homes and businesses required lower energy quantities for space heating in the winter of 2004 compared with the winter of 2003 due to milder temperatures. In 2004, the number of heating degree-days (HDDs), an indicator of the necessity for space heating due to the severity of cold weather, was down 2.3% on a national basis compared with 2003. Ontario, Alberta, and British Columbia all experienced 4–5% fewer HDDs in 2004 than in 2003; Quebec was down almost 1%. This fact almost certainly had an impact on fossil fuel consumption, specifically in the residential category, where emissions declined by 2 Mt from 2003.

Nevertheless, overall emissions grew in 2004. Heavy-duty diesel vehicles (HDDVs, large transport trucks) and light cars and trucks — consisting of light-duty gasoline vehicles (LDGVs), or automobiles, and light-duty gasoline trucks (LDGTs), or pickup trucks, sport utility vehicles (SUVs), and some vans — showed emission increases of 2.6 Mt and 2.1 Mt, respectively, between 2003 and 2004. This growth is a continuation of long-term trends in road transport.

Industrial Processes Sector GHG emissions grew by 4.2 Mt between 2003 and 2004. The two primary contributors were an increase in consumption of fuel for undifferentiated, non-energy uses and a maintenance-based shutdown of an N_2O emission abatement system at Canada's only adipic acid production plant. (Adipic acid is a key ingredient in the manufacture of nylon.)

Emissions from the Agriculture Sector grew by 2 Mt (4.5%) from 2003 to 2004, mainly owing to an increase in animal enteric fermentation (digestive processes that release CH_4) emissions, based primarily on an 8% increase in beef cattle population.

ES.3.2.2 Long-Term Trends

Although the long-term (1990–2004) sectoral emission trends showed declines and increases (Figure S-4), the increases were well ahead of the declines, for a net growth of 159 Mt, or 27%. The largest portion of the growth is observed in the Energy Sector, where the Energy Industries (Fossil Fuel Industries plus Electricity and Heat Generation), Road Transportation, Commercial & Institutional, and Mining categories made the greatest contributions.

The activities of the Energy Industries' Fossil Fuel Industries include both combustion sources (Fossil Fuel Industries and Pipelines) and fugitive sources (Coal Mining and Oil and Natural Gas). There is also some overlap with Mining, which (as a result of categorizations by the Alberta Energy Utilities Board and Statistics Canada) includes a portion of oil sands production activities.

Oil and gas activities, representing by far the largest portion of the fossil fuel industries, registered a net increase of about 52 Mt of GHG emissions from 1990 to 2004 (51% growth).[5] These emissions are related to the production, transmission, processing, refining, and distribution of all oil and gas products.

Over the period, total production of crude oil and natural gas increased by 65% (see Section ES.4.1), with an attendant 55% increase in subsector GDP.[6] Increasing demand in both Canada and the United States drove these trends, with the export market growing by far the most rapidly (see Section ES.4.1). Although increasing demand provides a portion of the explanation for the emission trend, it does not paint the complete picture.

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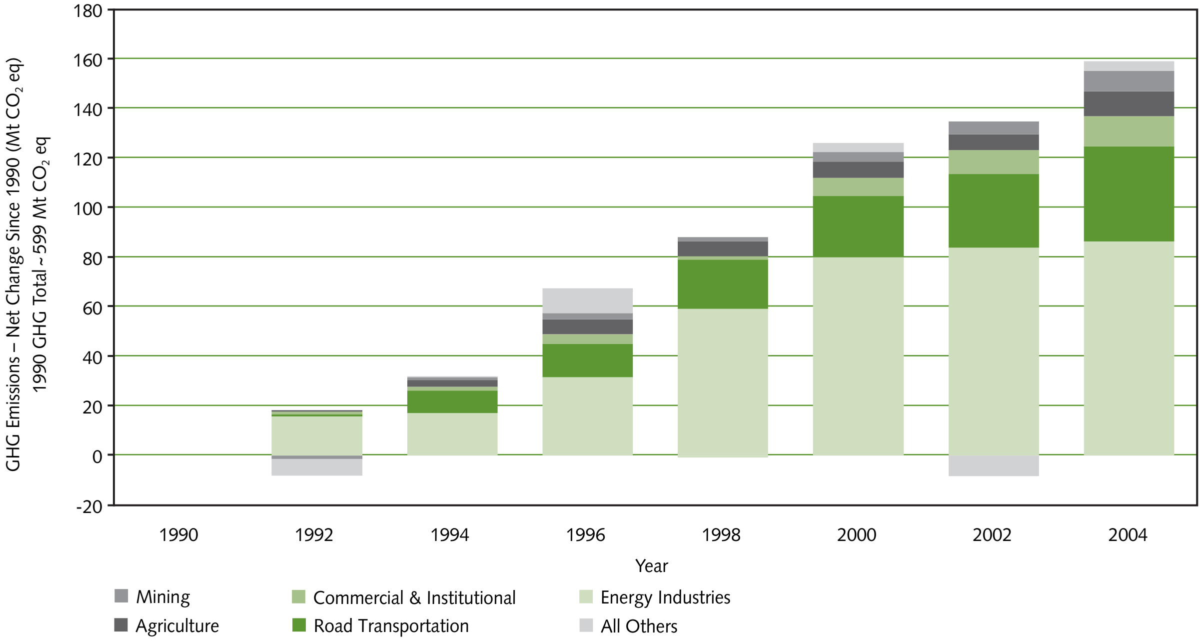
[5] Relative to the categorizations of Table S-3, the oil and gas industry emissions discussed here include Petroleum Refining, Fossil Fuel Production (minus coal), Transportation – Pipelines, all Oil and Natural Gas fugitives, and that part of Mining representing the oil sands. Since the industry also produces CO_2 from certain chemical processes, a portion of Industrial Processes Sector emissions (about 4 Mt of those categorized under Other and Undifferentiated Production) is included as well. See the analysis presented in Annex 10.

[6] Source for all sector economic growth figures: Informetrica Limited.

FIGURE S-4: **Change in GHG Emissions from 1990 Baseline, 1992–2004**



Note:

Mining excludes that portion of emissions associated with the oil sands industry (included in Energy Industries). Energy Industries includes both the Fossil Fuel Industries and Electricity and Heat Generation.

Since well before 1990, easily removable reserves of conventional crude have been falling. Thus, energy consumption per unit of conventional oil produced has been increasing (Neitzert *et al*., 1999). In fact, between 1990 and 2000, the energy requirements per barrel of conventional light/medium oil extracted nearly doubled (Nyboer and Tu, 2006). At the same time, highly energy- and GHG-intensive[7] synthetic oil production (i.e., from oil sands) has become increasingly competitive with conventional oil extraction. These trends then also contribute significantly to the rapidly rising emission increases in the oil and gas industry over the 1990–2004 period.

Electricity and Heat Generation, representing the other portion of the Energy Industries, also saw large increases. Rising demand for electricity, exacerbated by the increasing use of fossil fuels in the generation mix, drove GHG emissions up by almost 35 Mt between 1990 and 2004. In 2004, electricity demand was 109 terrawatt-hours (TWh) above the 1990 level. Although this increased demand was supplied in part by greater hydroelectricity and nuclear generation, fossil fuel generation rose even more. The result was that by 2004, hydropower's share of the generation mix had fallen from 63% to 59%, while fossil fuels' had risen from 21% to 25%, worsening the average GHG intensity of production. The end result was that from 1990 to 2004, generation rose 23%, while GHG emissions increased 37%, about 1.5 times the generation increase.

Of note in these trends is that coal's portion of electricity generation, which had been increasing since the mid-1990s, dropped off to about 16.5% in 2004, a level about the same as it was in 1990. As mentioned above, it appears as if this is largely the result of Ontario's program to reduce coal generation within the province.

Emissions from Road Transportation rose by 38 Mt (36%) between 1990 and 2004. Of particular interest in this subsector is a 22 Mt increase in emissions from LDGTs. This was partially offset by 4 and 1.3 Mt emission reductions from gasoline-fuelled cars (LDGVs) and alternatively fuelled cars (Propane & Natural Gas Vehicles).

The primary source of this net trend of rising emissions is the increase in the number of passenger-kilometres travelled (more people drove further) (NRCan, 2005). However, it was light trucks' passenger-kilometres

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

that increased, while cars' showed reductions. Substantiating this is the fact that the number of light trucks on the road doubled between 1990 and 2004, while the number of automobiles contracted slightly. Since light trucks have higher emissions per kilometre than automobiles, the rising popularity of SUVs and pickups worsened the emission impact of increasing numbers of people driving further.

Research suggests[8] that, over the period, about 10% of the emission increase from automobiles and light trucks can be attributed purely to the shift in the type of private vehicles being driven. Perhaps of greater concern is the overall trend towards increasing horsepower, which has negated the rather substantial efficiency improvements made in power plants for all classes of passenger vehicles.

Emissions from HDDVs (large freight trucks) rose by about 20 Mt between 1990 and 2004, an 83% increase. Spurred on by free trade and the deregulation of the trucking industry, the amount of freight shipped grew rapidly over the period. In addition, the quantity shipped by truck (as opposed to other modes of transport, such as rail) increased as a result of customer requirements for just-in-time delivery and cross-border freight (NRCan, 2005).

The Commercial & Institutional category displayed a 12 Mt (47%) growth in GHG emissions between 1990 and 2004. Driving this trend was a significant increase in the floor space (25% between 1990 and 2003) of commercial and institutional buildings (e.g., offices, schools, stores, and government edifices), a result of Canada's growing economy over the period (NRCan, 2005). Energy demand in commercial buildings is also influenced by weather. In terms of HDDs, 2004 was 8% colder than 1990, so this contributed to the emission growth; however, its impact was considerably less than that of increased floor space.

Mining showed a large increase in emissions between 1990 and 2004 — 9.2 Mt (about 149%), when excluding the portion related to oil sands activities — on the basis of a 48% growth in sector GDP.

Another sector that contributed, although to a lesser extent than Energy, to the longer-term growth in GHG emissions is Agriculture. This sector showed a 10 Mt increase (23%) between 1990 and 2004, resulting primarily from the expansion of the beef cattle, swine, and poultry industries, as well as an increase in synthetic nitrogen fertilizer consumption.

In addition to the already-mentioned reduction in emissions from automobiles, two subsectors, both within the Industrial Processes Sector, contributed towards counteracting 1990–2004 emission growth — Adipic Acid Production (Chemical Industry) and Aluminium Production (Metal Production).

While output increased at the sole adipic acid production plant in Canada, the installation of an emission abatement system in 1997 resulted in significant reductions of N_2O emissions. Despite being temporarily off-line in 2004, this system reduced GHG emissions by 7.6 Mt (71%) over the 1990–2004 period.

In the aluminium industry (which emits both CO_2 and PFCs), PFC emissions were reduced as a result of better control of anode events in smelters by increasing use of electronic monitoring and automated emission controls. As a result, between 1990 and 2004, total GHG process emissions from the aluminium industry decreased by 2.03 Mt (22%), while primary aluminium production increased by more than 60%.[9]

Although it does not contribute to national totals, it is of interest to consider the trends in the LULUCF Sector. The net flux, calculated as the sum of CO_2 emissions and removals and non-CO_2 emissions, displays high interannual variability over the reporting period. In fact, there is no discernible trend, with the flux ranging from net emissions of 190 Mt (in 1995) to net removals of 130 Mt (in 2000). Bracketing the period is a net removal of 82 Mt in 1990 and a net emission of 81 Mt in 2004. The interannual swings are primarily a consequence of the large and variable impact of emissions from wildfires, which are inventoried under the LULUCF Sector.

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[8] Adapted from NRCan (2005).

[9] Source: Aluminum Association of Canada. Data provided to Greenhouse Gas Division, Environment Canada.

ES.4 OTHER INFORMATION

ES.4.1 EMISSIONS ASSOCIATED WITH THE EXPORT OF OIL AND NATURAL GAS

Canada is rich in fossil fuel resources. The fossil fuel industry, with a GDP of $33 billion[10] in 2004, contributes significantly to the economy. A much greater quantity of Canada's oil and gas production is sold internationally now than in the past.

Growth in oil and gas exports, almost all to the United States, contributed significantly to emissions growth[11] between 1990 and 2004. In this period, net oil exports (exports minus imports) grew by 513% to 1572 petajoules (PJ)[12] (almost 10 times the rate of growth of oil production) (Table S-4), while net exports of natural gas increased 138% to 3600 PJ (almost twice the rate of growth of natural gas production) (Table S-5). Over the period, the sum total of net oil and gas energy exports increased by 192% (Table S-6).

The portion of emissions from all oil and gas production, processing, and transmission activities that is attributable to net exports[13] rose from about 22 Mt in 1990 to 48 Mt in 2004 (a 123% increase; Table S-6).[14] This 26 Mt increase is half of the total 52 Mt growth in emissions from the oil and gas industry, which is in turn about one-third of the 159 Mt national emission growth over the period.

It should be noted that natural gas exports fell between 2002 and 2003; although growth resumed between 2003 and 2004, it was relatively small. In fact, it has been forecasted that since the reserves in Canada's largest natural gas reservoir (the Western Sedimentary Basin) are reaching their limit, the country's natural gas production will not increase significantly in the future (Nyboer and Tu, 2006). As a result, gas exports may show very little growth from this point on.

TABLE S-4: Crude Oil: Production, Net Export, and GHG Emission Trends, 1990–2004

Crude Oil	1990	1995	2000	2003	2004
Domestic Production (PJ)	**3562**	**4170**	**4669**	**5427**	**5648**
Growth Since 1990	N/A	17%	31%	52%	59%
Energy Exported (PJ)	**1526**	**2466**	**3227**	**3596**	**3783**
Growth Since 1990	N/A	62%	111%	136%	148%
Net Energy Export (imports minus exports) (PJ)	**256**	**1070**	**1067**	**1452**	**1572**
Growth Since 1990	N/A	318%	316%	466%	513%
Emissions Associated with Net Exports (Mt CO_2 eq)	**8.8**	**17.8**	**16.5**	**20.7**	**22.0**
Growth Since 1990	N/A	102%	87%	135%	150%

Note:
N/A = not available

TABLE S-5: Natural Gas: Production, Net Export, and GHG Emission Trends, 1990–2004

Natural Gas	1990	1995	2000	2003	2004
Domestic Production (PJ)	**4184**	**6129**	**7060**	**7065**	**7136**
Growth Since 1990	N/A	47%	69%	69%	71%
Energy Exported (PJ)	**1537**	**3011**	**3846**	**3876**	**4015**
Growth Since 1990	N/A	96%	150%	152%	161%
Net Energy Export (imports minus exports) (PJ)	**1513**	**2985**	**3785**	**3506**	**3600**
Growth Since 1990	N/A	97%	150%	132%	138%
Emissions Associated with Net Exports (Mt CO_2 eq)	**12.7**	**25.1**	**31.1**	**25.6**	**25.9**
Growth Since 1990	N/A	98%	145%	101%	104%

Note:
N/A = not available

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[10] Constant 1997 dollars (source: Informetrica, January 2006).

[11] The source for all export and energy production data is Statistics Canada, #57-003. The 1990–1995 GHG emissions associated with net exports are taken from a report prepared for Environment Canada (McCann, 1997), while the 1996–2004 estimates were extrapolated from this report.

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

[13] Net export emissions are the Canadian emissions associated with extracting, processing, and transporting exported fuel minus the Canadian emissions associated with transporting and processing imported fuels.

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

TABLE S-6: Combined Crude Oil and Natural Gas: Production, Net Export, and GHG Emission Trends, 1990–2004

Combined Crude Oil and Natural Gas	1990	1995	2000	2003	2004
Domestic Production (PJ)	**7 746**	**10 299**	**11 729**	**12 492**	**12 784**
Growth Since 1990	N/A	33%	51%	61%	65%
Energy Exported (PJ)	**3 063**	**5 477**	**7 073**	**7 473**	**7 798**
Growth Since 1990	N/A	79%	131%	144%	155%
Net Energy Export (imports minus exports) (PJ)	**1 769**	**4 056**	**4 851**	**4 958**	**5 172**
Growth Since 1990	N/A	129%	174%	180%	192%
Emissions Associated with Net Exports (Mt CO_2 eq)	**21.5**	**42.9**	**47.5**	**46.2**	**47.8**
Growth Since 1990	N/A	100%	121%	115%	123%

Note:
N/A = not available

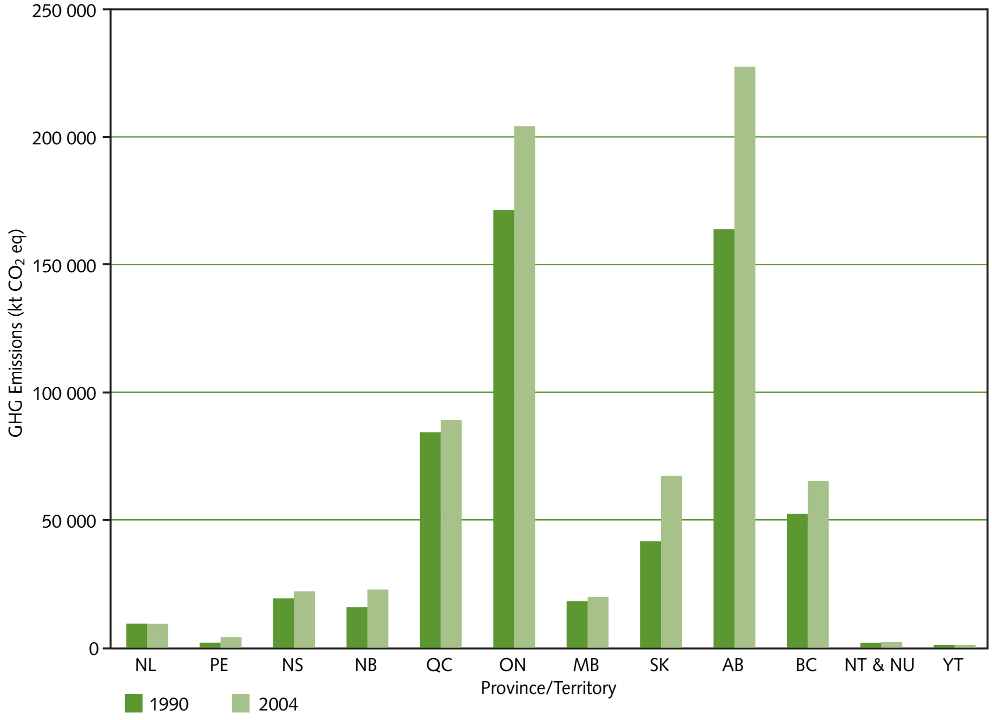
ES.4.2 PROVINCIAL/TERRITORIAL GREENHOUSE GAS EMISSIONS

It is important to note that Canada's GHG emissions vary from region to region. This is linked to the distribution of natural resources and heavy industry within the country. While the use of natural resources and industrial products benefits all regions of North America, emissions from their production tend to be concentrated in particular geographic regions. Thus, particular jurisdictions in Canada tend to produce more GHG emissions because of their economic and industrial structure and their relative dependence on fossil fuels for producing energy. Figure S-5 illustrates the provincial/territorial distribution of emissions and the change in these emissions between 1990 and 2004.

ES.4.3 THE INTERNATIONAL CONTEXT

Canada contributes about 2% of total global GHG emissions. It is one of the highest per capita emitters,

FIGURE S-5: Total Provincial/Territorial GHG Emissions, 1990 and 2004



largely the result of its size, climate (i.e., energy demands), and resource-based economy. In 2004, Canada emitted about 24 t of GHGs per capita, which represents a 10% growth since 1990 (see Table S-1).

In terms of total anthropogenic GHG emissions, Canada ranks sixth among the nine Annex I Parties whose emissions increased more than 20% over the 1990–2003 period[15] and first among the G8 nations. Canada's +24% growth (–6% Kyoto target) compares with Spain's +42% growth (–8% target), Greece's +26% rise (–8% target), and Japan's +13% increase (–6% target). Parties whose emissions decreased by 2003 include the European Union, by –1% (–8% target), the United Kingdom, by –13% (–8% target), and Germany, by –18% (–8% target).

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[15] These aggregate estimates are based on the most recent data from 39 Parties that submitted inventories to the UNFCCC in 2005 (Table 5 in UNFCCC, 2005).

1 INTRODUCTION

1.1 GHG INVENTORIES AND CLIMATE CHANGE

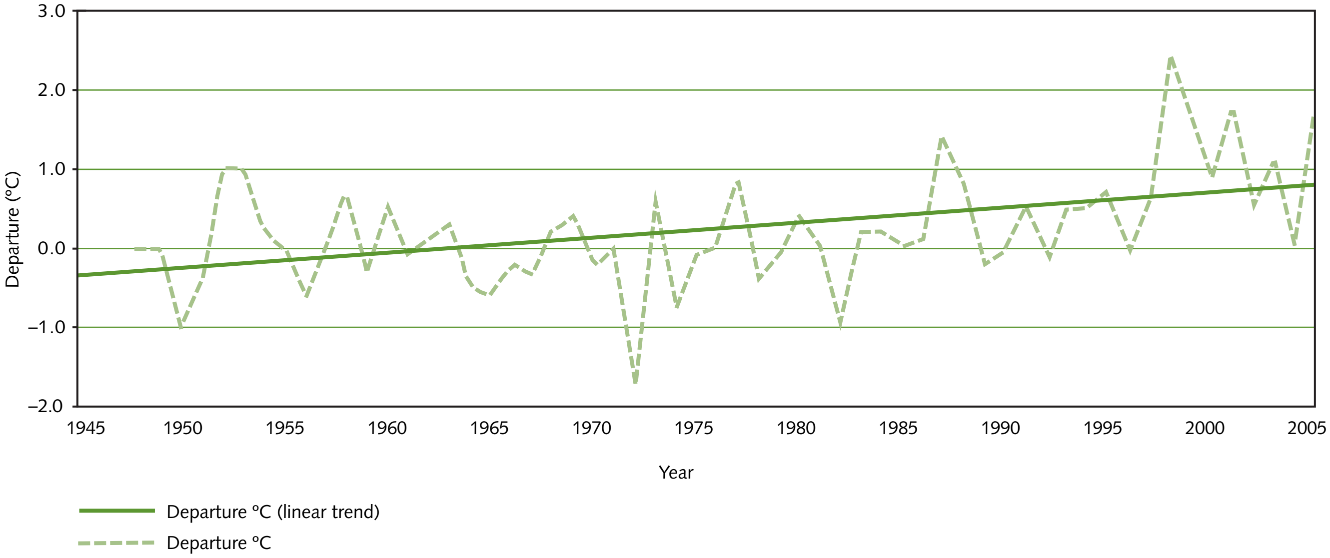
In order to understand climate change, it is important to differentiate between weather and climate. Weather is the state of the atmosphere at a given time and place and is usually reported as temperature, air pressure, humidity, wind, cloudiness, and precipitation. The term weather is used mostly when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

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

Climate change refers to changes in long-term weather patterns caused by natural phenomena and human activities that alter the chemical composition of the atmosphere through the buildup of GHGs, which trap heat and reflect it back to the Earth's surface. According to the IPCC's Third Assessment Report (IPCC, 2001b), climate change is predicted to manifest itself differently in different regions of the world. In general, temperatures and sea levels are expected to rise, and the frequency of extreme weather events is expected to increase. In some regions, the impacts could be devastating, while other regions could benefit from climate change. The impacts will depend on the form and magnitude of the change and, in the case of adverse effects, the ability of the natural and human systems to adapt to the changes. Canada's temperatures have generally been increasing nationally, with temperatures remaining above normal since 1996 and showing a warming trend of 1.2°C over the period 1948–2005 (Figure 1-1).

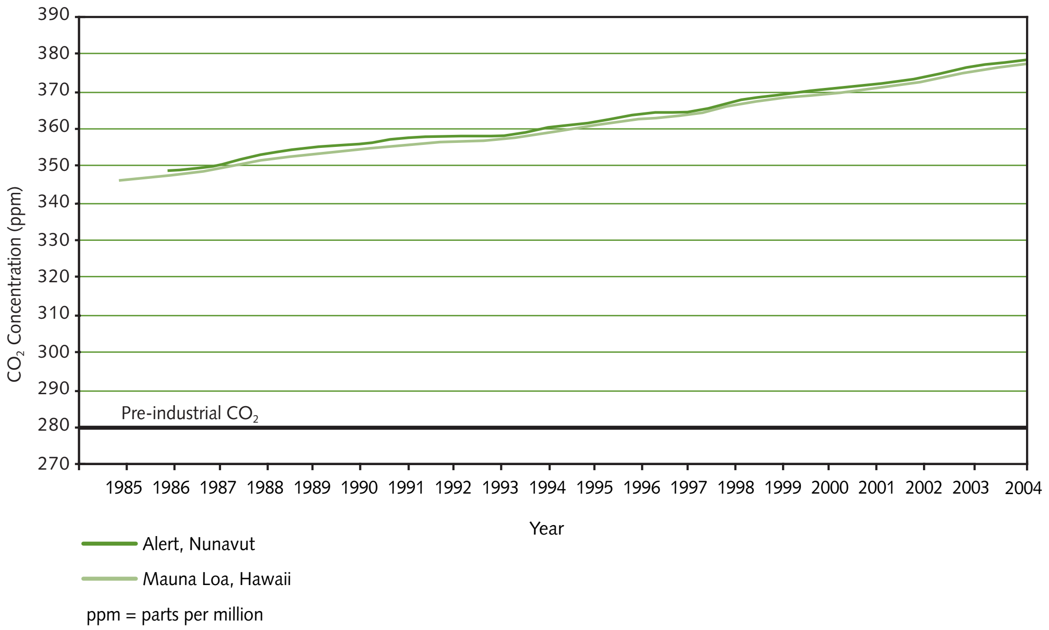
It is now well-known that atmospheric concentrations of GHGs have grown significantly since pre-industrial times (Figure 1-2). The concentration of CO_2 has increased by 31% since 1750, the concentration of CH_4 has increased by 151%, and the concentration of N_2O has increased by 17% (IPCC, 2001a). These trends can be largely attributed to human activities — mostly fossil fuel use and permanent loss of forest cover.

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



Source: Environment Canada
www.msc-smc.ec.gc.ca/ccrm/bulletin/

FIGURE 1-2: **Global Atmospheric Concentrations of CO_2**



Source: C.D. Keeling, T.P. Whorf, and the Carbon Dioxide Research Group, Scripps Institution of Oceanography, University of California
http://cdiac.esd.ornl.gov/ftp/trends/CO2/

The ultimate objective of the UNFCCC is to achieve stabilization of GHG concentrations in the atmosphere at a level that would prevent dangerous interference with the climate system. In its actions to achieve its objective and to implement its provisions, the UNFCCC lays out a number of guiding principles and commitments. Article 4.1 of the Convention commits all Parties to develop, periodically update,[16] publish, and make available to the Conference of the Parties national inventories of anthropogenic[17] emissions by sources and removals by sinks of all GHGs not controlled by the Montreal Protocol using comparable methodologies. This report provides estimates of Canada's emissions and removals of the following GHGs: CO_2, CH_4, N_2O, SF_6, PFCs, and HFCs. In addition, and in keeping with the UNFCCC reporting guidelines for Annex I Parties, this report contains estimates of the ozone precursors NO_x, CO, and NMVOCs, as well as SO_2.

1.1.1 CO_2

On a worldwide basis, CO_2 emissions generated from anthropogenic activities are known to be small. In comparison with the gross fluxes of carbon (C) from natural systems, they represent only a fraction (~2%) of total global emissions. However, evidence suggests that they account for most of the observed accumulated CO_2 in the atmosphere (Sullivan, 1990; Edmonds, 1992). On the basis of global emissions information, the primary sources of CO_2 generated from anthropogenic activities are fossil fuel combustion (including both stationary and mobile sources), deforestation (resulting in permanent loss of forest cover), and industrial processes, such as cement production.

Over the 45 years leading to 1996, global emissions of CO_2 grew from about 6.4 to 23.9 gigatonnes (Gt), an almost fourfold increase (Marland *et al.*, 1999).

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

[17] Anthropogenic refers to human-induced emissions and removals that occur on managed lands.

Deforestation, land-use practices, and ensuing soil oxidation have been estimated to account for about 23% of anthropogenic CO_2 emissions. The primary natural sources of CO_2 include respiration by plants and animals, decomposing organic matter and fermentation, volcanoes, forest/grass fires, and oceans. The two main natural carbon-balancing processes, photosynthesis in terrestrial and aquatic ecosystems and storage in ocean sediments, remove substantial amounts of CO_2 from the atmosphere. However, the absorption capacity of these natural sinks appears to be exceeded, as atmospheric concentrations of CO_2 and other GHGs are increasing.

1.1.2 CH_4

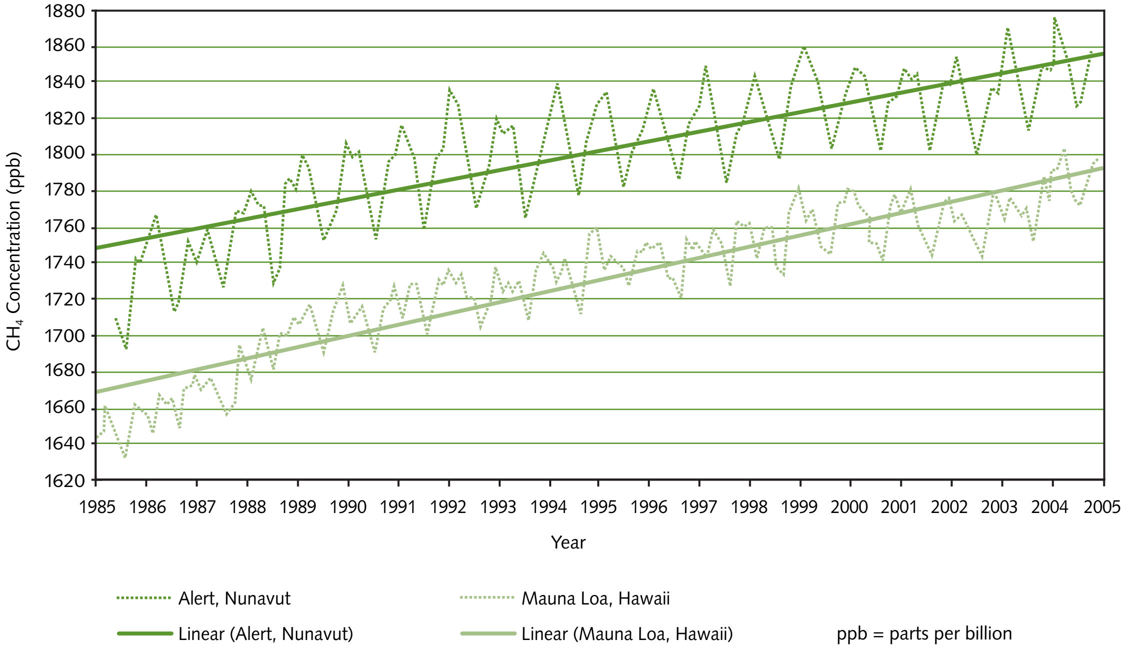
Excess global CH_4 emissions resulting from anthropogenic activities are considered to have caused an increase of about 145% in atmospheric concentrations of CH_4 since the mid-1700s (Thompson *et al.*, 1992). Recent atmospheric measurements of CH_4 concentrations are shown in Figure 1-3.

The current annual rate of accumulation of CH_4 is estimated to range between 40 and 60 Mt (~14–21 parts per billion by volume, or ppbv), or approximately 10% of total worldwide CH_4 emissions (Thompson *et al.*, 1992). Methane emissions generated from human activities, amounting to ~360 Mt, are primarily the result of activities such as livestock and rice cultivation, biomass burning, natural gas delivery systems, landfills, and coal mining (EPA, 1981). Although several uncertainties exist in the actual contributions and relative importance of these sources, emission reductions of about 8% are thought to be required to stabilize CH_4 concentrations at current levels (IPCC, 1996a).

1.1.3 N_2O

At present, it has been estimated that approximately one-third of global atmospheric N_2O is of human origin, resulting primarily from the application of nitrogen fertilizers, soil cultivation, and the combustion of fossil fuels and wood. Atmospheric concentrations of N_2O have grown by about 17% since the mid-1700s (IPCC, 2001a). Total annual emissions from all sources are estimated to be within the range of 10–17.5 Mt N_2O, expressed as nitrogen (N) (IPCC, 1996b).

FIGURE 1-3: Global Atmospheric Concentrations of CH_4, 1985–2004



Source: J.W. Elkins and G.S. Dutton, *Climate Monitoring and Diagnostics Laboratory*, World Data Centre for Greenhouse Gases http://gaw.kishou.go.jp/wdcgg.html

Figure 1-4 shows global atmospheric N_2O concentrations from 1988 to 2004. The other two-thirds of global atmospheric N_2O comes from soil and water denitrification under anaerobic conditions.

1.1.4 HFCs, PFCs, AND SF_6

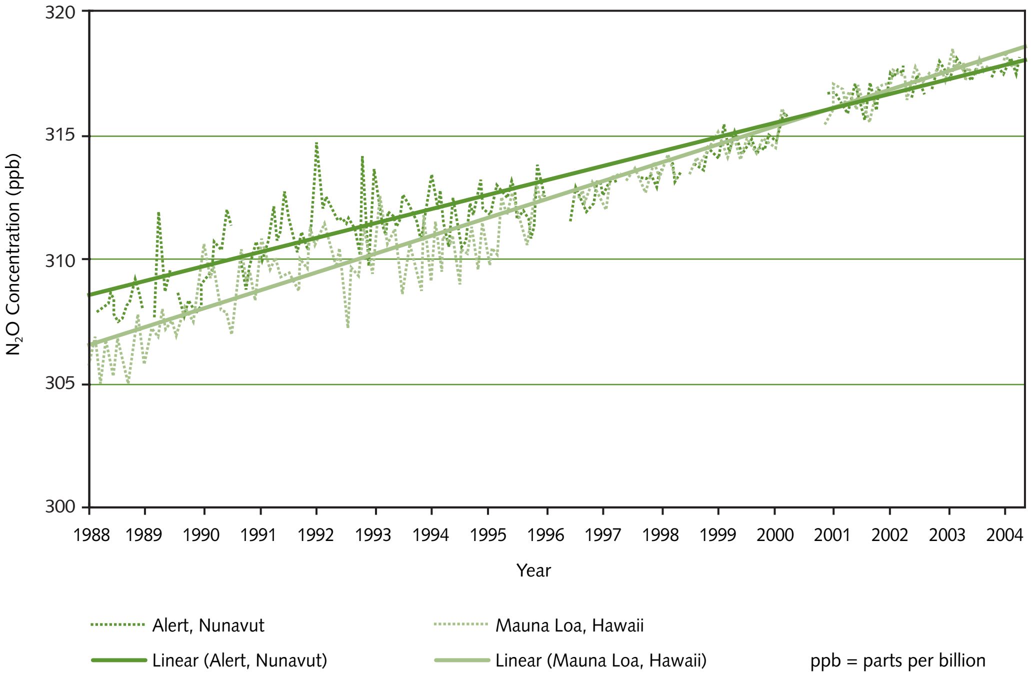
The final group of GHGs included in this report is the synthetic (not naturally occurring) fluorinated gases HFCs, PFCs, and SF_6. These gases, while emitted in very small amounts, are having a lasting effect on atmospheric composition and, potentially, the climate, because they are strong absorbers of infrared radiation and have very long atmospheric lifetimes. As shown in Table 1-1, all of the PFCs have atmospheric lifetimes of 2600 years or greater, with perfluoromethane estimated to last 50 000 years.

1.1.5 GHGs AND THE USE OF GWPs

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

The concept of "global warming potential" (GWP) has been developed to allow scientists and policymakers to compare the ability of each GHG to trap heat in the atmosphere relative to another gas. By definition, a GWP is the time-integrated change in radiative forcing due to the instantaneous release of 1 kg of the gas expressed relative to the radiative forcing from the release of 1 kg of CO_2. In other words, a GWP is a relative measure of the warming effect that the emission of a radiative gas (i.e., a GHG) might have on the surface troposphere. The GWP of a GHG takes into account both the instantaneous radiative forcing due to an incremental concentration increase and the lifetime of the gas. The 100-year GWPs, recommended by the IPCC (Table 1-1) and required for inventory reporting under the UNFCCC (adopted at the third Conference of the Parties), are used in this report.

FIGURE 1-4: Global Atmospheric Concentrations of N_2O, 1988–2004



Source: J.W. Elkins and G.S. Dutton, Climate Monitoring and Diagnostics Laboratory, World Data Centre for Greenhouse Gases http://gaw.kishou.go.jp/wdcgg.html

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

TABLE 1-1: GWPs and Atmospheric Lifetimes

GHG	Formula	100-Year GWP	Atmospheric Lifetime *(years)*
Carbon Dioxide	CO_2	1	Variable
Methane	CH_4	21	12 ± 3
Nitrous Oxide	N_2O	310	120
Sulphur Hexafluoride	SF_6	23 900	3 200
Hydrofluorocarbons (HFCs)			
HFC-23	CHF_3	11 700	264
HFC-32	CH_2F_2	650	5.6
HFC-41	CH_3F	150	3.7
HFC-43-10mee	$C_5H_2F_{10}$	1 300	17.1
HFC-125	C_2HF_5	2 800	32.6
HFC-134	$C_2H_2F_4$ (CHF_2CHF_2)	1 000	10.6
HFC-134a	$C_2H_2F_4$ (CH_2FCF_3)	1 300	14.6
HFC-143	$C_2H_3F_3$ (CHF_2CH_2F)	300	1.5
HFC-143a	$C_2H_3F_3$ (CF_3CH_3)	3 800	3.8
HFC-152a	$C_2H_4F_2$ (CH_3CHF_2)	140	48.3
HFC-227ea	C_3HF_7	2 900	36.5
HFC-236fa	$C_3H_2F_6$	6 300	209
HFC-245ca	$C_3H_3F_5$	560	6.6
Perfluorocarbons (PFCs)			
Perfluoromethane	CF_4	6 500	50 000
Perfluoroethane	C_2F_6	9 200	10 000
Perfluoropropane	C_3F_8	7 000	2 600
Perfluorobutane	C_4F_{10}	7 000	2 600
Perfluorocyclobutane	$c\text{-}C_4F_8$	8 700	3 200
Perfluoropentane	C_5F_{12}	7 500	4 100
Perfluorohexane	C_6F_{14}	7 400	3 200

Note:

The CH_4 GWP includes the direct effect and those indirect effects due to the production of tropospheric ozone and stratospheric water vapour. Not included is the indirect effect due to the production of CO_2.

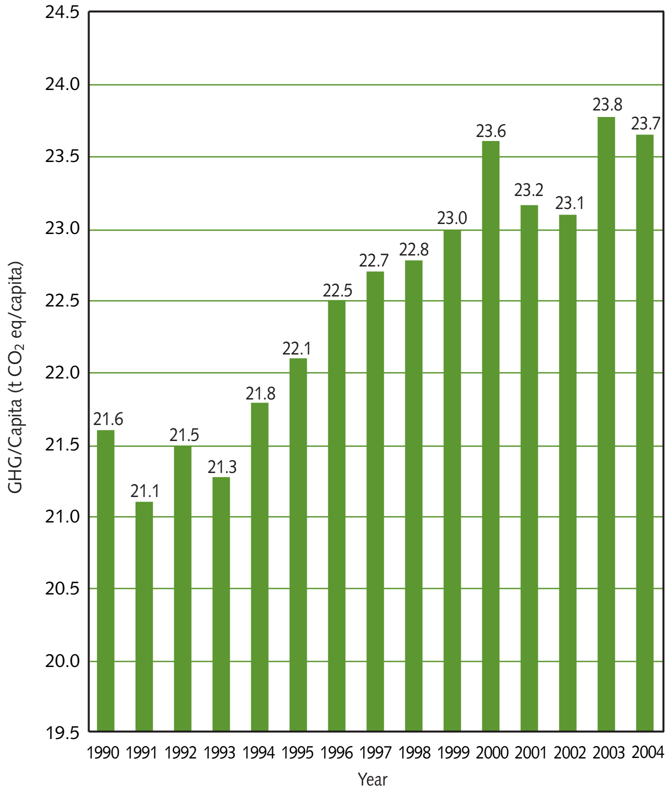
Sources:

GWP: IPCC (1996a).
Atmospheric Lifetime: IPCC (1995), Table 2.9, p. 121.

1.1.6 CANADA'S CONTRIBUTION

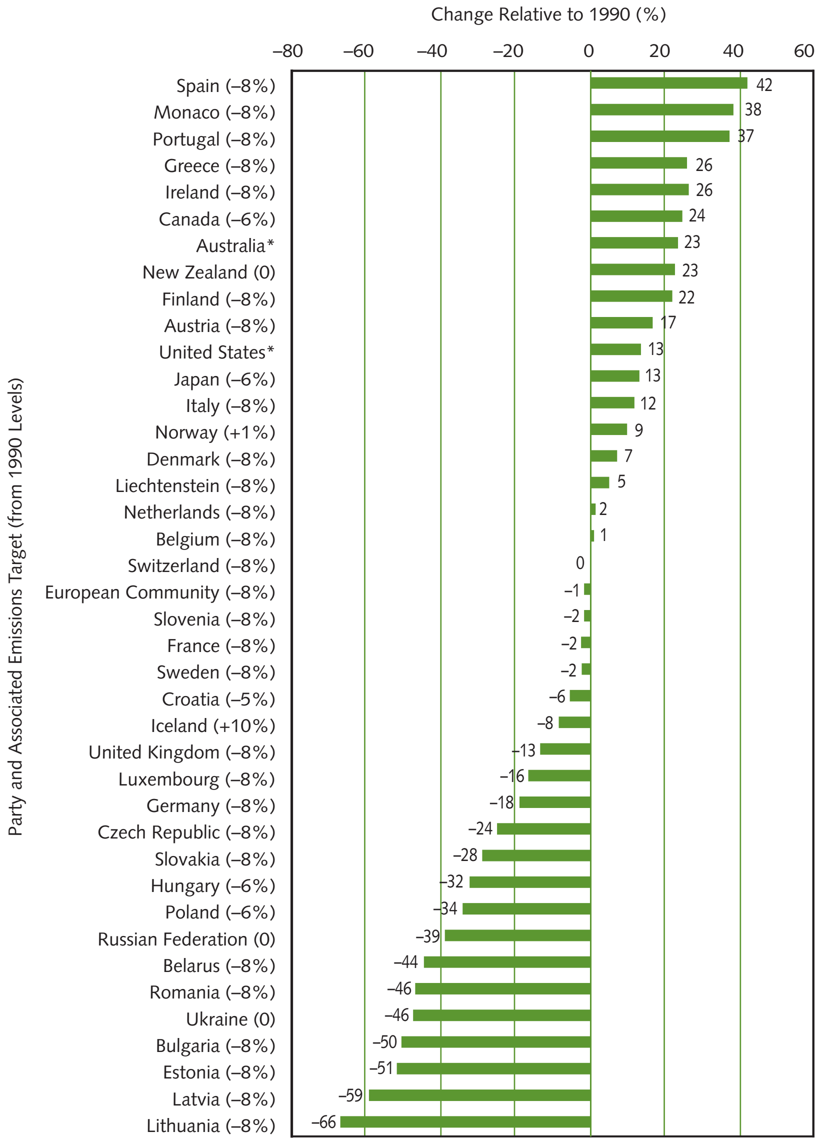
While Canada contributes only about 2% of total global GHG emissions, it is one of the highest per capita emitters, largely the result of its size, climate (i.e., energy demands), and resource-based economy. In 1990, Canadians released 21.6 t of GHGs per capita. By 2004, this had increased to 23.7 t of GHGs per capita (Figure 1-5).

FIGURE 1-5: Per Capita GHG Emission Trends for Canada, 1990–2004



In terms of growth in total anthropogenic GHG emissions, Canada ranks sixth among the nine Annex I Parties whose emissions increased more than 20% over the 1990–2003 period (Figure 1-6), and first among the G8 countries. These aggregate estimates are based on data from 39 Parties that submitted inventories to the UNFCCC in 2005 and on carrying forward the last reported inventory data taken from inventory submissions or national communications for those Parties where 2003 data were not reported.

FIGURE 1-6: **Change in Aggregate GHG Emissions for Annex I Parties, 1990–2003**



* Countries that have not ratified the Kyoto Protocol

Note: Changes are with respect to 2003 or the most recent year for which data were available.

Source: UNFCCC (2005), Table 5

1.2 INSTITUTIONAL ARRANGEMENTS FOR INVENTORY PREPARATION

1.2.1 THE NATIONAL INVENTORY SYSTEM

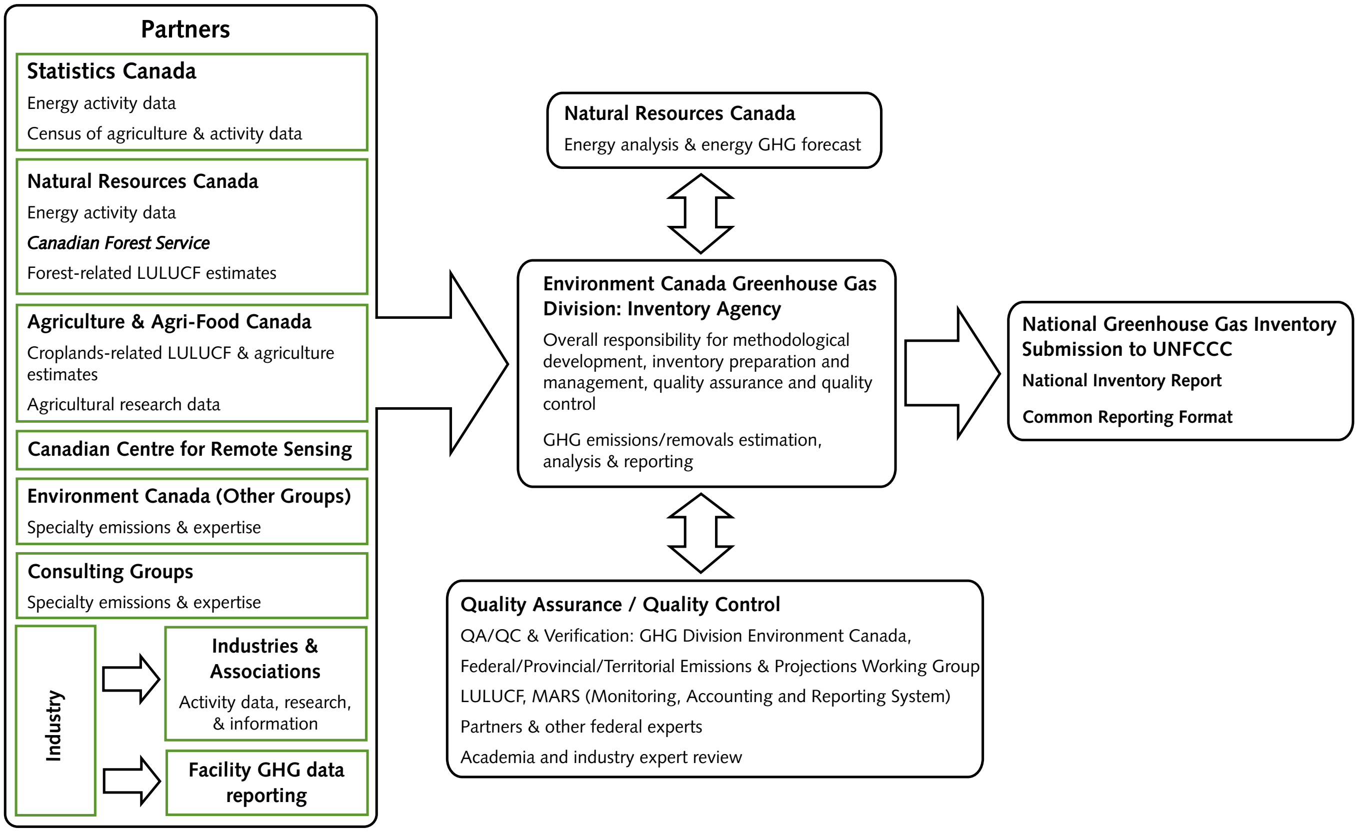
The Department of the Environment (Environment Canada) is responsible for monitoring and reporting on the environment in Canada. The *Canadian Environment Protection Act, 1999* (CEPA 1999) is the legislative authority for Environment Canada to establish the national inventory system and to designate Environment Canada's Greenhouse Gas Division as the single national entity with responsibility for the preparation and submission of the national inventory to the UNFCCC. As such, the Greenhouse Gas Division is responsible for the national GHG inventory and for the development and implementation of Canada's national inventory system. Both the system and the inventory must comply with international UNFCCC and Kyoto Protocol requirements and guidelines. The national system includes all institutional, legal, and procedural arrangements made within a Party for estimating emissions and removals of GHGs, as well as for reporting and archiving the inventory information. This requires that a number of key inventory planning, preparation, and management functions be performed. One of them is to define specific responsibilities in the inventory development process and to allocate them to other agencies as required. Responsibilities are described below under institutional arrangements, whereas the process for the preparation of the inventory is detailed in Section 1.3. In accordance with guidelines under Article 5.1 of the Kyoto Protocol, a full description of the national system is to be included in Canada's initial report, due January 1, 2007, to the UNFCCC. This report is also intended to facilitate the calculation of the assigned amount under Article 7.4.

1.2.2 INSTITUTIONAL ARRANGEMENTS

Underlying data and other estimates used to prepare the inventory are collected by the Greenhouse Gas Division from a variety of agencies, including Statistics Canada (e.g., energy, transport, livestock, crop production, and land statistics), Natural Resources Canada (NRCan) (e.g., mineral production and forestry-related statistics, activity data, and estimates), Agriculture and Agri-Food Canada (AAFC) (e.g., agricultural soil model results and parameters, activity data, and some GHG estimates), as well as other sections of Environment Canada (e.g., landfill gas capture, HFC and PFC use data, ozone, and aerosol precursors). Some of these institutional partnerships have been formalized through agreements, as detailed below. Figure 1-7 provides a schematic of responsibilities and arrangements for the national inventory system.

Environment Canada and Statistics Canada have legislated reporting provisions to ensure consistent reporting in Canada. The majority of the underlying activity data, in particular energy production and use data, are collected by Statistics Canada under the authority of the *Statistics Act*. To improve the accuracy of the inventory, Environment Canada has established

FIGURE 1-7: **Institutional Arrangements for the National Inventory System**



a formal agreement (Memorandum of Understanding) with Statistics Canada to provide Environment Canada with access to confidential facility-level information, which in turn helps to improve the quality of the inventory. Environment Canada uses mandatory reporting provisions of CEPA 1999 to collect HFC and PFC use data. The remainder of the data used for the inventory are collected from a variety of published sources. Section 1.4.1 describes current provisions for reporting GHG emissions by Canada's major emitters.

Clear roles have been established between Environment Canada and NRCan. This has been agreed to in a Memorandum of Understanding between the Greenhouse Gas Division of Environment Canada and the Analysis and Modelling Division of NRCan. Under the agreement, Environment Canada prepares and compiles the national GHG inventory, and NRCan is responsible for preparing GHG emission forecasts.

For the LULUCF Sector of the inventory, specific arrangements have been made to ensure that the latest scientific knowledge and expertise are used in the inventory. Chaired by the Greenhouse Gas Division of Environment Canada, the Monitoring, Accounting and Reporting System (MARS) for LULUCF is an interdepartmental steering committee that coordinates the activities of three federal departments and other relevant agencies to develop the necessary inventory estimation and accounting systems, ensuring that Canada meets both UNFCCC-specific and Kyoto Protocol–specific reporting requirements for the LULUCF Sector.[19] In 2004, Memoranda of Understanding were signed between Environment Canada and the Canadian Forest Service (CFS) and between Environment Canada and AAFC, delineating the respective responsibilities of those agencies to develop forest-, cropland-, and grassland-related estimates for inclusion in the inventory. The CFS has developed the National Forest Carbon MARS, and AAFC has put in place a National Carbon and GHG Accounting and Verification System for agriculture. For the first time in 2006, the inventory submission incorporates some GHG estimates for the LULUCF Sector developed by MARS partners (namely CFS, AAFC, and the Canadian Centre for Remote Sensing), leading to significant changes and improvements compared with previous submissions. These are described in Chapter 7.

1.3 PROCESS FOR INVENTORY PREPARATION

Continuous data collection and improvements are an integral part of the national inventory planning and quality management cycles (see also Section 1.6 below). The data used to compile the national inventory are generally from published sources. Data are collected either electronically or manually (hard copies) from the source agencies and are entered into spreadsheet-based emission accounting systems, databases, and/or models. Emissions are calculated by designated inventory experts, reviewed internally, and then reported according to UNFCCC guidelines in the CRF and the NIR. The inventory group also carries out methodological development, QA/QC procedures, documentation, uncertainty estimation, key category assessment, and trends analysis.

A draft inventory is prepared for external review and distribution to the Emissions and Projections Working Group (EPWG), composed of provincial/territorial and federal government representatives working in the field of air pollution measurement and estimation. Draft emissions and removals estimates (particularly for the Energy, Industrial Processes, and LULUCF sectors) are also examined by selected government, industry, and academia experts.

Comments from the review and any corrections arising from QA/QC are documented and incorporated in the NIR and CRF, which are normally submitted to the UNFCCC electronically prior to April 15 of each year. Initial checks on the April submission are performed by the UNFCCC in May and June. A final inventory report is prepared and submitted if necessary. Once finalized, the CRF and NIR are then further edited, translated, and readied for publication. The inventory cycle follows a continuous process of data and methods collection and development, reviews, and improvements to ensure time-series consistency. Results of the annual UNFCCC expert review as well as the external domestic review feed into improvement plans for the following

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[19] The committee consists of representatives from Environment Canada, AAFC, and NRCan (the Canadian Forest Service, CFS) and is divided into three working groups that cover forestry, agriculture, and land-use change issues.

year's inventory and help to identify priorities and areas for improvement.

1.4 METHODOLOGIES AND DATA SOURCES

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

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

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

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

- CO_2;
- CH_4;
- N_2O;
- HFCs;
- PFCs; and
- SF_6.

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

- sulphur oxides (SO_x);
- NO_x;
- CO; and
- NMVOCs.

For all categories except LULUCF, these gases (referred to as the Criteria Air Contaminants, or CACs) are inventoried and reported separately. CAC emissions in Canada are reported to the United Nations Economic Commission for the Environment (UNECE).[20] As noted, a summary of these emissions is also included in the NIR (see Annex 15: Ozone and Aerosol Precursors).

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

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

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

Manipulated biological systems, such as agricultural lands, forestry, and land converted to other uses, are typical sources or sinks diffused over very large areas.

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[20] See website: http://webdab.emep.int/.

Processes that cause emissions and removals display considerable spatial and interannual variability, and they also span several years or decades. The most practical approach to estimating emissions and removals may require a combination of repeated measurements and modelling. The need, unique to these systems, to separate anthropogenic impacts from large natural fluxes creates an additional challenge.

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

- *Direct Measurement*: With few exceptions, GHG emission or removal measurements apply to point sources. At present, a very limited number of sources have measured and reported GHG emissions.
- *Mass Balance*: This approach determines atmospheric emissions from the difference between the amounts of the component (e.g., carbon) contained in feed materials or fuels and those contained in the products, process wastes, or non-emitted residuals. Mass balances are most appropriately applied to fuel carbon contributions and mineral processing activities, where sufficient data are available to derive average carbon contents of process streams. Generally, CO_2 emissions resulting from fuel combustion are readily estimated by the carbon balance method.
- *Technology-Specific Emission Factor Calculations*: Company-specific emission factors can be used to estimate the rate at which a pollutant is released into the atmosphere (or captured) as a result of some process activity or unit throughput. Although emissions or removals may not be measured, individual facilities may have measured rate data for various parameters for their plants. These can be combined with other plant-specific information, such as throughput, activity data, and the number of such sources, to derive plant-specific emissions or removals for a point source or "bottom-up" inventory.
- *Average or General Emission Factor Calculations*: Where plant-specific data are not available, average or general-use emission factors can be used for a given source or sector. These can be combined with company-specific, sector-specific, process-specific, or general activity and population data to calculate emissions for a top-down inventory. Average or general emission factors for most of the sectors in the inventory have been developed by Environment Canada, in consultation with other government departments, industry associations, and agencies and organizations. These values reflect the most accurate methodologies based on currently available data and include information currently being developed by the IPCC for the UNFCCC.

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

For the 2006 submission, a number of changes have been implemented in all sectors of the inventory, resulting in the recalculations of estimates for the whole time series. The results of detailed studies on fugitive emissions from facilities in the upstream oil and gas and oil refining industries have been incorporated into the Energy Sector's emission estimates. A number of updates were performed in the Industrial Processes Sector. The LULUCF Sector methodologies have been entirely upgraded, as have the methods for determining N_2O emissions from agricultural soils. Also, a major overhaul of the estimation model for CH_4 emissions from solid waste disposal on land (landfills) has been made. For further information, refer to specific sectoral chapters as well as Chapter 9.

1.4.1 MANDATORY REPORTING SYSTEM FOR GHGs

In March 2004, Environment Canada announced the first phase of mandatory reporting of GHG emissions under Section 46 of CEPA 1999. This phase focused on a limited number of large emitters and set out basic reporting requirements that lay the foundation for the development of a harmonized domestic mandatory reporting system for GHG emissions designed to meet a variety of federal and provincial/territorial information needs.[21]

A total of 324 facilities reported GHG emissions for the 2004 calendar year, collectively emitting a total of 279 Mt of GHGs (CO_2 eq). Total facility GHG emissions represent just over one-third of Canada's total GHG emissions.

Facilities located in Alberta accounted for the largest share of reported emissions, about 39% of the total, followed by those in Ontario, which accounted for about 28%. Quebec and Saskatchewan were the next largest contributors, both at about 8% of reported emissions (see Table 1-2).

Three industrial sectors accounted for the largest share of GHG emissions. Utilities — primarily those generating electricity — accounted for 43%, while manufacturing and mining and oil and gas extraction accounted for 34% and 18%, respectively (see Table 1-3).

CO_2 represented the majority of total reported emissions — around 93% (see Table 1-4). CH_4 accounted for just 3%, while N_2O represented just over 2%. The remaining gases (HFCs, PFCs, and SF_6) accounted for the remaining 2% and originated primarily from the manufacturing sector.

By providing a more precise picture of the sources and quantities of Canada's GHG emissions, data from the mandatory reporting system can be used to improve and confirm emission estimates developed from national and provincial statistics. The extent to which information from the mandatory reporting system can be fully integrated into the inventory 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.

TABLE 1-2: Total Reported GHG Emissions by Province/Territory

Province/Territory	Total Reported Emissions *(kt CO_2 eq)*	% of Total
Alberta	109 504	39
Ontario	77 274	28
Quebec	22 905	8
Saskatchewan	22 425	8
British Columbia	13 842	5
New Brunswick	12 954	5
Nova Scotia	11 684	4
Newfoundland and Labrador	5 369	2
Manitoba	2 461	1
Northwest Territories	366	0
Prince Edward Island	107	0
Nunavut	N/A	–
Yukon	N/A	–
Total	**278 890**	**100**

Notes:
Totals may not add due to rounding.
N/A = not available.

TABLE 1-3: Total Reported GHG Emissions by Sector

NAICS[1]	Sector	GHG Emissions *(kt CO_2 eq)*	% of Total
21	Mining and Oil and Gas Extraction	50 760	18
22	Utilities	121 272	43
31–33	Manufacturing	94 848	34
Other[2]	Other	12 012	4
Total		**278 890**	**100**

Notes:
1 North American Industrial Classification System.
2 Includes a number of smaller sectors (e.g., transportation and warehousing, waste management, etc.).
Totals may not add due to rounding.

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[21] During Phase 1, the reporting threshold for facility emissions was set at 100 kilotonnes (kt) of CO_2 equivalent GHGs. 2004 emissions data will be disseminated on Environment Canada's website: www.ec.gc.ca/ghg-ges.

TABLE 1-4: Total Reported GHG Emissions by Gas Type

GHG	Total Emissions (kt CO_2 eq)	% of Total
CO_2	260 214	93
CH_4	7 455	3
N_2O	6 345	2
HFCs	25	0.000 08
PFCs	2 795	1
SF_6	2 057	0.7
Total	**278 890**	**100**

Note:
Totals may not add due to rounding.

1.5 KEY CATEGORIES

The IPCC Good Practice Guidance defines procedures (in the form of decision trees) for the choice of estimation methods within the context of the IPCC Guidelines (IPCC, 2000). The decision trees formalize the choice of estimation method most suited to national circumstances considering at the same time the need for accuracy and the available resources (both financial and human). Generally, inventory uncertainty is lower when emissions are estimated using the most rigorous methods; due to finite resources, however, this might not be feasible for every emission and removal category. Therefore, it is good practice to identify those categories (key categories) that have the greatest contribution to overall inventory uncertainty in order to make the most efficient use of available resources.

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

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

Good Practice Guidance indicates that a cumulative contribution total of 95% for both level and trend assessments is a reasonable approximation of categories that account for about 90% of the uncertainty in the inventory. In the absence of quantitative data on uncertainties, this method of identifying key categories provides a good approximation of those areas to which priority should be given to reduce uncertainties in the inventory.

For the 1990–2004 GHG inventory, level, trends, and qualitative key category assessments were performed on the inventory according to the Tier 1 approach, as presented in the IPCC *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC, 2000) and the IPCC *Good Practice Guidance for Land Use, Land-Use Change and Forestry* (IPCC, 2003). The emission and removal categories used for the key category assessment generally follow those in the CRF and the LULUCF CRF; however, they have been aggregated in some cases and are specific to the Canadian inventory.

Major key categories based on the level and trend assessments (including LULUCF) are the fuel combustion categories (Road Transportation, Public Electricity and Heat Production, Other Sectors, and Manufacture of Solid Fuels and Other Energy Industries) and the LULUCF category Forest Land Remaining Forest Land. Details and results of the assessments are presented in Annex 1.

1.6 QA/QC

The national inventory and NIR must be prepared in accordance with international reporting guidelines and methods agreed to by the UNFCCC. The inventory is developed according to the methodological procedures and guidelines prescribed by the IPCC, and it draws from the best available data and scientifically sound methodologies.

The annual cycle for the preparation of the national inventory begins in April with an examination of the United Nations (UN) Expert Review Team's (ERT) report and identification of the key areas to be targeted for improvement in methods and/or data. Once this assessment is complete, a prioritization of work is undertaken, and appropriate studies are initiated.

QA/QC and verification procedures are an integral part of the preparation of the inventory. This process takes the form of internal checks and external reviews and audits.

The Greenhouse Gas Division annually conducts detailed QA/QC activities during and after the development of the inventory and is systematically implementing formal procedures according to a plan consistent with international standards.

Each year, prior to its submission to the UNFCCC on April 15, the draft inventory, which must contain consistent data for 1990 and all subsequent years, undergoes a review by federal and provincial experts.

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

In addition, underlying data and methods are independently assessed each year by various groups in industry, academia, and government.

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

The inventory submission must be in the form of an NIR and CRF tables, whose contents and structure are mandated by the UNFCCC. The UN ERT assesses the inventory against five key criteria:

1. transparency (assumptions and methodologies clear);
2. consistency (all inventory years internally consistent with respect to data/methods);
3. comparability (IPCC methods and UNFCCC reporting guidelines used);
4. completeness (all sources/sinks, gases, years); and
5. accuracy (promoted via Good Practice Guidance, which describes QA/QC procedures, key category identification, uncertainty analysis, and formalized institutional arrangements).

The application and documentation of QA/QC procedures are essential components in the GHG inventory development and submission process. Moving from informal QC checks to a more systematic approach in line with a formal QA/QC plan has been initiated over the last few years. Full implementation of this plan is envisaged to span several years, encompassing both Tier 1 and Tier 2 QC procedures, as well as QA, reviews, and audits.

For this submission, QC procedures mirror those performed on the 2005 submission. Tier 1 QC procedures were implemented and the results documented for 44 key categories and 3 non-key categories by officers not directly involved in the preparation of these category estimates. Cross-cutting checks on the NIR and CRF were also performed prior to submission. The reader is referred to Annex 6 of this report for more information.

1.7 INVENTORY UNCERTAINTY

While national GHG inventories should be accurate, complete, comparable, transparent, and verifiable, estimates will always inherently carry some uncertainty. Uncertainties[22] in the inventory estimates may be caused by systematic model uncertainty or (more likely) may be due to random uncertainties present within the input parameters. While reducing model uncertainty requires in-depth reviews of the estimation models, random uncertainties may be reduced by improvements to the activity data regimes and evaluation of emission factors and other model parameters. The primary purpose of quantitative uncertainty information is to set priorities to improve the accuracy of future inventories and to guide decisions about which methods to use. Typically, the uncertainties associated with the trends and the

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

national totals are much lower than those associated with individual gases and sectors.

The UNFCCC reporting guidelines on annual inventories state that Annex I Parties shall quantitatively estimate uncertainties in data for all source and sink categories using at least the Tier 1 method, as provided in the IPCC Good Practice Guidance (IPCC, 2000). Parties may use the Tier 2 method in the IPCC Good Practice Guidance to address technical limitations in the Tier 1 method. The guidelines also require that uncertainty in the data used for all source and sink categories must be qualitatively discussed in a transparent manner in the NIR, in particular for those categories identified as key.

In Canada's 2005 NIR, the results of a Tier 2 quantitative study of uncertainty were provided (as performed on key and non-key source categories — except LULUCF — and on the inventory as a whole, as applied to the 2003 NIR). In this, the 2006 NIR, additional information from the Tier 2 study was incorporated, including information on the overall inventory trend uncertainty for 1990–2001 and the sensitivity of overall inventory uncertainty to the source category uncertainties.

The overall level uncertainty of the national inventory (without LULUCF), as at 2001 (2003 NIR submission), falls within a range of –3% to +6% for all GHGs combined, without consideration of the uncertainty within the GWPs. With GWP uncertainty considered, the overall uncertainty falls within a range of –5% to +10% (ICF, 2005). N_2O exhibits the highest uncertainty range in the national inventory, with a range of –8% to +80%, followed by HFCs, with a range of –22% to +58%. The largest contributor to the inventory, CO_2, exhibits an uncertainty of –4% to 0% (ICF, 2005). For uncertainty information on other gases, reference should be made to Annex 7. The Canadian inventory's uncertainty estimate falls within the range of uncertainty reported by other Annex I countries.

Although the study of uncertainty was performed on the 2003 NIR data, the level uncertainties assessed are assumed to be representative of the current inventory uncertainty for the majority of cases. Annex 7 provides details of uncertainty estimates for all sectors except LULUCF. Explanation of drivers of uncertainty for various categories and the inventory analysts' interpretation of the results from the study are provided within sector-specific chapters. Also provided in those chapters are updates to selected uncertainty estimates since the ICF (2005) study was completed, as affecting various source categories (in particular, the Agriculture Sector). Further improvements and updates to the uncertainty values are planned; see Chapter 9 for more details.

1.8 COMPLETENESS ASSESSMENT

The national GHG inventory, for the most part, is a complete inventory of the six GHGs required under the UNFCCC. Some minor source categories not included in Canada's 2003 inventory are now included, such as CO_2 from the use of magnesite in magnesium production, CO_2 from the use of limestone in the flue gas desulphurization process in power plants, N_2O from sludge incineration, and ethanol fuel use in transportation. In the LULUCF Sector, while significant changes have been made for this submission towards meeting the reporting requirements from UNFCCC Decision 13/CP.9, completeness has not yet been fully met. As part of the improvement plan, efforts are continuously being made to identify and assess relevant new sources and sinks for which cost-effective estimation methods are available. Further details on the completeness of the inventory can be found in Annex 5.

2 GREENHOUSE GAS EMISSION TRENDS, 1990–2004

2.1 SUMMARY OF EMISSION TRENDS

In 2004, Canada's GHG emissions were 758 Mt,[23] which is a 26.6% increase over 1990 emissions. Between 2003 and 2004, emissions grew by 0.6%. Over the year, there were increased emissions from HDDVs, Fossil Fuel Production, Adipic Acid Production, LDGTs, Enteric Fermentation, Iron and Steel Production, and Ammonia Production. Between 2003 and 2004, reductions were seen mainly in the areas of Electricity and Heat Generation, Residential (Heating), Petroleum Refining and Upgrading, Pipelines (Transport), and Off-Road Gasoline.

Since 1990, growth in emissions has resulted primarily from Electricity and Heat Generation and areas such as Fossil Fuel Industries, Mining, Transportation, Consumption of Halocarbons and SF_6, Enteric Fermentation, and Waste. There have been overall decreases in Manufacturing Industries and Construction (excluding Mining), the Chemical Industry, and Metal Production.

2.2 EMISSION TRENDS BY GAS

CO_2 is the largest contributor to Canada's GHG emissions. Figure 2-1 shows how the percent contributions of the six GHGs have changed between 1990 and 2004. CO_2 has changed only slightly in proportion, from 76.9% of emissions in 1990 to 78.2% in 2004.

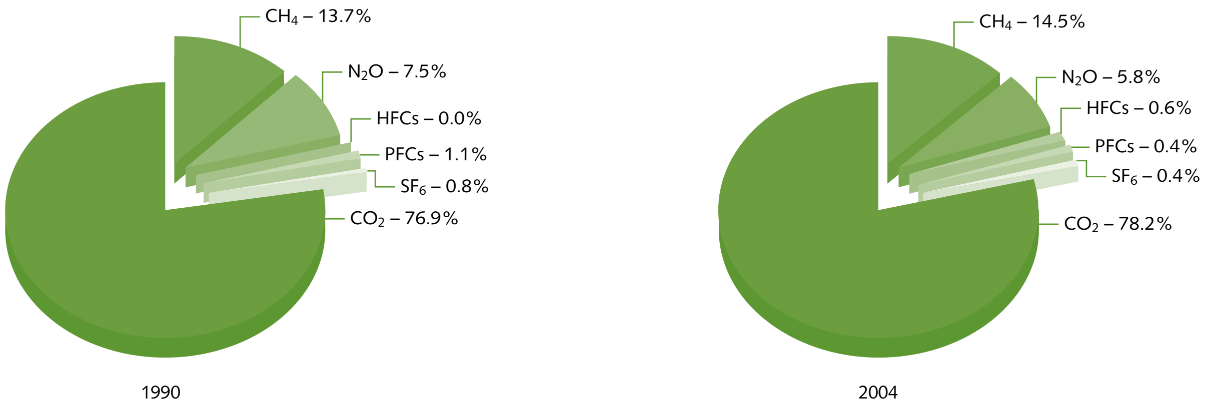
2.3 EMISSION TRENDS BY CATEGORY

2.3.1 ENERGY SECTOR (2004 GHG EMISSIONS, 620 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 fuel combustion 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 82% of total Canadian GHG emissions in 2004 (553 Mt and 66.5 Mt, respectively). Between 1990 and 2004, fuel combustion–related emissions increased 28%, while emissions from fugitive releases rose 53%. The five-year and the year-to-year changes in both fuel combustion and fugitive emissions through the period 1990–2004 are shown in Table 2-1.

FIGURE 2-1: **Canada's GHG Emissions by Gas, 1990 and 2004**



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[23] Unless explicitly stated otherwise, all emission estimates given in Mt represent emissions of GHGs in Mt CO_2 equivalent.

The Energy Industries, grouped in the Energy Sector, contribute more than any other category to Canada's emissions. These industries (consisting of fossil fuel production and electricity and heat production) generate both combustion and fugitive emissions. In terms of Table 2-1, these industries encompass the "Fuel Combustion – Energy Industries" category and the whole "Fugitive Emissions" subsector. Altogether, the Energy Industries contributed 275 Mt or 36% of Canada's total and about 44% of the Energy Sector's emissions for 2004.

TABLE 2-1: **GHG Emissions from Energy by UNFCCC Sector, 1990–2004**

GHG Source Category	GHG Emissions				
	Mt CO_2 eq				
	1990	1995	2000	2003	2004
1. Energy	**475**	**517**	**596**	**622**	**620**
A. Fuel Combustion (Sectoral Approach)	**432**	**460**	**531**	**556**	**553**
1. Energy Industries	148	157	202	216	209
2. Manufacturing Industries and Construction	63.0	62.1	64.6	66.5	67.7
3. Transport	150	160	180	190	190
4. Other Sectors	72	77	81	85	83
B. Fugitive Emissions	43.3	57.0	64.9	66.2	66.5
1. Solid Fuels (Coal)	2	2	1	1	1
2. Oil and Natural Gas	41.4	55.3	64.0	65.2	65.5

Table 2-1 divides energy sources by UNFCCC category — Fuel Combustion is categorized separately from Fugitive Emissions. By this breakdown, fuel combustion in the Energy Industries accounted for 209 Mt in 2004, while fugitive emissions were responsible for 66.5 Mt. In terms of relative growth, fugitive emissions from Oil and Natural Gas (including production, processing, transmission, and distribution activities) have increased faster than any other category in the Energy Sector — between 1990 and 2004, they rose by 58%.

2.3.1.1 Emissions from Fuel Combustion (2004 GHG emissions, 553 Mt)

GHG emissions from fuel combustion rose from 432 Mt in 1990 to 553 Mt in 2004, a 28% increase. Fuel combustion emissions are divided into the following UNFCCC subsectors: Energy Industries, Manufacturing Industries and Construction, Transport, and Other Sectors. The Other Sectors subsector comprises emissions from the residential and commercial categories, as well as minor contributions of stationary fuel combustion emissions from the agriculture and forestry category.

Energy Industries (2004 GHG emissions, 209 Mt)

The Energy Industries subsector accounts for the largest portion of Canada's fuel combustion emissions (38% of the total). Emissions included in this subsector are from stationary sources producing, processing, and refining energy. UNFCCC categories within this source category include Public Electricity and Heat Production, Petroleum Refining, and Manufacture of Solid Fuels and Other Energy Industries. In 2004, combustion emissions from the Energy Industries category totalled 209 Mt, an increase of 41% from the 1990 level of 148 Mt.

- **Public Electricity and Heat Production[24] (2004 GHG emissions, 130 Mt)**

This category accounted for 17% (130 Mt) of Canada's 2004 GHG emissions and was responsible for 22% of the total emissions growth between 1990 and 2004 — more than any other category in the national inventory. Overall, emissions increased 37%, or almost 35 Mt, since 1990.

Hydroelectric and coal-fired generation continue to be the major sources of Canadian electricity, accounting for 58.6% and 16.5%, respectively, of national electricity generation in 2004 (see Table 2-2). Nuclear energy provided 14.8% of the generated electricity, followed by natural gas with 5.2% and oil with 3.4%. In comparison, in 1990, coal accounted for 16.4% of Canadian electricity generation, oil 3.1%, natural gas 1.9%, nuclear energy 14.7%, and hydro 62.9%. Total annual electricity generation increased by 23% between 1990 and 2004.

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

This rate of growth exceeds the population growth rate of 15% for the same period, pointing to an increase in demand from economic sectors that depend on electric power and an ever-growing number of electrical appliances.

Coal has the highest GHG intensity (emissions per unit electricity) of all fuels — this is reflected in the fact that it accounted for only 16.5% of the total electricity generated in Canada in 2004 and produced 75% of GHG emissions, whereas natural gas generated 5.2% of Canada's electricity but accounted for only 12% of emissions. More explicitly, the intensity factor for coal was 1010 g CO_2 eq per kilowatt-hour (kWh) in 2004, while the intensity factor for natural gas generation was 523 g CO_2 eq/kWh. Refer to Annex 9 for more details on electricity intensity factors by regions.

The growth in emissions from 1990 to 2004 is directly related to rising demand for power from end users and the increased use of fossil fuels (coal, oil, and natural gas) in the generation mix. While increasing use of natural gas has helped mitigate the rate of emissions growth, the shift away from non-GHG-emitting sources (nuclear and hydro) in the latter part of the decade has resulted in large absolute increases.

Contributions from both nuclear and hydro generation declined in the latter part of the 1990s, when nuclear facilities in Ontario were decommissioned for maintenance and rehabilitation. The peak production was in 1994, and the low was in 1998. Since then, nuclear generation has been brought back into service in Ontario, and new hydroelectric capacity has been added throughout the country. Between 1998 and 2004, there was a 26% increase in the amount of electricity from nuclear generation. Hydroelectric generation increased nearly 15% from 1990 to 2004.

Overall electricity demand increased by 1.2% between 2003 and 2004. There was a 1% increase in hydroelectric generation between 2003 and 2004 due to higher water levels, while electricity generated by fossil fuels declined.

While imports rose and fell to meet the supply–demand gap, growth in demand since 1990 has largely been met by domestic generation from fossil fuels, primarily

TABLE 2-2: GHG Emissions and Electricity Generation for Canada[1]

Year	GHG Emissions					Electricity Generation[2]						
	Total	Coal	Refined Petroleum Products	Natural Gas	Others	Total	Coal	Refined Petroleum Products	Natural Gas	Nuclear	Hydro	Biomass and Others
	Mt CO_2 eq	*Percentage of Total*				*GWh*	*Percentage of Total*					
1990	**94.6**	83.3	12.1	4.3	0.4	**467 609**	16.4	3.1	1.9	14.7	62.9	1.0
1991	**96.0**	85.9	10.0	3.7	0.4	**493 043**	16.8	2.5	1.6	16.3	61.9	1.0
1992	**102**	83.7	10.3	5.7	0.5	**504 391**	16.7	2.7	2.4	15.1	62.1	1.1
1993	**93.3**	83.8	8.3	7.4	0.5	**515 974**	14.9	1.9	2.8	17.2	62.1	1.1
1994	**95.4**	85.6	6.3	7.4	0.7	**539 458**	15.0	1.4	2.9	18.9	60.6	1.3
1995	**99.7**	83.4	7.0	9.2	0.5	**542 744**	15.0	1.7	3.6	17.0	61.3	1.3
1996	**98.6**	86.0	5.7	7.9	0.4	**555 822**	15.1	1.4	3.1	15.7	63.4	1.3
1997	**110**	83.1	7.4	8.8	1.0	**556 084**	16.7	2.0	3.6	14.0	62.4	1.2
1998	**122**	79.9	9.8	9.7	0.9	**543 865**	18.4	3.0	4.5	12.4	60.4	1.3
1999	**120**	80.6	8.0	10.3	1.0	**559 937**	18.0	2.4	4.6	12.4	61.1	1.6
2000	**131**	80.0	6.7	12.3	1.0	**585 816**	18.8	2.1	5.4	11.7	60.6	1.4
2001	**132**	78.3	8.0	13.0	1.0	**569 422**	19.3	2.6	6.0	12.7	57.9	1.5
2002	**128**	79.6	6.6	12.2	1.1	**581 097**	18.8	2.1	5.5	12.3	59.7	1.6
2003	**138**	76.4	7.5	12.3	3.7	**569 489**	18.4	3.4	5.6	12.4	58.7	1.5
2004	**128**	75.0	9.6	12.1	3.4	**576 422**	16.5	3.4	5.2	14.8	58.6	1.6

Notes:

1 Refer to Annex 9 of this report for the complete time series of national and provincial GHG emissions, intensity, and generation values for the electricity sector.

2 Source: Statistics Canada, #57-003.

coal and natural gas. Coal-fired generation increased 24%, while natural gas generation increased 229% between 1990 and 2004. The growth in natural gas generation is also based on a structural shift towards more efficient industrial cogeneration sources. Of the total emissions from Public Electricity and Heat Production, a little less than 9% was produced by non-utility industrial sources.

- **Petroleum Refining and Manufacture of Solid Fuels and Other Energy Industries[25] (2004 GHG emissions, 78.6 Mt)**

The Petroleum Refining category includes emissions from the combustion of fossil fuels during the production of refined petroleum products and the upgrading of heavy oil and bitumen to produce synthetic crude oil. The Manufacture of Solid Fuels and Other Energy Industries category encompasses fuel combustion emissions associated with the upstream oil and gas industry. As shown in Table 2-3, between 1990 and 2004, emissions from these two categories increased by about 26 Mt, or 49%. This growth is due to increases in oil and natural gas production, largely for export.

TABLE 2-3: **GHG Emissions from Petroleum Refining and Manufacture of Solid Fuels and Other Energy Industries, 1990–2004**

GHG Source Category	GHG Emissions					% Increase
	Mt CO_2 eq					
	1990	1995	2000	2003	2004	1990–2004
Petroleum Refining	23	25	24	30	29	29
Manufacture of Solid Fuels and Other Energy Industries	30	32	45	47	49	64
TOTAL[1]	**53**	**56**	**70**	**77**	**79**	**49**

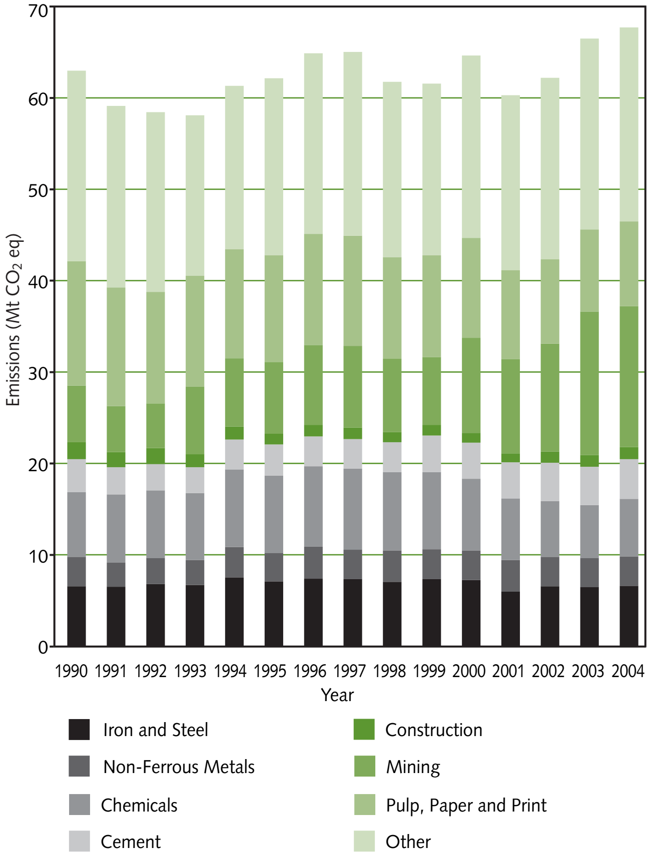
Note:

1 Totals may not add due to rounding.

Manufacturing Industries and Construction (2004 GHG emissions, 67.7 Mt)

Emissions from the Manufacturing Industries and Construction subsector include the combustion of fossil fuels by the iron and steel, non-ferrous metals, chemicals, cement, pulp, paper and print, construction, mining, and all other manufacturing industries.[26] In 2004, GHG emissions were 67.7 Mt, an increase of 7% from the 1990 level of 63 Mt; over the short term (2003–2004), emissions increased by 2%. Overall, this subsector was responsible for 8.9% of Canada's total GHG emissions for 2004. Figure 2-2 provides an overview of the changes in emissions for the various manufacturing industries and construction between 1990 and 2004. The amount of emissions in each category can be found in Table 2-4.

FIGURE 2-2: **GHG Emissions from Manufacturing Industries and Construction Source Categories, 1990–2004**



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

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

TABLE 2-4: GHG Emissions from Manufacturing, Mining, and Construction, 1990–2004

GHG Source Category	GHG Emissions					% Increase
	Mt CO_2 eq					
	1990	1995	2000	2003	2004	1990–2004
Iron & Steel	6.49	7.04	7.19	6.37	6.55	1
Non-Ferrous Metals	3.23	3.11	3.19	3.20	3.23	0
Chemicals	7.10	8.46	7.86	5.82	6.29	–11
Cement	3.59	3.42	3.97	4.18	4.33	21
Construction	1.88	1.18	1.08	1.30	1.35	–28
Mining	6.20	7.86	10.4	15.7	15.4	149
Pulp, Paper & Print	13.6	11.7	11.0	9.01	9.31	–32
Other Manufacturing	20.9	19.4	20.0	20.9	21.2	2
TOTAL[1]	**63.0**	**62.1**	**64.6**	**66.5**	**67.7**	**7**

Note:

1 Totals may not add due to rounding.

Between 1990 and 2004, there have been changes in the emissions produced by the various categories within the Manufacturing Industries and Construction subsector. This can be attributed to product demands, fuel switching, and changes in manufacturing operations. The majority of the overall increase can be attributed to the mining category, which has seen a 149% growth since 1990. From 2003 to 2004, the construction industry experienced a 4% increase in emissions.

Transport (2004 GHG emissions, 190 Mt)

Transport is a large and diverse subsector, accounting for 26% of Canada's GHG emissions in 2004. This subsector includes emissions from fuel combustion for the transport of passengers and freight in five distinct subcategories:

- road transportation;
- civil aviation;
- marine;
- rail; and
- other transportation.

From 1990 to 2004, GHG emissions from transport, driven primarily by energy used for personal transportation, rose 30%, or over 40 Mt. Overall, transport was the second largest emissions-producing category in 2004, contributing 190 Mt and accounting for 28% of Canada's emissions growth from 1990 to 2004.

Emissions from LDGTs, the subcategory that includes SUVs, pickups, and vans, increased 101% between 1990 and 2004 (from 22 Mt in 1990 to 44 Mt in 2004), while emissions from cars (LDGVs) decreased 7.4% (from 54 Mt in 1990 to 50 Mt in 2004) (Table 2-5).

TABLE 2-5: GHG Emissions from Transport, 1990–2004

GHG Source Category	GHG Emissions		
	Mt CO_2 eq		
	1990	2003	2004
Transport TOTAL	**150**	**190**	**190**
Domestic Aviation	6.4	7.3	7.8
Light-Duty Gasoline Vehicles	53.8	49.4	49.8
Light-Duty Gasoline Trucks	21.7	41.9	43.6
Heavy-Duty Gasoline Vehicles	3.14	4.14	4.21
Motorcycles	0.230	0.226	0.219
Light-Duty Diesel Vehicles	0.672	0.722	0.768
Light-Duty Diesel Trucks	0.591	0.796	0.893
Heavy-Duty Diesel Vehicles	24.5	42.3	44.9
Propane & Natural Gas Vehicles	2.2	0.82	0.87
Railways	7	6	6
Domestic Marine	5.0	6.1	6.6
Off-Road Gasoline	5	4	4
Off-Road Diesel	10	10	20
Pipelines	6.90	9.11	8.52

Note:

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

The growth in road transport emissions is due not only to the 24% increase in the total vehicle fleet, but also to a shift in light-duty vehicle purchases from cars (LDGVs) to trucks (LDGTs), which, on average, emit 40% more GHGs per kilometre.

Over the period 1990–2004, the increase of 22 Mt and 20 Mt for LDGTs and HDDVs, respectively, reflects the trend towards increasing use of SUVs, vans, and pickups for personal transportation and heavy-duty trucks for freight transport (Table 2-6).

TABLE 2-6: Trends in Vehicle Populations for Canada, 1990–2004

Year	Number of vehicles (all figures in 000s)							Total
	LDGVs	LDGTs	HDGVs	MCs	LDDVs	LDDTs	HDDVs	
1990	11 068	3 453	217	331	124	74	350	**15 616**
1991	11 033	3 650	234	324	120	73	398	**15 833**
1992	10 981	3 843	252	313	116	72	445	**16 022**
1993	10 942	4 039	269	309	112	71	493	**16 235**
1994	10 904	4 236	287	304	109	70	541	**16 451**
1995	10 864	4 432	305	295	105	69	589	**16 658**
1996	10 678	4 712	322	288	106	68	637	**16 811**
1997	10 665	4 980	321	299	105	78	641	**17 088**
1998	10 680	5 134	347	314	104	73	633	**17 285**
1999	10 809	5 810	272	315	105	79	658	**18 047**
2000	10 603	6 026	288	326	105	107	704	**18 159**
2001	10 877	6 286	270	330	112	113	712	**18 700**
2002	10 867	6 480	269	307	117	122	704	**18 866**
2003	10 875	6 720	269	306	124	125	731	**19 150**
2004	10 871	6 930	268	291	129	131	735	**19 355**

Notes:

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

In 2004, emissions from HDDVs contributed 45 Mt to Canada's total GHG emissions (an increase of 83% from 1990 emissions). Emissions from heavy-duty gasoline vehicles (HDGVs) were substantially lower, at 4 Mt for 2004, but this figure represents an increase of 34% over the 1990 level. While there are difficulties in obtaining accurate and complete data for the freight transport mode, the trends in data from major for-hire truck haulers in Canada show conclusively that freight hauling by truck has increased substantially and that this activity is the primary task performed by HDGVs and HDDVs.

Off-road fuel combustion emissions[27] in the Transport subsector also increased between 1990 and 2004. Emissions from off-road vehicles for mining, construction, and forestry, as well as snowmobiles, all-terrain vehicles (ATVs), etc., rose 15%.

The pipeline emissions included in the Transport subsector are combustion emissions primarily from natural gas transport. Due to increasing activity in the Energy Sector, these emissions rose 24%, from 6.9 Mt in 1990 to 8.5 Mt in 2004.

Other Sectors (2004 GHG emissions, 83.2 Mt)

The Other Sectors subsector comprises fuel combustion emissions from the residential and commercial categories, as well as stationary fuel combustion emissions from the agriculture and forestry category.[28] Overall, this subsector exhibited increases in GHG emissions of 15% from 1990 to 2004, while individual subcategories within it demonstrated a variety of changes.

■ Residential and Commercial

Emissions in these categories arise primarily from the combustion of fuel to heat residential and commercial buildings. Fuel combustion in the residential and commercial/institutional categories[29] accounted for 5.7% (43 Mt) and 5.0% (38 Mt), respectively, of all GHG emissions in 2004.

As shown in Figure 2-3, residential emissions have remained fairly constant between 1990 and 2004, decreasing 0.8 Mt or 1.8% over this period. In the short term, emissions decreased by 2.2 Mt or 4.8% between 2003 and 2004. Commercial/institutional emissions increased 12 Mt or 47% between 1990 and 2004. The combined effect between 1990 and 2004 for the two categories was an increase of 11 Mt,

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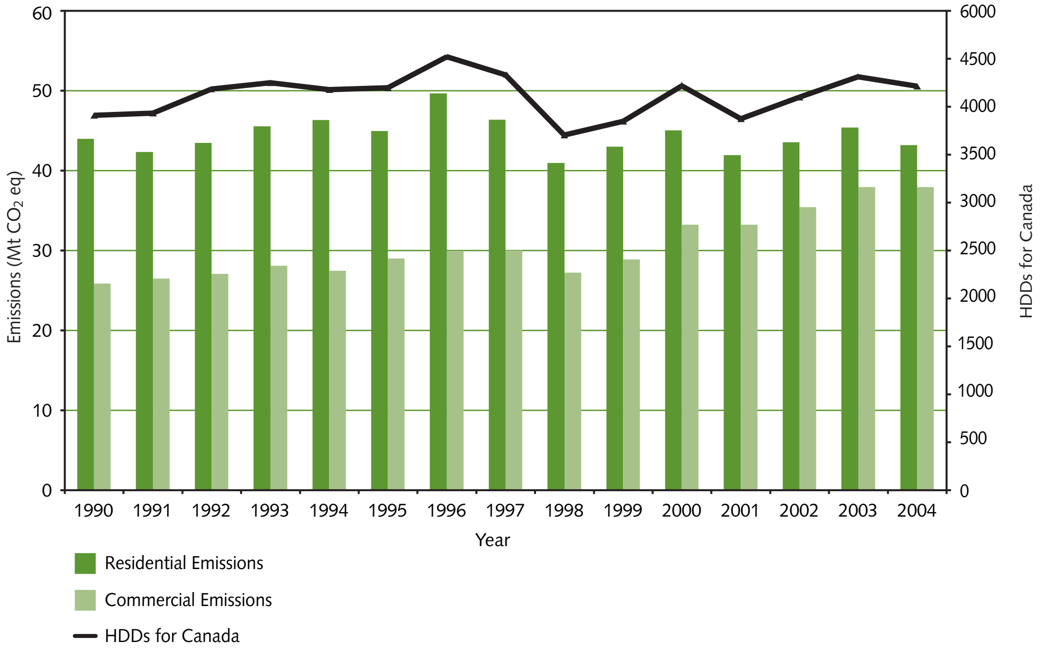
[27] Off-road emissions include those from the combustion of diesel and gasoline in a variety of widely divergent activities. Examples include the use of heavy mobile equipment in the construction, mining, and logging sectors, recreational vehicles such as snowmobiles and all-terrain vehicles (ATVs),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

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

[29] Commercial sector emissions are based on fuel use as reported in the *Report on Energy Supply–Demand in Canada* (RESD; Statistics Canada, 2005) for commercial and other institutional and public administration categories. The former is a catch-all category that includes fuel used by service industries related to mining, wholesale and retail trade, financial and business services, education, health and social services, and other industries that are not explicitly included elsewhere.

FIGURE 2-3: Emissions in the Residential and Commercial Sectors Relative to HDDs, 1990–2004



or 16%. GHG emissions, particularly in the residential sector, track HDDs[30] closely (as shown in Figure 2-3). This close tracking indicates the important influence of weather on space heating requirements and therefore on the demands for natural gas, home heating oil, and biomass fuels. Between 2003 and 2004, there was a 2.3% decrease in HDDs below 18.0°C (Statistics Canada, 2005).

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

- **Agriculture and Forestry**

Stationary fuel combustion–related emissions from the agriculture and forestry category amounted to 2.1 Mt in 2004, a decrease of 13% since 1990. Emissions decreased 4.9% between 2003 and 2004.

2.3.1.2 Fugitive Emissions from Fuels (2004 GHG emissions, 66.5 Mt)

As stated above, fugitive emissions from fossil fuels are the intentional or unintentional releases of GHGs from the production, processing, transmission, storage, and delivery of fossil fuels. Released gases that are combusted before disposal (e.g., flaring of natural gases at oil and gas production and processing facilities) are also considered fugitive emissions. Fugitive emissions have two sources: coal mining and handling, and activities related to the oil and natural gas industry. They constituted 8.8% of Canada's total GHG emissions for 2004 and contributed 15% to the growth in emissions between 1990 and 2004.

Table 2-1 summarizes the changes in fugitive emissions following the UNFCCC source categories for solid fuels

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[30] HDDs are calculated by determining the average, cross-Canada number of days below 18.0ºC and multiplying this value by the corresponding number of degrees below this temperature.

and for oil and natural gas. In total, fugitive emissions grew by about 53% between 1990 and 2004, from 43.3 Mt to 66.5 Mt, with emissions from the oil and natural gas category contributing 98% of the total fugitive emissions in 2004, far overshadowing the 2% contribution from coal mining. Although fugitive releases from the solid fuels category (i.e., coal mining) decreased by almost 1 Mt (over 48%) between 1990 and 2004 due to the closing of many mines in eastern Canada, emissions from oil and natural gas increased 58% during the same period.

This rise in emissions is a result of the increased production of natural gas and heavy oil since 1990, largely for export to the United States. Since 1990, there has been a 192% increase in the net energy exported from Canada, accompanied by a 123% increase in GHG emissions associated with those net energy exports.

2.3.2 INDUSTRIAL PROCESSES SECTOR (2004 GHG EMISSIONS, 54.3 Mt)

The Industrial Processes Sector includes GHG emissions that are direct by-products of processes, including Mineral Production, Chemical Industry, Metal Production, Consumption of Halocarbons and SF_6, and Other and Undifferentiated Production. GHG emissions from the Industrial Processes Sector contributed 54.3 Mt to the 2004 national GHG inventory, compared with 53.3 Mt in 1990. Figure 2-4 illustrates the changes in each of the categories over the period 1990–2004, and Table 2-7 provides an emission breakdown by category for selected years.

The largest single source of emissions in 2004 was Metal Production, with over 17 Mt of emissions, as shown in Table 2-7. The Other & Undifferentiated Production category accounted for the largest increase in emissions (about 45%) since 1990. These emissions are primarily from non-energy uses of fossil fuels, including the use of petroleum coke for anodes in metal production, the use of natural gas liquids (NGLs) and petroleum first derivatives as feedstock in the chemical industry, and the use of lubricants.

Between 1990 and 2004, the overall sector emissions increased by approximately 1 Mt (about 1.9%). This increase can be explained by the significant growth in emissions coming from non-energy use of fuels associated with petrochemical manufacturing and automotive lubricant use, as previously mentioned. The Consumption of Halocarbons category also contributed considerably to the overall sectoral emission augmentation, as more ozone-depleting substances (ODSs) were replaced by the HFCs within the refrigeration and air conditioning (AC) markets.

FIGURE 2-4: GHG Emissions from Industrial Processes by Category, 1990–2004

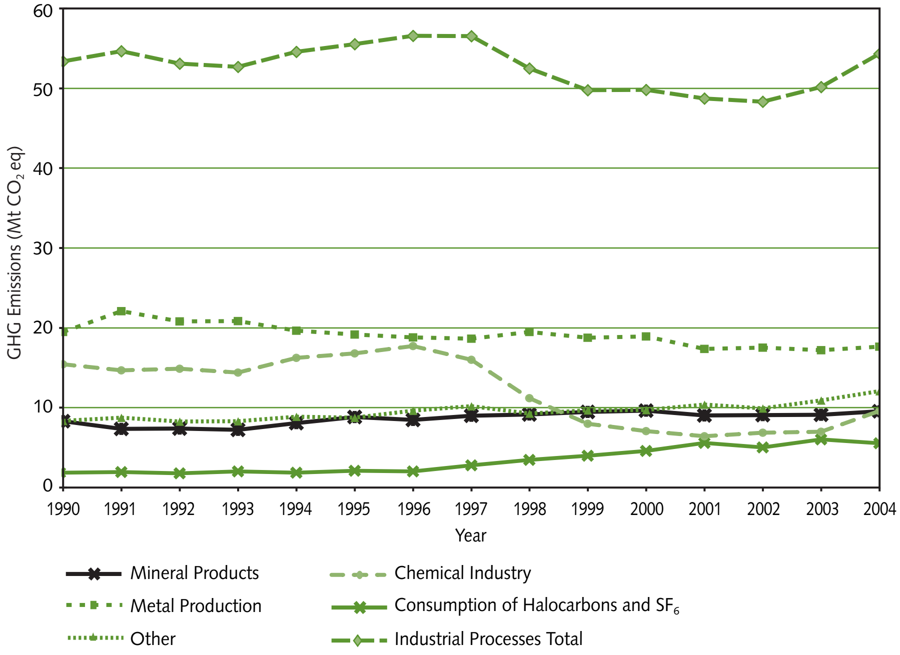


TABLE 2-7: GHG Emissions from Industrial Processes by Category, Selected Years

GHG Source Category	GHG Emissions				
	Mt CO_2 eq				
	1990	1995	2002	2003	2004
Industrial Processes TOTAL	**53.3**	**55.5**	**48.3**	**50.1**	**54.3**
a. Mineral Production	**8.3**	**8.8**	**9.0**	**9.1**	**9.5**
Cement	5.4	6.1	6.7	6.8	7.1
Lime	2	2	2	2	2
Limestone and Dolomite Use	0.73	0.53	0.30	0.28	0.29
Soda Ash Use	0.21	0.20	0.17	0.14	0.15
Magnesite Use	0.15	0.15	0.18	0.19	0.19
b. Chemical Industry	**15**	**17**	**6.8**	**7.0**	**9.6**
Ammonia Production	3.9	5.3	4.8	5.1	5.7
Nitric Acid Production	0.78	0.78	0.81	0.81	0.83
Adipic Acid Production	10.7	10.7	1.25	1.09	3.09
c. Metal Production	**19.5**	**19.2**	**17.5**	**17.2**	**17.6**
Iron and Steel Production	7.06	7.88	7.11	7.04	8.16
Aluminium Production	9.31	9.16	7.46	7.66	7.28
Magnesium Production	2.87	1.88	2.7	2.2	2.0
Magnesium Casting	0.24	0.23	0.26	0.26	0.19
d. Consumption of Halocarbons	**0**	**0.51**	**4.0**	**4.4**	**4.7**
e. SF_6 Use in Electric Utilities and Semiconductors	**1.8**	**1.6**	**1.0**	**1.6**	**0.81**
f. Other & Undifferentiated Production	**8.3**	**8.7**	**9.9**	**11**	**12**

Despite the overall sectoral rise from the 1990 level, some categories in this sector showed remarkable emission reductions. For instance, the emission levels in 2004 for limestone and dolomite use, adipic acid production, aluminium production, and magnesium smelting and casting dropped by 60%, 71%, 22%, 30%, and 18%, respectively (compared with the 1990 levels). Emission levels have gone down for the category of limestone use because of decreasing use of this mineral in the iron and steel and pulp and paper industries. The installation of an emission abatement system at Canada's only adipic acid facility in 1997, incorporation of automated emission controls in aluminium production, and progressive replacement of SF_6 with alternatives used as cover gas in magnesium production and casting contributed to the downward trend in the other categories.

From 2003 to 2004, the overall emissions for the Industrial Processes Sector increased by 8.3%. As a result of an increase in non-energy use of fuels, emissions coming from Other & Undifferentiated Production increased by 11% between 2003 and 2004. Also, the emission abatement at Canada's only adipic acid plant went off-line for a short period in 2004 for maintenance, causing an emission augmentation of 185% from its 2003 level.

2.3.3 SOLVENT AND OTHER PRODUCT USE SECTOR (2004 GHG EMISSIONS, 0.48 Mt)

The Solvent and Other Product Use Sector accounts for emissions related to the use of N_2O as an anaesthetic in medical applications and as a propellant in aerosol products. It contributed 480 kt CO_2 eq to the 2004 national GHG inventory, as compared with 420 kt CO_2 eq in 1990. Although the emissions coming from this sector represented less than 1% of the total Canadian GHG emissions in 2004, they were 15% and 1% above their 1990 and 2003 levels, respectively. Increase in population brought about emission growth in this sector.

2.3.4 AGRICULTURE SECTOR (2004 GHG EMISSIONS, 55 Mt)

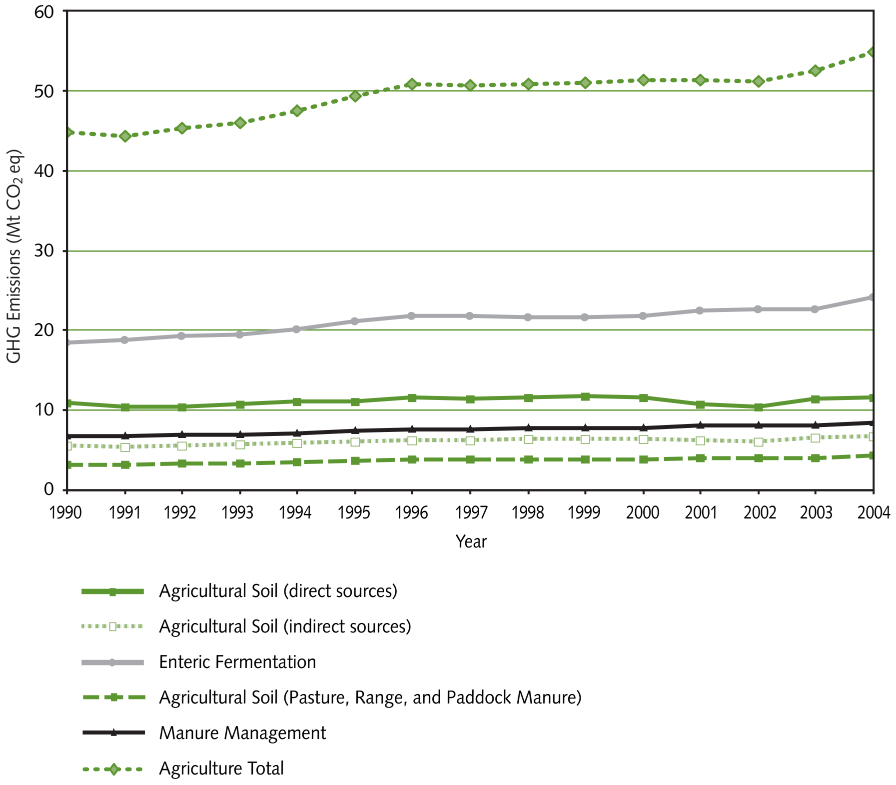
Canada's Agriculture Sector is composed of approximately 250 000 farms, 98% of which are family owned. Agricultural emissions accounted for 55 Mt or 7.2% of total 2004 GHG emissions for Canada, an increase of 10 Mt since 1990. All these emissions are from non-energy sources, with N_2O accounting for 50.5% of sectoral emissions and CH_4 for 49.5% in 2004.

The processes that produce GHG emissions in the Agriculture Sector are enteric fermentation by domestic animals, manure management, fertilizer application, and crop production (direct and indirect soil emissions and animal manure on pasture) (Figure 2-5).

Emissions in this sector were analyzed based upon the following two main categories:

1. Livestock emissions consist of enteric fermentation from domestic animals (i.e., digestive processes that release CH_4) and manure management (which releases CH_4 and N_2O). These emissions accounted

FIGURE 2-5: GHG Emissions from Agriculture, 1990–2004



for 59% of the Agriculture Sector's total GHG emissions in 2004.

2. Agricultural soil emissions consist of direct N_2O emissions from synthetic nitrogen fertilizers, animal manure applied to cropland, crop residue decomposition, summerfallow, tillage practices, and cultivation of organic soils; indirect N_2O emissions from volatilization and leaching of fertilizer, manure, and crop residue nitrogen; and N_2O emissions from manure on pasture, range, and paddock. These sources accounted for about 41% of the Agriculture Sector's total GHG emissions in 2004.

In the period from 1990 to 2004, enteric emissions increased by 30%, emissions from manure management systems by 26%, and soil N_2O emissions by 14%. These increases result mainly from the expansion of the beef cattle, swine, and poultry industry, as well as the increase in consumption of synthetic nitrogen fertilizer.

Between 2003 and 2004, there was a noticeable increase in agricultural emissions, amounting to 2 Mt. Most of this increase resulted from enteric fermentation, manure applied as fertilizers to cropland, manure on pasture, and animal waste management systems (AWMS), primarily because of a significant increase in beef cattle population (about 8% increase from 2003 to 2004).

In the 2004 GHG inventory for the Agriculture Sector, some major changes were made for the agricultural soil N_2O emission estimation through the adoption of country-specific methodologies and factors, taking into account local practices, topography, and climate conditions. For enteric and manure CH_4 emissions, modifications to the previous methodology were made to derive a time series of emission factors for dairy cattle to reflect changes in milk production over time. All of these changes significantly impacted the magnitude of emissions and, to a lesser extent, the long-term trends. A full explanation of changes can be found in Chapter 6.

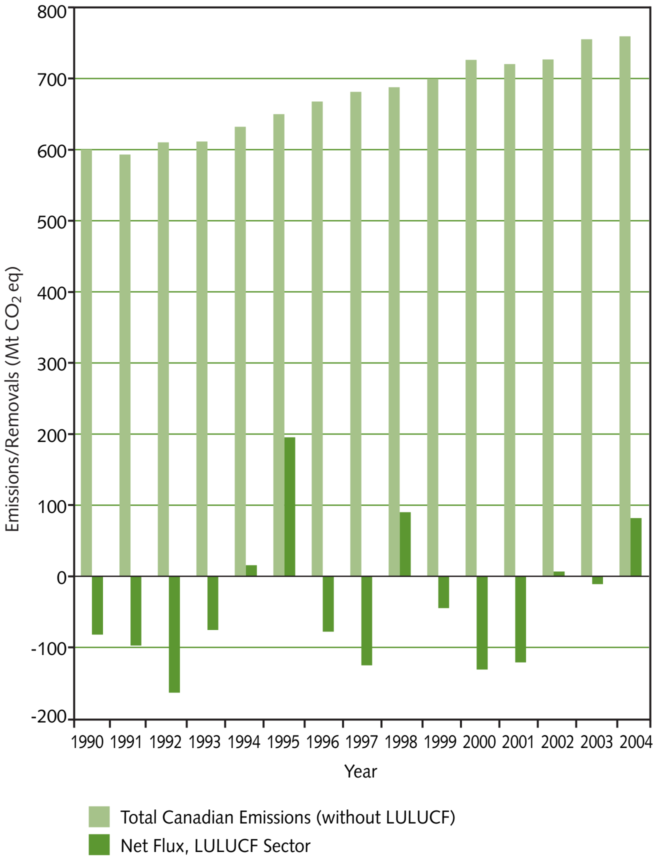
2.3.5 LAND USE, LAND-USE CHANGE AND FORESTRY SECTOR (2004 NET GHG EMISSIONS, 81 Mt, NOT INCLUDED IN NATIONAL TOTALS)

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

The net LULUCF flux, calculated as the sum of CO_2 emissions and removals and non-CO_2 emissions, displays high interannual variability over the reporting period. In 2004, this net flux amounted to emissions of 81 Mt (Figure 2-6).

All emissions and removals in the LULUCF Sector are excluded from the national totals. In 2004, the estimated 81 Mt would, if included, increase the total Canadian GHG emissions by 11%.

FIGURE 2-6: **LULUCF Sector's GHG Emissions Relative to Canada's Totals, 1990–2004**



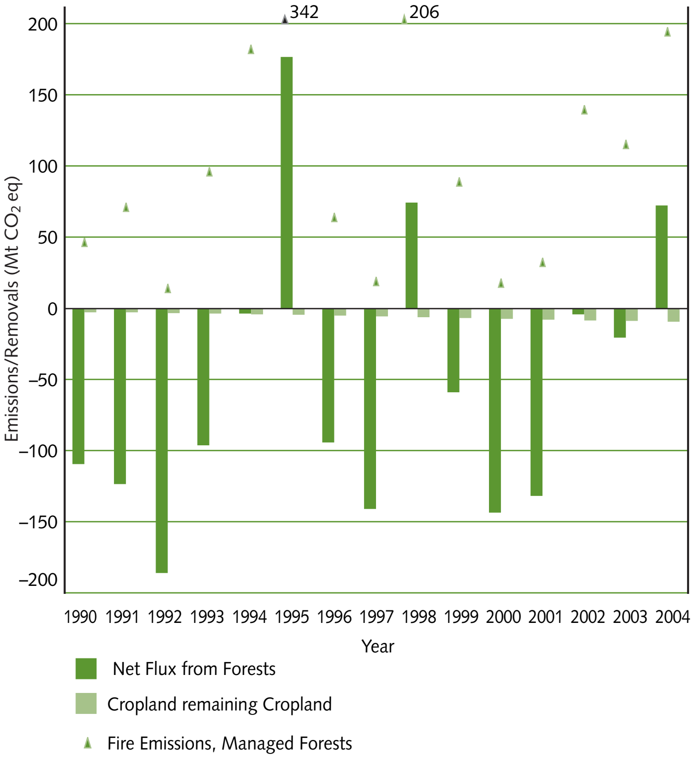
GHG emissions from sources and removals by sinks are estimated and reported for four land categories:

- Forest Land;
- Cropland;
- Wetlands; and
- Settlements.

The Forest Land category includes GHG emissions to and removals from Canada's managed forests. This category displays the highest interannual variability and exerts an overriding influence on the net sectoral GHG balance and trend. The net GHG flux reflects the difference between carbon uptake by tree growth and emissions due to anthropogenic and natural disturbances, specifically forest management activities, wildfires, and insect infestations. The high variability in the net flux from managed forests is associated with the immediate impact of wildfires, which alone accounted for annual emissions between 14 and 342 Mt over the period from 1990 to 2004 (Figure 2-7). Both short- and long-term trends should therefore be interpreted with caution, given that the sector as a whole retains the important interannual variability resulting from large fluctuations in the severity of the fire season, with an additional random effect due to the location of fires with respect to managed forests (as opposed to non-managed). The largest carbon fluxes to and from managed forests consist of carbon uptake by growing trees and its release due to the decay of organic matter (respectively −3200 and 2900 Mt in 2004). These large, opposite fluxes more or less balance each other throughout the 15 years covered by this assessment. Forest management activities account for annual average emissions of 122 Mt.

Readers should acquaint themselves with Chapter 7 and Section A3.5 of Annex 3 of the present report, which provide additional analysis of these estimates and an overview of the underlying estimation methodologies.

FIGURE 2-7: Selected Emissions and Removals in LULUCF, 1990–2004



The Cropland subcategory includes the effect of agricultural practices on CO_2 emissions and removals from arable soils and the impact on GHG emissions or removals associated with forest and grassland conversion to cropland. In 2004, carbon sequestration in arable soils almost exactly offset emissions from lands converted to cropland, for a net flux of 0.06 Mt. The continued adoption of no-till (NT) and reduced tillage (RT) practices and the reduction of summerfallow explain the steady trend of increasing removals in cultivated soils.

CO_2 emissions from peatlands managed for peat extraction and from flooding are reported for the first time under the Wetlands category. Managed peatlands contribute 1 Mt of emissions to the LULUCF Sector total. Flooded lands emitted 6 Mt in 1990, decreasing to 1 Mt in 2004. Note that reservoirs flooded for more than 10 years are excluded from the accounting (IPCC, 2003).

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

Forest losses to cropland, wetlands, and settlements amount to emissions of about 16 Mt, down from 28 Mt in 1990. This reduction is accounted for by declines of more than 6 Mt in emissions from forests converted to cropland and of 4 Mt in forests converted to wetlands (flooded lands). Again, the reader is referred to additional information in Chapter 7 and Section A3.5 of Annex 3 of the present report.

As explained in more detail in Chapter 7, Canada has begun the implementation of a multiyear effort to substantially improve its estimates for the LULUCF Sector. As a result, most LULUCF categories present completely revised time series, although, as in previous submissions, the overall trend remains uncertain, due to interannual variability. Explanations of those changes can be found in the corresponding sections of Chapter 7.

2.3.6 WASTE SECTOR (2004 GHG EMISSIONS, 29 Mt)

From 1990 to 2004, GHG emissions from the Waste Sector increased 16%, only slightly greater than the population growth of 15%, while over the same period the total national GHG emissions grew by 27% (Figure 2-8). In 2004, these emissions represented 3.8% of the total national GHG emissions, compared with a 4.2% contribution in 1990. Of the 29 Mt total emissions from this sector in 2004, solid waste disposal on land, which includes municipal solid waste (MSW) landfills and wood waste landfills, accounted for 27 Mt. CH_4 emissions produced by the decomposition of biomass in MSW were responsible for 95% of the emissions from this sector. Emissions from municipal wastewater treatment and incineration of waste (excluding emissions from incineration of biomass material) contributed 1.2 Mt and 0.25 Mt, respectively, to the total from the Waste Sector (Table 2-8). Figure 2-8 presents the emission trends for each of the three subsectors as compared with the total emissions for the Waste Sector between 1990 and 2004. The tables in Annex 8 summarize this information nationally by CO_2 equivalent and by category (i.e., individual gas and source).

TABLE 2-8: GHG Emissions from Waste Sector, Selected Years'

GHG Source Category	GHG Emissions					
	Mt CO_2 eq					
	1990	1995	2001	2002	2003	2004
Total Waste Sector	**25**	**26**	**28**	**28**	**29**	**29**
a. Solid Waste Disposal on Land	23	25	27	27	27	27
b. Wastewater Handling	1.1	1.1	1.2	1.2	1.2	1.2
c. Waste Incineration	0.40	0.33	0.25	0.23	0.24	0.25

CH_4 emissions from MSW landfills increased by 18% between 1990 and 2004, despite an increase in landfill gas capture and combustion of 48% over the same period. The quantity of CH_4 captured in 2004 was assumed to be the same as the 2003 value. Approximately 312 kt of CH_4 (or 6533 kt CO_2 eq) were captured by the 44 landfill gas collection systems operating in Canada (Environment Canada, 2003). Of the total amount of CH_4 collected, 55%, or 173 kt CH_4, was utilized for various energy purposes at 16 sites, and the remaining 45%, or 139 kt CH_4, was flared at 28 sites.

GHG emissions from landfills were estimated for two types of waste: MSW and wood waste landfills, both of which produce CH_4 anaerobically.[31] The CH_4 production rate at a landfill is a function of several factors, including the mass and composition of biomass being landfilled, the landfill temperature, and the moisture entering the site from rainfall.

CH_4 capture and waste diversion programs at landfills have made significant contributions to reductions in emissions during this period. The quantity of CH_4 captured at MSW landfills for flaring or combusted for energy recovery purposes in 2004 amounted to 21% of the total generated. Per capita emissions from the Waste Sector increased 0.5% from 1990 to 2004 due primarily to the increasing emissions from landfills (Figure 2-9). The amount of CH_4 captured increased

FIGURE 2-8: 1990–2004 National Waste Sector GHG Emission Trends

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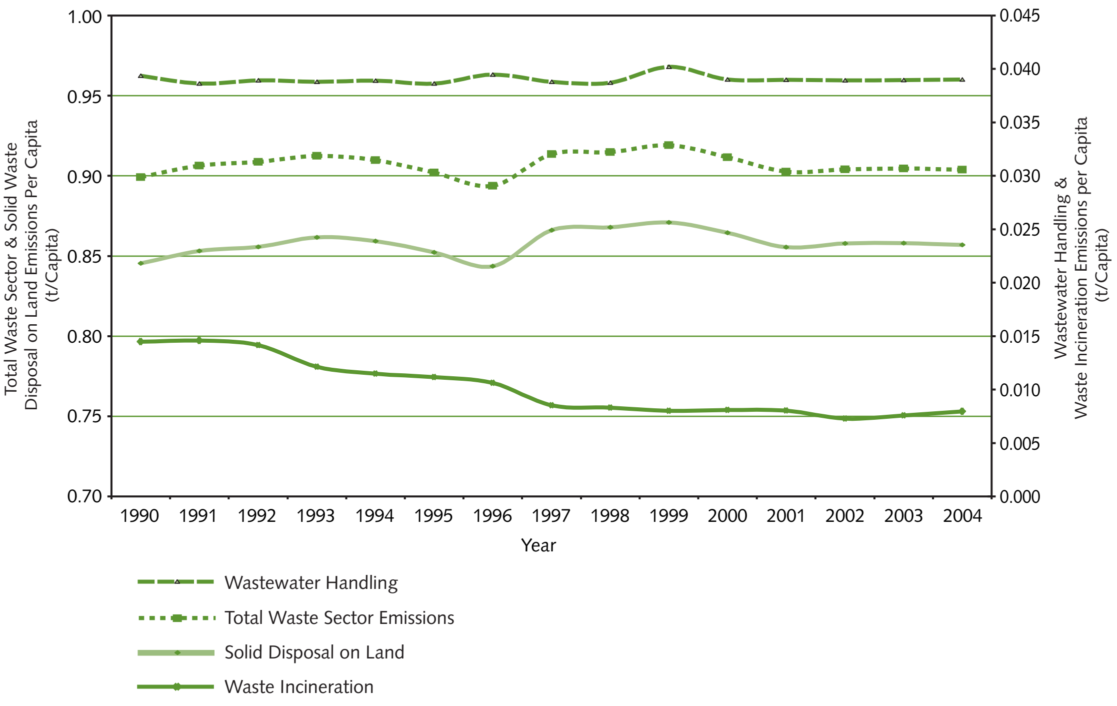
[31] When waste consists of biomass, the CO_2 produced from burning or aerobic decomposition is not accounted for in the Waste Sector, as it is deemed a sustainable cycle (carbon in CO_2 will be sequestered when the biomass regenerates). In theory, emissions of CO_2 are accounted for as part of the LULUCF Sector; however, waste that decomposes anaerobically produces CH_4, which is not used photosynthetically and therefore does not sequester carbon in biomass. The production and release of unburned CH_4 from waste are therefore accounted for in GHG inventories.

by 48% between 1990 and 2004, and the amount of waste diverted increased by 4.8% between 1998 and 2002, when diversion programs were initiated. Although the quantity of waste placed in MSW landfills increased by 17% from 1990 to 2002, the year of the last published Statistics Canada waste management survey, the landfilled quantity per capita increased by only 3.3% (Statistics Canada, 2000, 2003, 2004). Emission trend growth slightly exceeds population increases, since material landfilled in past decades is still contributing to CH_4 production. The decline in the growth of emissions per capita observed in the mid-1990s, shown in Figure 2-9, is directly attributable to CH_4 capture at landfills and waste diversion programs. However, in 1997, there was a reduction in landfill gas collection, which was followed by an increase in 2000. These changes have an inversely proportional influence on the emissions per capita, which is apparent in Figure 2-9. In addition to these two factors, the quantity of waste exported from Canada to the United States, which saw significant increases that started in the late 1990s and continued in the following years, is believed to be the major driver behind the plateau in the trend for Solid Waste Disposal on Land observed in the period 2001–2004 (Figure 2-8), since the quantity of landfill gas captured remained relatively unchanged. The amounts of waste exported for the years 1998 and 2004 were 560 kt and 2590 kt, respectively, giving a 363% increase in the amount of waste exported over this period. The greatest incremental increase in emissions (3.2%) was from 1996 to 1997, due to a significant decrease in the quantity of landfill gas collected. In the following years, emissions were seen to increase incrementally within a range of 0.1–1.3%.

In terms of emissions per capita as compared with 1990 emissions per capita for the other waste subsectors, GHG emissions from wastewater handling have remained fairly constant, while waste incineration has shown a significant decrease in GHG emissions over the 1990–2004 time series (Figure 2-9). Total incineration emissions per capita decreased by 45% over the time series, with the greatest decline in emissions per capita for incineration occurring between 1992 and 1997, due mainly to the closure of aging incinerators.

FIGURE 2-9: **Per Capita GHG Emission Trend for Waste, 1990–2004**



Source:

Statistics Canada (2004), *Waste Management Industry Survey: Business and Government Sectors, 2002*. Catalogue No. 16F0023X1E www.statcan.ca/english/sdds/2009.htm

2.4 EMISSION TRENDS FOR OZONE AND AEROSOL PRECURSORS

In summary, over the 1990–2004 period, emissions of ozone and aerosol precursors fell. CO fell by 33.9%, NO_x was down 9.7%, NMVOCs declined 20.1%, and SO_x was reduced by 28.7% (see Annex 15 for data tables).

3 ENERGY (CRF SECTOR 1)

3.1 OVERVIEW

Overall, the Energy Sector contributed about 82% (or 620 Mt CO_2 eq) of Canada's total GHG emissions in 2004 (refer to Table 3-1 for more detail). The Energy Sector accounts for all GHG (CO_2, CH_4, and N_2O) emissions from stationary and transport fuel combustion activities as well as fugitive emissions from fossil fuels (solid, liquid, and gaseous fuels). Fugitive emissions from fossil fuels are the intentional or unintentional (i.e., accidental) releases of GHGs that may result from the production, processing, transmission, storage, and use of fuels. Emissions from flaring activities by the oil and gas industry are reported in the fugitive category, since their purpose is not to produce heat or to generate mechanical work (IPCC/OECD/IEA, 1997).

Emissions resulting from stationary fuel combustion include, for example, the use of fossil fuels by the electricity generating industry, the oil and gas industry, the manufacturing and construction industry, and the residential and commercial sector. Only CH_4 and N_2O emissions resulting from the combustion of biomass fuels by the pulp and paper industry and by the residential sector are accounted for in the Energy Sector, while CO_2 emissions resulting from the use of biomass are reported as a memo item in the UNFCCC's CRF tables.

GHG emissions from the combustion (and evaporation) of fuel for all transport activities, such as rail, civil aviation, road transport, marine transport, and pipelines, are included in the Transport subsector. Usage of gasoline and diesel fuels by the mining, agriculture, forestry, and oil and gas industry is also included in the Transport subsector. Emissions from international bunker activities (only in regards to aviation and marine transport) are also reported as a memo item in the UNFCCC's CRF tables.

TABLE 3-1: GHG Emissions by Energy Sector

GHG Source Category	GHG Emissions		
	kt CO_2 eq		
	1990	2003	2004
Energy Sector	**475 000**	**622 000**	**620 000**
Fuel Combustion (1.A)	**432 000**	**556 000**	**553 000**
Energy Industries (1.A.1)	148 000	216 000	209 000
Manufacturing Industries and Construction (1.A.2)	63 000	66 500	67 700
Transport (1.A.3)	149 000	188 000	193 000
Other Sectors (1.A.4)	72 200	85 500	83 200
Fugitive Emissions from Fuels (1.B)	**43 300**	**66 200**	**66 500**

Note:

Totals may not add due to rounding.

3.2 FUEL COMBUSTION (CRF CATEGORY 1.A)

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

In 2004, about 553 Mt (or 73%) of Canada's GHG emissions were from the combustion of fossil fuels (Table 3-1). The overall GHG emissions from fuel combustion activities increased by 28% since 1990 and decreased by 0.5% since 2003. Between 1990 and 2004, combustion-related emissions from the Energy Industries and from the Transport category increased by about 41% and 30%, respectively.

3.2.1 ENERGY INDUSTRIES (CRF CATEGORY 1.A.1)

3.2.1.1 Source Category Description

The Energy Industries subsector includes all emissions from stationary fuel combustion sources in the electricity generation industry and the production, processing, and refining of fossil fuels. The Energy Industries subsector is divided into the following categories: Public Electricity and Heat Production, Petroleum Refining, and Manufacture of Solid Fuels and Other Energy Industries (which consists primarily of coke, coal, and natural gas production).

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

In 2004, the Energy Industries subsector accounted for 209 Mt (or about 28%) of Canada's total GHG emissions, with an overall increase of about 41% since 1990. Over 62% (or 130 Mt) of the GHG emissions are from Public Electricity and Heat Production, while Petroleum Refining and the Manufacture of Solid Fuels and Other Energy Industries contributed 14% (29 Mt) and 23.5% (49 Mt), respectively (Table 3-2). Additional discussions on trends in emissions from the Energy Industries are to be found in the Emission Trends chapter (Chapter 2) and in the industrial analysis annex (Annex 10).

TABLE 3-2: Energy Industries GHG Contribution

GHG Source Category	GHG Emissions		
		kt CO_2 eq	
	1990	2003	2004
Energy Industries TOTAL (1.A.1)	**148 000**	**216 000**	**209 000**
Public Electricity and Heat Production	**95 300**	**139 000**	**130 000**
Electricity Generation — Utilities	92 400	133 000	124 000
Electricity Generation— Industry	2 200	4 650	4 300
Heat/Steam Generation	700	1 700	2 000
Petroleum Refining (including oil sands upgrading activities)	**23 000**	**30 000**	**29 000**
Manufacture of Solid Fuels and Other Energy Industries	**30 000**	**47 000**	**49 000**

Note:
Totals may not add due to rounding.

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

The electric supply grid in Canada includes thermal combustion–derived electricity as well as hydro, nuclear, wind, and tidal power. The total power generated from wind, tidal, and solar power is relatively small. Nuclear, hydro, wind, solar, and tidal power generation are not direct emitters of GHGs. Therefore, GHG estimates reflect emissions from combustion-derived electricity only.

Two systems are used to generate electricity using thermal combustion:

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

Steam turbine boilers are fired with coal, heavy fuel oil, natural gas, or biomass. For steam turbines, the initial heat may be produced using light fuel oil, natural gas, kerosene, or diesel oil. Reciprocating engines use light fuel oil, diesel, natural gas, and/or a combination of all of these. Gas turbines are fired with natural gas or refined petroleum products.

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

Conventional crude oil is refined by distillation and other processes into petroleum products, such as heavy fuel oil (bunker C), residential fuel oil, jet fuel, gasoline, and diesel oil. The heat required for these processes is created by combusting either internally generated fuels (such as refinery fuel gas) or purchased fuels (such as natural gas). CO_2 is also generated as a by-product during the production of hydrogen in the steam reforming of natural gas. Emissions resulting from the use of natural gas to produce hydrogen are reported in the fugitive category.

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

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

This category comprises fuel combustion emissions associated with the upstream oil and gas industry (not including pipeline transmission systems) and coal mining. Emissions associated with pipeline transmission are reported under Transportation – Others.

3.2.1.2 Methodological Issues

Emissions for all source categories are calculated following the methodology described in Annex 2 and are based on national fuel consumption statistics reported in the *Report on Energy Supply–Demand in Canada* (RESD) (Statistics Canada, #57-003). The method is consistent with the IPCC Tier 2 approach with country-specific emission factors.

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

Emissions for this category are calculated using all fuel use (including diesel and any gasoline) reported for both industrial and utility electricity generation and for steam/heat generation (reported as fuel transformation) in the RESD.

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

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 the producer consumption line in the RESD. This includes all petroleum products (including still gas, petroleum coke, diesel, etc.) reported as producer consumption and purchases of natural gas for fuel use by refineries and oil sands extracting and upgrading operations.

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

Emissions for this category are calculated using natural gas, NGLs, and coal data reported for fossil fuel producers, titled *producer consumption*, in the RESD. The fuel-use data in the RESD include volumes of flared fuels; however, flaring emissions are calculated and reported separately in the fugitive category. The fuel-use and emission data associated with flaring are subtracted to avoid double-counting.

3.2.1.3 Uncertainties and Time-Series Consistency

The estimated uncertainty for the Energy Industries subsector ranges from –4% to +6% for all gases and from –6% to +2% for CO_2 alone. Refer to the Uncertainty annex (Annex 7) for additional discussion on the ICF (2004) uncertainty study and additional uncertainty values for the Energy Industries subsector.

The uncertainties for the Energy Industries subsector are largely dependent on the collection procedures used for the underlying activity data as well as on the representativeness of the emission factors for specific fuel properties. Commercial fuel volumes and properties are generally well-known, while there is greater uncertainty surrounding both the reported quantities and properties of non-marketable fuels (such as *in situ* use of natural gas from the producing wells and the use of refinery fuel gas). For example, in the Petroleum Refining category, the CO_2 emission factors for non-marketable fuels as consumed, such as refinery still gas, petroleum coke, and catalytic coke, have a greater influence on the uncertainty estimate than the CO_2 factors for commercial fuels.

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

Over 98% of the 2004 emissions from the Manufacture of Solid Fuels and Other Energy Industries category are associated with natural gas production and processing. The uncertainty for this category is influenced by the CO_2 emission factors (±6%) and CH_4 emission factors (0% to 240%) for the consumption of unprocessed natural gas. A national weighted emission factor was used to estimate emissions for the natural gas industry due to a lack of plant-level information, such as the physical composition of unprocessed natural gas (which will vary from plant to plant). Thus, the overall uncertainty estimate is based on a rather broad assumption as well.

The estimated uncertainty for CH_4 (1% to 230%) and N_2O (–23% to +800%) emissions for the Energy Industries subsector is influenced by the uncertainty associated with the emission factors. Additional expert elicitation is required to improve the CH_4 and N_2O uncertainty estimates for some of the emission factor uncertainty ranges and probability density functions developed by ICF (2004), since insufficient time was available to have these assumptions reviewed by industry experts.

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

3.2.1.4 QA/QC and Verification

Tier 1 QC checks as elaborated in the framework for the QA/QC plan (details and references in Annex 6) were performed on the CO_2 estimates for the following key source categories:

- Public Electricity and Heat Production;
- Petroleum Refining; and
- Manufacture of Solid Fuels and Other Energy Industries.

In addition, QC checks were performed on the N_2O estimates for Manufacture of Solid Fuels and Other Energy Industries.

QC checks were done in a form consistent with IPCC Good Practice Guidance (IPCC, 2000). Some of the 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 units labelling, as well as sample emission calculations.

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

3.2.1.5 Recalculations

The underlying 2003 fuel-use data were revised by Statistics Canada, and the estimates for the Energy Industries subsector were recalculated accordingly.

3.2.1.6 Planned Improvements

The Canadian Association of Petroleum Producers (CAPP) and its members are working jointly with NRCan and Environment Canada on the Canadian bitumen industry study, with the objective of compiling a comprehensive inventory of GHG emissions from all sources (i.e., combustion, processes, and fugitive sources) for 1990–2003.

The Canadian bitumen industry study was expected to be completed in 2005, but has been delayed. When finalized, the results of the report will assist with the refinement of the combustion and fugitive estimation methods for the oil sands mining, extracting, and upgrading industry.

A formal Working Group on Energy Statistics, consisting of members from Environment Canada, NRCan, and Statistics Canada, was established to address and improve the quality of the underlying energy statistics (for the RESD and the Industrial Consumption of Energy Survey) used for emissions inventory and forecasting development, for energy efficiency programs, for energy and emission policy development, for International Energy Agency reporting, for the Canadian Industry Program for Energy Conservation, and to streamline energy data collected by other departments.

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

3.2.2 MANUFACTURING INDUSTRIES AND CONSTRUCTION (CRF CATEGORY 1.A.2)

3.2.2.1 Source Category Description

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

In 2004, the Manufacturing Industries and Construction subsector accounted for 67.7 Mt (or 9%) of Canada's total GHG emissions, with an 8% decrease in emissions since 1990 (refer to Table 3-3 for more details). Within the Manufacturing Industries and Construction subsector, more than 42 Mt (or 62.5%) of the GHG emissions are from the Others category, followed by the Pulp, Paper and Print, the Iron and Steel, and the Chemicals categories, at 9.3 Mt (or 13.7%), 6.5 Mt (or 9.6%), and 6.3 Mt (or 9.3%), respectively. Emissions from Food Processing, Beverages and Tobacco are included in the Other Manufacturing subcategory.

The Others category is made up of Cement, Mining, Construction, and Other Manufacturing activities. Emissions from mining activities have increased by almost 149% between 1990 and 2004.

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

Emissions of CH_4 and N_2O from the combustion of biomass are included in the pulp and paper industrial category. CO_2 emissions from biomass combustion are not included in totals but are reported separately in the UNFCCC CRF tables as a memo item.

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

TABLE 3-3: Manufacturing Industries and Construction GHG Contribution

GHG Source Category	GHG Emissions		
	kt CO_2 eq		
	1990	2003	2004
Manufacturing Industries and Construction TOTAL (1.A.2)	**63 000**	**66 500**	**67 700**
Iron and Steel	6 490	6 370	6 550
Non-Ferrous Metals	3 230	3 200	3 230
Chemicals	7 100	5 820	6 290
Pulp, Paper and Print	13 600	9 010	9 310
Food Processing, Beverages and Tobacco[1]	IE	IE	IE
Others	32 500	42 100	42 300
Cement	3 590	4 180	4 330
Mining	6 200	15 700	15 400
Construction	1 880	1 300	1 350
Other Manufacturing	20 900	20 900	21 200

Notes:

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

Totals may not add due to rounding.

IE = included elsewhere

3.2.2.2 Methodological Issues

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

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

Fuel-use data for this category were obtained from the RESD (Statistics Canada, #57-003), reported as iron and steel (Standard Industrial Classification [SIC] 291 or North American Industrial Classification System [NAICS] 3311, 3312, and 33151). Emissions associated with the use of metallurgical coke as a reagent for the reduction of iron ore in blast furnaces have been allocated to the Industrial Processes Sector.

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

All fuel-use data for this category were obtained from the RESD (Statistics Canada, #57-003), reported as smelting and refining of non-ferrous metals (SIC 295 or NAICS 3313, 3314, and 33152).

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

All fuel-use data for this sector were obtained from the RESD (Statistics Canada, #57-003), reported as chemicals (SIC 371 and 3721 or NAICS 3251 and 3253). Note that emissions resulting from fuels used as feedstocks are reported under the Industrial Processes Sector.

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

All fuel-use data for this source category were obtained from the RESD (Statistics Canada, #57-003), reported as pulp and paper (SIC 271 and 2512 or NAICS 322). Included in this category are industrial wood wastes and spent pulping liquors combusted for energy purposes.

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

This category includes the remainder of industrial sector emissions, including construction, cement, mining, and food, beverage, and tobacco sectors. The mining data also include commercial fuels (i.e., diesel) used in the oil and gas production industry.

All fuel-use data for this category were obtained from the RESD (Statistics Canada, #57-003), as reported under cement, construction, mining, and other manufacturing (SIC 352, 071 10–39, and 401–429 or NAICS 311–321, 325, 3252, 3254–3259, 326, 327, excluding 32731, and 332–339).

3.2.2.3 Uncertainties and Time-Series Consistency

The estimated uncertainty for the Manufacturing Industries and Construction subsector ranges from –3% to +6% for all gases and from –3% to +2% for CO_2. Refer to the uncertainty annex (Annex 7) for a detailed discussion on the ICF (2004) uncertainty study and additional uncertainty values for the Manufacturing Industries and Construction subsector.

The underlying fuel quantities and CO_2 emission factors have low uncertainty because they are predominantly commercial fuels, which have consistent properties and a more accurate tracking of quantity purchased for consumption.

As stated in the Energy Industries subsector uncertainty discussion, additional expert elicitation is required to improve the CH_4 and N_2O uncertainty estimates for some of the emission factor uncertainty ranges and probability density functions developed by the ICF (2004) study, since these assumptions were not reviewed by industry experts, due to the lack of available time in the study's preparation.

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

3.2.2.4 QA/QC and Verification

Manufacturing Industries and Construction, identified as a key category for CO_2, underwent Tier 1 QC checks in a manner consistent with IPCC Good Practice Guidance (IPCC, 2000). No mathematical or referencing errors were found during the QC checks, and only trivial labelling problems were observed. The data, methodologies, and changes related to the QC activities are documented and archived in paper and electronic form.

3.2.2.5 Recalculations

The underlying 2003 fuel-use data were revised by Statistics Canada, and emission estimates were recalculated accordingly.

3.2.2.6 Planned Improvements

As a continuous improvement activity, Environment Canada, NRCan, and Statistics Canada are working jointly to improve the underlying quality of the national energy balance and to further disaggregate fuel-use information.

3.2.3 TRANSPORT (CRF CATEGORY 1.A.3)

Transport-related emissions account for over one-quarter of Canada's total GHG emissions. The greatest emission growth since 1990 has been observed in LDGTs and HDDVs; this growth amounts to 101% (21.9 Mt) for light trucks and 83% (20.4 Mt) for heavy-duty vehicles. A long-term decrease in some transport subsectors has also been registered:

specifically, reductions in emissions from LDGVs (cars), propane and natural gas vehicles, and off-road gasoline devices, for a combined decrease of 6.6 Mt since 1990. Generally, the Transport subsector has increased 30% and has contributed 28% of the total overall growth observed in Canada (see Table 3-4).

TABLE 3-4: Transport GHG Contribution

GHG Source Category	GHG Emissions		
	kt CO_2 eq		
	1990	**2003**	**2004**
Transport TOTAL (1.A.3)	**150 000**	**190 000**	**190 000**
Civil Aviation	**6 400**	**7 300**	**7 800**
Road Transport	**107 000**	**140 000**	**145 000**
Light-Duty Gasoline Vehicles	53 800	49 400	49 800
Light-Duty Gasoline Trucks	21 700	41 900	43 600
Heavy-Duty Gasoline Vehicles	3 140	4 140	4 210
Motorcycles	230	226	219
Light-Duty Diesel Vehicles	672	722	768
Light-Duty Diesel Trucks	591	796	893
Heavy-Duty Diesel Vehicles	24 500	42 300	44 900
Propane & Natural Gas Vehicles	2 200	820	870
Railways	**7 000**	**6 000**	**6 000**
Navigation (Marine)	**5 000**	**6 100**	**6 600**
Other Transport	**20 000**	**30 000**	**30 000**
Off-Road Gasoline	5 000	4 000	4 000
Off-Road Diesel	10 000	10 000	20 000
Pipelines	6 900	9 110	8 520

Note:

Totals may not add due to rounding.

3.2.3.1 Source Category Description

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

- Civil Aviation;
- Road Transport;
- Railways;
- Navigation (Marine); and
- Other Transport.

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 (M-GEM05). This model incorporates a version of the IPCC-recommended methodology for vehicle modelling (IPCC/OECD/IEA, 1997) and is used to calculate all transport emissions with the exception of those associated with pipelines (energy necessary to propel oil or natural gas) and aviation. The model is used primarily to further disaggregate on-road total fuel volume (RESD) to one of 23 subcategories (bins) per province/territory.

For on-road total fuel volume, M-GEM05 uses a vehicle population profile, fuel consumption ratios (FCRs), emission control technology penetration rates, and estimated vehicle kilometres travelled (Vkmt's) per "bin" to estimate its necessary fuel and adjusts Vkmt's to solve the equation (i.e., balancing the total fuel consumption reported for the Transport subsector with the fuel consumption calculated for each "bin"). The volume allocated to each of these "bins" will represent the estimated amount of fuel consumed by vehicles of similar emission characteristics determined as a function of their model year, fuel, and vehicle type.

Road transport CO_2 emission factors are fuel dependent (Jaques, 1992), whereas CH_4 and N_2O emission factors are highly dependent upon the specific pollution control devices on each vehicle. Emission factors associated with these gases vary with vehicle type and are listed in Annex 13, Table A13-5.

To calculate final emissions, a specific combination of emission factors (CO_2, CH_4, and N_2O) is multiplied by the total fuel in each of the unique consumption categories mentioned above. CH_4 and N_2O are then adjusted according to their specific GWP to convert their units to CO_2 eq. Emission values are then aggregated to IPCC categories as per their native fuel type and use category.

M-GEM was thoroughly updated in 2001 to include new findings on CH_4 and N_2O emissions. Additional data on vehicle populations were also incorporated. Emission factors used by the model have been adopted from many sources; however, emphasis has been on North American research and on Canadian studies in particular. Specific references are included in Annex 13, Table A13-5.

For the 2003 inventory year, a database model (M-GEM05) that addresses all years' emissions simultaneously was constructed to facilitate improvements in subsequent reporting years. This model emulates the operations of the previous spreadsheet-based M-GEM (Jaques *et al.*, 1997; Neitzert, 1998) but allows an increased ability to modify relationships as knowledge of historic assumptions evolves.

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

This category includes all GHG emissions from domestic air transport (commercial, private, military, agricultural, etc.). Although the IPCC Guidelines (IPCC/OECD/IEA, 1997) call for military air transportation emissions to be reported elsewhere, they have been included here. Excluded are emissions from fuel used at airports for ground transport (reported under other transport, off-road) and fuel used in stationary combustion applications at airports. Emissions arising from fuel sold to foreign airlines and fuel sold to domestic carriers but consumed during international flights are considered to be international bunkers and are reported separately.

The methodologies for civil aviation follow a modified IPCC Tier 1 sectoral approach. Emission estimates are calculated based upon the reported quantities of aviation gasoline and turbo fuel consumed (IPCC/OECD/IEA, 1997) as published in the RESD (Statistics Canada, #57-003). Fuel consumption is reported separately for Canadian airlines, foreign airlines, public administration (federal, provincial, and municipal governments), and commercial and other institutional (industries related to mining, transportation, communication, real estate, etc.).

Fuel purchased by public administration and commercial and other institutional is assumed to be consumed exclusively for domestic travel, whereas fuel purchased by foreign airlines is consumed solely for international travel, and the resulting emissions are considered international bunkers and are reported separately. Our concern is with domestic fuel purchase, as domestic carriers fly both domestically and internationally. Since the amount of fuel sold to domestic carriers consumed during domestic travel is not readily available from any source, a method was developed to estimate domestic fuel consumption given variables representing airline activities. Two such variables are published by Statistics Canada: tonne-kilometres (t-km) flown by Canadian carriers, and enplaned/deplaned passengers by sector (Statistics Canada, #51-206 — Canadian Civil Aviation; and Statistics Canada, #51-005 and #51-203 — Air Carrier Traffic at Canadian Airports).

Domestic tonne-kilometres are flown using fuel purchased in Canada; however, only a percentage of international tonne-kilometres are flown with fuel purchased in Canada. The initial assumption was that half (50%) of the international tonne-kilometres flown globally by Canadian carriers used fuel purchased in Canada. The emission estimates resulting from the initial assumption were compared with the results of more sophisticated aviation emission models (SAGE – USA and AERO2K – UK). Increasing the assumed percentage of tonne-kilometres flown internationally by domestic carriers on domestically purchased fuel to 69% in the Canadian model better emulated the aforementioned emission models.

Fuel consumed by domestic airlines to fly within Canada is then calculated by multiplying the percentage of domestic tonne-kilometres by the fuel consumed. The remainder of the fuel sold to domestic airlines is consumed during international flights, and the resulting emissions are reported as international bunkers and are reported separately.

Once national estimates are produced, additional activity data are needed to calculate provincial and territorial emission estimates. Based on statistics reporting enplaned and deplaned passengers, we can calculate the ratio of domestic to total aviation activity. By applying the ratio of domestic travel to the fuel sold to Canadian airlines for a particular region and then scaling the results to correspond to our tonne-kilometres calculation, we can estimate emissions on a regional level.

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

Gasoline and Diesel

The methodology used to evaluate road transport GHG emissions follows a detailed IPCC Tier 3 method, as outlined in IPCC/OECD/IEA (1997). M-GEM05 disaggregates vehicle data and calculates emissions of CO_2, CH_4, and N_2O from all mobile sources except aviation. However, the model was developed principally to handle the complex emission calculations for road transport.

M-GEM05 uses a detailed procedure for calculating emissions from road transport. For this subsector, data on fuel consumption, vehicle type, vehicle control technology, technology age, age distribution of the fleet, fuel efficiency, and average distance travelled per year are all considered. Emissions are calculated and assigned in accordance with the IPCC reporting procedure (IPCC/OECD/IEA, 1997).

In order to improve accuracy, it is necessary to subdivide road transport into numerous subsectors, as emissions are related to vehicle type. Light-duty vehicles (LDVs) comprise automobiles and light trucks. The IPCC road transport subsectors are (IPCC/OECD/IEA, 1997):

- *Cars*: Automobiles designated primarily for transport of persons and having a capacity of up to 12 passengers. The gross vehicle weight rating is 3900 kg or less.
- *Light-Duty Trucks*: Vehicles with a gross vehicle weight rating of 3900 kg or less that are designated primarily for transportation of light-weight cargo or that are equipped with special features such as four-wheel drive for off-road operation.
- *Heavy-Duty Trucks and Buses*: Any vehicle rated at more than 3900 kg gross vehicle weight or designed to carry more than 12 persons at a time.
- *Motorcycles*: Any motor vehicle designed to travel with not more than three wheels in contact with the ground and weighing less than 680 kg.

It is important to note that there are no universally accepted names or weight limits for the various road transport subsectors. However, for environmental emission purposes, Canada, the United States, and Mexico use designations that are closely aligned to those employed for use with the U.S. Environmental Protection Agency (EPA) *MOBILE* Emissions Factor Model. While similar to the above, there are slight differences. For example, the gross vehicle weight rating cut-off between light and heavy vehicles is 8500 lbs. or 3855.6 kg. Canada's emission estimates for CO, NMVOCs, and NO_x are calculated using the EPA designations. The EPA designations are:

- Light-Duty Gasoline Vehicles/Automobiles (LDGVs);
- Light-Duty Gasoline Trucks (LDGTs);
- Heavy-Duty Gasoline Vehicles (HDGVs);
- Motorcycles;
- Light-Duty Diesel Vehicles/Automobiles (LDDVs);
- Light-Duty Diesel Trucks (LDDTs); and
- Heavy-Duty Diesel Vehicles (HDDVs).

Both the UNFCCC and the EPA insert fuel-type descriptors (e.g., gasoline, diesel, natural gas, or propane) into their various vehicle subsectors where appropriate. While CO_2 releases from vehicles are not considered to be technology dependent, CH_4 and N_2O emission levels are affected by changes in emission control equipment. For CH_4 emissions, vehicles equipped with more sophisticated controls tend to have lower emission rates. The effect of pollution-limiting equipment on N_2O emissions is a more complex matter. Catalytic converters became the primary means to control hydrocarbon and, subsequently, NO_x emissions from gasoline vehicles in the late 1970s and early 1980s. Oxidation catalysts appeared first, followed later by "three-way catalysts." The earlier generations of three-way catalysts were part of emission control packages that are now labelled Tier 0 controls. Tier 1,[32] more advanced technology, was introduced to LDVs in North America in 1994. To date, however, research indicates that all catalytic control units increase N_2O emissions, compared with uncontrolled vehicles (De Soete, 1989; Barton and Simpson, 1995). After their introduction, Tier 0 catalytic control units were also shown to have deteriorating capacity to effectively reduce N_2O emissions as they aged (De Soete, 1989;

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[32] It is important not to confuse the Tier 0 and Tier 1 vehicle emission control system designators mentioned above with the IPCC use of "tier" to differentiate levels of sophistication for estimating emissions.

Prigent *et al.*, 1991). The full effects of aging were noted to occur after approximately one year of use. Note that the emission factors used for LDVs equipped with "aged" Tier 0 controls are approximately one order of magnitude higher (on a per unit of fuel basis) than those from uncontrolled vehicles (De Soete, 1989; Barton and Simpson, 1995).

Natural Gas and Propane

No breakdown by vehicle classification is utilized for natural gas and propane vehicles; therefore, it was assumed that virtually all such vehicles are light-duty and the vast majority are automobiles.

Fuel Ethanol

For the 2006 submission, fuel ethanol used in transportation for 1990–2004 is included. Ethanol properties were developed according to chemistry and resulted in a higher heating value (HHV) (gross calorific value, or GCV) of 24.12 TJ/ML, 52.14% carbon content, and 789.2 kg/m^3 density.

Fuel ethanol was introduced and modelled as if it were mixed into the total gasoline for the region(s). Total fuel available per province/territory was allocated to each mode (on/off-road, and vehicle technology class) as per the percentage of total gasoline calculated traditionally with M-GEM05. In lieu of reviewed emission factors for CH_4 and N_2O for ethanol, the representative gasoline emission factor was applied as per mode and technology class. CO_2 emission factors used are those based upon true chemical characteristics mentioned previously and a 98.5% oxidation rate.

On-Road versus Off-Road

The accuracy of the emission calculations depends upon the accuracy of the input data. For the latest inventory, information on the fuel sold for road transport was obtained from data for retail pump sales and sales to commercial fleets found in the RESD (Statistics Canada, #57-003). Statistics Canada also reports transport fuel use in the agricultural, commercial, industrial, and institutional economic sectors, but there is uncertainty as to whether these fuels are used by vehicles on- or off-road. In the RESD, on-road fuel use is a subset of all (non-rail) ground transportation fuel use. The RESD lists data on four fuels for ground transport in Canada — gasoline, diesel fuel oil, natural gas, and propane — and emissions are calculated separately for each fuel.

Emissions are calculated on the basis of Equation 3-1 (as adapted for vehicles):

Equation 3-1:

$$\mathbf{E = EF_{Category} * Fuel_{Category}}$$

where:

E = the total emissions in a given vehicle category

$EF_{Category}$ = the emission factor for the category

$Fuel_{Category}$ = the amount of fuel consumed in a given category

Because their emissions and emission factors differ, on-road fuel use must be separated from off-road fuel consumption. For the data from the RESD, the two are related in the following way:

Equation 3-2:

$$\mathbf{Fuel_{Ground\ (non\text{-}rail)} = Fuel_{Road} + Fuel_{Off\text{-}road}}$$

where:

$Fuel_{Ground\ (non\text{-}rail)}$ = the total fuel used by all categories of ground transport (except rail), as reported by Statistics Canada

$Fuel_{Road}$ = the quantity of fuel used for on-road transport

$Fuel_{Off\text{-}road}$ = the quantity of fuel used for off-road transport (including agricultural, industrial, and construction vehicles, as well as snowmobiles and other recreational vehicles, etc.)

For the purposes of the Transport subsector in this inventory, it was assumed that all natural gas and propane are used in on-road transport vehicles only. Although not completely correct, this assumption introduces only a small degree of error and allows a separate, simplified analysis of alternatively fuelled vehicles.

On-road consumption of diesel oil and gasoline by vehicle type is directly determined by M-GEM05 from available data. The governing equation is:

Equation 3-3:

$$\mathbf{Fuel_{Road\ Category} = (Vehicle\ population) * (Average\ distance\ travelled/year) * (Fuel\ Consumption\ Ratio)}$$

These parameters are different for each vehicle type; therefore, M-GEM05 calculates fuel use by division into relevant types. On-road vehicles are separated into seven major types, identical to those used by the U.S. EPA in its *MOBILE* Emissions Factor Model.

Vehicle Populations

Two separate vehicle in operation (VIO) databases are used to develop the complete vehicle population profile. Light-duty VIO data sets for 1989–2003 (DesRosiers) have been combined with commercial VIO data sets for 1994–2001 (Polk). Commercial vehicle estimates for 1989 (Environment Canada, 1996) provide an anchor point for the interpolation of the intervening years 1990–1993. Motorcycle data were obtained from Statistics Canada (#53-219) up to and including 1998. Motorcycle data for subsequent years are currently extrapolated. Because the territories are not covered by the commercial databases, Statistics Canada's publication #53-219 provided population data for all vehicles in the Canadian territories from 1990 to 1998, while subsequent years use the Canadian Vehicle Survey (CVS; Statistics Canada, #53F0004). For the 2006 submission, extrapolation was applied to the historic populations and was adjusted to produce growth (decline) that equalled that reported in the CVS for 2004.

Technology Penetration

While a simple division of fuel consumption by vehicle type enables the allocation of emissions of carbon to different vehicle categories, it does not take into account the effect that different pollution control devices have on emission rates. To account for the effects that these technologies have on emissions of CH_4 and N_2O, estimates of the number and types of vehicles equipped with catalytic converters and other controls were developed. LDGVs and LDGTs were both further subdivided. Five types of pollution control technology were defined:

- Tier 1 three-way catalyst;
- Tier 0 three-way catalyst (new);
- Tier 0 three-way catalyst (aged);
- oxidation catalyst; and
- non-catalyst.

Vehicles without emission controls were the norm in Canada in the 1960s. Non-catalyst-controlled vehicles were brought to market in the late 1960s. Emission control technology on these included modifications to ignition timing and air–fuel ratios, exhaust gas recirculation, and air injection into the exhaust manifold.[33] Oxidation (two-way) catalytic converters were first used on Canadian vehicles introduced in 1975, and their use continued on production vehicles until the 1987 model year. These so-called two-way converters oxidized hydrocarbons. The three-way (oxidation–reduction) catalytic emission control technology was introduced in Canada in 1980 (Philpott, 1993). Typical ancillary equipment included carburetors with simple electronic ignition. Later, for the 1984 model year, a portion of the fleet was equipped with electronic computer-controlled fuel injection, which became an integral part of the emission control system. By 1990, such computer systems were standard equipment on all gasoline vehicles. The broad category of control technologies produced from the time three-way catalytic converters were introduced up until 1993 has become known in North America as Tier 0 emission control. Tier 0 catalytic converter technology is further subdivided into "new" and "aged" types — the "new" subcategory representing units less than one year old. Tier 1, a more advanced emission control technology, was introduced to North American LDGVs in 1994. It consists of an improved three-way catalytic converter under more sophisticated computer control.

As noted, five technology categories were assigned in the LDGV and LDGT classes, each with a unique emission factor. In these two classes, the categories are based solely on catalytic control technology. All emission factors used are listed in the transport emission factor table (Table A13-5) located within Annex 13.

Detailed sales information was not available for vehicles other than LDGVs and LDGTs. For other categories, it was necessary to employ an estimated split of significant emission control technologies.

Fuel Consumption Ratios (FCRs)

FCRs, in litres of fuel per 100 km, are also available in more detail for light-duty gasoline transport than

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[33] Note that no separate category was used for vehicles without emission control, since these have virtually the same GHG emissions as those with non-catalytic control.

for the other vehicle categories. Fleet-average car and light-duty truck FCRs by model year were obtained from Transport Canada (2002) and the U.S. EPA (Heavenrich and Hellman, 1996). FCRs are determined by standard vehicle laboratory tests. However, recent research has shown that real-world fuel use is consistently higher than laboratory-generated data. Based on studies performed in the United States, on-road vehicle fuel consumption figures in the M-GEM05 have been adjusted to 25% above the laboratory FCR ratings (Maples, 1993). Average FCRs for all operating vehicles within each subcategory of LDGVs and LDGTs are calculated by apportioning the model-year consumption data according to the vehicle age and control technology distribution. FCR estimates for classifications other than light-duty cars and trucks have been set to values recommended by the IPCC/OECD/IEA (1997).

- **Vehicle Kilometres Travelled (Vkmt's)**

Estimates for distances travelled by each class of vehicle were from Environment Canada (1996). This information was based upon Statistics Canada data and surveys performed in the late 1980s. However, these surveys included only personal-use vehicles. Since it is likely that Canadian driving habits have changed in the interim, these data are less reliable than most of the other statistics used within M-GEM05.

- **Road-Taxed Fuel**

In an effort to improve accuracy, a balancing algorithm has been incorporated into the model. A comparison of two estimates of off-road fuel consumption is made. As indicated above, using Statistics Canada data, off-road use can be calculated as the difference between total apparent consumption and that used for on-road use. The primary computation of off-road consumption is made on the basis of internally calculated on-road fuel use. The other estimate is obtained using on-road vehicle road-taxed sales data for diesel oil and gasoline (Statistics Canada, CANSIM Table 405-0002). Statistics Canada reports data on the sales of fuel upon which road taxes are paid. The difference between total gasoline or diesel oil used for ground (non-rail) transport and road tax data constitutes a second estimate of off-road use. Sales data from provincial tax records are gathered in a much different manner from the surveys that Statistics Canada uses for most other energy data, as published in the RESD (Statistics Canada, #57-003). Consequently, the two off-road fuel-use estimates differ. However, it is assumed that the values agree within a certain window of accuracy. M-GEM05 is currently programmed to accept a ±20% difference between the two estimates. If the value obtained from the internally calculated on-road figure is not within 20% of the sales-derived value, vehicle distance travelled is corrected by the ratio required to bring calculated off-road consumption within the desired range. All diesel and gasoline vehicle subcategories are independently compared and corrected by the model as required. Estimated on-road fuel use and emissions have been calculated on the basis of the corrected vehicle distances travelled.

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

In Canada, locomotives are powered primarily by diesel fuel. Emissions associated with steam trains for tourist use are assumed to be negligible, while those associated with the generation of power for grid electrically driven locomotives are accounted for under electricity production.

The methodology is considered to be a modified IPCC Tier 1 (IPCC/OECD/IEA, 1997) methodology. Fuel consumption data from the RESD (Statistics Canada, #57-003), reported as railways, are multiplied by fuel-specific emission factors (see Annex 13).

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

The UNFCCC uses the title navigation for this category, but lists emissions related to international bunkers under marine.

The emission calculations methodology is considered to be modified IPCC Tier 1 (IPCC/OECD/IEA, 1997), and emission estimates are performed within M-GEM05. Fuel consumption data from the RESD (Statistics Canada, #57-003), reported as domestic marine, are multiplied by fuel-specific emission factors (see Annex 13).

Emission calculations are based on estimates of fuel use reported as being sold to Canadian-registered vessels. Inadvertently, some international travel may be included in the domestic inventory, since some domestically registered vessels do travel internationally. Data that would allow an accurate disaggregation of shipping activity by shipping route are not currently available, although the marine industry in Canada is currently engaged in talks to help illustrate the appropriate split.

Other: Transport (CRF Category 1.A.3.e)

This subsector comprises vehicles that are not licensed to operate on roads or highways[34] and the emissions from the combustion of fuel used to propel products in long-distance pipelines.

- **Off-Road Transport**

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

Industry uses a considerable amount of diesel fuel in non-road vehicles. The mining and construction industries both operate significant numbers of heavy non-road vehicles and are the largest diesel fuel users in the group.

Off-road vehicles are handled by a simpler IPCC Tier 1 approach. For these, emissions are based on fuel type, fuel emission factors, and total consumption only. Fuel consumption data are generated by M-GEM05 (see Road-Taxed Fuel under Road Transport above), and estimates are generated with country-specific emission factors (see Annex 13). Off-road emission factors are developed by estimating the relative amounts of fuel consumed by specific groups of equipment (agriculture, forestry, industry, household, inland waterways, two-stroke, four-stroke, gas/diesel) and developing a composite emission factor for each fuel type from sector-specific CORINAIR-based emission factors.

- **Pipeline Transport**

Pipelines[35] represent the only non-vehicular transport in this sector. They use fossil-fuelled combustion engines to power motive compressors that propel their contents. The fuel used is primarily natural gas in the case of natural gas pipelines, but some refined petroleum, such as diesel fuel, is also used. Oil pipelines tend to use electric motors to operate pumping equipment.

Combustion-related GHG emissions associated with this equipment are not calculated by M-GEM05. The methodology employed is considered an IPCC Tier 2 sectoral approach, with country-specific emission factors. Fuel consumption data from the RESD (Statistics Canada, #57-003), reported as pipelines, are multiplied by fuel-specific emission factors (refer to Annex 2 for a description of the methodology).

3.2.3.3 Uncertainties and Time-Series Consistency

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

Transport Subsector Fossil Fuel Combustion

The Transport subsector comprises i) the mobile sources of transport, including on-road and off-road vehicles, railways, civil aviation, and navigation, and ii) pipeline transport. The uncertainty in the 2001 estimates for CO_2 emissions from fossil fuel combustion in mobile sources was estimated at –4% to 0%, indicating that the inventory GHG values are likely overestimates.

Similar to the stationary fuel combustion sources, the uncertainty ranges of approximately a factor of four or more for the 2003 submission for the CH_4 and N_2O emissions from Transport subsector fossil fuel combustion were attributable to the large uncertainty ranges for several CH_4 and N_2O emission factors.

The uncertainty associated with the total GHG emissions from the mobile source category for the 2003 submission was estimated to be within the range of –3% to +19%, which reflected the predominance of CO_2 in the total GHG emissions from the mobile sources of transport and its relatively low uncertainty estimate.

CO_2 Emissions from Road Transport

The uncertainty associated with CO_2 emissions from on-road vehicles was estimated to be within the range of –8% to –3% relative to the 2003 inventory year estimate for this source category. This implied that the 2003 inventory value for this source category was

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

[35] Consisting of both oil and gas types.

likely an overestimate. The upward bias in the 2003 inventory estimate values for this key source category was related to estimated uncertainties for i) the amount of fuel consumed by motor gasoline and diesel on-road vehicles and ii) the CO_2 emission factors for motor gasoline. (The 95% confidence interval uncertainty range for the CO_2 motor gasoline emission factor was estimated to be –3% to –1% by McCann (2000).)

CO_2 Emissions from Railways

The uncertainty associated with CO_2 emissions from rail transport was estimated to be within the range of –5% to +3%. In terms of the contribution to the uncertainty in the inventory estimate of this key source category for the 2003 submission, it seemed that the input variables diesel consumption (with an uncertainty of ±3%) and CO_2 emission factor for diesel (with an uncertainty range of –4% to +2%) were equally responsible.

CO_2 Emissions from Civil Aviation

The uncertainty associated with the CO_2 emission estimates from civil aviation reported in ICF (2004) is no longer applicable. Since the study was completed, a new method to enhance resolution on the use of fuel purchased in Canada by Canadian airlines has been employed. This has affected the previous historic emissions reported as domestic and reduced them between 40% and 55% annually. The study's reported uncertainty reflects the low uncertainty range associated with the CO_2 emission factor and the fuel consumption estimate for aviation turbo fuel, which accounted for nearly 99% of the total CO_2 emissions from civil aviation in 2004. There is a rationale to suggest that the expert polled for his opinion on the uncertainty of the activity data (Apparent Consumption of Aviation Fuels) was misled by the configuration of the questions asked. This would have resulted in a lower-than-actual uncertainty estimate.

CO_2 Emissions from Other (or Off-Road) Transport

The off-road transport category includes both off-road gasoline and off-road diesel consumption. The uncertainty associated with the off-road mobile transport sources was estimated to be within the range of +4% to +45%, indicating that the 2003 submission estimates likely underestimated the CO_2 emissions from this source category. The CO_2 emissions from off-road diesel vehicles accounted for nearly 80% of the total CO_2 emissions from the off-road category in 2004. The main sources of uncertainty for this source category are the uncertainty associated with the 2004 inventory year values of the fuel consumption estimates for off-road gasoline and off-road diesel. Consistent with the inventory estimation methodology for this source category, the off-road diesel fuel consumption is calculated from the on-road diesel fuel consumption residual, and the off-road gasoline consumption is calculated from the on-road gasoline consumption residual, both of which are dependent upon dated estimates of vehicle kilometres travelled.

Summary

Generally, for the Transport subsector, the ICF (2004) study merely incorporated previous studies' reported values for the estimated uncertainty surrounding the CO_2, CH_4, and N_2O emission factors (McCann, 2000; SGA, 2000). ICF (2004) included these reports' values along with a limited expert elicitation addressing the uncertainty of the activity data contributing to the Transport subsector estimates within its Monte Carlo analysis.

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

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

3.2.3.4 QA/QC and Verification

Tier 1 QC checks as elaborated in the framework for the QA/QC plan (see Annex 6) were performed on the following six key categories for CO_2 from transport: Civil Aviation, Road Transport, Railways, Navigation, Pipelines, and Other Transport. In addition, N_2O emissions from road transport were subject to QC checks that complied with IPCC Good Practice

Guidance (IPCC, 2000). No significant mathematical errors were found during the QC activities; however, labelling and referencing errors were observed in the model. Corrections to the spreadsheets and model to address these issues will assist in the future production of accurate and error-free inventories. The data, methodologies, and changes related to 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 M-GEM05 uses national fuel data defined by type and region combined with country-specific emission factors, primary scrutiny is applied to the vehicle population profile, as this dictates the fuel demand per vehicle category and, hence, emission rates and quantities. Recently, interdepartmental partnerships have been developed among Environment Canada, Transport Canada, and NRCan to facilitate the sharing of not only data but also knowledge and history of vehicle population data. This increased perspective fosters a better understanding of actual vehicle use and subsequently should promote better modelling and emissions estimating. With support from Transport Canada, Statistics Canada publishes the CVS, a quarterly report that provides both vehicle population and kilometrage in aggregated regional classes. It provides alternative interpretation of provincial registration files and can therefore corroborate the commercially available data sets mentioned above. Unfortunately, the resolution necessary for emissions modelling is unavailable from the CVS, and therefore it cannot replace the annually purchased data sets.

3.2.3.5 Recalculations

The underlying fuel-use data were revised for 2003, and the estimates were recalculated accordingly.

Additionally, a reallocation of diesel fuel between a few adjacent provinces/territories in Canada (British Columbia, Northwest Territories, and Nunavut) contributed to a minor shift between on- and off-road emissions in 1997 and 1998. Finally, the introduction of fuel ethanol consumed in transport to the 2006 submission has increased annual estimates for on- and off-road emissions by between approximately 3 and 30 kt CO_2 eq spanning the time series 1990–2004.

3.2.3.6 Planned Improvements

The method currently used to evaluate emissions associated with the Transport sector provides for a fuel-constrained estimate and thus contributes the least uncertainty to the process. However, the previous (spreadsheet) model was limited in its ability to accommodate the volume of high-resolution data recently made available through increased data-sharing partnerships and reporting. It is expected that M-GEM05 will continuously evolve to exploit the power of the database model that will directly appropriate data from these new sources.

In general, future improvements will concentrate on revealing more details with respect to activity data.[36] These will include:

- higher-resolution vehicle population profiles, allowing for annual age distribution of technology penetration (currently static) and greater vehicle subcategory disaggregation;
- improved vehicle kilometres travelled estimates, to better allocate fuel consumption regionally; and
- industry cooperation with respect to obtaining marine (waterborne navigation) activity data, allowing more accurate disaggregation into domestic and international.

With respect to vehicle populations, the current data sets contributing to the Canadian vehicle population profile have been prepared by one of two North American firms that use similar methods to identify specific model year counts from provincial vehicle registries. Each firm provides a unique data set; when combined, the data sets define the entire Canadian fleet, except for the Canadian territories, whose vehicle populations are estimated using the CVS.

These data sets are primarily prepared as a market analysis tool for industries associated with the North American automobile industry. They are used to regionally define vehicle population profiles and have become a standard source of information for new business establishments, such as auto parts suppliers.

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[36] Ultimately fuel consumption.

Because of the continental acceptance as the industry-leading data sources, they are deemed the best available.

New estimating tools are becoming available that can accommodate enhanced vehicle class definitions, fuel types, and regions. As a result, the older market analysis data sets are undergoing scrutiny in an attempt to understand data anomalies. These include, specifically, increases observed in model years that have not been available for high-volume sale for 15–20 years. It is planned, therefore, to incorporate the results of some of these new tools in the future.

3.2.4 OTHER SECTORS (CRF CATEGORY 1.A.4)

3.2.4.1 Source Category Description

The Other Sectors subsector consists of three categories: commercial/institutional, residential, and agriculture/forestry/fisheries. Emissions consist primarily of fuel combustion related to space and water heating. Emissions from the use of transportation fuels in these categories are allocated to Transport (Section 3.2.3). Biomass[37] combustion is a significant source of emissions in the residential sector. The CO_2 emissions from biomass combustion are reported separately in the CRF tables as memo items and are not included in Energy Sector totals.

In 2004, the Other Sectors subsector contributed about 83.2 Mt (or 11%) of Canada's total GHG emissions, with an overall growth of about 15% since 1990. Within the Other Sectors category, residential emissions contributed about 43.2 Mt (or 52%), followed by a 37.9 Mt (or 46%) contribution from the commercial and institutional category, which also includes emissions from public administration (which is made up of federal, provincial, and municipal establishments). GHG emissions grew by about 47% for the commercial/institutional sector since 1990. Refer to Table 3-5 for additional details. Additional trend discussion for the Other Sectors subsector is presented in the Emission Trends chapter (Chapter 2).

TABLE 3-5: Other Sectors GHG Contribution

GHG Source Category	GHG Emissions		
	kt CO_2 eq		
	1990	2003	2004
Other Sectors TOTAL (1.A.4)	**72 200**	**85 500**	**83 200**
Commercial/Institutional	**25 800**	**37 900**	**37 900**
Commercial and Other Institutional	23 800	35 700	35 900
Public Administration	2 000	2 200	2 070
Residential	**44 000**	**45 000**	**43 000**
Agriculture/Forestry/Fisheries	**2 420**	**2 210**	**2 100**
Forestry	55.0	193	127
Agriculture	2 370	2 020	1 970

Note:
Totals may not add due to rounding.

3.2.4.2 Methodological Issues

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

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

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

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

Emissions are based on fuel-use data reported as residential in the RESD (Statistics Canada, #57-003).

The methodology for biomass combustion from residential firewood is detailed in the CO_2 Emissions from Biomass section (Section 3.4.2); although CO_2 emissions are not accounted for in the national residential GHG total, the CH_4 and N_2O emissions are reported here.

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[37] Typically firewood.

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

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

3.2.4.3 Uncertainties and Time-Series Consistency

The estimated uncertainty for the Other Sectors subsector ranges from –4% to +41% for all gases and from –3% to +2% for CO_2. Refer to the Uncertainty annex (Annex 7) for a detailed discussion on the ICF (2004) uncertainty study and additional uncertainty values for the Other Sectors subsector.

The underlying fuel quantities and CO_2 emission factors have low uncertainties, since they are predominantly commercial fuels, which have consistent properties and accurate tracking. Although the non-CO_2 emissions from biomass combustion contributed only 5% to the total Residential category, its CH_4 (–90% to +1500%) and N_2O (–65% to +1000%) uncertainties are high due to the uncertainty associated with their emission factors. As stated in the Energy Industries subsector, additional expert elicitation is required to improve the CH_4 and N_2O uncertainty estimates for some of the emission factor uncertainty ranges and probability density functions developed by the ICF (2004) study, since insufficient time was available to have these assumptions reviewed by industry experts.

These estimates are consistent over the time series.

3.2.4.4 QA/QC and Verification

Other Sectors was identified as a key category for both CH_4 and CO_2 and underwent Tier 1–level QC checks in a manner consistent with IPCC Good Practice Guidance (IPCC, 2000). No mathematical, referencing, or labelling errors were observed during the QC checks. The data and methodologies related to the QC activities are documented and archived in paper and electronic form.

3.2.4.5 Recalculations

The underlying fuel-use data were revised for 2003, and the estimates were recalculated accordingly.

3.2.4.6 Planned Improvements

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

3.2.5 OTHER: ENERGY — FUEL COMBUSTION ACTIVITIES (CRF CATEGORY 1.A.5)

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

3.3 FUGITIVE EMISSIONS (CRF CATEGORY 1.B)

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

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

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

In 2004, the Fugitives category accounted for about 66.5 Mt (or 8.8%) of Canada's total GHG emissions, with over a 53% growth in emissions since 1990. Of the growth in the Fugitives category, 98.5% is from oil and gas production, processing, transmission, and distribution activities, with the remaining 1.5% originating from coal mining. Refer to Table 3-6 for more detail.

TABLE 3-6: Fugitive GHG Contribution

GHG Source Category	GHG Emissions		
	kt CO_2 eq		
	1990	2003	2004
Fugitive Sources TOTAL (1.B)	**43 300**	**66 200**	**66 500**
Solid Fuels — Coal Mining	2 000	1 000	1 000
Oil and Natural Gas	41 400	65 200	65 500
Oil[1]	6 700	10 000	9 900
Natural Gas[1]	18 000	28 000	28 000
Venting and Flaring	17 000	27 000	27 000
Venting[2]	13 000	22 000	22 000
Flaring[2]	4 400	5 700	5 400

Notes:

1 All fugitive sources except venting and flaring.

2 Both oil and gas activities.

Totals may not add due to rounding.

3.3.1 SOLID FUELS (CRF CATEGORY 1.B.1)

3.3.1.1 Source Category Description

Coal in its natural state contains varying amounts of CH_4. In coal deposits, CH_4 is either trapped under pressure in porous void spaces within the coal formation or adsorbed to the coal. The pressure and amount of CH_4 in the deposit vary depending on the grade, the depth, and the surrounding geology of the coal seam. During coal mining, post-mining activities, and coal-handling activities, the natural geologic formations are disturbed, and pathways are created that release the pressurized CH_4 to the atmosphere. As the pressure on the coal is lowered, the adsorbed CH_4 is released until the CH_4 in the coal has reached equilibrium with the surrounding atmospheric conditions.

Mining activity emission sources are from the exposed coal surfaces, coal rubble, and the venting of CH_4 from within the deposit. Post-mining activities such as preparation, transportation, storage, or final processing prior to combustion also release CH_4.

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

3.3.1.2 Methodological Issues

An inventory of fugitive emissions from Canadian coal mining operations was developed in the early 1990s and used as the basis for the estimates presented here. The estimates from the inventory (King, 1994) were divided by appropriate coal production data to arrive at emission factors for subsequent years. A summary of the methodology used in the original study is provided here.

The method used by King (1994) to estimate emission rates from coal mining (emission factors in Annex 13) 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. It separates underground mining emissions from surface mining emissions and includes post-mining activity emissions within each of those activities.

Underground Mines

King (1994) estimated emissions for underground mines on a mine-specific basis by summing emissions from the ventilation system, degasification systems, and post-mining activities.

Emissions from the mine shaft ventilation system were estimated (if measured data were not available) using Equation 3-4:

Equation 3-4:

$$Y = 4.1 + (0.023 * X)$$

where:

Y = cubic metres (m^3) of CH_4 per tonne (t) of coal mined

X = depth of mine in metres (m)

Emissions from post-mining activities were estimated by assuming that 60% of the remaining coal CH_4 (after removal from the mine) is emitted to the atmosphere before combustion. If the gas content of the mined coal was not known, then it was assumed that the CH_4 content was 1.5 m^3/t (the global average CH_4 content of coals). Emissions from post-mining activities are included in the coal production emission factors.

Emissions in the national inventory were estimated by multiplying coal production data (from Statistics Canada, #45-002) by the emission factors in Annex 13.

Surface Mines

For surface mines, it was assumed that the average CH_4 content of surface-mined bituminous or sub-bituminous coals was 0.4 m^3/t (based on U.S. measured data). Of this, it was assumed that 60% is released to the atmosphere before combustion (King, 1994). For lignite, gas content values determined previously for Canada were used (Hollingshead, 1990).

A significant source of emissions from surface mines is the surrounding unmined strata. An attempt was made to account for this by applying a high-wall adjustment to account for the outgassing of the surrounding unmined strata to a depth of 50 m below the mining surface. It was estimated that base emission factors for surface mining should be increased 50% (King, 1994) to account for this. The emission factors shown in Annex 13 have been adjusted accordingly.

Emissions in the national inventory were estimated by multiplying coal production data (from Statistics Canada, #45-002) by the emission factors in Annex 13.

3.3.1.3 Uncertainties and Time-Series Consistency

The CH_4 uncertainty estimate for fugitive emissions from coal mining is estimated to be in the range of –30% to +130% (ICF, 2004). The production data are known to a high degree of certainty (±2%). On the other hand, a very significant uncertainty (–50% to +200%) was estimated for the emission factors. It is our view that further expert elicitation is required to validate assumptions made by the study in the development of the probability density functions and uncertainty ranges of emission factors and activity data from surface and underground mining activities. IPCC default uncertainty values were assumed for Canada's country-specific emission factors, and these will need to be reviewed. The use of IPCC default values will not result in a representative uncertainty estimate when country-specific information is used. Refer to the Uncertainty annex (Annex 7) for more details on the study.

3.3.1.4 QA/QC and Verification

The CH_4 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, and only minor issues with labelling and references were revealed. The data, methodologies, and changes related to the QC activities are documented and archived in paper and electronic form.

3.3.1.5 Recalculations

No recalculations were made to this sector.

3.3.1.6 Planned Improvements

No improvements are planned for this category.

3.3.2 OIL AND NATURAL GAS (CRF CATEGORY 1.B.2)

3.3.2.1 Source Category Description

The Oil and Natural Gas fugitive subsector includes emissions from conventional oil and gas production and processing (which also includes fugitive emissions from natural gas transmission), unconventional synthetic crude oil production (oil sands mining, extraction, and upgrading), and natural gas distribution. Fuel combustion emissions from facilities in the oil and gas industry (when used for energy) are included under the Petroleum Refining and Manufacture of Solid Fuels and Other Energy Industries categories (Section 3.2.1), whereas emissions associated with oil sands mining activities are included in the Other Transport category (CRF category 1.A.3.e).

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

Conventional Oil and Gas Production

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

The Conventional Oil and Gas Industry is vast and complex. The sources have been divided into major categories:

- *Oil and Gas Well Drilling and Associated Testing*: Oil and gas well drilling is a minor emission source. The emissions are from drill stem tests, release of entrained gas in drilling fluids, and volatilization of invert drilling fluids.
- *Oil and Gas Well Servicing and Associated Testing*: Well servicing is also a minor emission source. The emissions are mainly from venting, flaring, and fuel combustion, which are included in the Stationary Combustion section. Venting results from conventional service work, such as the release of solution gas from mud tanks and blowdown treatment for natural gas wells. It is assumed that there is no significant potential for fugitive emissions from leaking equipment. Fugitive emissions from absolute open flow tests are assumed to be negligible.
- *Natural Gas Production*: Natural gas is produced exclusively at gas wells or in combination with conventional oil, heavy oil, and crude bitumen production wells with gas conservation schemes. The emission sources associated with natural gas production are wells, gathering systems, field facilities, and gas batteries. The majority of emissions result from equipment leaks, such as leaks from seals; however, venting from the use of fuel gas to operate pneumatic equipment and line-cleaning operations are also significant sources.
- *Light/Medium Oil Production*: This type of production is defined by wells producing light- or medium-density crude oils (i.e., density <900 kg/m^3). The emissions are from the wells, flow lines, and batteries (single, satellite, and central). The largest sources of emissions are the venting of solution gas and evaporative losses from storage facilities.
- *Heavy Oil Production*: Heavy oil is defined as having a density above 900 kg/m^3. This viscous liquid requires a special infrastructure to produce. There are generally two types of heavy oil production systems: primary and thermal. The emission sources from both types are wells, flow lines, batteries (single and satellite), and cleaning plants. The largest source is venting of casing and solution gas.
- *Crude Bitumen Production*: Crude bitumen is a highly viscous, dense liquid that cannot be removed from a well using primary production means. Enhanced *in situ* recovery is required to recover the hydrocarbons from the formation. The sources of emissions are wells, flow lines, satellite batteries, and cleaning plants. The main source of emissions is the venting of casing gas.
- *Gas Processing*: Natural gas is processed before entering transmission pipelines to remove water vapour, contaminants, and condensable hydrocarbons. There are four different types of plants: sweet plants, sour plants that flare waste gas, sour plants that extract elemental sulphur, and straddle plants. Straddle plants are located on transmission lines and recover residual hydrocarbons. They have a similar structure and function and so are considered in conjunction with gas processing. The largest source of emissions is from equipment leaks.
- *Natural Gas Transmission*: Virtually all of the natural gas produced in Canada is transported from the processing plants to the gate of the local distribution systems by pipelines. The volumes transported by truck are insignificant and assumed to be negligible. The gas transmission system emission sources are from equipment leaks and process vents. Process vents include activities such as compressor start-up and purging of lines during maintenance. The largest source of emissions is equipment leaks.
- *Liquid Product Transfer*: The transport of liquid products from field processing facilities to refineries or distributors produces emissions due to loading and unloading of tankers, storage losses, equipment leaks, and process vents. The transport systems included are liquefied petroleum gas (LPG) (by both surface transport and high-vapour-pressure pipeline systems), pentane-plus systems (by both surface transport and low-vapour-pressure pipeline systems), and crude oil pipeline systems.
- *Accidents and Equipment Failures*: Fugitive emissions can result from human error or extraordinary equipment failures in all segments of the conventional upstream oil and gas industry. The major sources are emissions from pipeline ruptures,

well blowouts, and spills. Emissions from the disposal and land treatment of spills are not included due to insufficient data.

- *Surface Casing Vent Blows and Gas Migration*: At some wells, fluids will flow into the surface casing from the surrounding formation. Depending on the well, the fluids will be collected, sealed in the casing, flared, or vented. The vented emissions are estimated in this section. At some wells, particularly in the Lloydminster (Alberta) region, gas may migrate outside of the well, either from a leak in the production string or from a gas-bearing zone that was penetrated but not produced. The emissions from the gas flowing to the surface through the surrounding strata have been estimated.
- *Refining*: There are three main sources of fugitive emissions from refineries: process, fugitive, and flare. Process emissions result from the production of hydrogen as well as from process vents. Fugitive emissions are a result of equipment leaks, wastewater treatment, cooling towers, storage tanks, and loading operations. Emissions from flaring are a result of the combustion of hazardous waste gas streams (such as acid gas) and fuel gas (or natural gas). GHG emissions from the combustion of fuel for energy purposes are reported under the Energy Industries.

Unconventional Synthetic Crude Oil Production

This category includes emissions from oil sand open pit mining operations, extracting, and heavy/bitumen oil upgrading facilities in Canada. The fugitive emissions are primarily hydrogen production, flaring activities, and CH_4 from the open mine face and from methanogenic bacteria in the mine tailings settling ponds.

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

Natural Gas Distribution

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

3.3.2.2 Methodological Issues

Upstream Oil and Gas Production

Fugitive emission estimates from the conventional upstream oil and gas industry are based on the most recent CAPP study as prepared by Clearstone Engineering (CAPP, 2005). The latest report is an expansion of the previous 1999 CAPP study of the 1990–1995 inventory estimate for the upstream oil and gas industry. Key improvements and changes include i) a rigorous bottom-up IPCC Tier 3 approach in which emissions have been identified at the individual facility level by primary sources, ii) quantitative uncertainty estimates following the Tier 1 approach as presented in the IPCC Good Practice Guidance (IPCC, 2000), iii) QA/QC activities as outlined in the IPCC Good Practice Guidance, and iv) increased coverage of the oil and gas industry, such as offshore oil operations (CAPP, 2005). A summary of the method is provided here; details are available in Volumes 1, 3, and 5 of the 2005 CAPP report. For the year 2000, the emissions were identified at an individual facility level for over 5000 facilities. These emissions were then extrapolated to over 209 000 facilities and approximately 370 000 primary sources from fuel combustion, flaring, venting (both reported and unreported), fugitive equipment leaks, formation CO_2 venting, storage losses, loading/unloading losses, and accidental releases.

For the natural gas system, gas production and gas processing are considered to be part of the upstream petroleum industry, and the emissions for these sections were examined by Clearstone Engineering in the 2005 CAPP report.

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

The activity data used in the study were gathered from a number of different sources. As stated in the report by Clearstone Engineering (Volume 3 of CAPP, 2005), the required activity data included the following:

- measured volumes of natural gas taken from the process;
- vented and flared waste gas volumes;
- fuel purchases;
- fuel analyses;
- emissions monitoring results;
- process operating conditions; and
- spill reports.

Other data required, as stated in the report, included:

- processes being used;
- equipment inventories;
- emission source control features;
- sulphur content of fuels consumed and waste gas flared; and
- composition of inlet and outlet streams.

These data were collected from the producing provinces, and an additional survey of 1500 oil and gas facilities was conducted. A list of the various sources can be found in Volume 5 of the 2005 CAPP report.

To obtain the 1990–1999 and 2001–2004 fugitive emissions from conventional upstream oil and gas production, the 2000 emission results were extrapolated using annual industry activity-level data. The 1990–1999 extrapolation model is presented in Volume 1 of the 2005 CAPP report, while a consistent extrapolation model for 2001 and onward was developed by Clearstone Engineering for inventory use in developing annual national- and provincial-level GHG estimates. The emissions for both time spans were extrapolated using emission data from the year 2000 together with the annual production and activity data for the relevant years. Activity data reference sources are shown in Table 3-7.

Downstream Oil and Gas Production

Fugitive emissions from refineries for 1990–2004 are based on the Canadian Petroleum Products Institute (CPPI) study *Economic and Environmental Impacts of Removing Sulphur from Canadian Gasoline and Distillate Production*, as prepared by Gertz Inc. in association with Levelton Consultants Ltd. (CPPI, 2004). A summary of the details is available here; full details are in the report. Levelton used historical fuel, energy, and emission data gathered by the Canadian Industrial Energy End-Use Data Analysis Centre (CIEEDAC) in a study for CPPI (2004) and data collected directly from the refineries for the years 1990 and 1994–2002. Fugitive emissions for the years 1991–1993 were interpolated, while the 2003 and 2004 emissions were extrapolated using the fugitive, flare, and process data in the report and energy consumption and non-energy use of natural gas data from Statistics Canada's RESD (#57-003).

Levelton broke down the emissions into four categories: combustion, fugitive, process, and flare. Combustion emissions as determined by the study were not utilized in the inventory. They have been estimated using another method and are accounted for in the Energy Industries subsector (Section 3.2.1). Flare emissions were included in the combustion category of the CPPI (2004) study and were separated out to be included in the fugitive section of the inventory. CO_2 emissions from flaring were determined using fuel consumption data and emission factors collected by the CIEEDAC (CPPI, 2004). As CH_4 combustion emissions are technology dependent, these emissions were determined using emission factors that were developed from an analysis of combustion technologies typically used in Canada.

Process vent emissions are from such activities as catalytic cracking and hydrocracking, catalytic reforming, catalyst regeneration, thermal cracking, fluid coking, delayed coking, and hydrogen plants. The majority of process emissions are from the production of hydrogen. These emissions were calculated using emission factors based on HHV and non-energy use of natural gas (CPPI, 2004).

Sources of fugitive emissions that were included in the 2004 CPPI study are equipment leaks, wastewater treatment, cooling towers, storage tanks, and loading operations. CH_4 fugitive emissions were determined by the refineries as a percentage of total organic compound emissions as quantified by leak detection and repair measurements. In some cases, there were gaps in the data from the refineries. In these cases, Levelton used fugitive emission factors in conjunction with the energy use of the refinery to determine the fugitive emissions from the individual refinery.

TABLE 3-7: Oil and Gas Activities and Extrapolation Data

Activity	Extrapolation Data
Flaring	Less field flared and waste (Statistics Canada, #26-006)
Raw CO_2	Net Withdrawals of Natural Gas (Statistics Canada, #26-006)
Oil and Gas Well Drilling	Total Wells Drilled (Incl. Dry & Service) (Industry Facts and Information by Region and Province, CAPP)
Oil and Gas Well Servicing	Total Wells Drilled (Incl. Dry & Service) (Industry Facts and Information by Region and Province, CAPP)
Natural Gas Production	Gross New Production of Natural Gas (Statistics Canada, #26-006)
Light/Medium Oil Production	1) Total Production of Light & Medium Crude Oil (Statistics Canada, #26-006) (All Provinces except Saskatchewan) 2) Light + Medium Crude Oil Production (Saskatchewan Industry and Resources, Mineral Statistics Yearbook, Miscellaneous Report 2003-3, Table 2-1-9)
Heavy Oil Production	1) Total Production of Heavy Oil (Statistics Canada, #26-006) (All Provinces except Saskatchewan) 2) Heavy Crude Oil Production (Saskatchewan Industry and Resources, Mineral Statistics Yearbook, Miscellaneous Report 2003-3, Table 2-1-9)
Crude Bitumen Production	Total Production of Crude Bitumen (Statistics Canada, #26-006)
Natural Gas Processing	Gross New Production of Natural Gas (Statistics Canada, #26-006)
Natural Gas Transmission	Natural Gas Transmission Pipeline Length (Statistics Canada, #57-205)
Liquid Product Transport	1) Total Production of Light & Medium Crude Oil (Statistics Canada, #26-006) (All Provinces except Saskatchewan) 2) Light + Medium Crude Oil Production (Saskatchewan Industry and Resources, Mineral Statistics Yearbook, Miscellaneous Report 2003-3, Table 2-1-9) 3) Total Production of Heavy Oil (Statistics Canada, #26-006) (All Provinces except Saskatchewan) 4) Heavy Crude Oil Production (Saskatchewan Industry and Resources, Mineral Statistics Yearbook, Miscellaneous Report 2003-3, Table 2-1-9) 5) Total Production of Crude Bitumen (Statistics Canada, #26-006)
Accidents & Equipment Failures	Sum of Blowout, Blow, Kick, Pipeline Rupture, and Spill Incidents in Alberta (Field Surveillance Provincial Summary, Alberta Energy and Utility Board, EUB ST57) All provinces except Alberta constant at 2000 levels over 2001–2004
Thermal Heavy Oil Production	1) Total Production of Heavy Oil (Statistics Canada, #26-006) (All Provinces except Saskatchewan) 2) Total Production of Crude Bitumen (Statistics Canada, #26-006) 3) Heavy Crude Oil Production (Saskatchewan Industry and Resources, Mineral Statistics Yearbook, Miscellaneous Report 2003-3, Table 2-1-9)
Surface Casing, Vent Blows, and Gas Migration	1) Alberta – Capable Oil and Gas Wells (Alberta Drilling Statistics, Alberta Energy and Utility Board, EUB ST-59) 2) Saskatchewan – Total Capable Wells (Saskatchewan Industry and Resources, Mineral Statistics Yearbook, Miscellaneous Report 2003-3, Table 5-2-4) 3) British Columbia – Sum of Producing Oil Wells and Producing Gas Wells (Drilling and Production Statistics 1993–2004, British Columbia Ministry of Energy and Mines) 4) Manitoba – Wells Capable of Producing (December) (Table Manitoba Oil and Water Production 1951–2004, Oil Activity Review 2004, Manitoba Industry, Economic Development and Mines) 5) Newfoundland – Sum of all oil producers and gas injectors (Development Wells – Hibernia, Development Wells – Terra Nova, Development Wells – White Rose, Canada–Newfoundland Offshore Petroleum Board) 6) Nova Scotia, Northwest Territories, Ontario, and Yukon Territory – Total capable wells assumed to be constant at the 2000 number over 2001–2004

Sources:

Statistics Canada, #26-006 and #57-205.

Unconventional Synthetic Crude Oil Production

The emission data reported are based on estimates made by the operators of the unconventional crude oil production facilities. These data were compiled in a study for CAPP (1999). Descriptions of the methods are available in the full report. Due to lack of new data, emissions have been assumed constant since 1996.

Natural Gas Distribution

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

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

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

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

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

3.3.2.3 Uncertainties and Time-Series Consistency

Upstream Oil and Gas Production

The upstream oil and gas fugitive emissions for 2000 are taken directly from the CAPP (2005) study. The emissions from 1990 to 1999 and from 2001 to 2004 have been extrapolated using the 2000 data along with other factors discussed above. The uncertainty for the overall 2000 emissions (in CO_2 eq) is ±1.5%. The uncertainties for the 2000 emissions (in CO_2 eq) for the oil and natural gas industry are listed in Table 3-8 and Table 3-9. The detailed uncertainties for each gas can be found in the 2005 CAPP report.

TABLE 3-8: Uncertainty in Oil Production Industry Fugitive Emissions (CO_2 eq)

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 (CO_2 eq)

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

Source:
CAPP (2005).

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

Downstream Oil and Gas Production

The emission data used in the inventory for fugitive emissions from refineries for 1990 and for 1994–2002 are directly from the CPPI (2004) study. The data for 1991–1993, 2003, and 2004 are based on an extrapolation of the emissions from that study. The uncertainty for the extrapolated data is greater due to the available level of disaggregation for the activity. Levelton completed a Tier 1 and Tier 2 analysis, for comparison purposes, on the uncertainty of the emission factors and activity data, for an overall uncertainty for CO_2 in 2002 (CPPI, 2004).

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

TABLE 3-10: Uncertainty in Oil Refining Fugitive Emissions (CO_2 eq)

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

3.3.2.4 QA/QC and Verification

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

Tier 1 QC checks consistent with IPCC Good Practice Guidance (IPCC, 2000) were performed on the CO_2 and CH_4 estimates for the following key subcategories:

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

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

3.3.2.5 Recalculations

Recalculation activities were performed consistently on the 1990–2003 estimates for the conventional oil and gas production industry based on the updated 2005 CAPP study. Based on this study, there was an increase in GHG emissions for all years from 1990 to 2003. This can be attributed to various factors. In the current study, emissions are expected to be more representative, as they are estimated based on actual infrastructure data, production data, and disposition data. The previous study (CAPP, 1999) used 1995 as a base year. Between 1995 and 2000, there has been significant growth in the industry, resulting in increased emissions. Furthermore, production levels have varied in the different provinces. For example, in Newfoundland, there was no oil production from 1995 until 1998. Nova Scotia switched from being an oil-producing province between 1992 and 1999 to a gas-producing province starting in 2000. There have also been changes in the processes and technology used in the industry. Reciprocating engines are consuming more fuel than estimated in the last study, resulting in increases in N_2O and CH_4 emissions. Furthermore, there has been an increase in venting from some heavy oil operations.

Changes in technology and regulations have also impacted the emission estimates. Heavy oil production has increased over the years as improving technology allows for production from wells that were previously inaccessible. Increased production has resulted in increased production and processing infrastructure. Regulations to control venting and flaring have also come into effect. In Alberta Energy and Utility Board (AEUB) Guide 60 (AEUB, 1999) and other AEUB regulations (AEUB, 2001, 2002), specific requirements have been imposed on industry for flaring and venting activities in Alberta. Currently, other provinces are considering similar regulations.

In comparing the two studies, CAPP (1999) and CAPP (2005), the total GHG emissions have increased for all years, including 1990–1995. The difference between the two studies for 1990 is a 0.3% increase. In 1995, there is a 2.3% increase between the old and new emission estimates. The differences between the two studies for the earlier years are due to the use of refined emission factors, more detailed activity data, and better accounting for casing gas venting from heavy oil operations.

In previous reports, fugitive venting and flaring emissions from refineries were not included, since no studies were available to characterize them. This year, the emissions have been estimated and included in the fugitive source category for the complete time series.

3.3.2.6 Planned Improvements

Environment Canada is currently conducting a detailed study of the fugitive emissions from the oil sands mining, extraction, and upgrading industry. Results will be incorporated in future methodological improvements of the estimation model for the fugitive oil and gas category. Refer to the discussion in Section 3.2.1.6 for more details.

3.4 MEMO ITEMS (CRF CATEGORY 1.C)

3.4.1 INTERNATIONAL BUNKER FUELS (CRF CATEGORY 1.C.1)

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

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

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

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

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

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

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

3.4.2 CO_2 EMISSIONS FROM BIOMASS

As per the UNFCCC reporting guidelines, CO_2 emissions from the combustion of biomass used to produce energy are not included in the Energy Sector totals but are reported separately as memo items. They are accounted for in the LULUCF Sector and are recorded as a loss of biomass (forest) stocks. CH_4 and N_2O emissions from the combustion of biomass fuels for energy are reported in the fuel combustion section in the appropriate categories.

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

3.4.2.1 Residential Firewood

Firewood is used as a primary or supplementary heating source for many Canadian homes. Combustion of firewood results in CO_2, CH_4, and N_2O emissions.

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

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

1. Conventional stoves
- non-airtight
- airtight, non-advanced technology
- masonry heaters

2. Stove/fireplace inserts with advanced technology or catalyst control
- advanced-technology fireplaces
- advanced-technology stoves
- catalytic fireplaces
- catalytic stoves

3. Conventional fireplaces
- without glass doors
- with non-airtight glass doors
- with airtight glass doors

4. Furnaces
- wood-burning fireplaces

5. Other equipment
- other wood-burning equipment

The firewood consumption data for the other years were extrapolated based on the number of houses in each province using wood as a principal or supplementary heat source (from Statistics Canada, 1995) in relation to 1995.

The N_2O and CH_4 emission factors for different wood-burning appliances are from the U.S. EPA's AP-42, supplement B (EPA, 1996). These emissions are included in the fuel combustion sector of the inventory.

The emission factors for CO_2 are from an Environment Canada study (ORTECH Corporation, 1994).

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

3.4.2.2 Industrial Wood Wastes

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

Industrial firewood CO_2 and CH_4 emission factors are those assigned by the U.S. EPA to wood fuel/wood waste (EPA, 1996). For CH_4, emission factors were given for three different types of boilers; the emission factor used in the Canadian inventory is an average of the three.

Industrial firewood N_2O emission factors are those assigned to wood fuel/wood waste (Rosland and Steen, 1990; Radke *et al.*, 1991) (see Annex 13).

The emission factor for CO_2 from spent pulping liquor combustion was developed based on two assumptions:

1. The carbon content of spent pulping liquor is 41% by weight.
2. There is a 95% conversion of the carbon to CO_2.

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

$$\begin{aligned} \text{EF } CO_2 &= 0.41 * 0.95 * (44 \text{ g/mol} / 12 \text{ g/mol}) \\ &= 1.428 \text{ t } CO_2\text{/t spent pulping liquor} \end{aligned}$$

Emissions are calculated by applying emission factors to the quantities of biomass combusted. The CH_4 and N_2O emissions are included in the manufacturing sector of the inventory.

3.4.2.3 Fuel Ethanol

For the 2006 submission, fuel ethanol used in transportation for 1990–2004 was included. Ethanol properties were developed according to chemistry and resulted in an HHV (GCV) of 24.12 TJ/ML, 52.14% carbon content, and 789.2 kg/m^3 density.

Fuel ethanol was introduced and modelled as if it were mixed into the total gasoline for the region(s). Total fuel available per province was allocated to each mode (on/off-road, and vehicle technology class) as per the percentage of total gasoline calculated traditionally with M-GEM05. In lieu of reviewed emission factors for CH_4 and N_2O for ethanol, the representative gasoline emission factor was applied as per mode and technology class. CO_2 emission factors used are those based upon true chemical characteristics mentioned previously and a 98.5% oxidation rate.

3.5 OTHER ISSUES

3.5.1 COMPARISON OF SECTORAL AND REFERENCE APPROACHES

The UNFCCC reference approach was compared with the sectoral approach (Canada's fuel energy methodology) as a check of combustion-related emissions. The check was performed for all years from 1990 to 2004 and is an integral part of reporting to the UNFCCC. Additional reference approach details are documented in Annex 4.

A direct comparison of the energy and emission outputs from the reference approach and the sectoral approach used in the CRF shows a reference approach total that is consistently larger than the sectoral approach total. The reference approach, in theory, includes all CO_2 emissions from all fossil fuel uses (such as combustion, process, and flaring activities) in a country and should be compared with a set of emissions from the sectoral approach that includes all CO_2 emissions from energy and non-energy (including feedstock) use of fossil fuels.

In the CRF reporting software, the reference approach is directly compared with the sectoral fuel combustion total. This comparison produces a significant discrepancy, since the sectoral approach total for combustion does not include fossil fuel–derived CO_2 from industrial processes and non-energy uses of fuels for activities such as flaring. This can be seen in Table 3-11. When the reference approach and sectoral approach are directly compared, there is a 1.6–10.7% variation in kilotonnes CO_2 equivalent emissions and a 9.0–14.5% variation in petajoules of fuel use, with the reference approach values being consistently larger than the sectoral approach values. To ensure that energy information is comparable, the apparent energy consumption output excluding non-energy use and feedstock (as presented in CRF Table 1.A.(c) Comparison of CO_2 Emissions from Fuel Combustion) should be used to compare with the energy consumption from the sectoral approach.

In Canada, a significant amount of fossil fuel is used for feedstock in industrial processes, such as aluminium production, ammonia production, ethylene production, and iron and steel production. The emissions resulting from these processes are reported under industrial processes, while CO_2 emissions resulting from non-energy use of fossil fuels in the oil and gas industries (e.g., natural gas used for flaring or hydrogen production) are reported in the "Fugitive emissions from oil, natural gas and other sources" table of the CRF. Due to these discrepancies, the predefined comparison of emissions used in the CRF Table 1.A.(c) is not appropriate for Canada, since this table is not comparing similar emission sources. However, this can be rectified by incorporating the non-combustion emissions into the comparison.

The Canadian reporting procedure does follow the IPCC Guidelines (IPCC/OECD/IEA, 1997). When the reference approach energy amount is corrected to exclude non-energy feedstock use of fuels, the variation between the sectoral and adjusted reference approaches ranges between −0.3% and +4.1%. If the reference approach is corrected for emissions in the same way by subtracting the industrial process and fugitive emissions calculated by the sectoral approach, the totals match within −3.54% to +4.0%. A reconciliation of the reference and sectoral approaches is shown in Table 3-11.

TABLE 3-11: Reconciliation of Reference Approach and Sectoral Approach for Canada

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Energy – PJ															
Reference Approach Value	7 378	7 124	7 336	7 327	7 575	7 711	7 984	8 136	8 192	8 453	8 726	8 769	8 823	9 175	9 334
Sectoral Approach Value	6 446	6 296	6 533	6 549	6 777	6 936	7 131	7 267	7 400	7 644	7 997	7 874	8 051	8 420	8 359
Difference	14.5%	13.2%	12.3%	11.9%	11.8%	11.2%	12.0%	12.0%	10.7%	10.6%	9.1%	11.4%	9.6%	9.0%	11.7%
Adjusted Reference Approach Value Excluding Non-Energy Use and Feedstocks	6 712	6 464	6 653	6 611	6 848	6 955	7 192	7 312	7 428	7 640	7 963	7 932	7 945	8 297	8 337
Adjusted Difference	4.12%	2.67%	1.83%	0.94%	1.04%	0.28%	0.85%	0.61%	0.39%	–0.05%	–0.42%	0.73%	–1.32%	–1.46%	–0.26%
Emissions – kt CO_2															
Non-Energy Use of Fossil Fuels and Feedstock															
Ammonia Production	3 942	3 896	4 152	4 510	4 472	5 262	5 430	5 299	5 326	5 429	5 361	4 822	4 775	5 083	5 660
Iron and Steel Production	7 058	8 316	8 500	8 182	7 537	7 878	7 745	7 549	7 685	7 890	7 893	7 279	7 113	7 041	8 161
Aluminium Production	2 715	3 147	3 273	3 908	3 771	3 643	3 863	3 929	3 977	3 949	3 899	4 202	4 419	4 581	4 224
Other & Undifferentiated Production	8 312	8 716	8 262	8 291	8 841	8 718	9 610	10 189	9 264	9 645	9 685	10 368	9 894	10 894	12 052
Hydrogen Production from Refineries	526	500	473	562	383	402	744	764	621	355	869	1 006	1 030	1 035	1 057
Fugitive Flare CO_2 Emissons	5 288	5 242	5 286	5 523	5 594	6 248	6 571	6 640	6 550	6 950	5 351	7 377	7 376	5 351	5 351
Total Non-Energy Use of Fossil Fuels and Feedstock	27 841	24 075	24 187	24 891	24 622	25 500	26 648	26 965	26 253	26 913	26 838	26 672	26 201	27 599	30 097
Reference Approach Value	463 848	445 540	455 987	448 561	464 354	468 512	481 688	490 001	494 455	506 431	524 503	526 994	525 278	548 324	553 073
Sectoral Approach Value	419 210	409 582	423 195	420 585	433 494	444 498	455 751	467 137	474 283	490 561	513 847	507 914	515 579	539 815	536 894
Difference	10.65%	8.78%	7.75%	6.65%	7.12%	5.40%	5.69%	4.89%	4.25%	3.24%	2.07%	3.76%	1.88%	1.58%	3.01%
Adjusted Reference Approach Value Excluding Emissions from Non-Energy Use of Fossil Fuel and Feedstocks	436 007	421 465	431 800	423 669	439 732	443 012	455 040	463 035	468 202	479 518	497 665	500 322	499 077	520 725	522 976
Adjusted Difference	4.01%	2.90%	2.03%	0.73%	1.44%	–0.33%	–0.16%	–0.88%	–1.28%	–2.25%	–3.15%	–1.49%	–3.20%	–3.54%	–2.59%

In Canada, as in the United States, HHV is used to record the energy content of fuels, and this has been used for energy data reporting in the CRF for the reference and sectoral approaches. Canada developed country-specific higher heating energy conversion and carbon emission factors for the majority of the raw fuels except for crude oil, lubricants, solid biomass, and liquid biomass, where default IPCC carbon emission factors were used along with the Organisation for Economic Co-operation and Development's (OECD) conversion factor of 95% for solid and liquid fuels from lower heating value (LHV) to HHV.

To elaborate on the method of developing HHV conversion factors, a table has been included (Table 3-12) to illustrate the method and data sources used for this inventory's reference approach. The energy conversion factors are taken directly from the RESD (Statistics Canada, #57-003), except for NGLs, LPG, gasoline, gas/diesel oil, natural gas, and other bituminous coal, where the factors are based upon the proportion of their components.

TABLE 3-12: Reference Approach Conversion Factors for Canada

Fuel Types			Energy Conversion Factor - HHV			Carbon Emission Factor - HHV (t C/TJ)		
			2004 Value	Unit	Reference	2004 Value	Derivation	Reference
Liquid Fossil	Primary Fuels	Crude Oil	39.28	TJ/ML	Ref. 4	19.00	20.00 × 95%	Ref. 1
		Orimulsion	N/A	–	–	N/A	–	–
		NGLs	21.38[1]	TJ/ML	Ref. 4	16.13[1]	–	Ref. 2
	Secondary Fuels	Gasoline	35.00[2]	TJ/1000 m^3	Ref. 4	18.54[2]	–	Ref. 3
		Jet Kerosene	37.40	TJ/1000 m^3	Ref. 4	19.32	–	Ref. 3
		Other Kerosene	37.68	TJ/1000 m^3	Ref. 4	18.45	–	Ref. 3
		Shale Oil	N/A	–	–	N/A	–	–
		Gas/Diesel Oil	38.38[3]	TJ/1000 m^3	Ref. 4	18.60[3]	–	Ref. 3
		Residual Fuel Oil	42.50	TJ/1000 m^3	Ref. 4	20.18	–	Ref. 3
		LPG	26.38[4]	TJ/1000 m^3	Ref. 4	16.48[4]	–	Ref. 2
		Ethane	17.22	TJ/1000 m^3	Ref. 4	15.61	–	Ref. 2
		Naphtha	35.17	TJ/1000 m^3	Ref. 4	19.33	–	Ref. 3
		Bitumen	44.46	TJ/1000 m^3	Ref. 4	20.90	22.00 × 95%	Ref. 1
		Lubricants	39.16	TJ/1000 m^3	Ref. 4	19.66	–	Ref. 3
		Petroleum Coke	40.57	TJ/1000 m^3	Ref. 4	26.00	–	Ref. 2
		Refinery Feedstocks	35.17	TJ/1000 m^3	Ref. 4	19.33	–	Ref. 3
		Other Oil	39.82	TJ/1000 m^3	Ref. 4	19.84	–	Ref. 3
Solid Fossil	Primary Fuels	Anthracite	27.70	TJ/kt	Ref. 4	23.53	–	Ref. 2
		Coking Coal	N/A	–	–	N/A	–	–
		Other Bituminous Coal	28.42[5]	TJ/kt	Ref. 4	21.97[5]	–	Ref. 2
		Sub-Bituminous Coal	19.15	TJ/kt	Ref. 4	24.68	–	Ref. 2
		Lignite	15.00	TJ/kt	Ref. 4	25.73	–	Ref. 2
		Oil Shale	N/A	–	–	N/A	–	–
		Peat	N/A	–	–	N/A	–	–
	Secondary Fuels	BKB & Patent Fuel	N/A	–	–	N/A	–	–
		Coke Oven/Gas Coke	28.83	TJ/kt	Ref. 4	23.46	–	Ref. 3
Gaseous Fossil		Natural Gas	38.21[6]	TJ/GL	Ref. 4	13.87[6]	–	Ref. 2
Biomass		Solid Biomass	15.80[7]	TJ/kt	Ref. 4	23.22[7]	29.90 × 95%	Ref. 1
		Liquid Biomass	24.12	TJ/kt	Ref. 5	17.06	–	Ref. 5
		Gas Biomass	N/A	–	–	N/A	–	–

References:

(1) IPCC/OECD/IEA (1997); (2) McCann (2000); (3) Jaques (1992); (4) Statistics Canada, #57-003 (2003 data); (5) Heat of Combustion of Fuels, retrieved April 12, 2006, from: www.webmo.net/curriculum/heat_of_combustion/heat_of_combustion_key.html.

Notes:

1 Composite value is based on proportions of propane, butane, and ethane in Canada for the specific inventory year.

2 Composite value is based on proportions of motor gasoline and aviation gasoline in Canada for the specific inventory year.

3 Composite value is based on proportions of diesel fuel oil and light fuel oil in Canada for the specific inventory year.

4 Composite value is based on proportions of refinery propane and butane in Canada for the specific inventory year.

5 Composite value is based on provincial (domestic and imported) proportions for the specific inventory year.

6 Composite value is based on proportions of marketable natural gas and producer-consumed gas.

7 Composite value is based upon IPCC default values for solid and liquid biomass.

N/A = not applicable; BKB = charcoal briquettes

3.5.2 FEEDSTOCKS AND NON-ENERGY USE OF FUELS

Emissions from fuel use in the Energy Sector are those related to the combustion of the fuels for the purpose of generating heat or work. In addition to being combusted for energy production, fossil fuels are also consumed for non-energy purposes. Non-energy uses of fossil fuels include application as waxes, solvents, lubricants, and feedstocks (including the manufacturing of fertilizers, rubber, plastics, and synthetic fibres). Emissions from the non-energy use of fossil fuels have been included in the Industrial Processes Sector, while emissions from the use of natural gas as a feedstock in the upstream and downstream oil refining or processing industry are included in the fugitive section.

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

3.5.3 CO_2 CAPTURE AND STORAGE

CO_2 is used in the Canadian petroleum industry as a means of enhancing oil recovery from depleted oil reservoirs. It is also disposed of with hydrogen sulphide in geologic reservoirs as part of some gas processing operations. These are normal operational activities in the upstream industry. The quantities are not known or accounted for in the inventory (imported CO_2 used to enhance oil recovery is also not accounted for). However, current inventory procedures are designed to estimate the net CO_2 actually emitted to the atmosphere from all energy sources within Canada.

3.5.4 COUNTRY-SPECIFIC ISSUES — EMISSIONS ASSOCIATED WITH THE EXPORT OF FOSSIL FUELS

Canada exports a great deal of its produced fossil resources, mostly to the United States. In 2004, Canada exported over 60% (energy equivalent) of its gross natural gas and crude oil production. The GHGs associated with this production have historically been estimated using a 1997 Environment Canada study as the basis. *Fossil Fuel Energy Trade & Greenhouse Gas Emissions*, prepared for Environment Canada by T.J. McCann and Associates (McCann, 1997), integrates the authors' expert perspective and national energy data to achieve a reasonable estimate of GHG emissions associated with natural gas and crude oil production in Canada for the years 1990–1995.

To update this work, 1996–2004 emission estimates have been calculated using similar energy data from Statistics Canada, while emissions attributable to the net exports were extrapolated based on the study. Using the emission results presented in the study, an empirical relationship was established between those emissions and the net exported energy associated with the volumes of crude oil and natural gas, as recorded by Statistics Canada. This trend was then applied to the actual 1996–2004 net exports to develop the emission estimates (see Section ES.4.1 for further details).

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

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

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

4 INDUSTRIAL PROCESSES (CRF SECTOR 2)

4.1 OVERVIEW

The Industrial Processes Sector includes emissions of all GHGs produced as a direct by-product of non-energy-related industrial activities. GHG emissions from fuel combustion for supplying energy for industrial activities are assigned to the Energy Sector.

The processes addressed in this sector include production and use of mineral products, ammonia production, nitric acid production, adipic acid production, ferrous metal production, aluminium production, magnesium production and casting, production and consumption of halocarbons, production and consumption of SF_6, and other and undifferentiated production.

CO_2 emissions resulting from the use of fossil fuels as feedstock for the production of any chemical products other than ammonia, nitric acid, and adipic acid are reported under other and undifferentiated production (Section 4.11).

Emissions of indirect GHGs and SO_2 from activities including asphalt roofing, road paving with asphalt, pulp and paper production, and production of food and drink have not been estimated.

As shown in Table 4-1, the GHG emissions from the Industrial Processes Sector contributed 54 Mt to the 2004 national GHG inventory, as compared with 53 Mt in 1990. These emissions represented 7.2% of the total Canadian GHG emissions in 2004. The overall increase of 1.9% (as compared with the 1990 level) in this sector could be explained by significant emission growths in four categories: consumption of halocarbons, other and undifferentiated production, ammonia production, and cement production. Emissions from HFC consumption were considered negligible for the period 1990–1994. However, since the Montreal Protocol came into effect in 1996, the progressive replacement of chlorofluorocarbons (CFCs) by HFCs has resulted in upward HFC emissions. The use of fuels such as butane and ethane for non-energy purposes (i.e., use as feedstock) has also considerably increased over the years. This has caused an important emission growth of 45% from 1990 to 2004 for the category of other and undifferentiated production. For cement production, the expansion in clinker production capacity may explain the emission increase of 31% from 1990 to 2004. The rise in ammonia production volume justifies by and large the emission growth of 44% that this industry has experienced since 1990. It should be noted that, from 1990 to 2004, exports of urea have also increased, but not at the same pace as ammonia production.

Although an overall increase from the 1990 level was observed in 2004, some categories in the Industrial Processes Sector showed noticeable emission reductions. From 1990 to 2004, emissions coming from limestone and dolomite use, adipic acid production, aluminium production, magnesium smelting, and magnesium casting dropped by 60%, 71%, 22%, 30%, and 18%, respectively. Statistics showed that there was considerably less limestone and dolomite use as flux in iron and steel furnaces in 2004 than in 1990. The quantity of limestone used in glass manufacturing also dropped between 1990 and 2004. In the case of adipic acid production, the Invista Maitland plant has been using an emission abatement system since 1997. Aluminium producers have also tried to reduce PFC emissions by means of emission control technologies, while increasing their production volume. The emission decreases for magnesium production and casting were due to the progressive replacement of SF_6 used as cover gas with alternatives and reduction of production activity due to plant closures.

The overall emissions for the Industrial Processes Sector increased by 8.3% from 2003 to 2004. This augmentation was mainly due to increases in emissions coming from adipic acid production (185%) and other and undifferentiated production (11%). The non-energy use of fuels showed an increase from 2003 to 2004. Also, the emission abatement at Canada's only adipic acid plant went off-line for a short period in 2004 for maintenance, causing an emission augmentation for this category. Even though the overall emissions from industrial processes climbed between 2003 and 2004, some categories, such as aluminium production and magnesium production and casting, showed an emission decrease, for the same reasons as described above.

TABLE 4-1: Industrial Processes Sector GHG Emissions Summary for Selected Years

GHG Source Category	GHG Emissions		
	kt CO_2 eq		
	1990	2003	2004
Industrial Processes TOTAL	**53 300**	**50 100**	**54 300**
a. Mineral Production and Use	**8 300**	**9 100**	**9 500**
Cement Production	5 400	6 800	7 100
Lime Production	2 000	2 000	2 000
Limestone and Dolomite Use	730	290	290
Soda Ash Use	210	140	150
Magnesite Use	150	190	190
b. Chemical Industry	**15 000**	**7 000**	**9 600**
Ammonia Production	3 900	5 100	5 700
Nitric Acid Production	780	810	830
Adipic Acid Production	10 700	1 090	3 090
c. Metal Production	**19 500**	**17 200**	**17 600**
Iron and Steel Production	7 060	7 040	8 160
Aluminium Production	9 310	7 660	7 280
Magnesium Production	2 870	2 230	2 000
Magnesium Casting	236	255	194
d. Consumption of Halocarbons	**0**	**4 400**	**4 700**
e. SF_6 Use in Electric Utilities and Semiconductors	**1 800**	**1 600**	**800**
f. Other and Undifferentiated Production	**8 300**	**11 000**	**12 000**

Note:
Totals may not add due to rounding.

Uncertainties associated with emission estimates in the Industrial Processes Sector were assessed in a study conducted by ICF Consulting (ICF, 2004). Because the ICF report was prepared based on the 2001 inventory submitted in 2003 and a number of methodological improvements have been made since the completion of the study, the actual uncertainty values for some of the 2004 estimates shown in this inventory may be lower than those provided in the ICF report, as explained in the sections below. An updated analysis would be necessary to reassess the uncertainty range around the emission estimates for which there have been improvements in the calculation methods. Details on the uncertainty values for each category are discussed throughout Chapter 4.

According to the ICF (2004) report, the uncertainty in the 2001 total GHG emission estimate (excluding halocarbon consumption) for this sector was estimated to be within the range of −7% to +5%. Provided that improvements have been made to some categories, as mentioned above, this overall sectoral uncertainty range is considered to be conservative for the current emission estimate. The uncertainties associated with the 2001 HFC and PFC emissions from consumption of halocarbons were evaluated at −20% to +55% and −28% to +70%, respectively. These also represent conservative uncertainty estimates for the 2004 numbers (see Section 4.9.3 for details).

To ensure that the inventory was correctly prepared, the key, new, and updated categories of this sector have all undergone Tier 1–level QC checks. It is important to note that the Tier 1 QC procedures have been carried out and documented by staff members of the Greenhouse Gas Division who were not originally involved in the subject work. Details on the QA/QC plan for the national inventory as a whole and QC procedures can be found in Annex 6. For non-key categories, informal QC measures, such as double-checking calculations and checking activity data and emission estimates against the ones of previous years, have been taken.

4.2 MINERAL PRODUCTS (CRF CATEGORY 2.A)

4.2.1 SOURCE CATEGORY DESCRIPTION

This subsector accounts for CO_2 emissions related to the production and use of non-metallic minerals, including cement, lime, limestone, dolomite, soda ash, and magnesite. Possible GHG emissions associated with the production and/or use of other mineral products have not been estimated.

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

CO_2 is generated during the production of clinker, an intermediate product from which cement is made. Calcium carbonate ($CaCO_3$) from limestone, chalk, or other calcium-rich materials and other raw ingredients such as silicates are heated in a high-temperature kiln, forming lime (CaO) and CO_2 in a process called calcination or calcining, which occurs in the lower-temperature section of the kiln (800–900°C) and can be represented as follows:

$$CaCO_3 + \text{heat} \rightarrow CaO + CO_2$$

The lime is then combined with silica-containing materials in the higher-temperature section of the kiln (1350–1450°C) to produce clinker (greyish-black pellets about the size of 12-mm-diameter marbles). The clinker is removed from the kiln, cooled, and pulverized, while gypsum is added to produce portland cement. Almost all of the cement produced in Canada is of the portland cement type (ORTECH Corporation, 1994), which contains 60–67% lime by weight. Other specialty cements are lower in lime, but are typically used in small quantities.

CO_2 emissions from cement production are essentially directly proportional to lime content. The emissions resulting from the combustion of fossil fuels to generate the heat to drive the reaction in the kiln fall under the Energy Sector and are not considered here.

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

Calcined limestone (quicklime or CaO) is formed by heating limestone to decompose carbonates. As with cement production, this is usually done at high temperatures in a rotary kiln, and the calcination process releases CO_2. Primarily high-calcium limestone (calcite) is processed in this manner from quarried limestone to produce quicklime in accordance with the same reaction discussed in Section 4.2.1.1 on cement production.

Dolomitic limestone, which is a mix of calcite and magnesite ($MgCO_3$), may also be processed at high temperature to obtain dolomitic lime (and release CO_2) in accordance with the following reaction:

$CaCO_3 \bullet MgCO_3$ (dolomite) + heat → $CaO \bullet MgO$ (dolomitic lime) + $2CO_2$

Emissions from the regeneration of lime from spent pulping liquors at pulp mills are not accounted for in the Industrial Processes Sector. Since this CO_2 is biogenic in origin, it is recorded as a change in forest stock in the LULUCF Sector.

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

Limestone is a basic raw material used in a number of industries. In addition to its consumption in the production of cement and lime for resale, limestone is used as a raw material in glass factories. As well, significant amounts of limestone are used as flux 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. Since limestone at high temperatures is calcined to lime in these industries, CO_2 is produced by the same reaction described in Section 4.2.1.1 on cement production.

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

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

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

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

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

Magnesite, or magnesium carbonate ($MgCO_3$), is a silver-white solid that is used as a raw material in the making of a variety of products, including magnesium metal (Mg) and magnesia (MgO).

CO_2 is emitted when magnesite is used during the leaching step of the magnesium production process, as shown below:

$MgCO_3 + 2HCl \rightarrow MgCl_2 + H_2O + CO_2$

Magnesite can also be processed to become lighter-fired caustic magnesia and sintered magnesia, which are then used in refractory manufacturing (AMEC, 2006). CO_2 is generated along with magnesia when magnesium carbonate decomposes at high temperatures:

$MgCO_3$ + heat → $MgO + CO_2$

4.2.2 METHODOLOGICAL ISSUES

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

To estimate national CO_2 emissions from cement production, Equation 3.1 of the IPCC Good Practice Guidance (IPCC, 2000), as shown below, was used:

CO_2 emissions = $EF_{clinker}$ * Clinker Production * CKD Correction Factor

where:

$EF_{clinker}$ = emission factor based on clinker production

Clinker Production = clinker production data

CKD Correction Factor = factor that corrects for the loss of cement kiln dust (CKD)

The IPCC default $EF_{clinker}$ of 0.507 t CO_2/t clinker produced was applied. This factor was developed based on an average lime percentage of 64.6% and the molecular weight ratio of CO_2 to CaO in the raw material, which is 0.785 (IPCC/OECD/IEA, 1997). The IPCC Good Practice Guidance (IPCC, 2000) suggests 1.02 (i.e., adding 2% to the CO_2 calculated for clinker) as the default CKD Correction Factor.

Clinker production data for 1990–1996 were obtained from *Review of Energy Consumption and Related Data: Canadian Cement Manufacturing Industry, 1990 to 2002* (CIEEDAC, 2005) and for 1997–2003 from Statistics Canada (#44-001). To be noted is that CIEEDAC data on clinker production are obtained from the Portland Cement Association, which is a North American association representing cement companies operating in the United States and Canada.

Applying Equation 3.1 to the clinker production data is considered a Tier 2–type approach.

To estimate CO_2 provincial/territorial emissions, data on clinker capacity of cement plants across Canada were used. The source of data was the *Canadian Minerals Yearbook* (NRCan). These data were used to derive the percentage of total national clinker capacity attributed to each province/territory. CO_2 emissions on a provincial/territorial level were estimated by multiplying the percentage attributed to each province/territory by the national emission estimate.

It should be noted that for any given year, the clinker capacity data used are related to the preceding year. For example, in the most recent 2004 *Canadian Minerals Yearbook* (NRCan), only 2003 capacity data are provided. Therefore, it is assumed that there was no change in clinker production capacity from 2003 to 2004.

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

CO_2 emissions from lime production were estimated using an emission factor of 750 g CO_2/kg high-calcium lime (or quicklime) and an emission factor of 860 g CO_2/kg dolomitic lime. These IPCC default emission factors are based on the associated calcination reaction stoichiometry and IPCC default values for the lime content of the two types of lime (IPCC, 2000).

Total lime production and lime plant calcining capacity data were obtained from the *Canadian Minerals Yearbook* (NRCan). For any given year, the most recent lime production numbers provided are preliminary and are subject to revision in subsequent publications. The lime production data were corrected for the proportion of hydrated lime using national hydrated lime production data and the IPCC default water content of 28% (IPCC, 2000). Furthermore, the IPCC default ratio of high-calcium lime to dolomitic lime, 85/15, was applied to the lime production data to estimate the quantity of each type of lime. National CO_2 emissions were calculated by applying the above-noted emission factors to the estimated yearly national lime production data, by lime type.

Data on calcining capacities of lime production facilities across Canada also came from the *Canadian Minerals Yearbook* (NRCan). These data were used to derive the percentage of total national calcining capacity attributed to each province/territory. It should be noted that the same 85/15 split was applied to the calcining capacities of those facilities known to produce both lime types. CO_2 emissions on a provincial/territorial level were estimated by multiplying the capacity percentage attributed to each province/territory by the national emission estimate.

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

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

CO_2 emissions from limestone and dolomite were calculated separately using two different emission factors.

Based on the process stoichiometry, it was determined that 440 g of CO_2 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%, which originally came from a report prepared for Limestone Industries of Ontario in 1983, was applied, resulting in the overall emission factor of 418 g CO_2/kg of limestone used (AMEC, 2006).

Dolomite consists of both limestone ($CaCO_3$) and magnesite ($MgCO_3$). As mentioned in the 2006 AMEC study, a major Canadian producer of dolomite reported that the composition of its dolomite ranged from 56% to 58% $CaCO_3$ and from 38% to 41% $MgCO_3$. An overall emission factor of 468 g CO_2/kg of dolomite used was derived based on the emission factors for pure limestone (440 kg of CO_2 per tonne) and magnesite (522 kg of CO_2 per tonne) and the assumption that dolomite is composed of 58% $CaCO_3$ and 41% $MgCO_3$ (AMEC, 2006).

Data on raw stone use in iron and steel furnaces, non-ferrous smelters, glass factories, pulp and paper mills, and other chemical uses were obtained from the *Canadian Minerals Yearbook* (NRCan). These are the emissive parts of the stone use data. Data on consumption of stone as flux in iron and steel furnaces were disaggregated into limestone and dolomite use based on a 70/30 split (AMEC, 2006). National CO_2 emissions were estimated by multiplying the quantities of limestone/dolomite consumed by the corresponding emission factors. The most recent activity data published by NRCan were for 2003; therefore, the consumption data for 2004 were estimated based on the assumption that the increase in limestone and dolomite consumed was the same in 2004 as in 2003. An appropriate method for estimating limestone use emissions on a provincial/territorial basis has not yet been developed.

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

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

According to a recent study (AMEC, 2006), use of soda ash is not limited to glass manufacturing. This mineral may also be used for other purposes, such as chemical production, pulp and paper mills, and flue gas desulphurization, resulting in CO_2 emissions.

For each mole of soda ash used, 1 mol of CO_2 is emitted. The emission factor (EF) for the mass of CO_2 emitted is estimated from the stoichiometry of the chemical process as follows:

Equation 4-1:

$$\mathbf{EF = (1000\ g/kg) * (44.01\ g\ CO_2/mol) / (105.99\ g\ Na_2CO_3/mol)}$$
$$= 415\ g\ CO_2/kg\ Na_2CO_3$$

National CO_2 emissions were calculated by applying the emission factor of 415 g CO_2/kg to the national data on soda ash consumption. Quantities of soda ash used were estimated based on soda ash import and export data obtained from the Global Trade Information Services by AMEC (2006). It should be noted that since the Global Trade Information Services did not report trade data before 1995, it was assumed that the trade data for the years 1990–1994 were the same as those for 1995.

This method is considered to be Tier 1–type, as it is based on the use of national consumption data and an emission factor derived from the stoichiometry of the process. An appropriate method for estimating soda ash use emissions on a provincial/territorial basis has not yet been developed.

Methodological issues for calculating CO_2 emissions from soda ash use are not addressed specifically in the IPCC Good Practice Guidance (IPCC, 2000).

Although most CO_2 coming from the Solvay process used to produce soda ash is recovered for reuse (as mentioned above), some CO_2 may be released from vents on absorbers, scrubbers, and distillation units, depending on the effectiveness of the recovery process. However, the amount of net CO_2 emissions is assumed to be minimal in the Canadian context (AMEC, 2006).

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

For use of magnesite, an emission factor of 522 g CO_2/kg was developed using the process stoichiometry. Since commercial magnesite is not 100% pure, the emission factor was adjusted to reflect the fractional purity. Three facilities in Canada have used magnesite as a raw material in the years 1990–2004. According to the AMEC (2006) report, one of the facilities reported (in the *5th Strategic Diversification Newsletter*) 97% as the purity fraction for the magnesite it used. It was assumed that all facilities have used magnesite with the same purity fraction (97%). Considering the purity of magnesite, the emission factor of 522 g CO_2/kg was converted to 506 g CO_2/kg (AMEC, 2006).

The facility-specific magnesite use data originally came from the British Columbia Ministry of Energy, Mines and Petroleum Resources and Environment Canada (Quebec Region, Environmental Protection Branch) (AMEC, 2006). Multiplying the consumption data by the above-mentioned emission factor gives the national emission estimates for this subsector.

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

4.2.3 UNCERTAINTIES AND TIME-SERIES CONSISTENCY

4.2.3.1 Cement Production

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

According to the IPCC Good Practice Guidance (IPCC, 2000), estimation via direct clinker production data, as in the case of the 2004 estimate, results in an error of about 10%. It should be recognized that this is an approximate IPCC default uncertainty value. A more complete and updated uncertainty assessment would be necessary to analyze in detail the uncertainty in the current emission estimate of this subsector.

Equation 3.1 of the IPCC Good Practice Guidance (IPCC, 2000) has been consistently applied over the time series. The activity data sources were *Review of Energy Consumption and Related Data: Canadian Cement Manufacturing Industry, 1990 to 2002* (CIEEDAC, 2005) for 1990–1996 and Statistics Canada publication #44-001 for 1997–2004. Clinker production capacity information for the time series was obtained from the *Canadian Minerals Yearbook* (NRCan).

4.2.3.2 Lime Production

The ICF (2004) study shows an uncertainty range of −2% to +110% for the emission estimate for lime production for the year 2001. The current emission estimation technique, which includes a correction factor for hydrated lime and accounts for different types of lime, makes the provided uncertainty highly conservative for the 2004 inventory estimate. However, the IPCC default ratio of high-calcium lime to dolomitic lime, 85/15, can be a source of uncertainty, since it may not be absolutely true in a Canadian context.

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

4.2.3.3 Limestone and Dolomite Use

Uncertainties associated with CO_2 emissions from limestone use range from 4.0% to 25.6%. The uncertainties are mostly associated with the activity data: quantities of limestone use as flux in iron and steel furnaces and other chemical uses. Additional uncertainties in this category come from the 70/30 limestone/dolomite split applied to disaggregate the amount of raw stone used as flux in iron and steel furnaces (AMEC, 2006).

Uncertainties associated with CO_2 emissions from dolomite were estimated to be 30.4%. This uncertainty relates to the 70/30 limestone/dolomite split (AMEC, 2006).

4.2.3.4 Soda Ash Production and Use

The uncertainties associated with emissions from soda ash use stem mostly from activity data for the years 1990–1994. The soda ash import and export data were available from the Global Trade Information Services only from 1995 onwards. The data for these years were assumed to be the same as those for 1995. The uncertainty associated with activity data before 1995 was estimated to be 23.1%, and for 1995 and onwards to be 2% (AMEC, 2006).

4.2.3.5 Magnesite Use

The uncertainty associated with emissions from magnesite use ranges from 4.9% to 6.0%. The main sources of uncertainty for magnesite are the assumed purity fraction of magnesite for two of the three plants and the activity data (AMEC, 2006).

4.2.4 CATEGORY-SPECIFIC QA/QC AND VERIFICATION

4.2.4.1 Cement Production

This key category in the Industrial Processes Sector has undergone for this submission Tier 1 QC checks as elaborated in the *Framework for a Quality Assurance and Quality Control Plan* (SNC Lavalin, 2004). The checks performed are consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC, 2000). No issues of importance were detected from the Tier 1 QC process.

4.2.4.2 Lime Production

This key category in the Industrial Processes Sector has undergone for this submission Tier 1 QC checks as elaborated in the *Framework for a Quality Assurance and Quality Control Plan* (SNC Lavalin, 2004). The checks performed are consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC, 2000). No anomalies were observed.

4.2.4.3 Soda Ash Use and Production

Although CO_2 from soda ash use is not a key category, it has undergone for this submission Tier 1 QC checks as elaborated in the *Framework for a Quality Assurance and Quality Control Plan* (SNC Lavalin, 2004). A Tier 1 QC was necessary to ensure the accuracy of the revised emission estimates for this category. The checks performed are consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC, 2000). No issues of importance were detected from the Tier 1 QC process.

4.2.4.4 Limestone and Dolomite Use

This key category in the Industrial Processes Sector has undergone for this submission Tier 1 QC checks as elaborated in the *Framework for a Quality Assurance and Quality Control Plan* (SNC Lavalin, 2004). The checks performed are consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC, 2000). No anomalies were observed.

4.2.4.5 Magnesite Use

Although CO_2 from magnesite use is not a key category, it has undergone for this submission Tier 1 QC checks as elaborated in the *Framework for a Quality Assurance and Quality Control Plan* (SNC Lavalin, 2004). A Tier 1 QC was necessary to ensure the accuracy of emission estimates developed for this new category. The checks performed are consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC, 2000). No issues of importance were detected from the Tier 1 QC process.

4.2.5 CATEGORY-SPECIFIC RECALCULATIONS

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

The national 1990–1996 cement production emission estimates were recalculated due to the acquisition of actual clinker production data from CIEEDAC for these years. In the previous inventory, emissions at the national level for the years 1990–1996 were calculated based on cement production, clinker export/import, and IPCC default clinker fractions in different types of cement.

The impact of the recalculations was a decrease in national CO_2 emission estimates for all the recalculated years except 1995. The differences in emission values calculated using the two methods ranged from –8.4% to +3.9%.

The 2003 CO_2 emissions from cement production at a provincial/territorial level were also recalculated. This recalculation was due to the acquisition of new data on cement plant clinker capacity from the latest *Canadian Minerals Yearbook* (NRCan).

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

The 2003 CO_2 emissions from lime production at national and provincial/territorial levels were recalculated. This recalculation was due to the update of data on national lime production and national hydrated lime production obtained from the *Canadian Minerals Yearbook* (NRCan).

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

Estimates for this subsector have been recalculated for 1990–2003 to take into account additional emissions coming from the use of limestone in pulp and paper mills and other chemical uses, which were not reported in the previous inventory. Also, two different emission factors have been applied to estimate separately emissions coming from limestone and those from dolomite used as flux in iron and steel furnaces.

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

CO_2 emissions from soda ash use for 1990–2003 have been recalculated based on soda ash import and export data.

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

Since magnesite use is a new subsector in this year's inventory, its associated emissions were not reported in the last submission. Hence, there have been no recalculations related to magnesite use.

4.2.6 CATEGORY-SPECIFIC PLANNED IMPROVEMENTS

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

During the preparation of the last inventory, significant differences were observed, for the years 1990–1996, between the cement production statistics (export/import and cement production data) found in Statistics Canada publication #44-001 and those in the *Canadian Minerals Yearbook* (NRCan).

Since then, Environment Canada has started to resolve the issue by initiating discussions with Statistics Canada and NRCan to try to find out the reasons for such discrepancies. As a result of these discussions, clinker data for 1990–1996 were obtained as mentioned previously and used in the CO_2 estimate recalculations of those years. Environment Canada will continue to resolve potential cement statistical differences in collaboration with Statistics Canada and NRCan.

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

There are currently no improvements planned specifically for estimating CO_2 emissions from lime production.

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

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

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

There are currently no improvements planned specifically for estimating CO_2 emissions from soda ash production and use.

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

There are currently no improvements planned specifically for estimating CO_2 emissions from magnesite use.

4.3 AMMONIA PRODUCTION (CRF CATEGORY 2.B.1)

4.3.1 SOURCE CATEGORY DESCRIPTION

As one of the main usages of ammonia (NH_3) is to manufacture fertilizing agents, fertilizer plants are often large producers of ammonia as well. Ammonia is produced in the Haber-Bosch process in which nitrogen and hydrogen react together. Although natural gas steam reformation emitting CO_2 is usually used to generate the hydrogen needed, some hydrogen fed to the process may come from chemical reactions that do not involve any CO_2 emissions. Also to be noted is the fact that not all CO_2 emissions from the production of ammonia go directly to the atmosphere; some are recovered and utilized for making urea. The carbon is trapped in urea only temporarily and is emitted upon its application to agricultural soils. It is assumed that all CO_2 generated in ammonia manufacture is released to the atmosphere at the ammonia plant, except for the portion of CO_2 in urea destined to export markets.

4.3.2 METHODOLOGICAL ISSUES

Emissions from ammonia production were estimated by multiplying CO_2-related ammonia production by an emission factor of 1.56 t CO_2/t NH_3 produced. Subtracting the portion of non-CO_2-releasing ammonia production from the total amount of Canadian ammonia production (Statistics Canada, #46-002) gave the CO_2-related production estimate that was used in the calculation. The emission factor was developed using typical energy and material requirements for ammonia production in Canada (Jaques, 1992). As mentioned above, some CO_2 coming from ammonia production has been used to make urea destined for export, and hence the CO_2 would be emitted only outside Canada. Therefore, to avoid overestimation, the amount of CO_2 sequestered in exported urea was taken into account in the calculation of net CO_2 emissions from ammonia production. The quantity of CO_2 found in exported urea was determined by multiplying urea export (Statistics Canada, #65-004) by a factor of 0.73 t CO_2 trapped/t urea. The latter factor was developed based on the stoichiometry of the urea manufacturing process.

To calculate emissions at provincial/territorial levels, the national emission estimate was prorated by provincial/territorial ammonia production capacities (published by the Canadian Fertilizer Institute in 1999).

This technique is considered to be a Tier 1–type method, as it is based on the use of national production data and an average national emission factor. Methodological issues for calculating CO_2 emissions from ammonia production are not addressed specifically in the IPCC Good Practice Guidance (IPCC, 2000).

It should be noted that the quantity of natural gas used to produce hydrogen for ammonia production was also recorded by Statistics Canada with all other non-energy uses of natural gas. Therefore, to avoid double-counting, the CO_2 emissions from ammonia production were subtracted from the total non-energy fossil fuel use CO_2 emissions.

4.3.3 UNCERTAINTIES AND TIME-SERIES CONSISTENCY

The ICF (2004) report shows an uncertainty range of −23% to +55% for the CO_2 emission estimate for ammonia production. The provided uncertainty value is considered as conservative for this year's estimate because of the calculation improvement made since the completion of the uncertainty study. Accounting for the amount of CO_2 trapped in exported urea would have lowered the uncertainty in the emission estimate of this category. The emission factor is responsible for most of the uncertainty in this category. Another contributing factor would be the portion of ammonia production attributed to hydrogen produced as a chemical process by-product, which is assumed to be constant for the whole time series. A sensitivity analysis needs to be conducted to determine the relative contribution of the activity data and emission factor to the uncertainty associated with this category.

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

4.3.4 CATEGORY-SPECIFIC QA/QC AND VERIFICATION

Ammonia production is a key category that has undergone for this submission Tier 1 QC checks as elaborated in the *Framework for a Quality Assurance and Quality Control Plan* (SNC Lavalin, 2004). The checks performed are consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC, 2000). No issues of importance were detected from the Tier 1 QC process.

4.3.5 CATEGORY-SPECIFIC RECALCULATIONS

The whole time series has been recalculated to take into account the amount of CO_2 trapped in exported urea. Improvements made to the methodology have resulted in emission decreases ranging from –23.5% to –16.8% for 1990–2003.

4.3.6 CATEGORY-SPECIFIC PLANNED IMPROVEMENTS

Efforts are being made to update the quantity of ammonia production for which the hydrogen used is a by-product of chemical processes and which, therefore, does not involve any CO_2 emissions. The current country-specific CO_2 emission factor, based on mass of ammonia produced, will also be reviewed.

4.4 NITRIC ACID PRODUCTION (CRF CATEGORY 2.B.2)

4.4.1 SOURCE CATEGORY DESCRIPTION

Nitric acid (HNO_3) is an inorganic compound used primarily in the production of synthetic commercial fertilizers. It may also be used for producing explosives and other chemicals, such as adipic acid. N_2O is emitted during the production of nitric acid from ammonia. Hence, the quantity of N_2O released is proportional to the amount of ammonia fed to the process. The concentration of N_2O in the exhaust gases depends on the type of plant and its emission controls.

4.4.2 METHODOLOGICAL ISSUES

Canada-specific emission factors were developed based on the type of abatement technology that is employed at individual plants.

One of the first attempts to estimate emissions of N_2O for this sector used information provided by the global industry, which was based on company-specific measurements and calculations (McCulloch, 1991; Norsk Hydro, 1991). These estimates reported emissions ranging from 2 to 20 kg N_2O/t NH_3 consumed in the production of nitric acid. However, subsequent investigations indicated that emissions from Canadian plants were at the low end of this range. As a result, the following emission factors (EF) were developed (Collis, 1992):

- plants with catalytic converters:
  EF = 0.66 kg N_2O/t HNO_3 produced
- plants with extended absorption for NO_x abatement type 1:
  EF = 9.4 kg N_2O/t HNO_3 produced
- plants with extended absorption for NO_x abatement type 2:
  EF = 12 kg N_2O/t HNO_3 produced

Annual national nitric acid production data were obtained from the publication *Industrial Chemicals and Synthetic Resins* (Statistics Canada, #46-002). All nitric acid plants in Canada, with the exception of those in Alberta, are of the catalytic converter type. For Alberta, it was assumed that 175 kt of nitric acid were produced by plants with extended type 1 and 30 kt of nitric acid were produced by plants with extended type 2. The remainder were from catalytic converter–type plants. Nitric acid plant capacity data were subsequently used to estimate N_2O emissions on a provincial/territorial basis.

This technique is considered to be a Tier 2–type method, as it is based on abatement-specific emission factors. The emission factors are within the range published by IPCC/OECD/IEA (1997).

4.4.3 UNCERTAINTIES AND TIME-SERIES CONSISTENCY

The N_2O emission estimate for nitric acid production has an uncertainty of –15% to +16%. The uncertainty range provided in the ICF (2004) report is applicable to the 2004 inventory estimate because the current methodology and data source are the same as the ones used for the 2001 inventory. One possible source of uncertainty would be the emission factors, which may require an update. The assumption made for plants in Alberta, as mentioned above, may also bring about uncertainty in the N_2O emissions for this category. A sensitivity analysis needs to be performed to relate the uncertainty of this category to its input parameter uncertainties.

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

4.4.4 CATEGORY-SPECIFIC QA/QC AND VERIFICATION

Informal QC measures, such as double-checking calculations and checking emission estimates against the ones of previous years, have been taken. In addition, the published nitric acid production estimates have been compared with the aggregate national nitric acid plant capacities to determine the reasonableness of the activity data.

4.4.5 CATEGORY-SPECIFIC RECALCULATIONS

There have been no recalculations of N_2O emissions related to nitric acid production.

4.4.6 CATEGORY-SPECIFIC PLANNED IMPROVEMENTS

The possibility of updating the emission factors and the production capacity data used to develop provincial/territorial emission estimates is being investigated in an ongoing study. Any update obtained from this study will be included in the next inventory.

4.5 ADIPIC ACID PRODUCTION (CRF CATEGORY 2.B.3)

4.5.1 SOURCE CATEGORY DESCRIPTION

Adipic acid is a dicarboxylic acid produced via a two-stage oxidation process and used primarily in the production of Nylon 66. N_2O is generated as a by-product of the second oxidation stage and is generally vented to the atmosphere in a waste gas stream.

The only adipic acid production facility in Canada is operated by Invista (formerly DuPont) and located in Maitland, Ontario. An emission abatement system was installed at the facility in 1997, for which Invista implemented a program of emissions monitoring to determine its performance efficiency.

4.5.2 METHODOLOGICAL ISSUES

The emission estimates for adipic acid production were provided by the Invista Maitland plant. For the period 1990–1996, when no emission controls were in place, the reported emission estimates were calculated by multiplying adipic acid production by an emission factor of 0.3 kg N_2O/kg adipic acid. From 1997 to 2004, the reported emission data came from direct monitoring.

This technique is considered to be a Tier 3–type method, as it is based on reported facility-specific emission data.

4.5.3 UNCERTAINTIES AND TIME-SERIES CONSISTENCY

According to the ICF (2004) report, the 2001 N_2O emission estimate for adipic acid production had an uncertainty of ±2%, reflecting the random component of the uncertainty related to monitoring and reporting of emissions. The provided uncertainty value is applicable to the 2004 estimate of this category.

The data source remains consistent over the time series, but the methodology has evolved, as previously mentioned. Prior to 1997, N_2O emissions from adipic acid production were estimated by Invista based on production, whereas emissions reported from 1997 to the present are directly measured using emissions monitoring equipment.

4.5.4 CATEGORY-SPECIFIC QA/QC AND VERIFICATION

Adipic acid production is a key category that has undergone for this submission Tier 1 QC checks as elaborated in the *Framework for a Quality Assurance and Quality Control Plan* (SNC Lavalin, 2004). The checks performed are consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC, 2000). No issues of importance were detected from the Tier 1 QC process.

4.5.5 CATEGORY-SPECIFIC RECALCULATIONS

There have been no major recalculations of N_2O emissions related to adipic acid production. However, more precise 1999–2003 emission data were obtained from the adipic acid plant for this submission. The recalculated data differ from those that were previously reported by less than 1%.

4.5.6 CATEGORY-SPECIFIC PLANNED IMPROVEMENTS

There are currently no improvements planned specifically for estimating N_2O emissions from adipic acid production in Canada. However, as part of an ongoing study, efforts are being made to obtain additional information on the abatement technology employed, the N_2O monitoring system, and the accuracies involved.

4.6 IRON AND STEEL PRODUCTION (CRF CATEGORY 2.C.1)

4.6.1 SOURCE CATEGORY DESCRIPTION

Crude (pig) iron is produced in a blast furnace through the reduction of iron oxide (ore), with the carbon in coke or charcoal as the reducing agent. In most iron furnaces, the process is aided by the use of limestone fluxes (IPCC, 2000). Steel can be made in electric arc furnaces (EAFs), basic oxygen furnaces, or cupola furnaces. Low-carbon steel is produced in basic oxygen furnaces, where a mixture of pig iron and iron scrap is remelted in the presence of pure oxygen, which oxidizes the dissolved carbon to CO or CO_2. Carbon and alloy steels are produced in EAFs, refractory-lined pots that utilize electric heating through graphite electrodes, which are consumed in the process (IPCC/OECD/IEA, 1997).

In the production of pig iron, carbon plays the dual role of fuel and reductant. Emissions from the combustion of fuels such as coke oven gas are not reported in this category, but rather under the appropriate industrial category in the Energy Sector. CO_2 emissions from carbon oxidation, which occurs when iron ore is reduced to pig iron, are included in this category. Also accounted for in this category are emissions during steel production, which occur to a much lesser extent. These come from the oxidation of carbon in crude iron and electrode consumption. Additional CO_2 given off by limestone flux in the blast furnace is covered under Limestone and Dolomite Use (see Section 4.2).

4.6.2 METHODOLOGICAL ISSUES

To estimate CO_2 emissions from iron and steel production at a national level, the Tier 2 method, as described in the IPCC Good Practice Guidance (IPCC, 2000), was used. With this methodology, the fate of carbon was tracked throughout the production process, and emissions from iron production and steel production were calculated separately. The following equation was used to estimate emissions from pig iron production:

Equation 4-2:

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

where:

Emission $\text{Factor}_{\text{reductant}}$ = 2.479 t CO_2/t of coke used (Jaques, 1992) [Note that it was assumed that the reductant used in the process was 100% metallurgical coke.]

mass of reductant = mass of metallurgical coke used in the process

mass of carbon in pig iron = total pig iron production * carbon content in pig iron

44/12 = ratio of the molecular weight of CO_2 to the molecular weight of carbon

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

Emissions from steel production were estimated using the following equation:

Equation 4-3:

$\text{Emissions}_{\text{crude steel}}$ = [(mass of carbon in pig iron used for crude steel – mass of carbon in crude steel) * 44/12] + (Emission $\text{Factor}_{\text{EAF}}$ * steel produced in EAFs)

where:

mass of carbon in pig iron used for crude steel = total pig iron charged to steel furnaces * 4%

mass of carbon in crude steel = total steel production * carbon content in crude steel

44/12 = ratio of the molecular weight of CO_2 to the molecular weight of carbon

Emission $\text{Factor}_{\text{EAF}}$ = emission factor for steel produced in EAFs

Steel produced in EAFs = the amount of steel produced in EAFs

Data on the total pig iron charged to steel furnaces, on total steel production, and on the amount of steel produced in EAFs were obtained from Statistics Canada (#41-001). The value of the carbon content in crude steel applied in the equation was 1.25%, and it was also the midpoint of the IPCC default range (0.5–2%). The emission factor for steel produced in EAFs of 4.58 kg CO_2/t steel was derived from the IPCC default value for the mass of carbon released from consumption of electrodes per tonne of steel produced (IPCC, 2000).

Data on metallurgical coke use at provincial/territorial levels from the RESD (Statistics Canada, #57-003) were used to derive the percentage of total reductant consumption attributed to each province and territory. CO_2 emissions at provincial/territorial levels were then estimated by multiplying the percentage derived by the national emission estimate.

It should be noted that RESD data (Statistics Canada, #57-003) published for any given year are preliminary and subject to revision in subsequent publications.

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

4.6.3 UNCERTAINTIES AND TIME-SERIES CONSISTENCY

The uncertainty in the 2001 inventory's CO_2 emission estimate for iron and steel production is ±5% (ICF, 2004). It should be noted that this represents a conservative uncertainty value for the 2004 inventory emission estimates because the methodology for calculating CO_2 emissions has improved since the 1990–2002 inventory. The shift from a Tier 1 to Tier 2 approach is expected to lower the uncertainty. However, an updated analysis would be needed to fully assess the uncertainty in the emission estimates calculated using a Tier 2–type technique.

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

4.6.4 CATEGORY-SPECIFIC QA/QC AND VERIFICATION

Iron and steel production is a key category that has undergone for this submission Tier 1 QC checks as elaborated in the *Framework for a Quality Assurance and Quality Control Plan* (SNC Lavalin, 2004). The checks performed are consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC, 2000). No major issues were detected during the Tier 1 QC process.

4.6.5 CATEGORY-SPECIFIC RECALCULATIONS

Since the 2003 metallurgical coke consumption data in the revised 2003 RESD (Statistic Canada, #57-003) have stayed the same as in the preliminary version, there have been no recalculations of CO_2 emissions related to iron and steel production.

4.6.6 CATEGORY-SPECIFIC PLANNED IMPROVEMENTS

There are currently no improvements planned specifically for estimating CO_2 emissions from iron and steel production in Canada.

4.7 ALUMINIUM METAL PRODUCTION (CRF CATEGORY 2.C.3)

4.7.1 SOURCE CATEGORY DESCRIPTION

Primary aluminium is produced in two steps. First, bauxite ore is ground, purified, and calcined to produce alumina (Al_2O_3). Next, the alumina is electrically reduced to aluminium by smelting in large pots with carbon-based anodes. The pot itself (a shallow steel container) forms the cathode, while the anode consists of one or more carbon blocks suspended within it. Inside the pot, alumina is dissolved in a fluorine bath consisting primarily of cryolite (Na_3AlF_6). Passing a current through the resistance of the cell causes the heating effect, which maintains the contents in a liquid state. Molten aluminium is evolved while the anode is consumed in the reaction. The aluminium forms at the cathode and gathers on the bottom of the pot.

Three GHGs — CO_2, carbon tetrafluoride (CF_4), and carbon hexafluoride (C_2F_6) — are known to be emitted during the reduction process. CF_4 and C_2F_6 are part of a larger class of GHGs known as PFCs. PFCs are considered potent GHGs, as reflected by their high GWPs.

As the anode is consumed, CO_2 is formed in the following reaction, provided that enough alumina is present at the anode surface:

$$Al_2O_3 + \frac{3}{2}C \rightarrow 2Al + \frac{3}{2}CO_2$$

Most of the CO_2 forms from the reaction of the carbon anode with alumina, but some is formed as the anode reacts with other sources of oxygen (especially air). This occurs during cell operation and, in the case of pre-baked electrodes, also during anode production and manufacture.

Aluminium plants are characterized by the type of anode technology employed. In general, older plants with Søderberg technology have higher emissions than newer plants, which usually use pre-baked anodes. The trend in the Canadian aluminium industry has been towards modernizing facilities, since production efficiency is improved. In some cases, this has meant taking old lines out of production as new ones are installed to meet increasing demand.

Primary aluminium smelting is the only known major source of PFCs (Jacobs, 1994). PFC gases are formed during an occurrence known as the anode effect or anode event, when alumina levels are low. If the concentration of alumina at the anode is reduced to below ~2% (by weight), an anode event may begin. In theory, when an anode event occurs, the cell resistance increases very suddenly (within a 50th of a second). As a result, the voltage rises and the temperature goes up, forcing the molten fluorine salts in the cell to chemically combine with the carbon anode (Laval University, 1994).

During the anode event, competing reactions occur to produce CO, CF_4, and C_2F_6, in addition to CO_2. The two reactions of interest at this point are:

$Na_3AlF_6 + \frac{3}{4}C \rightarrow Al + 3NaF + \frac{3}{4}CF_4$

$Na_3AlF_6 + C \rightarrow Al + 3NaF + \frac{1}{2}C_2F_6$

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 "centre-break" types, also tend to reduce emissions (Øye and Huglen, 1990).

In addition to CO_2, CF_4, and C_2F_6, a small amount of SF_6 is also emitted from its use in degassing at some aluminium plants. The degassing process involves the removal of unwanted hydrogen from molten aluminium. Hydrogen in dissolved state results from the metal's exposure to moisture, hydrocarbons, and other process elements. If not taken out, it will get trapped in the metal during the solidification process, leading to porous aluminium with inferior properties. Hydrogen degassing of aluminium is based on the principle that hydrogen gas will move from an area of high pressure (in the melt) to an area of low pressure (in the inert gas). Chlorine was the original gas of choice; due to its hazardous nature, however, most foundries switched to other gases, such as SF_6 (AACCM, 2006).

Although aluminium production consumes extremely large quantities of electrical energy, currently estimated to be 13.5 kWh/kg of aluminium (AIA, 1993), GHG emissions associated with this consumption are not necessarily high. All of Canada's primary aluminium smelters are located in Quebec and British Columbia, where almost all (95%) of the electricity generated is produced by hydraulic generators; these are believed to emit a negligible amount of GHGs compared with conventional fossil fuel–based electricity generators.

4.7.2 METHODOLOGICAL ISSUES

Process-related emission estimates for aluminium production were directly obtained from the Aluminum Association of Canada (AAC). In addition to the smelter-specific emission estimates, information on the methodologies used by the aluminium producers to calculate CO_2, PFC, and SF_6 emissions was obtained from the AAC. The estimation techniques applied may be Tier 3–, Tier 2–, or Tier 1–type, as described below, depending on data availability; a Tier 3–type technique has mostly been applied for estimating emissions for recent years.

Typically, the equations used by smelters to estimate CO_2 emissions from the reaction of the carbon anode with alumina are (AAC, 2002):

Equation 4-4: For Pre-baked Anode Consumption

$$E_{CO_2}\,(t) = [CC * MP * (100 - \%S_a - \%Ash_a - \%Imp_a)/100] * 44/12$$

where:

CC = baked anode consumption per tonne of aluminium (t C/t Al)
MP = total aluminium production (t)
S_a = sulphur content in baked anodes (wt %)
Ash_a = ash content in baked anodes (wt %)
Imp_a = fluorine and other impurities (wt %)*
44/12 = ratio of the molecular weight of 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 4-5: For Søderberg Anode Consumption

$$E_{CO_2}\,(t) = \{(PC \ast MP) - (BSM \ast MP/1000) - [\%BC/100 \ast PC \ast MP \ast (\%S_p + \%Ash_p + [\%H_2/100])] - [(100 - \%BC)/100 \ast PC \ast MP \ast (\%S_c + \%Ash_c)/100]\} \ast 44/12$$

where:

PC = paste consumption (t paste/t Al)

MP = total aluminium production (t)

BSM = emissions of benzene-soluble matter (kg/t Al)

BC = average binder content in paste (wt %)

S_p = sulphur content in pitch (wt %)

Ash_p = ash content in pitch (wt %)

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 equations above with actual process data to estimate CO_2 emissions is considered Tier 3–type methodology. A Tier 2–type technique involves the application of some measured data in combination with industrial typical values (as provided by AAC) to these equations.

When no process data other than aluminium production are available, emission factors for a Tier 1 method (as shown below) can be used. These factors depart slightly from the IPCC default ones. According to a supporting document provided by the AAC (2002), this is because the IPCC Tier 1 default factors reflect 1990 emissions and would produce considerable errors if applied to current production. The factors below reflect the considerable progress that has been made over the period from 1990 to 2001 (AAC, 2002):

- Søderberg: EF = 1.7 t CO_2/t Al produced; and
- Pre-baked: EF = 1.6 t CO_2/t Al produced.

CF_4 and C_2F_6 emitted during anode effects can be calculated by smelters using either the Slope or Pechiney Overvoltage Method, depending on the smelter technology (AAC, 2002):

Equation 4-6: Slope Method

$$E_{PFC}\,(t\ CO_2\ eq) = slope \ast AEF \ast AED \ast MP \ast GWP / 1000$$

where:

slope = slope (for CF_4 or C_2F_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_2F_6

Equation 4-7: Pechiney Overvoltage Method

$$E_{PFC}\,(t\ CO_2\ eq) = overvoltage\ coefficient \ast AEO / CE \ast GWP \ast MP / 1000$$

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_2F_6

MP = total aluminium production (t)

The use of the equations above with actual process data to estimate PFC emissions is considered Tier 3–type methodology. The estimation technique is considered as Tier 2–type when the default coefficients shown in Table 4-2 are used together with smelter-specific operating parameters. Most of these coefficients are found in Table 3-9 of the IPCC Good Practice Guidance (IPCC, 2000). The overvoltage coefficients for C_2F_6, which are not provided by the IPCC Good Practice Guidance, can be estimated as either A) 10% of that for CF_4 or B) the ratio of the slope coefficient for C_2F_6 to the one for CF_4, depending on the smelter (AAC, 2002).

TABLE 4-2: Default Slope and Overvoltage Coefficients

Type of Cell	Slope Coefficients		Overvoltage Coefficients		
	([kg PFC/t Al]/ [AE-minutes/cell-day])		([kg PFC/t Al]/ [mV/cell-day])		
	CF_4	C_2F_6	CF_4	C_2F_6	
				A	B
Centre Worked Pre-Baked	0.14	0.018	1.9	0.19	0.13
Side Worked Pre-Baked	0.29	0.029	1.9	0.19	0.10
Vertical Stud Søderberg	0.068	0.003	N/A	N/A	N/A
Horizontal Stud Søderberg	0.18	0.018	N/A	N/A	N/A

Note:
N/A = not applicable

If only production statistics are available (i.e., no data on anode effect frequency, anode effect duration, or anode effect overvoltage), the emission factors shown in Table 4-3 can be used by smelters (AAC, 2002).

TABLE 4-3: PFC Emission Factors

Type of Cell	Emission Factors					
	(kg PFC/t Al)					
	1990–1993		1994–1997		1998–2000	
	CF_4	C_2F_6	CF_4	C_2F_6	CF_4	C_2F_6
Centre Worked Pre-Baked	0.4	0.068	0.3	0.051	0.2	0.034
Side Worked Pre-Baked	1.4	0.336	1.4	0.336	1.4	0.336
Vertical Stud Søderberg	0.6	0.036	0.5	0.03	0.4	0.024
Horizontal Stud Søderberg	0.7	0.063	0.6	0.054	0.6	0.054

According to the methodology documents supplied by the AAC, SF_6 emissions are equal to consumption in the aluminium industry. This method is consistent with the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA, 1997). SF_6 emission estimates for Alcan's smelters were not provided for the years 1991–1994 and 1996–1999 due to data unavailability. To complete the time series, it was assumed that SF_6 emissions for 1991–1994 stayed constant at the 1990 and 1995 levels. For 1996–1999, linear interpolation between the provided 1995 and 2000 data was applied.

It should be noted that the use of petroleum coke in anodes for the production of aluminium was also reported by Statistics Canada with all other non-energy uses of petroleum coke. The CO_2 emissions from the consumption of anodes in the aluminium smelting process were therefore subtracted from the total non-energy emissions associated with the consumption of petroleum coke, to avoid double-counting.

4.7.3 UNCERTAINTIES AND TIME-SERIES CONSISTENCY

The uncertainties in CO_2 and PFC emission estimates for aluminium production provided in the ICF (2004) report are not applicable to the 2004 inventory year estimates due to the change in methodology from Tier 1, at the time when the ICF study was conducted, to Tier 3, for recent years of the time series. Emission data coming directly from the AAC, which are included in this year's submission, are believed to be significantly more accurate than the estimates shown in the 1990–2001 inventory report. Moreover, as estimates of SF_6 emissions from aluminium production were not included in the 1990–2001 inventory, uncertainties around these were not examined by ICF (2004). An updated uncertainty analysis would be necessary in order to determine the range of uncertainty around the reported CO_2, PFC, and SF_6 values (also see Section 4.7.6, Category-Specific Planned Improvements).

The AAC has consistently been used as the data source of estimates shown in this inventory over the time series. The methodology applied by smelters may be Tier 3–, Tier 2–, or Tier 1–type, depending on data availability. However, for recent years, a Tier 3–type technique has been applied by all smelters for estimating emissions.

4.7.4 CATEGORY-SPECIFIC QA/QC AND VERIFICATION

CO_2 and PFC emissions from aluminium production are key categories that have gone through Tier 1 QC checks as elaborated in the *Framework for a Quality Assurance and Quality Control Plan* (SNC Lavalin, 2004). The checks performed are consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC, 2000). No issues of importance were detected from the Tier 1 QC process.

4.7.5 CATEGORY-SPECIFIC RECALCULATIONS

For this inventory, all companies have provided revised 1990–2003 plant-specific CO_2 and PFC emission data.

According to the AAC, emissions were recalculated due to an update to the plant-specific coefficient values applied in the methods described above. Acquisition of new data has resulted in a change of approximately −1.0% to +19.2% in the PFC emissions over the period of 1990–2003. CO_2 emissions for the same period have also slightly varied by −0.03% to +6%.

4.7.6 CATEGORY-SPECIFIC PLANNED IMPROVEMENTS

There are currently no improvements planned specifically for estimating CO_2, PFC, and SF_6 emissions from aluminium production in Canada. However, attempts to obtain, through expert elicitation, uncertainty values around the emission estimates provided by the AAC will be made. Efforts will also be made to acquire more information on the QC procedures followed by member companies when estimates were developed.

In previous inventories, the addition of SF_6 emissions was only considered as a potential improvement for this sector, but no estimates were included. The SF_6 emissions, which simply equal consumption, are now part of the inventory. Details on the estimation methodology are provided above.

4.8 MAGNESIUM METAL PRODUCTION AND CASTING (CRF CATEGORIES 2.C.4 & 2.C.5)

4.8.1 SOURCE CATEGORY DESCRIPTION

SF_6 is emitted during magnesium production and casting, where it is used as a cover gas to prevent oxidation of the molten metals. Although emitted in relatively small quantities, SF_6 is an extremely potent GHG, with a 100-year GWP of 23 900. SF_6 is not manufactured in Canada. All SF_6 is imported.

In 2004, there were only two magnesium producers in Canada: Norsk Hydro and Timminco Metals. Norsk Hydro has improved its production technologies to minimize the consumption of SF_6, while production has increased over the same period. Métallurgie Magnola has been shut down since April 2003.

There were 11 known magnesium casting facilities in operation during the period 1990–2004 (Cheminfo Services, 2005). Only a few of them have used SF_6 every year during the entire period. Some casters started using SF_6 towards the mid- or late 1990s, while others have replaced it with an alternative gas, such as SO_2. Two facilities have ceased their casting operations over the last few years. In 2004, only seven facilities still used SF_6.

4.8.2 METHODOLOGICAL ISSUES

For SF_6 emissions from magnesium production, data for 1999–2003 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). For previous years, the data were provided voluntarily by the producers over the telephone.

The technique applied to estimate emissions from magnesium production is considered to be a Tier 3–type method, as it is based on the reporting of facility-specific emission data.

For calculating SF_6 emissions, the IPCC Guidelines (IPCC/OECD/IEA, 1997) provide one general equation that assumes that all SF_6 used as a cover gas is emitted to the atmosphere. To apply this equation, attempts have been made to collect 1990–2004 data on SF_6 consumption from casting facilities. A couple of facilities have indicated that they do not hold any historical records of their past SF_6 consumption. Therefore, to estimate SF_6 use for the entire time series, results of a previous study (Cheminfo Services, 2002) were used in combination with the data received from the 2005 study (Cheminfo Services, 2005).

For casters that have SF_6 data for only a year, it was assumed that their SF_6 use stayed constant, during the other operating years, at the level of the year for which the actual SF_6 data were obtained. For casters that have data for more than one year, linear interpolation between two data points was applied to estimate SF_6 consumption for the other years.

The technique applied to estimate emissions from magnesium casting is considered to be a modified Tier 3–type method, as it is based on the reporting of facility-specific emission data and some assumptions.

4.8.3 UNCERTAINTIES AND TIME-SERIES CONSISTENCY

The uncertainty in the SF_6 emission estimate for magnesium production, provided in the ICF (2004) report, was evaluated at ±1%. It is applicable to the 2004 estimate because there has been no change in the data source since the ICF study was completed.

For the subsector of magnesium production, the methodology and data sources remain consistent over the time series. Emissions from two primary magnesium smelters, Norsk Hydro and Timminco, have been reported directly to Environment Canada since 1990. Estimates of SF_6 emissions from all three smelters, including Magnola, which started up in 2000 and shut down in 2003, have been submitted to the NPRI since 1999.

According to the Cheminfo Services (2005) study, the SF_6 emission estimate for magnesium casters has an uncertainty of 4%. This is a weighted average, depending on each company's consumption of SF_6 and the overall data availability. The uncertainty estimate is applicable to the 2004 estimate because there has been no change in the data source since the Cheminfo study was completed.

The data source remains consistent over the time series. The methodology, which is equating consumption of SF_6 as a cover gas by magnesium casters to emissions of SF_6, is applied over the time series with some assumptions, as discussed in the methodology section.

4.8.4 CATEGORY-SPECIFIC QA/QC AND VERIFICATION

Magnesium production is a key category that has undergone for this submission Tier 1 QC checks as elaborated in the *Framework for a Quality Assurance and Quality Control Plan* (SNC Lavalin, 2004). The checks performed are consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC, 2000). No issues of importance were detected from the Tier 1 QC process.

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

4.8.5 CATEGORY-SPECIFIC RECALCULATIONS

There have been no recalculations of SF_6 emissions related to magnesium production.

Only a few questionnaires filled in by casting facilities were received and used in the previous inventory. More completed questionnaires have been received since the last inventory submission. As a result of the acquisition of more reported data on SF_6 use, recalculations of the 1990–2003 emissions have been done. These estimates have changed by about −3.4% to +74% as compared with the ones shown in the previous inventory.

4.8.6 CATEGORY-SPECIFIC PLANNED IMPROVEMENTS

There are currently no improvements planned specifically for estimating SF_6 emissions from magnesium production and casting in Canada.

4.9 PRODUCTION AND CONSUMPTION OF HALOCARBONS (CRF CATEGORIES 2.E & 2.F)

4.9.1 SOURCE CATEGORY DESCRIPTION

Since HFCs were not widely used before the ban on the production and use of CFCs came into effect in 1996 (as a result of the Montreal Protocol), emissions from HFC consumption were considered negligible for the period 1990–1994. CFCs are GHGs that are not included under the UNFCCC because they are already controlled under the Montreal Protocol. As a result, CFCs are not inventoried herein. AC equipment and refrigeration equipment represent the primary sources of HFC emissions. There is no known production of HFCs/PFCs in Canada.

Emissions from the consumption of PFCs are minor relative to the by-product emissions of PFCs from aluminium production. PFC emissions from aluminium production are discussed in Section 4.7 on Aluminium Production. All HFCs/PFCs consumed in Canada are imported in bulk or in products (e.g., refrigerators).

4.9.2 METHODOLOGICAL ISSUES

HFC emission estimates for 1995 were based on data gathered from an initial HFC survey conducted by the Chemical Controls Division of Environment Canada in 1996. Environment Canada has revised subsequent surveys to obtain more detailed activity data. The 1998, 1999, and 2001 HFC surveys were the source of activity data for emission estimates for the years 1996–2000. In some cases, one survey was done to collect data for two years. HFC sales data for 2001–2003 were also collected in 2005 from major HFC importers in Canada (Cheminfo Services, 2005). These data were provided by market segment, such that the total quantity used for each type of application could be determined. Since HFC data for 2004 were not available, it was assumed that the 2004 HFC consumption stayed at the 2003 levels. However, it should be noted that the assumption of constant HFC use would not mean constancy of HFC emissions, as the Tier 2 method of estimation is used for calculating HFC emissions in 2004. This method considers the HFC stock levels as the basis for emissions (see Section 4.9.2.2 below).

In addition, data on the quantities of HFCs contained in imported and exported products, except imported and exported vehicles, were not available for the years 1995 and 1999–2004. The 1999 and 2000 amounts of HFC found in imported and exported vehicles were provided by the Chemical Controls Division. For 1995, HFC quantities in imported and exported products were assumed to be zero. For 1999–2004, these quantities were assumed to stay at 1998 levels and at the 2000 level for imported/exported vehicles.

Detailed 1995 HFC data were not available, so an IPCC Tier 2 estimate could not be applied. Instead, a modified Tier 1 methodology was used to obtain a representative estimate of the actual 1995 HFC emissions for the following groups: Aerosols; Foams; AC Original Equipment Manufacture; AC Service; Refrigeration; and Total Flooding System. To estimate 1996–2004 HFC emissions, an IPCC Tier 2 methodology was applied.

The IPCC Tier 2 methodology was used to estimate emissions from the consumption of PFCs for the years 1995–2004. 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 based on the assumption that the use quantities in various applications stayed constant since 2000.

4.9.2.1 1995 HFC Emission Estimates for Refrigeration and Air Conditioning

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

AC Original Equipment Manufacture

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

AC Service

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

Refrigeration

It was assumed that all refrigeration in Canada falls under the IPCC other (i.e., commercial and industrial) category, since this was the dominant emission source. It was further assumed that refrigeration HFCs represented those used for initial and subsequent recharging of equipment. Therefore:

Equation 4-8:

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:

$$\text{HFC (refrig)} = \text{Charge} + 0.17(\text{Charge}) = 1.17(\text{Charge})$$

or

$$\text{Charge} = \text{HFC (refrig)}/1.17$$

Assuming assembly leakage was minimal:

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

Thus,

Equation 4-9:

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

4.9.2.2 1995–2004 HFC/PFC Emission Estimates: Emission Factors and Assumptions

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

System Assembly

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

Equation 4-10:

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

where:

$E_{\text{assembly, t}}$ = emissions during system manufacture and assembly in year t

$E_{\text{charged, t}}$ = quantity of refrigerant charged into new systems in year t

k = assembly losses in percentage of the quantity charged

The k value was chosen from a range of values that were provided for each equipment category in the IPCC Guidelines (IPCC/OECD/IEA, 1997) (see Table 4-4).

TABLE 4-4: Equipment Categories and k Values

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

Annual Leakage

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

Equation 4-11:

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

where:

$E_{\text{operation, t}}$ = quantity of HFCs/PFCs emitted during system operations in year t

$E_{\text{stock, t}}$ = quantity of HFCs/PFCs stocked in existing systems in year t

x = annual leakage rate in percentage of total HFC/PFC charge in the stock

The amount of HFCs/PFCs stocked in existing systems includes the HFCs/PFCs in equipment manufactured in Canada, the amount of HFCs/PFCs in imported equipment, and the amount of HFCs in converted CFC equipment and excludes the amount of HFCs/PFCs in exported equipment. The amount of HFCs used in converted CFC equipment was estimated based on the amount of HFCs used for servicing equipment. It was assumed that no leakage occurred in the year of manufacturing or conversion. The IPCC Guidelines (IPCC/OECD/IEA, 1997) give a range of values for the annual leakage rate (x) for each of the different equipment categories. The annual leakage rate chosen for each category is shown in Table 4-5 (IPCC/OECD/IEA, 1997).

TABLE 4-5: Annual Leakage Rate (x)

Equipment Category	x Values (%)
Residential Refrigeration	1.0
Commercial Refrigeration	17.0
Stationary Air Conditioning	17.0
Mobile Air Conditioning	15.0

System Disposal

It was assumed that there were no HFC/PFC emissions from system disposal during 1995–2004, since refrigeration and AC systems have a lifetime of 12–15 years and HFC use began only in 1995.

Foam Blowing

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

The IPCC Tier 2 methodology presented in the IPCC Guidelines (IPCC/OECD/IEA, 1997) was used to estimate HFC and PFC emissions from foam blowing from 1996 onward. Foams are grouped into two main categories: open cell and closed cell.

■ Open Cell Foam Blowing

In the production of open cell foam, 100% of the HFCs used are emitted (IPCC/OECD/IEA, 1997). At present, there is no known PFC use in open cell foam blowing. Open cell foam production categories that release HFC emissions include:

- Cushioning — Automobiles;
- Cushioning — Others;
- Packaging — Food;
- Packaging — Others; and
- Other Foam Uses.

■ Closed Cell Foam Blowing

During the production of closed cell foam, approximately 10% of the HFCs/PFCs used are emitted (IPCC/OECD/IEA, 1997). The remaining quantity of HFCs/PFCs is trapped in the foam and is emitted slowly over a period of approximately 20 years. The IPCC Tier 2 equation (as shown below) was used to calculate emissions from closed cell foam:

Equation 4-12:

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

where:

$E_{\text{foam, t}}$ = emissions from closed cell foam in year t

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

$E_{\text{original charge}}$ = original charge blown into the foam

The following are closed cell foam production categories that emit HFC emissions:

- Thermal Insulation — Home and Building;
- Thermal Insulation — Pipe;
- Thermal Insulation — Refrigerator and Freezer; and
- Thermal Insulation — Other.

Fire Extinguishers

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

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

■ Portable Fire-Extinguishing Equipment

The IPCC Tier 2 methodology in the IPCC Guidelines (IPCC/OECD/IEA, 1997) estimated emissions as 60% of HFCs used in newly installed equipment.

■ Total Flooding Systems

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

Aerosols/Metered Dose Inhalers

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

The IPCC Tier 2 methodology presented in the IPCC Guidelines (IPCC/OECD/IEA, 1997) was used to calculate HFC emissions from aerosols from 1996 onward. The emission estimate for the current year is equal to half of the HFCs used in aerosols in the current year plus half of the HFCs used in aerosols in the previous year. The amount of HFCs used each year is equal to the amount of HFCs used to produce aerosols and the amount of HFCs in imported aerosol products and excludes the amount of HFCs in exported aerosol products.

Since no data on PFC used in aerosols were gathered from Environment Canada's PFC surveys, it was assumed that PFC emissions coming from its use in aerosols were negligible.

Solvents

The IPCC Tier 2 methodology presented in the IPCC Guidelines (IPCC/OECD/IEA, 1997) was used to estimate HFC and PFC emissions from solvents. The emission estimate for the current year is equal to half of the HFCs/PFCs used as solvents in the current year plus half of the HFCs/PFCs used as solvents in the previous year. The amount of HFCs/PFCs used each year is equal to the amount of HFCs/PFCs produced and imported as solvents and excludes the amount of HFCs/PFCs exported as solvents. HFCs/PFCs used as solvents include the following categories:

- electronics industries;
- laboratory solvents; and
- general cleaning.

Semiconductor Manufacture

There are two main uses of PFCs in the semiconductor manufacturing industry: plasma etching of silicon wafers and plasma cleaning of chemical vapour deposition chambers.

IPCC Tier 2b methodology, as shown below, was used to estimate PFC emissions from the semiconductor manufacturing industry.

Equation 4-13:

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

where:

E_{SC} = total PFC emissions from semiconductor

E_{FC} = emissions resulting from the use of PFCs (see below)

E_{CF_4} = CF_4 emitted as a by-product during the use of PFCs (see below)

Equation 4-14:

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

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 4-15:

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

where:

$B_{i,p}$ = fraction of gas i transformed into CF_4 for each process type p

and other terms are as defined above.

Different default values for variables used in equations above are shown in Table 4-6 (IPCC, 2000).

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

TABLE 4-6: PFC Emission Rates[1]

Process	IPCC Default Emission Fractions			
	CF_4	C_2F_6	C_3F_8	$c\text{-}C_4F_8$
(1-C) Plasma Etching	0.7	0.4	0.4	0.3
(1-C) Chemical Vapour Deposition Chamber	0.8	0.7	0.4	ND
B Plasma Etching	N/A	0.1	ND	N/A
B Chemical Vapour Deposition Chamber	N/A	0.1	0.2	N/A

Notes:

1 Tier 2b, from IPCC (2000).

N/A = not applicable

ND = no data available

As no information on emission control technologies for these processes was available, $a_{i,p}$ was assumed to equal 0 and $d_{i,p}$ to equal 1. Also, h was assumed to equal 0.1, as suggested in IPCC (2000).

Other Sources

Minor amounts of PFC emissions have been identified as related to its use in the electronics industry for emissive applications, including reliability testing (inert liquids), coolants (direct evaporative cooling for electric and electronic apparatuses and indirect coolants in closed circuit electronic apparatuses), and precision cleaning (IPCC, 2000). More specifically, these emissions can come from two types of sources: emissive and contained.

Emissive sources include the following:

- electrical environmental testing;
- gross leak testing; and
- thermal shock testing.

Unidentified and miscellaneous PFC uses reported in the PFC survey were also considered as part of emissive sources. According to the IPCC Tier 2 methodology, 50% of PFCs used for the above purposes would be released during the first year and the remaining 50% released in the following year.

Contained sources consist of PFC use as an electronic insulator and a dielectric coolant for heat transfer in the electronics industry. The IPCC Tier 2 emission factors (IPCC, 2000) are applied to the PFC use data obtained from the PFC survey to estimate PFC emissions from contained sources, as follows:

Equation 4-16:

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

where:

$E_{\text{contained}, t}$ = emissions from contained sources
$E_{\text{consumed}, t}$ = quantity of PFC sale for use or manufacturing of contained sources in year t
$E_{\text{stock}, t}$ = quantity of PFCs in stock in year t
k = manufacturing emission rate (1% of annual sales)
x = leakage rate (2% of stock)
d = disposal emission factor (5% of annual sales)

4.9.3 UNCERTAINTIES AND TIME-SERIES CONSISTENCY

The uncertainty in the HFC emission estimate, provided in the ICF (2004) report, was estimated to be within the range of –21% to +55%. The ICF (2004) report stated that since the uncertainty models for consumption of halocarbons as well as the uncertainty assessment of input data were done with several assumptions, the uncertainty estimates developed for this subsector should be considered preliminary.

By and large, the uncertainty range corresponds to a highly conservative estimate for the total 2004 HFC emissions. Improvements made for estimating "E_{stock}" (in Equations 4-4 and 4-5) and acquisition of more recent consumption data are believed to have brought down the uncertainty around the HFC emission estimate. To assess the quantitative impact that these changes have on the uncertainty range, an updated detailed analysis needs to be conducted. Possible sources of uncertainty for this category are i) the IPCC default emission rates, which may not be totally applicable to a Canadian context, and ii) data on HFC quantities found in imported/exported products.

An uncertainty range of –28% to +70% was reported in the ICF (2004) study for the 2001 PFC emission estimate. This uncertainty range is considered to be conservative for the 2004 emission estimate because this estimate was developed based on more recent consumption data.

For both HFC and PFC emissions from this subsector, the IPCC default emission rates have been consistently applied over the time series. The source for PFC consumption data was surveys conducted by the Chemical Controls Division of Environment Canada. Both surveys conducted by the Chemical Controls Division and the 2005 Cheminfo Services study were data sources for HFC emission estimates.

4.9.4 CATEGORY-SPECIFIC QA/QC AND VERIFICATION

Consumption of halocarbons resulting in HFC emissions is a key category that has undergone for this submission Tier 1 QC checks as elaborated in the *Framework for a Quality Assurance and Quality Control Plan* (SNC Lavalin, 2004). The checks performed are consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC, 2000).

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

4.9.5 CATEGORY-SPECIFIC RECALCULATIONS

HFC emissions for 1996–2000 were recalculated because corrections were made to the activity data used for estimating emissions from fire extinguishers. These adjustments resulted in emission estimate changes ranging from –3.1% to +4%. As opposed to the previous inventory, in which 2001–2003 emission estimates had been assumed to stay constant at the 2000 level, this inventory used activity data gathered from the 2005 Cheminfo Services study to recalculate emissions for this period. The acquisition of new data brought about increases in emissions during 2001–2003 that vary between 14.8% and 41.4%.

The 1995–1997 PFC emissions were recalculated, since corrections were made to the methods used for estimating PFC emissions from various end uses. These adjustments caused changes in the emission estimates of around −3.5% to −2.2%. The 1998–2003 emissions were also reestimated based on more recent (1998–2000) data obtained from the Chemical Controls Division. Details on how the data were used and the assumptions made are found in the Methodological Issues section above (Section 4.9.2).

4.9.6 CATEGORY-SPECIFIC PLANNED IMPROVEMENTS

Efforts will be made to obtain the 2004 HFC survey data and more recent data on PFCs and HFCs in imported/exported products.

4.10 PRODUCTION AND CONSUMPTION OF SF_6 (CRF CATEGORIES 2.E & 2.F)

4.10.1 SOURCE CATEGORY DESCRIPTION

There is currently no production of SF_6 in Canada; therefore, all Canadian supply of SF_6 is obtained through imports. From 1990 to 1996, SF_6 imports from the United States comprised more than 95% of total imports; however, in recent years, this percentage has declined, with an increase in SF_6 imports from Germany (Cheminfo Services, 2002).

In addition to magnesium production and casting, electrical equipment in utilities and semiconductors are known sources of SF_6 emissions. In electric utilities, SF_6 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.

4.10.2 METHODOLOGICAL ISSUES

The method used for estimating SF_6 emissions from electrical equipment in utilities was a top-down approach, assuming that all SF_6 purchased from gas distributors replaces SF_6 lost through leakage.

In a study conducted by Cheminfo Services (2002) to review and assess potential SF_6 emission sources in Canada, several Canadian utilities reported that new equipment is typically delivered with a few cylinders of SF_6 supplied for charging by the original equipment manufacturer (OEM). This implies that the amount of SF_6 purchased from OEMs can be small compared with the quantity bought from gas distributors. Hence, it is assumed that 100% of the SF_6 sales from gas distributors to utilities are used to refill leaking equipment and that SF_6 supplied by OEMs is added to new stock and not emitted.

This method would be considered a modified Tier 1 method because it follows the Tier 1 logic in assuming that all of the SF_6 purchased from gas distributors goes to replace SF_6 lost through leakage. However, it would be considered as “modified” because it focuses only on gas distributor SF_6 sales (Cheminfo Services, 2005).

Gas distributors have been requested to submit their annual SF_6 sales data by market segment so that this modified Tier 1 method can be applied. However, only sales data for 1995–2000 inclusively were collected. Alternative approaches were applied to estimate SF_6 sales for the other years of the time series. For example, a backcast from 1995 data on global SF_6 sales to the utilities market segment has been done to estimate 1990–1994 sales. The 2001–2004 sales estimates were based on data on imports obtained from Statistics Canada and the use of SF_6 in other sectors (Cheminfo Services, 2005).

Similar to the case of electrical equipment, SF_6 emissions from semiconductors were estimated based on sales data, and it was assumed that the quantities sold by gas distributors were equal to the amount that had been emitted. This top-down approach would be considered as a Tier 1–type method. Since only 1995–2000 sales data were obtained from major Canadian gas suppliers, it was assumed that the quantity sold per year in 1990–1994 was at the 1995 level. The sales per year for 2001–2004 were assumed to be the average value between 1995 and 2000 (Cheminfo Services, 2005).

4.10.3 UNCERTAINTIES AND TIME-SERIES CONSISTENCY

The 2005 Cheminfo Services study provides an uncertainty range of −50% to +19% for the SF_6 emission estimate for electrical equipment. The uncertainty can generally be explained by the drawbacks that the current methodology may have. For example, not all SF_6 purchased from a gas distributor is used in its entirety, and oversupplied SF_6 cylinders could be returned to the distributors (Cheminfo Services, 2005); however, the methodology assumes that SF_6 emissions in a year are equal to the SF_6 sales in that year. Nevertheless, it is recognized that given the current lack of electricity release data, this approach would be the simplest method for estimating SF_6 emissions until SF_6 emission data reported by utilities, through the Canadian Electricity Association's (CEA) Environmental Commitment and Responsibilities program, become available to the Greenhouse Gas Division.

Uncertainty in the SF_6 emission estimate for semiconductor manufacturing has not been assessed. However, since the method used to calculate SF_6 emissions from semiconductor manufacturing is similar to that used for electrical equipment, the uncertainty sources for both categories should be comparable.

The data source and methodology used (for both electrical equipment and semiconductor manufacturing) are consistent over the time series.

4.10.4 CATEGORY-SPECIFIC QA/QC AND VERIFICATION

SF_6 consumption in electrical equipment is a key category that has undergone for this submission Tier 1 QC checks as elaborated in the *Framework for a Quality Assurance and Quality Control Plan* (SNC Lavalin, 2004). The checks performed are consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC, 2000).

Informal QC checks have been done for the category of SF_6 use in semiconductor manufacturing.

4.10.5 CATEGORY-SPECIFIC RECALCULATIONS

The 1990–2003 emissions arising from consumption of SF_6 were recalculated due to addition of semiconductors as a new SF_6 emission source. The impact of including the new source was emission growth of around 2–3% for this category during 1990–2003.

4.10.6 CATEGORY-SPECIFIC PLANNED IMPROVEMENTS

As a planned improvement, the possibility of getting the SF_6 purchase data directly from member companies of the CEA is being examined.

4.11 OTHER AND UNDIFFERENTIATED PRODUCTION (CRF CATEGORY 2.G)

4.11.1 SOURCE CATEGORY DESCRIPTION

Emissions from this subsector are from the non-energy use of fossil fuels and are not accounted for under any of the other subsectors of Industrial Processes. Examples of fuels in non-energy applications are the use of NGLs and feedstocks in the chemicals industry and the use of lubricants. All of them result in varying degrees of oxidation of the fuel, producing CO_2 emissions.

The use of fossil fuels as feedstock or for other non-energy uses is reported in an aggregated manner by Statistics Canada (#57-003) under "Non-Energy Use" for each individual fuel. In the event that CO_2 emissions resulting from non-energy fuel use are allocated to another category of the Industrial Processes Sector (as is the case for ammonia production and aluminium production), those emissions are subtracted from the total non-energy emissions to avoid double-counting.

4.11.2 METHODOLOGICAL ISSUES

General emission rates for non-energy use of fuels, expressed as grams of CO_2 emitted per unit of fossil fuel used as feedstock or non-energy product, were developed based on the total potential CO_2 emission rates and the IPCC default percentages of carbon stored in products. The potential CO_2 emission rates were derived from the carbon emission factors shown in the McCann (2000) study.

Fuel quantity data for non-energy fuel usage were reported by the RESD (Statistics Canada, #57-003). It should be noted that the RESD data for any given year are preliminary and subject to revisions in subsequent publications. These data were multiplied by the emission rates mentioned above (also shown in Annex 13) to estimate CO_2 emissions for this subsector.

This technique is considered to be a Tier 1–type method, as it is based on the use of national consumption data and average national emission factors. Methodological issues for calculating CO_2 emissions from the non-energy use of fossil fuels are not addressed specifically in the IPCC Good Practice Guidance (IPCC, 2000).

Further details with respect to the calculation method used are provided in Section A3.2 of Annex 3.

4.11.3 UNCERTAINTIES AND TIME-SERIES CONSISTENCY

An uncertainty range of –40% to +1% reported in the ICF (2004) study for estimates of CO_2 emissions from non-energy use of fuels is generally applicable to the 2004 estimate, because there has been no change in the methodology and data source used since the ICF study was completed. The uncertainty range implies that emissions from this category are likely to be overestimated. It also seems to reflect the predominant influence of the uncertainty associated with i) the emission factor for petroleum coke and ii) the CO_2 emissions from ammonia production (ICF, 2004).

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

4.11.4 CATEGORY-SPECIFIC QA/QC AND VERIFICATION

Other and undifferentiated production is a key category that has undergone for this submission Tier 1 QC checks as elaborated in the *Framework for a Quality Assurance and Quality Control Plan* (SNC Lavalin, 2004). The checks performed are consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC, 2000).

4.11.5 CATEGORY-SPECIFIC RECALCULATIONS

The 1990–2003 emissions have been recalculated, since emissions coming from the use of natural gas to produce hydrogen in oil refining and oil sands upgrading (reported as natural gas transformed to refined products and natural gas inter-product transfer, respectively, in the RESD), which used to be accounted for in this subsection, are reported under the Energy Sector of this inventory. As a result of this emission reallocation, the overall emissions from this category decreased by 22% to 8% when comparing last year's 1990–2003 estimates with this year's.

4.11.6 CATEGORY-SPECIFIC PLANNED IMPROVEMENTS

There are currently plans to apply a Tier 2–type methodology to estimate emissions arising from non-energy-related use of hydrocarbons in future inventories. This may become possible with the use of industrial consumption of energy data obtained from Statistics Canada and application-specific emission factors from a research study under way.

5 SOLVENT AND OTHER PRODUCT USE (CRF SECTOR 3)

5.1 OVERVIEW

One distinction between the sources in the Solvent and Other Product Use Sector and those in the Industrial Processes Sector is that the former are generally area sources.

Emissions in this sector are related to the use of N_2O as an anaesthetic and propellant. Emissions from paint application, degreasing, dry cleaning, and chemical products manufacture and processing are not estimated.

5.2 N_2O FROM ANAESTHETICS AND PROPELLANTS

5.2.1 SOURCE CATEGORY DESCRIPTION

N_2O is used in medical applications, primarily as a carrier gas but also as an anaesthetic in various dental and veterinary applications. It has been assumed that all of the N_2O used for anaesthetics will eventually be released to the atmosphere.

N_2O is also used as a propellant for pressure and aerosol products, primarily in the food industry. The largest application is for pressure-packaged whipped cream as well as other dairy products. Applications outside of the food industry include the cosmetic industry and the use as a substitute for Freon or hydrocarbons, such as butane and isobutane.

5.2.2 METHODOLOGICAL ISSUES

Based on the 1990 population statistics and the N_2O consumption patterns in medical applications (Fettes, 1994), an emission factor of 46.2 g N_2O per capita was developed for estimating N_2O emissions from its use as an anaesthetic. This factor is slightly lower than the one developed for the United States.

For N_2O used as a propellant, an emission factor of 2.38 g N_2O per capita was derived based on consumption patterns in Canada in 1990. It was assumed that all the N_2O used in propellants was emitted to the atmosphere during the year of sale.

The annual population statistics from Statistics Canada's publication #91-213 were multiplied by each of the emission factors to estimate N_2O emissions for this sector.

5.2.3 UNCERTAINTIES AND TIME-SERIES CONSISTENCY

The uncertainty associated with the 2001 emission estimate for this sector was estimated to be within the range of –23% to +22% (ICF, 2004). As the methodology and data source have not changed since the completion of the ICF study, this is applicable to the 2003 inventory estimate. It can primarily be attributed to the uncertainty around the emission factors.

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

5.2.4 QA/QC AND VERIFICATION

Informal QC checks, such as double-checking calculations and checking population data and emission estimates against the ones of previous years, have been done.

5.2.5 RECALCULATIONS

Recalculations were conducted for 2002–2003 based on revised demographic statistics provided by Statistics Canada.

5.2.6 PLANNED IMPROVEMENTS

As the uncertainty around the emission factors seems to have caused uncertainty in the emission estimates, the possibility of updating the emission factors is being investigated as part of an ongoing study. This study also has as an objective an assessment of whether there are other sources emitting significant amounts of GHGs that should be accounted for in this sector. Any major findings will be included in future inventories.

6 AGRICULTURE (CRF SECTOR 4)

6.1 OVERVIEW

Emission sources from agriculture include CH_4 and N_2O emissions from animal production — namely, enteric fermentation and manure management — and N_2O released from agricultural soils. CO_2 emissions from and removals by croplands are reported under the LULUCF Sector under the Cropland Remaining Cropland category (see Chapter 7).

A number of changes have been introduced this year in the inventory for this sector to take into account method and data improvements. First, inventory methodologies for enteric fermentation and manure management of dairy cattle have been modified to derive a time series of emission factors that reflect changes in milk production over time using the IPCC Tier 2 approach. Secondly, CH_4 emission factors for dairy and non-dairy cattle have been modified using gross energy intake following the IPCC Good Practice Guidance (IPCC, 2000) as well as updates of maximum CH_4 producing potential (B_0) and CH_4 conversion factors (MCFs) in the 2006 IPCC Guidelines (IPCC, 2006). Thirdly, manure nitrogen excretion rates for various livestock categories have been revised based on the 2006 IPCC Guidelines (IPCC, 2006). Finally, methodologies for estimating direct and indirect N_2O emissions from agricultural soils have been upgraded from IPCC Tier 1 to IPCC Tier 2 as required for key categories. Some animal population accounts have been revised based on most recent updates from Statistics Canada. All these changes have resulted in recalculations, explained in more detail below. In addition, biological nitrogen (N_2) fixation by the legume–rhizobium association is no longer included in this inventory. This decision is supported by the conclusion of Rochette and Janzen (2005) (and reflected in the 2006 IPCC Guidelines) that there is no evidence that measurable amounts of N_2O are produced during the nitrogen fixation process. Therefore, Canada decided to report this source as "not occurring." However, the contribution of legume nitrogen to N_2O emissions is included from crop residue decomposition on agricultural soils.

Some minor GHG sources are not included. CH_4 emissions from rice production in Canada are considered to be negligible and are not inventoried. Similarly, field burning of agricultural residues is not considered a common practice in Canadian agriculture and is therefore not estimated. Prescribed burning of savannas is not a relevant practice in Canada. GHG emissions from on-farm fuel combustion are included in the Energy Sector (Chapter 3).

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

Total GHG emissions from the Canadian Agriculture Sector were 45 Mt in 1990, 53 Mt in 2003, and 55 Mt in 2004 (Table 6-1). This represents an increase of approximately 23% between 1990 and 2004, mainly resulting from the expansion in the beef cattle, swine, and poultry industry as well as an increase in synthetic nitrogen fertilizer consumption.

There was a significant increase in emissions of nearly 2.4 Mt between 2003 and 2004. Most of this increase in emissions resulted from enteric fermentation, manure applied as fertilizers to cropland, manure on pasture, and AWMS, primarily because of a significant increase in beef cattle population over that period (+8%).

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

GHG Source Category		GHG Emissions		
		kt CO_2 eq		
		1990	**2003**	**2004**
Agriculture TOTAL		**45 000**	**53 000**	**55 000**
Enteric Fermentation		*18 400*	*22 600*	*24 000*
— CH_4	Dairy Cattle	3 360	3 010	3 010
	Beef Cattle	14 400	18 600	20 000
	Others	640	1 010	1 010
Manure Management		*6 700*	*8 100*	*8 400*
— CH_4	Dairy Cattle	740	660	660
	Beef Cattle	670	790	830
	Swine	1 100	1 600	1 500
	Poultry	70	90	90
	Others	20	20	40
— N_2O	All Animal Types	4 100	5 000	5 300
Agricultural Soils		*20 000*	*22 000*	*22 000*
Direct Sources (N_2O)		11 000	11 000	12 000
	Synthetic Nitrogen Fertilizers	4 800	5 800	5 800
	Manure Applied as Fertilizers	1 900	2 100	2 100
	Crop Residue Decomposition	3 800	3 600	3 800
	Cultivation of Organic Soils	60	60	60
	Conservation Tillage[1]	–220	–580	–630
	Summerfallow	730	440	430
Pasture, Range, and Paddock Manure (N_2O)		3 200	4 000	4 300
Indirect Sources (N_2O)		6 000	6 000	7 000

Notes:

[1] The negative values reflect a reduced N_2O emission due to the adoption of conservation tillage.

Totals may not add due to rounding.

6.2 ENTERIC FERMENTATION (CRF CATEGORY 4.A)

6.2.1 SOURCE CATEGORY DESCRIPTION

Large quantities of CH_4 are produced from herbivores through a process called enteric fermentation.

During the normal digestive process, microorganisms break down carbohydrates into simple molecules for absorption into the bloodstream, where CH_4 is produced as a by-product. This process results in CH_4 in the rumen, which is emitted by eructation and exhalation. Some CH_4 is released later in the digestive process by flatulation. Ruminant animals, such as cattle, generate the most CH_4.

6.2.2 METHODOLOGICAL ISSUES

CH_4 emissions from enteric fermentation of cattle are estimated using the IPCC Tier 2 methodology. Emission factors for various cattle categories were determined following the guidance provided by IPCC (2000) and based on a study by Boadi *et al*. (2004). To achieve this, it was necessary to characterize the cattle population according to animal type, physiological status, age, sex, weight, rate of gain, level of activity, and production environment. Much of this information was not available in the published literature and required contact with beef and dairy cattle specialists across the country. In addition, milk productivity and milk fat data were factored into the method to derive a time series of emission factors for dairy cattle, reflecting the fact that CH_4 production increases with milk productivity.

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

For non-cattle categories, CH_4 emissions from enteric fermentation continue to be estimated using IPCC Tier 1 methodology. Poultry are excluded from enteric fermentation estimates, since no emission factors are available from the IPCC Guidelines (IPCC/OECD/IEA, 1997). CH_4 emissions are calculated for each animal category by multiplying the animal population by the emission factor associated with the specific animal category.

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

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

Category	Sources/Notes
Cattle	
Dairy Cattle	Dairy cows
Non-Dairy Cattle	All other cattle Data source: Statistics Canada (#23-012)
Bison	Data from the 1996 and 2001 farm census (Statistics Canada #93356 and #95F0301) have been used to derive the 1990–2004 time series.
Sheep and Lambs	Data source: Statistics Canada (#23-011)
Goats	Data from the 1991, 1996, and 2001 farm census (Statistics Canada #93350, #93356, and #95F0301) have been used.
Camels and Llamas	Considered a negligible source in Canada
Horses	Data from the 1991, 1996, and 2001 farm census (Statistics Canada #93350, #93356, and #95F0301) have been used.
Mules and Asses	Considered a negligible source in Canada
Swine	All pigs Data source: Statistics Canada (#23-010)
Poultry	Chicken, layer, and turkey population data are available from the 1991, 1996, and 2001 farm census (Statistics Canada #93350, #93356, and #95F0301).

6.2.3 UNCERTAINTIES AND TIME-SERIES CONSISTENCY

The uncertainty associated with CH_4 emissions from enteric fermentation was determined using the Monte Carlo technique based on the IPCC Tier 2 methodology (IPCC, 2000). Uncertainties associated with animal populations were relatively low, ranging from ±1% for poultry, ±2% for sheep and lambs, ±3% for dairy cattle, ±5% for non-dairy cattle, ±10% for swine, and ±15% for horses and goats. Uncertainties associated with input variables and parameters for deriving emission factors based on the IPCC Tier 2 equations for dairy and non-dairy cattle were estimated as ±4% for feed digestibility, ±5% for percentage of cows giving birth, ±10% for CH_4 conversion rate, ±8% for average milk production, ±8% for milk fat content, and ±5% for weight gains. Uncertainties associated with emission factors taken from the IPCC Tier 1 defaults for non-cattle categories were estimated to be ±20% (IPCC/OECD/IEA, 1997). The overall level uncertainty for emission estimates from 1990 to 2004 was estimated to be ±18% (Hutchinson *et al.*, 2006). Uncertainty estimates reported here for the Agriculture Sector sources have been updated since the study by ICF (2004), as reported in Annex 7.

The same methodology is used for the entire time series of emission estimates (1990–2004). Data sources are also the same, with a few exceptions.

6.2.4 QA/QC AND VERIFICATION

Enteric fermentation, as a key category, has undergone for this submission the Tier 1–level QC checks as elaborated in the framework for the QA/QC plan (SNC Lavalin, 2004; see Annex 6) in a manner consistent with IPCC Good Practice Guidance (IPCC, 2000). In addition, the activity data, methodologies, and changes are documented and archived in both paper and electronic form. The IPCC Tier 2 emission factors for cattle, derived from Boadi *et al.* (2004), have been reviewed by independent experts (T. McAllister, AAFC; J. Basarab, Alberta Agriculture, Food and Rural Development).

Direct measurements of CH_4 emissions from enteric fermentation in Canada are recent, and data are still scarce. Over the last few years, a number of Canadian researchers have adopted a tracer technique for measuring CH_4 emissions from grazing cattle using SF_6 (McCaughey *et al.*, 1997, 1999; Boadi and Wittenberg, 2002; Boadi *et al.*, 2002a, 2002b; McGinn *et al.*, 2004, 2006; Beauchemin and McGinn, 2005). CH_4 measurements in the scientific literature are currently being compiled by the Greenhouse Gas Division for purposes of future comparison and verification.

6.2.5 RECALCULATIONS

Recalculations have been carried out because of changes in emission factors for dairy cattle to account for the milk productivity time series and some updates in animal populations. Overall, these recalculations decreased the 1990 emissions reported in the 2005 submission by about 0.3 Mt and increased the 2003 emissions reported in the 2005 submission by 0.2 Mt and have had a relatively modest impact on the long-term trend (now +22.8% compared with +20%).

The greatest impact occurred for dairy cattle emissions, whose previous trend showed a decrease of about 22% between 1990 and 2003 due to a decrease in the dairy population in Canada in the 1990s. Current emission estimates show a drop of 10% over the same period, the increasing emission factor compensating somewhat for the drop in population.

6.2.6 PLANNED IMPROVEMENTS

In the current methodology, the value for digestible energy for beef and dairy cattle is constant over time, based on 2001 feed rations. Updates to the emission factor to account for changes in feed ration digestibility over time are being investigated. The uncertainty for the trend associated with enteric fermentation emission estimates will be determined.

6.3 MANURE MANAGEMENT (CRF CATEGORY 4.B)

During the handling or storage of livestock manure, both CH_4 and N_2O are emitted. The magnitude of the emissions depends upon the quantity of manure handled, the manure properties, and the type of manure management system. Typically, poorly aerated manure management systems generate large quantities of CH_4 but smaller amounts of N_2O, whereas well-aerated systems generate little CH_4 but more N_2O.

6.3.1 CH_4 EMISSIONS FROM MANURE MANAGEMENT (CRF CATEGORY 4.B (a))

6.3.1.1 Source Category Description

Shortly after manure is excreted, it begins to decompose. If little oxygen is present, the decomposition is mainly anaerobic and thus produces CH_4. The quantity of CH_4 produced depends on the type of waste management system — in particular, the amount of aeration and the quantity of manure.

6.3.1.2 Methodological Issues

CH_4 emissions from manure management are estimated using the IPCC Tier 2 methodology (IPCC, 2000). Emission factors were derived from a recent study by Marinier *et al.* (2004), with modifications and updates following the 2006 IPCC Guidelines (IPCC, 2006). Marinier *et al.* (2004) estimated volatile solids for cattle and non-cattle through expert consultations. Dry matter intake (and therefore volatile solids) for dairy and non-dairy cattle was estimated using the same characterization data as used for the enteric fermentation Tier 2 method by Boadi *et al.* (2004). For dairy cows, the emission factor time series reflects the increase in milk productivity of cows over time. In addition, B_0 and MCFs have been updated drawing from the 2006 IPCC Guidelines (IPCC, 2006). Emissions were calculated for each animal category by multiplying the animal population by the average emission factor associated with the specific animal category. The animal population data are the same as those used for the enteric fermentation emission estimates.

6.3.1.3 Uncertainties and Time-Series Consistency

The uncertainty associated with CH_4 emissions from manure management was determined using the Monte Carlo technique based on the IPCC Tier 2 methodology. Uncertainties associated with animal populations were estimated as reported in Section 6.2.3. Uncertainties associated with variables and input parameters for estimating dry matter intake for dairy and non-dairy cattle using the IPCC Tier 2 equations were the same as noted under enteric fermentation. Uncertainties or ranges associated with other parameters for estimating emission factors for various animal categories were taken from the IPCC defaults for MCF and B_0 (IPCC, 2006) and Marinier *et al.* (2004) for animal manure distributions. The overall level uncertainty for emission estimates from 1990 to 2004 was estimated to be ±23% (Hutchinson *et al.*, 2006).

The same methodology and data source are used for the entire time series (1990–2004).

6.3.1.4 QA/QC and Verification

CH_4 emissions from manure management have undergone for this submission the Tier 1–level QC checks as elaborated in the framework for the QA/QC plan (see details and references in Annex 6) in a manner consistent with IPCC Good Practice Guidance (IPCC, 2000). The activity data and methodologies are documented and archived in both paper and electronic form. The IPCC Tier 2 CH_4 emission factors from manure management practices by various animal categories derived from Marinier *et al.* (2004) have been reviewed by independent experts (N. Patni and R. Desjardins, AAFC).

6.3.1.5 Recalculations

Recalculations have been carried out for the entire time series because of an update in animal populations and emission factors. Overall, these recalculations resulted in a decrease of CH_4 emissions by 0.6 Mt annually and had a minimal impact on the emission trend.

6.3.1.6 Planned Improvements

In the current methodology, dry matter intake and digestible energy by animal category are static over time based on the 2001 feed rations. Updates to the emission factor to account for changes in feed ration digestibility over time are being investigated. The uncertainty for the trend associated with CH_4 emission estimates from manure management will be determined.

6.3.2 N_2O EMISSIONS FROM MANURE MANAGEMENT (CRF CATEGORY 4.B (b))

6.3.2.1 Source Category Description

The production of N_2O during storage and treatment of animal waste occurs during nitrification and denitrification of nitrogen contained in the manure. Nitrification is the oxidation of ammonium (NH_4^+) to nitrate (NO_3^-), and denitrification is the reduction of NO_3^- to N_2O or N_2. Generally, as the degree of aeration of the waste increases, so does the amount of N_2O produced.

In Canada, four major types of AWMS are typically used: liquid systems, solid storage and drylot, pasture and paddock, and other systems. It is assumed that no manure is burned as fuel.

Table 6-3 presents Canada's breakdown of manure nitrogen by AWMS. The distribution of manure management systems by animal category is based on a study by Marinier *et al.* (2004). Note that the N_2O emissions from manure on pasture, range, and paddock systems are not included here but are reported under a separate category (see Manure on Pasture, Range, and Paddock, Section 6.4.2).

TABLE 6-3: Percentage of Manure Nitrogen Handled by Animal Waste Management Systems

Animal Type	(% of manure nitrogen)			
	Liquid Systems	Solid Storage and Drylot	Pasture and Paddock	Other Systems
Non-Dairy Cattle	1	47	48	4
Dairy Cattle	42	40	18	0
Poultry	10	88	2	0
Sheep & Lambs	0	38	62	0
Swine	96	3	0	1
Other (Goats, Horses, and Bison)	0	42	58	0

Source: Marinier *et al*. (2004).

6.3.2.2 Methodological Issues

N_2O emissions from manure management are estimated using the IPCC Tier 1 methodology. Emissions are calculated for each animal category by multiplying the animal population by the average nitrogen excretion rate associated with the specific animal category and by the fraction of available nitrogen based on the type of waste management system.

The animal population data are the same as those used for the Enteric Fermentation estimates (Section 6.2) and CH_4 Emissions from Manure Management (Section 6.3.1). The average annual nitrogen excretion rates for domestic animals are taken from the 2006 IPCC Guidelines (IPCC, 2006). The amount of manure nitrogen subject to losses because of leaching and volatilization of NH_3 and NO_x is adjusted by animal types and manure management systems according to the default values provided in the 2006 IPCC Guidelines (IPCC, 2006).

The fraction of nitrogen available for conversion into N_2O is estimated by applying system-specific emission factors to the manure nitrogen handled by each management system. The IPCC default emission factors (IPCC, 2006) for a developed country with a cool climate are used to estimate manure nitrogen emitted as N_2O for each type of AWMS. This factor is multiplied by the breakdown of AWMS by animal category (shown in Table 6-3) to derive the fraction of nitrogen that is converted into N_2O.

6.3.2.3 Uncertainties and Time-Series Consistency

Uncertainties associated with N_2O emission estimates from manure management result from uncertainties associated with estimates of animal populations from the Census of Agriculture, ranging from ±1% to ±15% as noted in the enteric fermentation and manure management sections. Uncertainties associated with rates of nitrogen excretion are ±20% (IPCC, 2006), with types of AWMS are ±20% (Marinier *et al.*, 2004), and with the emission factors associated with AWMS are ±20% (IPCC, 2006). The overall level uncertainty associated with this source of emission estimates from 1990 to 2004 was estimated to vary from −31% to +40% (Hutchinson *et al.*, 2006).

The same methodology, emission factors, and data sources are used for the entire time series (1990–2004).

6.3.2.4 QA/QC and Verification

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

6.3.2.5 Recalculations

Recalculations have been carried out because of changes in manure nitrogen excretion rates and modest updates to animal population accounts. Most noticeable is the increase in manure nitrogen excretion rates of non-dairy cattle from 44.7 to 58.1 kg N/head per year (IPCC, 2006). Overall, these recalculations increased the 1990 emissions reported in the 2005 submission by 0.6 Mt and increased the 2003 emissions reported in the 2005 submission by 1 Mt and have increased the long-term trend for this category from +17.1% to +23.1%.

6.3.2.6 Planned Improvements

Direct measurements of N_2O emissions from manure management in Canada have only recently been initiated, and data are still scarce. Recent scientific advances on analytical techniques allow direct measurements of N_2O emissions from point sources, such as lagoons, using a flux tower. However, it will likely take several years before N_2O emissions can be reliably measured and verified from various manure management systems in Canada. The uncertainty for the trend associated with N_2O emission estimates from manure management will be determined.

6.4 N$_2$O EMISSIONS FROM AGRICULTURAL SOILS (CRF CATEGORY 4.D)

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

6.4.1 DIRECT N$_2$O EMISSIONS FROM SOILS (CRF CATEGORY 4.D.1)

6.4.1.1 Synthetic Nitrogen Fertilizers

Source Category Description

Synthetic fertilizers add large quantities of nitrogen to agricultural soils. This added nitrogen undergoes transformations, such as nitrification and denitrification, which release N_2O. Emission factors associated with fertilizer application depend on many factors, such as the quantity and type of nitrogen fertilizers, crop types, soil types, climate, and other environmental conditions.

Methodological Issues

As elaborated in detail in Section A3.4 in Annex 3, Canada has developed a country-specific, Tier 2–type methodology to estimate N_2O emissions from synthetic nitrogen fertilizer application on agricultural soils, which takes into account local climate (precipitation and potential evapotranspiration) and topographic conditions. Emissions of N_2O are estimated by ecodistrict, by province, and for the country as a whole. The amount of nitrogen applied is obtained from yearly fertilizer sales data, which are available from regional fertilizer associations (Korol, 2002, 2003). These data include the amount of fertilizer nitrogen sold by retailers on or before June 30 of the inventory year.

Uncertainties and Time-Series Consistency

Uncertainties associated with N_2O emission estimates from synthetic nitrogen fertilizer applications result from uncertainties associated with estimates of nitrogen fertilizer sales (±20%), RF_{THAW} (±300%), F_{TOPO} (±300%), and EF_{BASE} (−48% to +100%). These terms and emission calculations are explained in the methodological section A3.4 of Annex 3. The overall level uncertainty associated with this source of emission estimates from 1990 to 2004 was estimated to vary from −39% to +49% (Hutchinson *et al.*, 2006).

The same methodology and emission factors are used for the entire time series (1990–2004).

QA/QC and Verification

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

N_2O emissions associated with synthetic fertilizer nitrogen applications on agricultural soils in Canada vary widely. There is a close agreement between the aggregated, measured emission factor and the IPCC default value in eastern Canada (Gregorich *et al.*, 2005).

Recalculations

Recalculations have been carried out for the full time series because of the complete change in methodology. Overall, these recalculations decreased the 1990 emissions reported in the 2005 submission by about 1.9 Mt, decreased the 2003 emissions reported in the 2005 submission by 3.0 Mt, and have decreased the long-term trend from about +34% to +21%. This is explained by the fact that the growth in synthetic fertilizer use since 1990 has been the highest in the Prairies, whereas the new "moisture-specific" N_2O emission factors have been revised downwards quite significantly in this semiarid region.

Planned Improvements

The effect of irrigation on N_2O emissions and the relationships between soil texture and N_2O emissions will be investigated for inclusion in the emission factor equations. Annual adjustments to emission factors based on growing season–specific precipitation and evapotranspiration data for each agricultural ecodistrict will also be explored. The uncertainty for the trend associated with N_2O emission estimates from synthetic nitrogen fertilizers will be determined.

6.4.1.2 Animal Manure Applied to Soils

Source Category Description

The application of animal manure as fertilizer to soils can increase the rate of nitrification and denitrification and result in enhanced N_2O emissions from agricultural soils. Note that emissions from this category include manure managed by drylot, liquid, and other AWMS. Manure deposited on grazing land is accounted for in Section 6.4.2, Manure on Pasture, Range, and Paddock.

Methodological Issues

Similar to the methodology used to estimate emissions from synthetic fertilizer, the methodology used to estimate these N_2O emissions is a country-specific IPCC Tier 2–type method that takes into account local climate, such as precipitation and potential evapotranspiration, and topographic conditions. Emissions are calculated by multiplying the amount of manure nitrogen applied to agricultural soils by the non-volatilized fraction (available for nitrification and denitrification) and by an emission factor, at the ecodistrict, provincial, and, finally, national level. All manure that is handled by the AWMS, except for the manure on pasture, range, and paddock from grazing animals, is assumed to be applied to agricultural soils (see Section 6.4.2).

Uncertainties and Time-Series Consistency

Uncertainties associated with N_2O emission estimates from animal manure applied as fertilizers result from uncertainties associated with estimates of manure nitrogen based on types of animal populations (±1% to 15%), average animal manure nitrogen excretion rate (±20%), manure nitrogen loss (±20%), RF_{THAW} (±300%), F_{TOPO} (±300%), and EF_{BASE} (−48% to +100%). The overall level uncertainty associated with this source of emission estimates from 1990 to

2004 was estimated to vary from –35% to +41% (Hutchinson *et al.*, 2006).

The same methodology and emission factors are used for the entire time series (1990–2004).

QA/QC and Verification

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

Recalculations

Recalculations have been carried out because of updates in animal populations and animal manure nitrogen excretion rates as well as losses of manure nitrogen through leaching and volatilization from various manure management systems. Overall, these recalculations decreased the 1990 emissions reported in the 2005 submission by 0.9 Mt and decreased the 2003 emissions reported in the 2005 submission by 1.1 Mt. Growth over 1990–2004 in N_2O from this source has been revised from +18% to about +11% for the same reason as for synthetic fertilizer N_2O emissions.

Planned Improvements

The effect of irrigation on N_2O emissions and the relationships between soil texture and N_2O emissions will be investigated for inclusion in the emission factor equations. The uncertainty for the trend associated with N_2O emission estimates for animal manure applied as fertilizers on cropland will be determined.

6.4.1.3 Nitrogen-Fixing Crops

Source Category Description

Biological nitrogen fixation by the legume–rhizobium association was a major source of N_2O emissions in previous national GHG inventories reported by Canada in accordance with the IPCC Guidelines methodology (IPCC/OECD/IEA, 1997). This source is not included in the 2006 IPCC Guidelines (IPCC, 2006), however. This decision is supported by the conclusion of Rochette and Janzen (2005) that there is no evidence that measurable amounts of N_2O are produced during the nitrogen fixation process. Therefore, Canada decided to report this source as "not occurring." However, the contribution of legume nitrogen to N_2O emissions is included from crop residue decomposition on agricultural soils.

6.4.1.4 Crop Residue Decomposition (CRF Category 4.D.4)

Source Category Description

When a crop is harvested, a portion of the crop (crop residue) is left on the field to decompose. The remaining plant matter is a nitrogen source for nitrification and denitrification processes and thus produces N_2O. In some cases, the remaining crop residue is burned, but it is assumed that the amount of burning is negligible in Canada.

Methodological Issues

Emissions are estimated using an IPCC Tier 2 approach. The amount of nitrogen contained in crop residues from both nitrogen-fixing and non-nitrogen-fixing crops is estimated using country-specific crop characteristics (Janzen *et al.*, 2003). Emission factors are determined using the same approach as for synthetic fertilizer nitrogen, using moisture regimes and topographic conditions. Emissions of N_2O are estimated using the amount of nitrogen contained in crop residue multiplied by the emission factor at the ecodistrict level and scaled up to the provincial and national levels.

Uncertainties and Time-Series Consistency

Uncertainties associated with N_2O 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 (±15%), above- and belowground crop residue nitrogen concentration (±15%), RF_{THAW} (±300%), F_{TOPO} (±300%), and EF_{BASE} (–48% to +100%). The overall level uncertainty associated with this source of emission estimates from 1990 to 2004 was estimated to vary from –44% to +48% (Hutchinson *et al.*, 2006).

The same methodology and emission factors are used for the entire time series (1990–2004).

QA/QC and Verification

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

Recalculations

Recalculations have been carried out because of changes in emission factors and revised estimates of nitrogen contained in crop residue based on country-specific crop characteristics. Overall, these recalculations decreased the 1990 emissions reported in the 2005 submission by 2.2 Mt and the 2003 emissions reported in the 2005 submission by 2.6 Mt and have decreased the long-term trend from +2.5% to –4.8%.

Planned Improvements

The effect of irrigation on N_2O emissions and the relationships between soil texture and N_2O emissions will be investigated for inclusion in the emission factor equations. Annual adjustments to emission factors based on growing season–specific precipitation and evapotranspiration data for each agricultural ecodistrict will also be explored. The uncertainty for the trend associated with N_2O emission estimates from crop residue decomposition will be determined.

6.4.1.5 Cultivation of Organic Soils (Histosols)

Source Category Description

Cultivation of organic soils (histosols) for crop production usually involves drainage, lowering the belowground water table, increasing aeration, and speeding up the decomposition of organic matter. Denitrification and nitrification also take place, releasing N_2O emissions.

Methodological Issues

The IPCC Tier 1 methodology is used to estimate N_2O emissions from cultivated organic soils. N_2O emissions are calculated by multiplying the area of cultivated histosols by an emission factor.

Areas of cultivated histosols at a provincial level are not covered in the Census of Agriculture, which is carried out regularly at five-year intervals by Statistics Canada. In the absence of these data, consultations with numerous soil and crop specialists across Canada have been made. The total area of cultivated organic soils in Canada has been updated to 16 154 ha for the period 1990–2004 (G. Padbury and G. Patterson, personal communication).

Uncertainties and Time-Series Consistency

Uncertainties associated with N_2O emission estimates from cultivation of histosols result from uncertainties associated with area estimates of cultivated histosols (±50%) and emission factors (±50%). The overall level uncertainty associated with this source of emission estimates from 1990 to 2004 was estimated to be ±50% (Hutchinson *et al.*, 2006).

The same methodology and emission factors are used for the entire time series (1990–2004).

QA/QC and Verification

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

Recalculations

Recalculations have been carried out because of an update in activity data. This change in activity data resulted in a small increase of N_2O emissions and had no impact on the long-term trend.

Planned Improvements

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

6.4.1.6 Reduced N_2O Emissions as a Result of Adoption of No-Tillage and Reduced Tillage on the Canadian Prairies

Source Category Description

This is a new category in Canada's inventory of direct N_2O emissions from soils. This does not derive from additional nitrogen input but reflects reduced emissions (hence the negative sign) from fertilizer and crop inputs because of the switch to conservative soil management practices — namely, reduced tillage (RT) and no-tillage (NT). Compared with conventional or intensive tillage (IT), direct seeding or NT as well as RT affect several factors that influence N_2O production, including decomposition of soil organic matter, soil carbon and nitrogen availability, soil bulk density, and water content. The trend shows a moderate increase in "reduced N_2O emissions" because of the increase in cropland area under NT and RT over time.

Methodological Issues

The method used is country specific. Reduced emissions of N_2O resulting from the adoption of NT and RT are estimated as a reduction of N_2O through modifications of emission factors for synthetic fertilizers, manure nitrogen applied to cropland, and crop residue nitrogen decomposition. This subcategory is kept separate from the fertilizer and crop residue decomposition source categories to increase the transparency in reporting. The tillage ratio factor, defined as the ratio of mean N_2O fluxes on NT or RT to mean N_2O fluxes on IT (N_2O_{NT}/N_2O_{IT}), represents the effect of NT or RT on N_2O emissions (F_{TILL}). Field studies in Quebec and Ontario comparing emissions between NT and mouldboard plowing yielded an F_{TILL} of 1.0 (Gregorich *et al.*, 2005), while a similar exercise for the Prairie region yielded an F_{TILL} of 0.8 for the Brown, Dark Brown, Grey, and Black soil zones. Thus, reduced N_2O emissions are estimated as 20% of the total emissions from synthetic nitrogen fertilizers, manure nitrogen applied to cropland, and crop residue decomposition multiplied by the fraction of NT and RT for the Brown, Dark Brown, Grey, and Black soil zones on the Canadian prairies.

Currently, because negative values are not allowed to be entered under "Other" of Direct Soil N_2O Emissions in the CRF Reporter, Canada has combined and reported the reduced N_2O emissions from adoption of NT and RT on the Canadian prairies with N_2O estimates under the category "Synthetic Fertilizer Nitrogen." Thus, the implied emission factors as shown in the CRF Reporter for "Synthetic Fertilizer Nitrogen" do not reflect actual emissions for this category.

Uncertainties and Time-Series Consistency

Uncertainties associated with reduced N_2O emission estimates from adoption of NT and RT on the Canadian prairies result from uncertainties associated with area estimates of NT and RT from the Census of Agriculture (±15%), F_{TILL} (±300%), F_{TOPO} (±300%), and EF_{BASE} (–48% to +100%). The overall level uncertainty associated with this source of emission estimates from 1990 to 2004 was estimated to be ±42% (Hutchinson *et al.*, 2006).

The same methodology and emission factors are used for the entire time series (1990–2004).

QA/QC and Verification

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

Recalculations

No recalculation has been carried out for this source category.

Planned Improvements

AAFC is planning to publish experimental data on reduced N_2O emissions from adoption of NT and RT relative to IT on the Canadian prairies. This will increase the scientific credibility and international acceptance for inclusion of this new category in the NIR. The uncertainty for the trend associated with reduced N_2O emission estimates from adoption of NT and RT on the Canadian prairies will be determined.

6.4.1.7 N_2O Emissions Resulting from Summerfallowing

Source Category Description

This is a new category in Canada's inventory of direct N_2O emissions from soils (CRF subcategory "Other"). Summerfallowing is a farming practice typically used in the Prairie region to conserve soil moisture by leaving the soil unseeded for an entire growing season in a crop rotation. During the fallow year, several factors may stimulate N_2O emissions relative to a cropped situation, such as higher soil water content, temperature, and available carbon and nitrogen (Campbell *et al.*, 1990).

Methodological Issues

Experimental studies have shown that N_2O emissions in fallow fields are similar to emissions from continuously cropped fields (see details in Section A3.4 in Annex 3). The emissions due to summerfallow are calculated through a country-specific method by summing emissions from fertilizer and manure application to annual crops for a given ecodistrict and multiplying the sum by the proportion of that ecodistrict under summerfallow.

Uncertainties and Time-Series Consistency

Uncertainties associated with N_2O emission estimates from summerfallow result from uncertainties associated with area estimates of summerfallow from the Census of Agriculture (cropland area: 1.25% to 10%; $Frac_{FALLOW}$: 1.25% to 10%), F_{TILL} (±300%), F_{TOPO} (±300%), and EF_{BASE} (–50% to +200%). The overall level uncertainty associated with this source of emission estimates from 1990 to 2004 was estimated to be ±45% (Hutchinson *et al.*, 2006).

The same methodology and emission factors are used for the entire time series (1990–2004).

QA/QC and Verification

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

Recalculations

No recalculation has been carried out for this source category.

Planned Improvements

AAFC is planning to publish experimental data on N_2O emissions from summerfallow. This will increase the scientific credibility and international acceptance for inclusion of this new category in NIR. The uncertainty for the trend associated with N_2O emission estimates from summerfallow will be determined.

6.4.2 MANURE ON PASTURE, RANGE, AND PADDOCK (CRF CATEGORY 4.D.2)

Source Category Description

When manure is excreted on pasture and paddock from grazing animals, nitrogen in the manure undergoes transformations such as ammonification, nitrification, and denitrification. During these transformation processes, N_2O is produced.

Methodological Issues

The emissions from manure excreted by grazing animals are calculated using the IPCC Tier 1 methodology (IPCC/OECD/IEA, 1997). Emissions are calculated for each animal category by multiplying the animal population by the appropriate nitrogen excretion rate and by the fraction of manure nitrogen available for conversion to N_2O.

The animal population data are the same as those used in Section 6.2. The nitrogen excretion rates are based on the IPCC defaults (IPCC, 2006). The fraction of manure nitrogen available for conversion to N_2O is calculated as the percentage of total manure nitrogen produced on pasture, range, and paddock multiplied by the IPCC default values of 0.02 kg N_2O-N/kg N for cattle, poultry, and swine and 0.01 kg N_2O-N/kg N for sheep/lamb, goat, and horse (IPCC, 2006), which represents the fraction of excreted manure nitrogen converted to N_2O.

Uncertainties and Time-Series Consistency

Uncertainties associated with N_2O emission estimates from animal manure on pasture, range, and paddock result from uncertainties associated with animal populations (±1% to ±15%), manure nitrogen excretion rate (±20%), fraction of manure nitrogen on pasture, range, and paddock (±20%), as well as emission factors (–25% to +50%). The overall level uncertainty associated with this source of emission estimates from 1990 to 2004 was estimated to vary from –26% to +33% (Hutchinson *et al.*, 2006).

The same methodology and emission factors are used for the entire time series (1990–2004).

QA/QC and Verification

The activity data, methodologies, and changes to methodologies are documented and archived in both paper and electronic form. QC checks and cross-checks have been carried out to identify data entry errors and calculation errors. In general, there are very few data available on the quantity of N_2O emissions from the manure on pasture and paddock from grazing animals in Canada. Therefore, it is extremely difficult to verify how well the IPCC emission factor reflects Canadian conditions.

Recalculations

Recalculations have been carried out because of updates in animal populations and manure nitrogen excretion rates and the revision in the emission factors. Overall, these recalculations increased the 1990 emissions reported in the 2005 submission by 0.6 Mt and the 2003 emissions reported in the 2005 submission by 0.7 Mt, but have had a minimal impact on the long-term trend.

Planned Improvements

The uncertainty for the trend associated with N_2O emission estimates from animal manure on pasture, range, and paddock will be determined.

6.4.3 INDIRECT EMISSIONS OF N_2O FROM SOILS (CRF CATEGORY 4.D.3)

A fraction of the nitrogen from both synthetic fertilizer and manure that is applied to agricultural fields is transported off site through volatilization and subsequent redeposition or leaching, erosion, and runoff. The nitrogen that is transported from the agricultural field in this manner provides additional nitrogen for subsequent nitrification and denitrification to produce N_2O.

Note that the nitrogen leaving an agricultural field may not be available for the process of nitrification and denitrification for many years, particularly in the case of nitrogen leaching into groundwater.

6.4.3.1 Volatilization and Redeposition of Nitrogen

Source Category Description

When synthetic fertilizer or manure is applied on cropland, a portion of this nitrogen is lost through volatilization in the form of NH_3 or NO_x. This volatilized nitrogen can be redeposited somewhere else and can undergo further transformations, such as nitrification and denitrification, thus resulting in N_2O emissions off site. The quantity of this volatilized nitrogen depends on a number of factors, such as rates of fertilizer application, fertilizer types, methods and time of nitrogen application, soil texture, rainfall, temperature, soil pH, etc.

Methodological Issues

The IPCC Tier 1 methodology is used to estimate indirect N_2O emissions due to volatilization and redeposition of nitrogen from applied synthetic fertilizer and manure (IPCC/OECD/IEA, 1997). However, the portions of volatilized NH_3 or NO_x from animal manure vary with animal types and manure management systems based on the default values from the 2006 IPCC Guidelines (IPCC, 2006). The amount of synthetic fertilizer and manure nitrogen is multiplied by the fraction of nitrogen that is volatilized as NH_3-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 regional fertilizer associations. The amount of nitrogen that volatilizes is assumed to be 10% of the total amount of synthetic fertilizer applied (IPCC/OECD/IEA, 1997). The default IPCC emission factor, 0.01 kg N_2O-N/kg N, is applied to derive the N_2O emission estimate (IPCC/OECD/IEA, 1997).

Uncertainties and Time-Series Consistency

Uncertainties associated with N_2O emission estimates from volatilization of NH_3 and NO_x due to applications of synthetic and manure nitrogen result from uncertainties associated with estimates of synthetic fertilizer nitrogen consumption (±20%), fraction of volatilized $NH_3 + NO_x$ from synthetic nitrogen fertilizers (–30% to +300%), animal populations (±1% to ±15%), manure nitrogen excretion rate (±20%), fraction of volatilized $NH_3 + NO_x$ from animal manure (–25% to +250%), as well as emission factors (–20% to +200%). The overall level uncertainty associated with this source of emission estimates from 1990 to 2004 was estimated to vary from –45% to +59% (Hutchinson *et al.*, 2006).

The same methodology and emission factors are used for the entire time series (1990–2004).

QA/QC and Verification

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

Recalculations

Recalculations have been carried out because of updates in animal populations, animal manure nitrogen excretion rates, as well as fractions of manure nitrogen lost as NH_3-N and NO_x-N by animal types and manure management systems. Overall, these recalculations increased the 1990 emissions reported in the 2005 submission by 0.6 Mt and the 2003 emissions reported in the 2005 submission by 0.7 Mt, but have had a minimal impact on the long-term trend.

Planned Improvements

The uncertainty for the trend associated with N_2O emission estimates from volatilization and redeposition of nitrogen will be determined.

6.4.3.2 Leaching, Erosion, and Runoff

Source Category Description

When synthetic fertilizer or manure nitrogen is applied to cropland, a portion of this nitrogen is lost through leaching, erosion, and runoff. The magnitude of this nitrogen loss depends on a number of factors, such as rates, methods, and time of nitrogen application, crop type, soil texture, rainfall, landscape, etc. This portion of lost nitrogen can further undergo transformations, such as nitrification and denitrification, thus producing N_2O emissions off site.

Methodological Issues

A modified IPCC Tier 1 methodology is used to estimate indirect N_2O emissions from leaching, runoff, and erosion of fertilizers, manure nitrogen, and crop residues from agricultural soils.

The default value for the fraction of nitrogen that is lost through leaching and runoff ($Frac_{LEACH}$) in the 1996 IPCC Guidelines (IPCC/OECD/IEA, 1997) was 0.3. $Frac_{LEACH}$ can reach values as low as 0.05 in regions where rainfall is much lower than potential evapotranspiration (IPCC, 2006), such as in the Prairie region of Canada. Accordingly, it was assumed that $Frac_{LEACH}$ would vary among ecodistricts from a low of 0.05 to a high of 0.3. For ecodistricts with a precipitation/potential evapotranspiration (P/PE) value for the growing season (May through October) greater than or equal to 1, the maximum $Frac_{LEACH}$ value recommended by the 2006 IPCC Guidelines (IPCC, 2006) of 0.3 was assigned. For ecodistricts with the lowest P/PE value (0.21), a minimum $Frac_{LEACH}$ value of 0.05 was assigned. For ecodistricts with a P/PE value that ranged between 0.21 and 1, $Frac_{LEACH}$ was estimated by the linear function that joins the points (P/PE, $Frac_{LEACH}$) = (1, 0.3; 0.21, 0.05).

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 0.0125 kg N_2O-N/kg N (IPCC, 2006).

Uncertainties and Time-Series Consistency

Uncertainties associated with N_2O emission estimates from leaching, runoff, and erosion of nitrogen from synthetic, manure, and crop residue nitrogen result from uncertainties associated with estimates of synthetic fertilizer nitrogen consumption (±20%), manure nitrogen excretion rate (±20%), animal populations (±1% to ±15%), crop residue nitrogen (±15%), $Frac_{LEACH}$ (±30%), as well as the leaching/runoff emission factor EF_{LEACH} (–50% to +200%). The overall level uncertainty associated with this source of emission estimates from 1990 to 2004 was estimated to vary from –45% to +57% (Hutchinson *et al.*, 2006).

The same methodology and emission factors are used for the entire time series (1990–2004).

QA/QC and Verification

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

Recalculations

Recalculations have been carried out because of changes in $Frac_{LEACH}$ and emission factor, updates of animal populations, changes in manure nitrogen excretion rates, changes in fractions of manure nitrogen lost as NH_3-N and NO_x-N by animal categories and manure management systems, as well as the addition of crop residue nitrogen for estimating this source of emissions. Overall, these recalculations decreased the 1990 emissions reported in the 2005 submission by 0.3 Mt and the 2003 emissions reported in the 2005 submission by 1 Mt and have had some impact on the long-term trend.

Planned Improvements

The uncertainty for the trend associated with N_2O emission estimates from leaching, runoff, and erosion of nitrogen will be determined.

7 LAND USE, LAND-USE CHANGE AND FORESTRY (CRF SECTOR 5)

7.1 OVERVIEW

The LULUCF Sector reports GHG fluxes between the atmosphere and Canada's managed lands, as well as those associated with land-use changes. The assessment includes emissions and removals of CO_2, additional emissions of CH_4, N_2O, and CO due to wildfires and controlled burning, and N_2O released following land conversion to cropland. All emissions from and removals by the LULUCF Sector are excluded from the national totals.

In 2004, the estimated net GHG flux in the LULUCF Sector, calculated as the sum of CO_2 emissions and removals and non-CO_2 emissions, amounted to emissions of 81 Mt. If these emissions were included in the national totals, they would increase the total Canadian GHG emissions by 11%. Table 7-1 provides the net flux estimates for the base and most recent years in the major LULUCF Sector categories and subcategories.

In view of the high interannual variability displayed by some categories and the effect on the sectoral trends, the reader is cautioned against interpreting the figures in Table 7-1 as trends. The full time series of LULUCF Sector estimates is available in Table 5 of the CRF series.

The Forest Land category has the largest influence on sectoral totals. In general, the net fluxes are negative (removals), with notable exceptions in 1995, 1998, and 2004, which were years with large areas burned by wildfire. As a consequence, the interannual variability is high, with net category totals fluctuating between –190 Mt (1992) and 180 Mt (1995). These fluctuations are carried over to the LULUCF Sector totals, which vary between net emissions and net removals, depending on the net flux from managed forests.

Over the entire period, the Cropland category displays a steady trend towards decreasing emissions, for a nearly neutral GHG budget in 2004. The decline of emissions from land converted to cropland and growing removals by cropland remaining cropland equally contribute to the 14 Mt reduction in net emissions over the period.

TABLE 7-1: LULUCF Sector Net GHG Flux Estimates for Selected Years

GHG Source/Sink Categories	Net GHG Flux		
	(kt CO_2 eq)		
	1990	2003	2004
Land Use, Land-Use Change and Forestry TOTAL[1]	**–82 000**	**–11 000**	**81 000**
a. Forest Land	**–110 000**	**–20 000**	**73 000**
Forest Land Remaining Forest Land	–110 000	–19 000	74 000
Land Converted to Forest Land	–1 300	–1 200	–1 200
b. Cropland	**14 000**	**830**	**58**
Cropland Remaining Cropland	–2 300	–8 500	–9 000
Land Converted to Cropland	16 000	9 300	9 100
c. Grassland	**–**	**–**	**–**
Grassland Remaining Grassland	NE	NE	NE
Land Converted to Grassland	NE	NE	NE
d. Wetlands	**6 000**	**1 000**	**1 000**
Wetlands Remaining Wetlands	80	100	100
Lands Converted to Wetlands	6 000	1 000	1 000
e. Settlements	**8 000**	**7 000**	**7 000**
Settlements Remaining Settlements	–100	–200	–200
Land Converted to Settlements	8 000	7 000	7 000
Forest conversion (memo item)[2]	28 000	17 000	16 000
Grassland conversion (memo item)[2,3]	800	600	500

Notes:

1 Totals may not add due to rounding.

2 Already included in lands converted to cropland, wetlands, and settlements.

3 Conversion of non-agricultural grassland (tundra).

NE = not estimated

Estimates in the Wetlands category (managed peatlands and flooded lands) are reported for the first time in the GHG inventory. The contribution of wetlands remaining wetlands is minor; the category includes only managed peatlands. Emissions from land converted to wetlands declined from 6 Mt to 1 Mt during the period; flooded lands account for over 99% of these emissions.

With this submission, Canada has begun the implementation of a multiyear effort to substantially improve its estimates for the LULUCF Sector.[38] As a result, all LULUCF land categories except Grasslands present completely revised and expanded estimates, in

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[38] First described in the 2004 NIR.

addition to new ones (Wetlands category; N_2O from land conversion to cropland). The most important recalculations are presented under each of the corresponding headings in Sections 7.4 to 7.8 of this chapter.

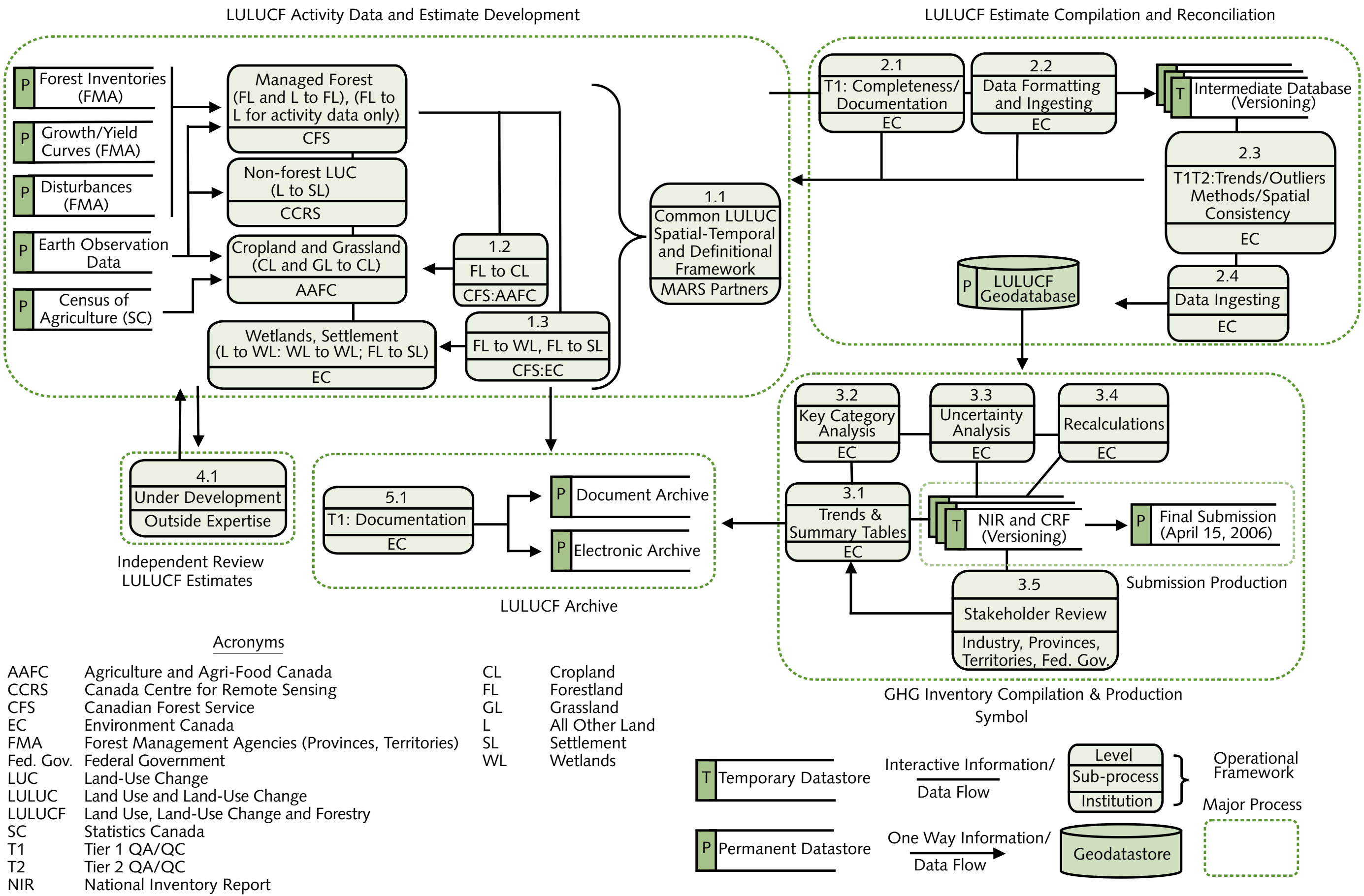
The contribution of the best Canadian expertise to this submission has been made possible by Canada's national, multidisciplinary framework for monitoring, accounting, and reporting emissions and removals in managed lands. This framework provides a means for coordinating, planning, and integrating the activities of many groups of scientists and experts across several government levels and research institutions. The MARS for LULUCF is expected to continue its work in the next several years. In addition to enhanced collaboration within the MARS framework, planned improvements include the development of formal and documented uncertainty estimates in the Forest Land and Cropland categories, documented Tier 2 QA/QC, and more comprehensive documentation.

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

7.2 CHANGES SINCE PREVIOUS SUBMISSION

Improvements in the 2006 submission are largely due to the enhanced contribution of Canadian science and expertise to estimate development. The coverage, complexity, and spatial resolution of data, as well as the specificity of approaches, methods, and data sources, are all greatly enhanced, calling for a process and infrastructure expansion to support the reconciliation of data and estimates, the preparation of the inventory, and its documentation. Figure 7-1 illustrates the data

FIGURE 7-1: LULUCF Data and Information Flow



Acronyms

AAFC	Agriculture and Agri-Food Canada
CCRS	Canada Centre for Remote Sensing
CFS	Canadian Forest Service
EC	Environment Canada
FMA	Forest Management Agencies (Provinces, Territories)
Fed. Gov.	Federal Government
LUC	Land-Use Change
LULUC	Land Use and Land-Use Change
LULUCF	Land Use, Land-Use Change and Forestry
SC	Statistics Canada
T1	Tier 1 QA/QC
T2	Tier 2 QA/QC
NIR	National Inventory Report
CFR	Common Reporting Format
MARS	Monitoring, Accounting and Reporting System
CL	Cropland
FL	Forestland
GL	Grassland
L	All Other Land
SL	Settlement
WL	Wetlands

and information flow underlying the LULUCF Sector submission preparation. Similar systems are being put in place in each of the institutions involved in estimate development.

7.2.1 METHODOLOGICAL CHANGES

Very significant methodological improvements were incorporated in the estimation procedures for Forest Land, Cropland, and forest conversion to other land uses. For Forest Land, these include an entirely new, model-based approach that represents all forest carbon pools; the incorporation of detailed activity data from regional and local forest inventories; spatially referenced data on natural disturbances (fires and insects); and numerous, detailed parameters to simulate carbon transfers among pools and with the atmosphere due to natural processes, forest management, and disturbances. The same approach and tools were used to estimate all emissions from and removals by managed forests and forest-related land-use change (i.e., lands converted to forest and forest conversion to other uses).

The new estimates reported in this submission for cropland remaining cropland were derived using a comprehensive description of land-use and management changes at a fine spatial resolution, using a consistent spatial framework and methodology. In addition to the Census of Agriculture, complementary sources of information on activity data included remote sensing and various annual and semiannual statistics. The definitional framework for cropland and agricultural grassland was modified, and its implementation was based on Census data corrected with circa 1995 land cover imagery (see Section 7.3). Hence, areas of cropland and agricultural grassland reported in this submission differ from previous ones. Improved methods were also implemented to estimate soil emissions from the conversion of forest land and grassland to cropland.

All estimates of forest areas, managed and unmanaged, converted to other uses were developed with a consistent approach and spatial framework. The approach is based on the change detected between satellite images of the same area at different dates, supplemented by numerous records and other information from both earth observation and non-earth observation sources to correctly attribute the change as a forest conversion event. The outcome is a consistent set of estimates of the area of forests converted to cropland, urban and recreational lands, forest roads, other transportation infrastructure including power transmission, oil and gas exploration and mining, and managed wetlands.

New categories were added to the set of inventory estimates:

- lands converted to managed wetlands, both peatlands and reservoirs;
- wetlands remaining wetlands (managed peatlands only);
- conversion of non-forest, vegetated lands to settlements in the Canadian north; and
- emissions of N_2O from lands converted to cropland.

Table 7-2 compares the 2003 estimates submitted in the previous and current submissions. More information on new methods and recalculations is provided in subsequent sections of this chapter and Section A3.5 of Annex 3. Owing to modifications in the definition of the Grassland category, the previous approach is obsolete (see Section 7.6).

TABLE 7-2: 2003 GHG Estimates in the 2005 and 2006 Submissions

GHG Source/Sink Categories	Net GHG Flux	
	(kt CO_2 eq)	
	2005 Submission	2006 Submission
TOTAL[1]	**–44 000**	**–11 000**
Forest Land	**–69 000**	**–20 000**
Forest Land Remaining Forest Land	–68 000	–19 000
Land Converted to Forest Land	–1 000	–1 200
Cropland	**14 000**	**830**
Cropland Remaining Cropland	–1 500	–8 500
Land Converted to Cropland	16 000	9 300
Grassland	**5 000**	**–**
Grassland Remaining Grassland	NE	NE
Land Converted to Grassland	5 000	NE
Wetlands	**–**	**1 000**
Wetlands Remaining Wetlands	NE	100
Lands Converted to Wetlands	NE	1 000
Settlements	**6 000**	**7 000**
Settlements Remaining Settlements	–200	–200
Land Converted to Settlements	6 000	7 000

Notes:

1 Totals may not add due to rounding.

NE = not estimated

7.3 LAND CATEGORY DEFINITION AND REPRESENTATION OF MANAGED LANDS

In order to harmonize all land-based estimates, a common, definitional framework was elaborated and adopted by all groups involved in estimate preparation. Definitions are consistent with the IPCC (2003) land categories, while remaining relevant to land management practices, prevailing environmental conditions, and available data sources in Canada.

Forest land includes all areas of 1 ha or more where tree formations can reach 25% crown cover and 5 m in height *in situ*. Not all Canadian forests are under the direct influence of human activities, prompting the non-trivial question of what areas properly embody the "managed forests." For the purpose of the GHG inventory, managed forests are those potentially subject to harvesting or to measures of fire protection. Section A3.5 of Annex 3 provides more detail on the implementation of the "managed forests" concept.

Cropland includes all lands in annual and perennial crops, long-term forage (usually herbaceous perennials), specialty crops (berries, grapes, nursery crops, vegetables, and fruit trees), and summerfallow.

Agricultural grassland is defined as "unimproved" pasture or rangeland that is used only for grazing domestic livestock. It occurs only in geographical areas where the grassland would not naturally revert to forest if abandoned: the natural shortgrass prairie in southern Saskatchewan and Alberta and the dry, interior mountain valleys of British Columbia. All agricultural land that is not grassland is classified as cropland, including unimproved pastures where natural vegetation would be forest (eastern Canada and most of British Columbia). Agricultural land comprises both cropland and agricultural grassland.

Vegetation that does not meet the definition of forest land or cropland is generally classified as grassland: extensive areas of tundra in the Canadian north are considered non-managed grasslands.

Wetlands are areas where permanent or recurrent saturated conditions allow the establishment of vegetation and soil development typical of these conditions and that are not already in forest land, cropland, or agricultural grasslands. A national wetland inventory is under preparation (Hélie *et al*., 2003).

Settlements include all built-up land: urban, rural residential, industrial, and recreational; roads, rights-of-way, and other transportation infrastructure; and resource exploration, extraction, and distribution (mining, oil and gas). The diversity of this category has so far precluded an assessment of its extent in the Canadian landscape; however, it is often involved in land conversion, and the impact of forest land conversion to settlements is assessed in this GHG inventory.

As a consequence of the land categorization scheme, some land-use transitions cannot occur — for example, forest conversion to agricultural grassland, since these by definition exclude areas where forests can grow naturally. Note that in theory the opposite can happen (i.e., grassland conversion to forest). 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 2004. Cumulative land-use change areas are the total land areas converted over the past 20 years (10 years for reservoirs). The grassland diagonal cell refers to the total area of agricultural grasslands, whereas grassland converted to settlements refers to land conversion of non-managed tundra to settlements in northern Canada.

The MARS land monitoring system includes the conversion of non-managed forests and grasslands to other land categories. Unmanaged land converted to any use always becomes "managed"; once land has become managed, it does not revert to "unmanaged" status, even if management practices are discontinued. Parks and protected areas are included in managed lands.

With a few exceptions (e.g., emissions due to liming), the LULUCF estimates as reported in the CRF are spatially attached to "reporting zones" (Figure 7-2), a major improvement in this submission. These reporting zones are essentially the same as the terrestrial ecozones (Marshall and Shut, 1999), with three exceptions: the Boreal Shield and Taiga Shield ecozones are split into their east and west components to form four reporting zones; and the Prairies ecozone is divided into a semiarid and a subhumid component. Estimates are reported for 15 of the 18 reporting zones, leaving out the three northernmost ecozones of Canada: Arctic Cordillera, Northern Arctic, and Southern Arctic. More details on the spatial estimating and reporting framework can be found in Section A3.5 in Annex 3.

TABLE 7-3: Land Areas (kha) of Land Use and Land-Use Change in 2004[1]

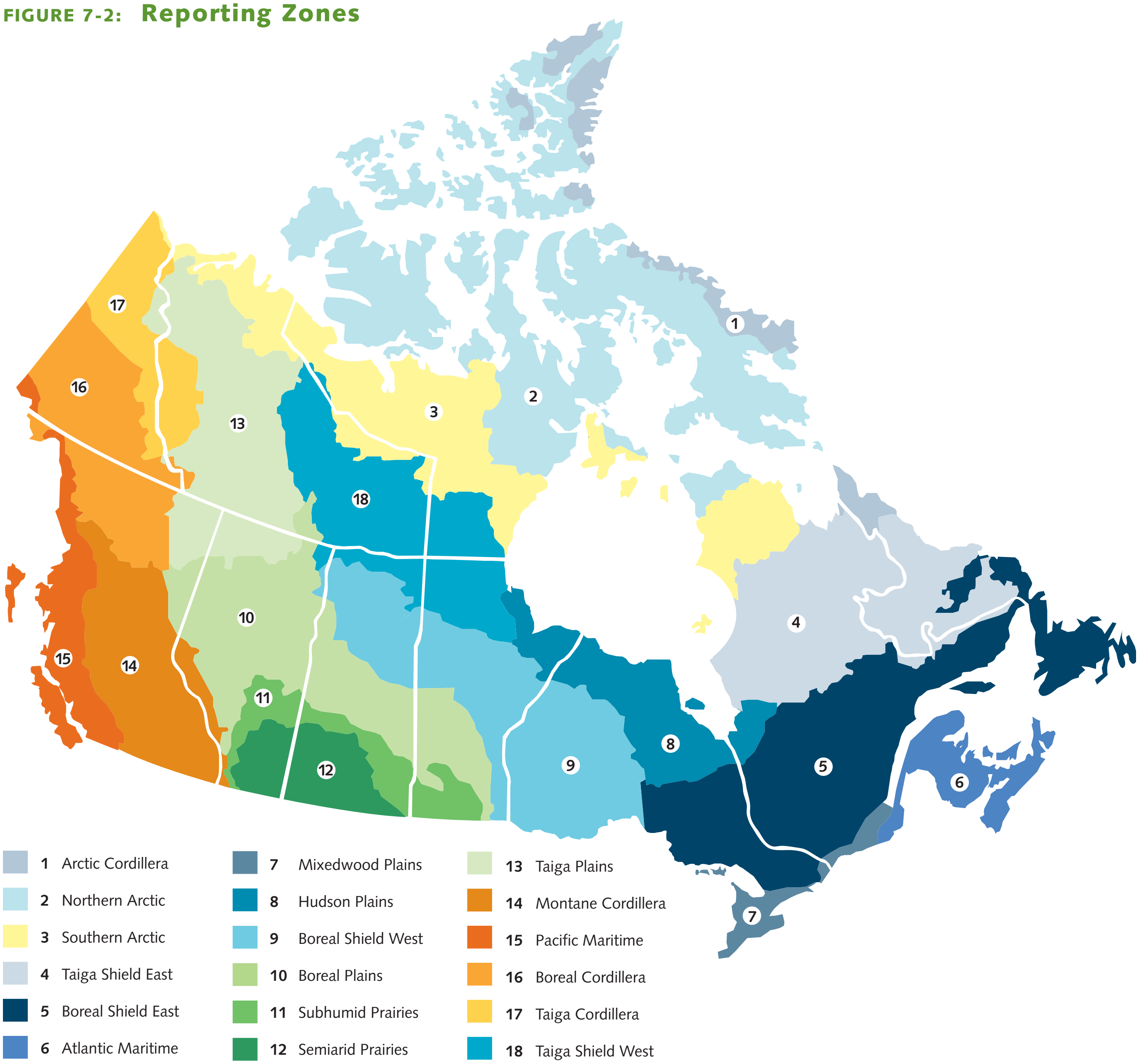
Initial Land Use	Final Land Use					
	Forest	Cropland	Grassland	Wetlands	Settlements	Other
Forest	255×10^3	696	NO	98	396	NO
Cropland	187	49.6×10^3	NO	NE	NE	NO
Grassland	NO	8.3	Ag: 15.4×10^3	NE	0.7	NE
Wetlands	NO	NE	NE	5	NE	NE
Settlements	NO	NE	NO	NO	NE	NO
Other	NO	NO	NO	75	NE	NE

Notes:

1 Non-diagonal cells refer to cumulative areas, i.e., total land converted over the last 20 years (10 years for reservoirs).

NE = not estimated; NO = not occurring; Ag = agriculture

FIGURE 7-2: Reporting Zones



It is important to note that the areas reported in the CRF tables represent those used for annual estimate development, but not always the total land area under a land category or subcategory in a specific inventory year. Hence, areas used for estimate development in the Cropland category represent areas subjected to changes in soil management practices only; areas of land converted to wetlands (reservoirs) represent a fraction of total reservoir areas (those flooded for 10 years or less), not the total area of reservoirs in Canada.

Similarly, the areas of land conversion reported in the CRF tables refer to the cumulative total land area converted over the last 20 years (10 years for reservoirs) and should not be confused with annual rates of land-use change. The trends observed in the land conversion categories of the CRF (e.g., land converted to forest land, land converted to cropland, etc.) result from the balance between land area newly converted to a category and the transfer of lands converted more than 20 years ago (10 years for reservoirs) into the "land remaining land" categories.

7.4 FOREST LAND

Forest and other wooded lands cover 402 Mha of the Canadian territory; forest lands alone occupy 310 Mha (NRCan, 2001). Managed forests, those under the direct influence of humans, extend over 255 Mha, or 83% of all forests. Five reporting zones account for 74% of managed forests (see Table 7-4).

In 2004, the net GHG balance of managed forest land amounted to emissions of 73 Mt (Table 7-1 and CRF Table 5). For the purpose of UNFCCC reporting, managed forest lands are divided into forest lands remaining forest lands (254 943 kha, net emissions of 74 Mt) and land converted to forests (187 kha, net removals of 1.2 Mt). Both categories include net emissions and removals of CO_2, as well as N_2O, CO, and CH_4 emissions from wildfires.

GHG fluxes from and to managed forests are not spatially homogeneous. Table 7-4 illustrates how the 2004 net balance is divided among reporting zones. Note that the spatial distribution of emissions and removals is influenced by the occurrence and location of disturbances and would therefore not be constant in successive years.

TABLE 7-4: GHG Balance of Managed Forests by Reporting Zone, 2004

Reporting Zone Number	Reporting Zone Name	Net GHG Balance (Mt CO_2 eq)
1	Arctic Cordillera	N/A
2	Northern Arctic	N/A
3	Southern Arctic	N/A
4	Taiga Shield East	–3.0
5	Boreal Shield East	–5.9
6	Atlantic Maritime	8.7
7	Mixedwood Plains	–7.4
8	Hudson Plains	N/A
9	Boreal Shield West	–20.0
10	Boreal Plains	37.1
11	Subhumid Prairies	–1.4
12	Semiarid Prairies	N/A
13	Taiga Plains	–18.7
14	Montane Cordillera	3.7
15	Pacific Maritime	22.6
16	Boreal Cordillera	52.8
17	Taiga Cordillera	0.6
18	Taiga Shield West	3.8

Note:
N/A = not applicable

7.4.1 FOREST LAND REMAINING FOREST LAND

7.4.1.1 Methodological Issues

Vegetation absorbs CO_2 from the atmosphere through photosynthesis, and some of this carbon is sequestered in standing vegetation, dead biomass, and soils. CO_2 is returned to the atmosphere by vegetation respiration and the decay of organic matter in dead biomass and soils. The natural CO_2 exchanges between the atmosphere and biota are large fluxes, recycling on the order of one-seventh of the total atmospheric CO_2 content annually. In reality, these large fluxes result from the accumulation of minute processes dispersed over vast land areas.

Human interactions with the land directly alter the size and rate of these natural exchanges of GHGs, in both the immediate and long term. Land-use changes and land-use practices in the past still affect current GHG fluxes to and from the terrestrial biosphere. This long-term effect is a unique characteristic of the LULUCF Sector, which makes it very distinct from other sectors, such as Energy.

While the focus is on anthropogenic impacts on the GHG balance, it is recognized that separating human from natural effects in the LULUCF Sector poses a unique challenge. Humans manipulate biological processes in a myriad of ways and intensities. What we observe is typically the outcome of these various manipulations and their combined interactions with an equally varied biophysical environment. Untangling the various cause-and-effect relationships is still the object of complex scientific inquiries.

In this submission, Canada is implementing a Tier 3 methodology for estimating GHG emissions and removals in managed forests. Substantial methodological improvements were incorporated in the scope and level of detail of the estimation methodology. These include a model-based approach (Carbon Budget Model, CBM-CFS3), which integrates all forest carbon pools; the incorporation of detailed activity data from regional and local forest inventories; spatially referenced data on natural disturbances (fires and insects); and numerous, detailed parameters to simulate natural and disturbance-driven carbon transfers among pools and with the atmosphere. The conceptual approach remains that recommended by the IPCC (2003), in which net removals or emissions are calculated as the difference between CO_2 uptake by growing trees and emissions from forest management activities (harvesting) and natural disturbances (wildfires, insect infestations). The interested reader will find additional information on estimation methodology in Section A3.5 of Annex 3.

Carbon stock changes in managed forests are reported in CRF Table 5A, by reporting zone. The largest carbon fluxes to and from managed forests consist of carbon uptake by growing trees and its release due to the decay of organic matter (respectively –3223 and 2933 Mt CO_2 in 2004). These large, opposite fluxes more or less balance each other throughout the 15-year time series. Much of the interannual variability of the GHG budget of managed forests hinges on the occurrence and severity of fires. During 1990–2004, annual wildfire emissions fluctuated between 14 and 342 Mt. During fires, emissions from dead organic matter are on average 3.7 times higher than emissions from biomass; much biomass is killed by forest fires, but it is not immediately consumed. Hence, a large amount of the actual fuel load consists of dead wood and litter on the forest floor. On average, 8% of immediate fire emissions in CO_2 equivalents are in the form of CO, 7% as CH_4, and 4% in the form of N_2O.

Forest management activities (harvesting) account for annual average emissions of 122 Mt.

In order to avoid double-counting, estimates in CRF Table 5A exclude carbon emissions as CO_2, CH_4, and CO due to biomass burning, which are reported in Table 5(V). Emissions and removals are automatically tallied in CRF Table 5.

In keeping with the current IPCC (2003) default methodology, emissions from forest management activities comprise all the CO_2-C contained in harvested roundwood and harvest residues. All carbon transferred out of managed forests as wood products is deemed an immediate emission. Three alternative approaches — atmospheric flow, production, and stock change — have been preliminarily evaluated in Canada to attempt to correctly account for delayed emissions due to long-term carbon storage in harvested wood products (HWPs). These approaches account for carbon storage in HWPs and emissions from the decay of products harvested, imported (stock change, atmospheric flow), or exported (production) in the current and previous years; they are therefore more spatially and temporally realistic than the current default, which does not account for emissions from HWPs where or when they actually occur. They differ with respect to their allocation of emissions and removals. A breakdown and brief discussion of each of the accounting approaches, along with implications for Canada, are contained in Section A3.5 of Annex 3.

7.4.1.2 Uncertainties and Time-Series Consistency

Considering the already important efforts required for the implementation of improved approaches in this submission, it was not possible, due to resource limitations, to develop formal uncertainty estimates on time for this submission. A discussion of the main uncertainty sources is provided for each land category in Annex 7. The preparation of uncertainty estimates for future inventory submissions has been given a high priority.

All estimates have been developed in a consistent manner, except for wildfire areas in 2004, which were derived from real-time, remotely sensed imagery.

7.4.1.3 QA/QC and Verification

The existing QC procedures described in Annex 6 were adapted to the new inventory preparation flow illustrated in Figure 7-1. New QC checks, implemented and documented by the Canadian Forest Service (CFS), specifically address estimate development in the Forest Land category. Environment Canada, while maintaining its own QA/QC procedures for estimates developed internally, has implemented new ones for estimates obtained from partners, as well as for all estimates and activity data contained in the geodatabase and entered into the CRF reporter.

7.4.1.4 Recalculations

Recalculations in Forest Land estimates are important, in both absolute and relative terms (Figure 7-3). They derive from changes in methods and activity data.

Key methodological changes are the modelling of all forest ecosystem carbon pools, higher spatial resolution of input data, the long-term monitoring of forest ecosystem dynamics and disturbance regimes, and inclusion of insect disturbances. Because the previous and current approaches are radically different, their components are not always comparable. For example, rates of carbon uptake by growing trees should be compared with caution (Table 7-5), because they represent different indicators. Mean annual increment (MAI) and net biomass increment (NBI) were both derived from thousands of inventory records; however, the latter has been updated for the specific time period considered and incorporates more detailed provincial inventories when these were available. Contrary to MAI, NBI is calculated prior to losses from natural processes and includes biomass production that goes to litterfall, root turnover, and non-disturbance mortality (whereas MAI did not). Moreover, NBI refers to total biomass (i.e., including roots), whereas MAI applied to aboveground biomass.

FIGURE 7-3: Trends in the Forest Land Category Reported in the 2005 and 2006 Submissions

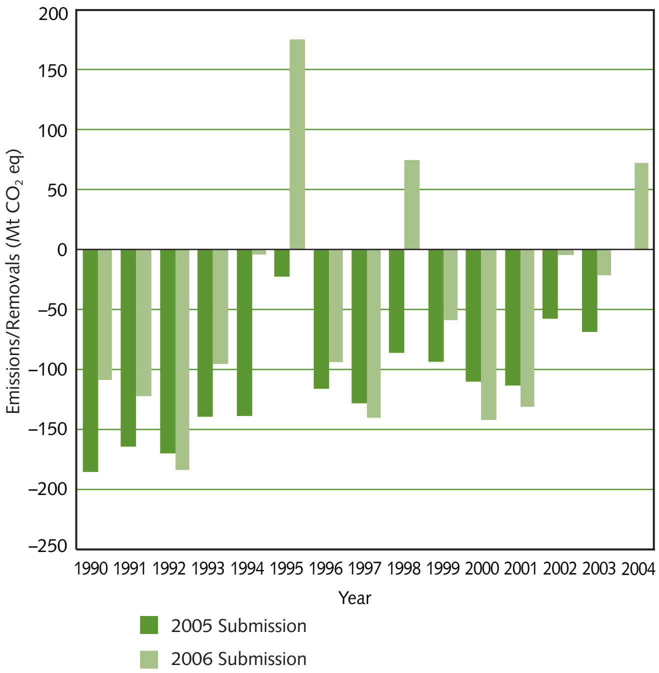


TABLE 7-5: Rates of Carbon Uptake by Growing Vegetation, Reported in the 2005 and 2006 Submissions

Reporting Zone	Mean Annual Increment (2005 Submission) Aboveground Biomass *(t C/ha per year)*	Net Biomass Increment (2006 Submission) Total Biomass *(t C/ha per year)*
Boreal Shield East	0.64	0.48
Taiga Shield East	0.24	0.13
Atlantic Maritime	0.64	0.81
Mixedwood Plains	0.89–1.01	0.83
Boreal Shield West	0.64	0.44
Boreal Plains	0.64	0.65
Prairies (Semiarid and Subhumid)	0.56	0.38
Taiga Plains	0.24	0.52
Taiga Shield West	0.24	0.50
Montane Cordillera	0.66–0.78	0.62
Boreal Cordillera	0.24	0.54
Pacific Maritime	0.71	0.56
Taiga Cordillera	0.28	0.90

Decay was not modelled in previous assessments. It is a large flux, more or less balancing net primary productivity.

In this submission, an empirical implementation of the managed forest area was used that is based not only on forest inventory data, but also on fire protection (Section A3.5 in Annex 3). The comparison of managed forest areas between the 2005 and 2006 submissions is given in Table 7-6. The inclusion of fire protection as a definitional parameter results in large changes in the managed forest area in the Taiga Plains and Taiga Shield reporting zones.

Changing the spatial configuration of managed forest areas altered the areas affected by wildfires, although not in a consistent fashion (Table 7-7). The largest change is in 1994, where wildfires previously deemed outside of the managed forests are now considered within them. In addition, a different approach was used to estimate direct fire emissions, based on disturbance matrices. In each matrix, for each of the 20 carbon pools modelled, a fixed proportion of predisturbance carbon stocks in the pool is transferred to other pools or to the atmosphere. There is no single emission factor, since the proportion of predisturbance carbon emitted as different gases (CO_2, CH_4, and CO) depends on its distribution in the ecosystem carbon pools (see Section A3.5 in Annex 3). Likewise, the GHGs emitted in a unit area of forest burned depend on species composition and the average fire characteristics, which are described with the disturbance matrices defined for each ecological region (Kurz and Apps, 2006).

Insect disturbances affect very large forest areas. However, their immediate impact on carbon emissions is minimal, since most of the biomass killed is transferred into the dead organic matter pool.

TABLE 7-6: Managed Forest Area in the 2005 and 2006 Submissions

2005 Submission		2006 Submission	
Ecozone	**Managed Forest Area** *(kha)*	**Reporting Zone**	**Managed Forest Area** *(kha)*
Arctic Cordillera	0	Arctic Cordillera	0
Northern Arctic	1	Northern Arctic	0
Southern Arctic	32	Southern Arctic	0
Taiga Plains	9 940	Taiga Plains	29 055
Taiga Shield	3 026	Taiga Shield (E + W)	11 638
Boreal Shield	96 372	Boreal Shield (E + W)	85 152
Atlantic Maritime	15 792	Atlantic Maritime	15 943
Mixedwood Plains	3 468	Mixedwood Plains	2 726
Boreal Plains	30 343	Boreal Plains	36 320
Prairies	2 039	Semiarid and Subhumid Prairies	1 832
Taiga Cordillera	266	Taiga Cordillera	904
Boreal Cordillera	11 574	Boreal Cordillera	18 758
Pacific Maritime	9 839	Pacific Maritime	14 897
Montane Cordillera	29 600	Montane Cordillera	37 906
Hudson Plains	1 221	Hudson Plains	0
Total	**213 512**	**Total**	**255 230**

TABLE 7-7: Forest Area Burned in Managed Forests, 2005 and 2006 Submissions

Year	2005 Submission		2006 Submission
	(ha)		
	Total Forest Area Burned	Forest Area Burned in Managed Forests	Forest Area Burned in Managed Forests
1990	994 380	334 769	350 884
1991	1 603 923	827 781	656 818
1992	932 510	275 667	123 004
1993	2 149 462	761 879	979 005
1994	6 220 960	446 754	1 808 272
1995	6 943 520	3 075 418	3 209 054
1996	1 773 956	827 439	684 714
1997	588 449	328 159	201 663
1998	4 406 150	1 476 411	1 920 796
1999	1 739 637	645 817	790 876
2000	522 583	96 464	192 980
2001	570 540	257 687	231 388
2002	2 633 574	1 533 260	1 010 576
2003	2 035 684	898 364	775 625

7.4.1.5 Planned Improvements

Work is under way to develop uncertainty estimates in the Forest Land category. Priorities for method improvements will be elaborated from the results of a sensitivity analysis and ongoing research activities to refine the CBM-CFS3 calibration. Improvements are also planned in data and information management and better integration with MARS partners.

7.4.2 LAND CONVERTED TO FOREST LAND

7.4.2.1 Category Description

This category includes all lands converted to forest land through direct human activity. Post-harvesting tree planting is not included, nor is abandoned farmland where natural vegetation is allowed to grow; hence, the category more precisely refers to forest plantations where the previous land use was not forest (typically abandoned farmland). This definition differs from ones used in previous submissions; differences in areas are provided under the heading Recalculations.

In 1990–2002, softwood plantations, especially spruce and pine, accounted for 90% of the area planted (White and Kurz, 2005). The total cumulative area of land converted to forest land declined from 220 kha in 1990 to 187 kha in 2004. This trend reflects decreasing rates of forest planting in eastern Canada and the gradual transfer of lands afforested more than 20 years ago to the forest land remaining forest land category.

Net removals are stable throughout the period at approximately 1.2 Mt per year. Because the activity data are restricted to plantations younger than 20 years, and considering the relatively slow net increment of plantations in the early years, the subcategory as a whole is not expected to contribute significantly to the net balance of forest lands.

7.4.2.2 Methodological Issues

Up to very recently, afforestation records in Canada were not available. The Feasibility Assessment of Afforestation for Carbon Sequestration (FAACS) initiative collected and compiled afforestation records for 1990–2002 (NRCan, 2005a); activities for 1970–1989 and 2003–2004 were estimated based on activity rates observed in the FAACS data, complemented with 6000 ha of plantations established in 2004 for the Forest 2020/Plantation Demonstration Assessment (NRCan, 2005b) (see Section A3.5 in Annex 3 for details).

GHG emissions and removals on lands newly converted to forests were estimated using CBM-CFS3, as described in Section A3.5 of Annex 3. Changes in soil carbon stocks are highly uncertain, because of difficulties in locating data about the carbon stocks prior to plantation. It was assumed that the ecosystem would generally accumulate soil carbon at a slow rate; the limited time frame of this analysis and the scale of the activity relative to other land-use and land-use change activities suggest that the impact of this uncertainty, if any, is minimal.

7.4.2.3 Uncertainties and Time-Series Consistency

It was not possible, due to resource limitations, to develop formal uncertainty estimates on time for this submission. The preparation of uncertainty estimates for future inventory submissions has been given a high priority.

7.4.2.4 QA/QC and Verification

New QC checks, implemented and documented by the CFS, specifically address estimate development in the Forest Land category. Environment Canada, while maintaining its own QA/QC procedures for estimates developed internally, has implemented new ones for estimates obtained from partners, as well as for all estimates and activity data contained in the geodatabase and entered into the CRF reporter.

7.4.2.5 Recalculations

The total area of lands converted to forest land in 2004 was estimated at 187 kha. The previous submission estimated an annual rate of conversion of approximately 9 kha of abandoned cropland reverting to natural vegetation, and twice as much for grassland. Since the land category definitions have also been modified, a comparison between the two sets of estimates is probably unwarranted.

Removal estimates in the 2005 submission were 0.75 Mt per year, half of the updated ones: indeed, the carbon uptake rates used in the past were admittedly very conservative (0.30–0.44 t C/ha in soils, and 0.5 t C/ha in aboveground biomass).

7.5 CROPLAND

Croplands cover approximately 50 Mha of the Canadian territory. In 2004, the net GHG balance of the Cropland category amounted to emissions of 0.06 Mt (Table 7-1 and CRF Table 5). For the purpose of UNFCCC reporting, Croplands are divided into cropland remaining cropland (net removals of about 9 Mt in 2004) and land converted to cropland, mainly from forest conversion (net emissions of about 9 Mt in 2004). The latter subcategory includes net emissions and removals of CO_2, as well as N_2O, CO, and CH_4 emissions.

7.5.1 CROPLAND REMAINING CROPLAND

This section briefly reviews the methodological issues related to the estimation procedures for CO_2 emissions from and removals by cropland remaining cropland. An enhanced Tier 2 approach is implemented for the first time in this submission to estimate CO_2 emissions from and removals by mineral soils. The calculations and data sources are described in more detail in Section A3.5 of Annex 3.

Cropland remaining cropland includes CO_2 emissions/removals in mineral soils, CO_2 emissions from agricultural lime application and cultivation of organic soils, and CO_2 emissions/removals resulting from changes in woody biomass from specialty crops. Table 7-8 summarizes the trend in emissions and removals for these categories.

TABLE 7-8: Emissions and Removals Associated with Various Land Management Changes on Croplands since 1990

Land Management Practices	Land Management Change	Emissions/Removals		
			(Gg CO_2)	
		1990	2003	2004
Change in Crop Mixture	Increase in Perennial	–1814	–4337	–4567
	Increase in Annual	3188	3885	3954
Change in Tillage	Conventional to RT	–908	–1017	–997
	Conventional to NT	–563	–3345	–3571
	Other Tillage Change	NO	–323	–358
Change in Summerfallow	Increase in Summerfallow	1619	1298	1276
	Decrease in Summerfallow	–4688	–7466	–7646
Residual Emissions[1]		337	2267	2336
Total Mineral Soils		**–2830**	**–9037**	**–9573**
Cultivation of Histosols		296	296	296
Liming		204	288	288
Perennial Woody Crops		38	45	40
Total Cropland Remaining Cropland		**–2292**	**–8408**	**–8949**

Notes:

[1] These net residual CO_2 emissions come from conversion of forest land and grasslands to croplands that occurred more than 20 years prior to the inventory year.

NO = not occurring; RT = reduced tillage; NT = no-tillage

7.5.1.1 CO_2 Emissions and Removals in Mineral Soils

Cultivated agricultural land in Canada includes area of field crops, summerfallow, hayland, and tame or seeded pasture. Cropland occurs in only the nine southernmost reporting zones. About 83% of Canada's cropland is in the interior plains of western Canada, made up of the Semiarid and Subhumid Prairies and Boreal Plains reporting zones.

Mineral soils constitute the majority of cropland areas. The amount of organic carbon retained in soil is a function of primary production and rate of decomposition of soil organic carbon (SOC). Cultivation and management practices can lead to an increase or decrease in organic carbon stored in soils. This change in SOC results in a CO_2 emission to or removal from the atmosphere, as described in the methodological section below.

As can be found in Table 7-8, management of mineral soils amounted to a net CO_2 removal of about 2.8 Mt in 1990. This net sink has steadily increased since then to about 9.6 Mt CO_2 in 2004 because of continuous efforts in reducing summerfallow and increasing conservation tillage (Campbell *et al*., 1996; Janzen *et al*., 1998; McConkey *et al*., 2003). The increase in net sink due to change in summerfallow (from –3.1 Mt in 1990 to –6.4 Mt in 2004) is supported by a 40% decrease in total summerfallow area over 1990–2004. The increase in net sink due to adoption of conservation practices (from –1.5 Mt in 1990 to –4.9 Mt in 2004) is substantiated by a net total increase of 7 Mha in NT area and 2 Mha in RT over the 1990–2004 period. The net change in perennial versus annual crops has had a much more modest impact.

The net increase in sink from the change in management practices over time was partially offset by an increase since 1990 in net residual CO_2 emissions from annual dead organic matter and soil decomposition on land converted to cropland more than 20 years prior to the inventory year (emissions from land converted for less than 20 years are included in the land converted to cropland category). The increase since 1990 in these residual emissions after 20 years is due to an accounting artefact, because deforestation monitoring goes back only to 1970. In the CRF, these emissions are split under the dead organic matter and soil pools (as opposed to only the soil pool).

Methodological Issues

Following the IPCC Good Practice Guidance for LULUCF (IPCC, 2003), it was assumed that the changes in SOC were driven by changes in soil management. Where no change in management was detected, it is assumed that mineral soils are neither sequestering nor losing carbon.

VandenBygaart *et al*. (2003) compiled published data from long-term studies in Canada to assess the effect of agricultural management on SOC. A number of management practices are known to increase SOC in cultivated cropland. They include a reduction in tillage intensity, intensification of cropping systems, adoption of yield-promoting practices, and reestablishment of perennial vegetation (Janzen *et al*., 1997; Bruce *et al*., 1999). This compendium provided the basis for selecting the key management practices and management changes to be used for estimating changes in soil carbon stocks. The availability of activity data (time series of management practices) from the Census of Agriculture was also taken into account.

CO_2 estimates in mineral soils were derived from the following land management change (LMC) types:

- change in mixture of cropland type;
- change in tillage practices; and
- change in area of summerfallow.

Other LMCs, such as changes in irrigation, manure application, and fertilization, are also known to have positive impacts on SOC, although the effect is often small. The lack of activity data for these LMCs was a barrier for inclusion in the inventory at this time. It was assumed that LMCs not considered would not result in large changes in soil carbon stocks in mineral soils.

Carbon emissions and removals were estimated by applying country-specific carbon emission and removal factors multiplied by the relevant area of land that underwent a management change. Calculations were performed at a high degree of spatial disaggregation — namely, by Soil Landscapes of Canada (SLC) polygons (see Annex 3, Section A3.5.1). The carbon emission/removal factors represent the rate of SOC change per year and per unit area that underwent an LMC. For a given year, the annual soil carbon emissions from and removals by an area that underwent a specific LMC in a specific polygon can be expressed as:

Equation 7-1:

$$\Delta C = F * A$$

where:

ΔC = change in soil carbon stock (Mg C)

F = average annual change in SOC subject to LMC (Mg C/ha per year)

A = area of change in LMC (ha)

In theory, a more accurate estimate of soil carbon stock change could be derived by individually considering the cumulative effects of the long-term management history of each piece of land or farm field. However, limits are imposed by the availability of activity data. At this point of development, the inventory relies extensively on the Census of Agriculture to estimate the areas of LMC involved (i.e., changes in tillage, types of crop, and fallow). Since only the area of each practice is known for each Census year, only the net area of change in land management practice can be estimated for each SLC polygon. Estimates based on these LMCs are as close to gross area of LMC as is feasible for regional or national analyses. The area of LMC was determined individually for 3264 SLC polygons having agricultural activities, each one having an area in the order of 1000–100 000 ha. This is the finest possible resolution of activity data, given the limitations imposed by confidentiality requirements of Census data.

The methods require two key assumptions: additivity and reversibility of carbon factors. Additivity assumes that the combined effects of different LMCs or LMCs at different times would be the same as the sum of factors for each individual LMC. Reversibility is the assumption that the carbon effects of an LMC in one direction (e.g., converting annual crops to perennial crops) is the opposite of the carbon effects of the LMC in the opposite direction (e.g., converting perennial crops to annual crops).

The various carbon factors associated with each particular situation (in both space and time) were derived using the CENTURY model (Version 4.0) by comparing output for scenarios "with" and "without" the management change in question. In specific instances, empirical data were used to complement the results of the CENTURY runs. More detailed methodologies for determining carbon factors and other key parameters can be found in Section A3.5 of Annex 3.

Uncertainties and Time-Series Consistency

The following presents partial results of the preliminary uncertainty analysis, which will be completed in the next submission. Uncertainties associated with the area of land management on an ecodistrict scale decreased from ±20%, where the land management area represented a small proportion of total agricultural area (e.g., 5%), to ±5%, where the land management area represented half of the agricultural area. These uncertainties were corroborated where possible by comparing Census data with results from earth observation or other independent data sources.

Uncertainties in carbon change factors were estimated from i) variability in factors predicted by the CENTURY-based procedure described previously over ecozones and ii) variability in empirical results when there were numerous experiments within an ecozone. The uncertainties of carbon stock change factors were typically in the range of ±100% (B. McConkey, AAFC, personal communication). Much of this variability was due to varying effects of LMCs given various initial carbon stock levels that reflect different historical management and interactions of specific LMCs with other current management practices.

The same methodology was used for the entire time series of estimates.

QA/QC and Verification

Emissions and removals of CO_2 from cropland remaining cropland, as a key category, have undergone for this submission the Tier 1–level QC checks as elaborated in the framework for the QA/QC plan (SNC Lavalin, 2004: see Annex 6 for further details) in a manner consistent with IPCC Good Practice Guidance (IPCC, 2000). Quality checks were also performed and documented by AAFC, which derived these estimates. In addition, the activity data, methodologies, and changes are documented and archived in both paper and electronic form.

Recalculations

Recalculations have been carried out for the full time series because of the complete change in methodologies and activity data. The 1990 estimate for mineral soils reported in 2005 was a net source of 7.1 Mt. The 1990 value now displays a net sink of 2.8 Mt.

Recalculations also increased the 2003 sink from 1.7 Mt to 9 Mt. The long-term trend of increased sequestration between 1990 and 2003 was reduced by about 2.7 Mt. The new methodology is radically improved, as it is more consistent in both time and space. The new approach provides for a more complete coverage of croplands (increased area because of the change in definitions and broader data sources). The approach is more comprehensive and balanced, as the land management practices that most affect SOC (through change, both positively and negatively) are tracked and included.

Planned Improvements

In addition to completing the uncertainty analysis for this category, work is ongoing to reduce uncertainties associated with the modelled carbon factors, through general improvements to factor methodologies, validation, and removal of assumptions where possible. Publication of the methodology is also planned. Improvements to the CENTURY model and the use of alternative models are also being explored, to improve the simulation of Canadian agricultural conditions.

7.5.1.2 CO_2 Emissions from Lime Application

Limestone ($CaCO_3$) or dolomite ($CaMg(CO_3)_2$) is often used to neutralize acidic mineral and organic soils, increase the availability of soil nutrients, in particular phosphorus, reduce the toxicity of heavy metals, such as aluminium, and improve the crop growth environment. During this neutralization process, CO_2 is released in the following bicarbonate equilibrium reactions that take place in the soil:

$CaCO_3 + 2H^+ = CO_2 + Ca^{2+} + H_2O$

$CaMg(CO_3)_2 + 4H^+ = 2CO_2 + Ca^{2+} + Mg^{2+} + 2H_2O$

The rate of release will vary with soil conditions and the types of compounds applied. In most cases where lime is applied, applications are repeated every few years. For the purposes of the inventory, it was assumed that the rate of lime addition is in near equilibrium with the rate of lime consumed from previous applications.

Methodological Issues

Emissions associated with the use of lime were calculated from the amount and composition of the lime applied annually — specifically, the respective stoichiometric relationships that describe the breakdown of limestone and dolomite into CO_2 and other minerals. Methods and data sources are outlined in Section A3.5 of Annex 3.

Uncertainties and Time-Series Consistency

The uncertainty associated with annual lime consumption activity data was assessed to be ±50% (B. McConkey, AAFC, personal communication). The overall uncertainty associated with this source of emissions using the IPCC Tier 2 approach has not been estimated at this time.

The same methodology is used for the entire time series of emission estimates (1990–2004).

QA/QC and Verification

This category has undergone for this submission the Tier 1–level QC checks as elaborated in the framework for the QA/QC plan (SNC Lavalin, 2004: see Annex 6 for further details) in a manner consistent with IPCC Good Practice Guidance (IPCC, 2000). The activity data, methodologies, and changes to methodologies are documented and archived in both paper and electronic form.

Recalculations

No recalculation has been carried out for this source category.

Planned Improvements

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

7.5.1.3 CO_2 Emissions from Cultivation of Organic Soils

Category Description

In Canada, cultivated organic soils are defined as the conversion of organic soils to agriculture for annual crop production, normally accompanied by artificial drainage, cultivation, and liming. Organic soils used for agriculture in Canada include the Peaty Phase of Gleysolic soils, Fibrisols over 60 cm thick, and Mesisols and Humisols over 40 cm thick.

Methodological Issues

The emissions from the cultivation of organic soils were calculated by multiplying the total area of cultivated histosols by the updated default emission factor of 5 t C/ha per year as found in the 2006 IPCC Guidelines (IPCC, 2006).

Areas of cultivated histosols are not provided by the Census of Agriculture; area estimates were based on the expert opinion of soil and crop specialists across Canada (G. Padbury and G. Patterson, personal communication). The total area of cultivated organic soils in Canada (constant for the period 1990–2004) was estimated to be 16 kha.

Uncertainties and Time-Series Consistency

The uncertainty associated with the area estimate of cultivated histosols is assessed to be ±50% (Hutchinson *et al*., 2006). The uncertainty associated with the emission factor as provided in the 2006 IPCC Guidelines (IPCC, 2006) is ±90%. The overall uncertainty associated with this source of emissions through simple Tier 1 error propagation is ±100%.

The same methodology and emission factors are used for the entire time series of emission estimates (1990–2004).

QA/QC and Verification

This category has undergone for this submission the Tier 1–level QC checks as elaborated in the framework for the QA/QC plan (SNC Lavalin, 2004: see Annex 6 for further details) in a manner consistent with IPCC Good Practice Guidance (IPCC, 2000). The activity data, methodologies, and changes to methodologies are documented and archived in both paper and electronic form.

Recalculations

Recalculations have been carried out because of updates in activity data and the emission factor and have resulted in a small increase in emissions. Recalculations had no impact on the long-term trend.

Planned Improvements

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

7.5.1.4 CO_2 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 in the present submission, and they contribute a minuscule source of about 40 Gg CO_2; changes in woody biomass from “abandoned cropland” on cropland remaining cropland are excluded.

Methodological Issues

Vineyards, fruit orchards, and Christmas tree farms are intensively managed for sustained yields. Vineyards and fruit trees are pruned annually, and old plants are replaced on a rotating basis for disease prevention, stock improvement, or introduction of new varieties. For all three crops, it was assumed that, because of rotating practices and the requirements for sustained yield, a uniform age-class distribution is generally found on production farms. Hence, there would be no net increase or decrease in biomass carbon within existing farms, as carbon lost from harvest or replacement would be balanced by gains due to new plant growth. The approach therefore was limited to detecting changes in areas under vineyards, fruit orchards, or Christmas tree plantations and estimating the corresponding carbon stock changes in total biomass. More information on assumptions and parameters can be found in Section A3.5 of Annex 3.

Uncertainties and Time-Series Consistency

Uncertainty of the carbon stock change in woody biomass of vineyards, fruit trees, and Christmas tree farms was not estimated.

The same methodology was used for the entire time series of emission estimates (1990–2004).

QA/QC and Verification

This category has undergone for this submission the Tier 1–level QC checks as elaborated in the framework for the QA/QC plan (SNC Lavalin, 2004: see Annex 6 for further details) in a manner consistent with IPCC Good Practice Guidance (IPCC, 2000). The activity data, methodologies, and changes to methodologies are documented and archived in both paper and electronic form.

Recalculations

No recalculation has been carried out for this new category.

Planned Improvements

The uncertainty of these estimates will be assessed.

7.5.2 LAND CONVERTED TO CROPLAND

This section covers the conversion of forest land and grassland to cropland. The methods for area determination and estimate development differ in each case. This section describes estimate development only for soil carbon and soil N_2O emissions following land conversion to cropland. Estimation approaches for other pools (upon forest conversion to cropland such as biomass and dead organic matter), including those due to controlled burning, are described in Section 7.9, Forest Conversion.

7.5.2.1 Forest Land Converted to Cropland

Clearing forest for use as agricultural land is an ongoing but declining practice in Canada. The total cumulative area of forest land converted to cropland was 1300 kha in 1990 and decreased to 696 kha in 2004. Total emissions in 2004 from soils amounted to 1.5 Mt. This includes the net carbon losses from soils due to the actual land conversion and a very small net CO_2 sink from change in management practices (tillage, etc.) since the cropland was converted (using the same methods as for cropland remaining cropland), as well as the N_2O emissions following the conversion. As explained below, patterns of change in SOC after the conversion of forest to cropland clearly differ between eastern and western Canada.

Methodological Issues

- **Eastern Canada**

Generally, all land in the provinces of Ontario, Quebec, New Brunswick, Prince Edward Island, Nova Scotia, and Newfoundland and Labrador was forested before its land use was changed to agriculture. There are many observations that compare SOC for land under forest with SOC for adjacent land used for agricultural purposes in eastern Canada. The mean loss of carbon was 20.3% for depths to approximately 20–40 cm (see Section A3.5). Average nitrogen change was –5.2%, representing 0.4 Mg N/ha. For those comparisons where both nitrogen and carbon losses were determined, the corresponding carbon loss was 19.9 Mg C/ha. Therefore, it was assumed that nitrogen loss was a constant 2% of carbon loss.

The CENTURY model (Version 4.0) is used to estimate the SOC dynamics from conversion of forest land to cropland in eastern Canada. More details of methodologies for determining the maximal carbon loss and its rate constant associated with the conversion of forest land can be found in Section A3.5.

Following a Tier 2–type methodology, as was done for direct N_2O emissions from agricultural soils (see Agriculture Sector, Chapter 6), emissions of N_2O from forest conversion to cropland were estimated by multiplying the amount of carbon loss by the fraction of nitrogen loss per unit of carbon and by an emission factor (EF_{BASE}). EF_{BASE} was determined for each ecodistrict using the precipitation over evapotranspiration variable P/PE (Section A3.5).

- **Western Canada**

Much of the current agricultural soil in western Canada (Saskatchewan, Alberta, and British Columbia) was under grassland in native condition. Hence, deforestation has been primarily of forest that lies on the fringe of former grassland areas.

The Canadian Soil Information System (CanSIS) data provide the most numerous comparisons of SOC under forest with that under agriculture. On average, these data suggest that there is no loss of SOC from deforestation and that, in the long term, the balance between carbon input and SOC mineralization under agriculture remains similar to what it was under forest.

It is important to recognize that along the northern fringe of western Canadian agriculture, where most deforestation is occurring, the land is marginal for arable agriculture, and pasture and forage crops are important land uses.

For western Canada, no loss of SOC over the long term was assumed from deforestation to cropland managed exclusively for seeded pastures and hayland. The carbon loss from deforestation in western Canada is therefore from the loss of above- and belowground tree biomass and from loss or decay of other above- and belowground coarse woody dead organic matter that existed in the forest at the time of deforestation (see Section A3.5). The average nitrogen change in western

Canada for sites at least 50 years from breaking was +52%, reflecting substantial added nitrogen in agricultural systems compared with the situation in forests (Section A3.5). However, recognizing the uncertainty about actual carbon–nitrogen dynamics for deforestation, loss of forest land to cropland in western Canada was assumed not to be a source of N_2O.

Uncertainties and Time-Series Consistency

The overall uncertainty associated with emissions on forest land converted to cropland has not been estimated at this time. Uncertainty of the deforestation area estimates can be found in Section 7.9.

The same methodology and emission factors are used for the entire time series of emission estimates (1990–2004).

QA/QC and Verification

This category has undergone for this submission the Tier 1–level QC checks as elaborated in the framework for the QA/QC plan (SNC Lavalin, 2004: see Annex 6 for further details) in a manner consistent with IPCC Good Practice Guidance (IPCC, 2000). Quality checks were also performed internally by AAFC, which derived the estimates of SOC change. The activity data, methodologies, and changes to methodologies are documented and archived in both paper and electronic form.

Recalculations

As in all forest-related land categories, forest land conversion to cropland has undergone substantial recalculations, due to the implementation of new approaches for estimating the areas of forest land conversion and the corresponding carbon stock changes and emissions. For the sake of conciseness, Section 7.9.4 discusses these recalculations and their impact on all forest conversion estimates.

Planned Improvements

Work to estimate the uncertainty of SOC change and N_2O estimates in this category is being undertaken, as well as work to improve and validate the soil carbon change factors.

7.5.2.2 Grassland Converted to Cropland

Conversion of native grassland to cropland occurs in the Prairie region of the country and generally results in losses of SOC and soil organic nitrogen and emissions of CO_2 and N_2O to the atmosphere. It was assumed that there was no loss of aboveground, belowground, or dead organic matter upon conversion. Total emissions in 2004 from soils amounted to 0.4 Mt. This includes the carbon losses and N_2O emissions from the conversion itself, as well as a sink from adoption of new practices on the croplands since conversion.

Methodological Issues

A number of studies on changes of SOC and soil organic nitrogen in grassland converted to cropland have been carried out on the Brown, Dark Brown, and Black soil zones of the Canadian Prairies, and these results are summarized in Section A3.5 of Annex 3. The average loss of SOC, weighted for number of locations across landscape positions, was 22%, and the corresponding average change in soil organic nitrogen was 0.06 kg N lost/kg C.

The CENTURY model (Version 4.0) is used to estimate the SOC dynamics from breaking of grassland to cropland for the Brown and Dark Brown Chernozemic soils. More details of methodologies for determining the maximal carbon loss and its rate constant associated with the breaking of grassland can be found in Section A3.5.

Similar to N_2O emissions in forest converted to cropland, emissions of N_2O in grassland converted to cropland were estimated by a Tier 2 methodology, multiplying the amount of carbon loss by the fraction of nitrogen loss per unit of carbon by an emission factor (EF_{BASE}). EF_{BASE} was determined for each ecodistrict using precipitation over potential evapotranspiration (P/PE) data (see Section A3.5).

Uncertainty and Time-Series Consistency

Conversion of grassland to cropland was determined from information in the Census, so the basic method of estimating the uncertainty of carbon change is similar to that outlined for LMCs on cropland. The exception was that error propagation was not used because it was assumed that uncertainty of carbon loss from conversion of grassland to cropland was skewed, so that there is more likelihood of larger carbon losses than of small carbon losses. The distribution was assumed to be lognormal, with a standard deviation of 50% of mean loss. This uncertainty reflects the fact that there are no instances where there has not been an observed loss of carbon from the conversion of grassland to cropland and several instances of large relative losses. However, the overall uncertainty estimation associated with emission estimates on grassland converted to cropland has not been completed in time for this submission.

The same methodology and emission factors are used for the entire time series of emission estimates (1990–2004).

QA/QC and Verification

This category has undergone for this submission the Tier 1–level QC checks as elaborated in the framework for the QA/QC plan (SNC Lavalin, 2004: see Annex 6 for further details) 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

This is a new reporting category for Canada, and no recalculations have been carried out.

Planned Improvements

Work to estimate uncertainty of SOC change and N_2O estimates for this category is being undertaken, as well as work to improve and validate the soil carbon change factors.

7.6 GRASSLAND

Estimation of GHG emissions from and removals by (managed) grassland remaining grassland is a reporting requirement under the UNFCCC brought about by the IPCC Good Practice Guidance for LULUCF (IPCC, 2003: Chapter 3.4, "Grassland").

Agricultural grassland is defined under the Canadian LULUCF framework as "unimproved" pasture or rangeland that is used only for grazing domestic livestock. It occurs only in geographical areas where the grassland would not naturally revert to forest if abandoned: the natural shortgrass prairie in southern Saskatchewan and Alberta and the dry, interior mountain valleys of British Columbia. Agricultural grassland is found in two reporting zones: Semiarid Prairies (5566 kha in 2001) and the Montane Cordillera (159 kha in 2001). IPCC Good Practice Guidance for LULUCF (IPCC, 2003) methodology indicates that it is the change in management that triggers a change in carbon stocks. Very little information is available on management practices on agricultural grassland as defined in the land-use framework. Where there is grazing, it is unknown whether the land is improving or degrading. Therefore, Canada reports this grassland remaining grassland category as not estimated. More details on the rationale for not estimating this category are provided in Section A3.5 of Annex 3. The category land converted to grassland, within the current definitional framework as explained in Section 7.3, is reported either as not estimated (wetlands converted to grassland) or as not occurring (Table 7-3).

7.7 WETLANDS

In Canada, a wetland is land that is saturated with water long enough to promote wetland or aquatic processes, as indicated by poorly drained soils, hydrophytic vegetation, and various kinds of biological activity that are adapted to a wet environment — in other words, any land area that can keep water long enough to let wetland plants and soils develop. As such, wetlands cover about 14% of the land area of Canada (Environment Canada, 2003). The Canadian Wetland Classification System groups wetlands into five broad categories: bogs, fens, marshes, swamps, and shallow water (National Wetlands Working Group, 1997).

However, for the purpose of this report and in compliance with land categories as defined in IPCC (2003), the Wetlands category should be restricted to those wetlands that are not already in the forest, cropland, or grassland categories. There is no corresponding area estimate for these wetlands in Canada.

This submission is the first to report on emissions from and removals by managed wetlands. Reporting requirements under this category arose from the adoption of the IPCC *Good Practice Guidance for Land Use, Land-Use Change and Forestry* report (IPCC, 2003), where the Wetlands category was established. The IPCC Good Practice Guidance for LULUCF report (IPCC, 2003) emphasized the conversion of forest to managed wetlands. As the conversion of forest to wetlands is believed to occur in Canada, the submission of estimates under the Wetlands category will enhance compliance with reporting requirements and improve the estimate of forest conversion.

Two types of managed wetlands are considered, where human intervention has directly altered the water table level and thereby the dynamics of GHG emissions/removals: peatlands drained for peat harvesting; and flooded land (namely, the creation of reservoirs). Owing to their differences in nature, GHG dynamics, and the general approaches to estimating emissions and removals, these two types of managed wetlands are considered separately.

7.7.1 MANAGED PEATLANDS

7.7.1.1 Source Category Description

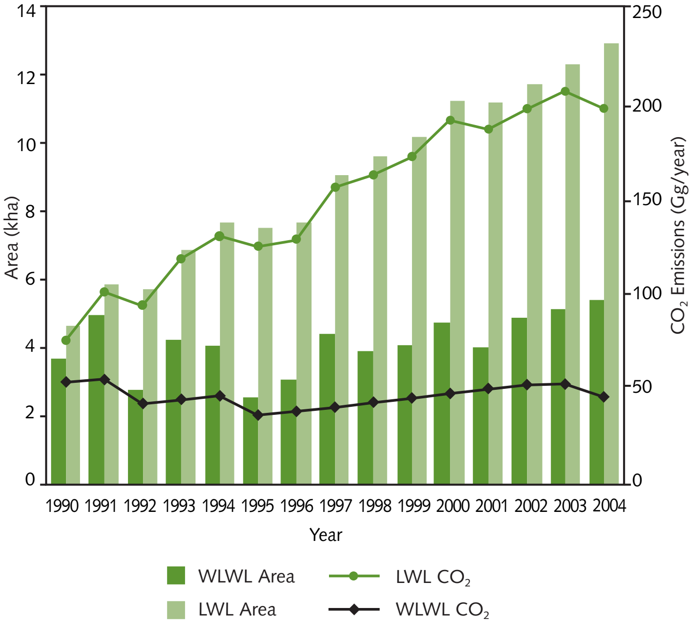
Of the estimated 123 Mha of peatlands in Canada,[39] approximately 18 kha are, or were at some point in the past, drained for peat extraction. Some 14 kha are currently being actively managed, the difference (4 kha) being peatlands that are no longer under production. In the Canadian context, generally only bog peatlands with a peat thickness of 2 m or greater and an area of 50 ha or greater are of commercial value for peat extraction (Keys, 1992 in Cleary, 2003). Peat production is concentrated in the provinces of New Brunswick, Quebec, and Alberta. Canada produces only horticultural peat.

Since the 1980s, virtually all peat extraction in Canada has relied on the vacuum harvest technology; approximately 100 t/ha (wet basis) of horticultural peat is extracted with this technology (Cleary, 2003). A drawback of the technology, as opposed to the former cut-block method, is poor natural vegetation regrowth in the post-production phase. In the 1990s, peatland restoration activities took on greater significance.

Peat extraction activities expanded in the 1990s, with a doubling of the land area under active peat extraction. Owing to this expansion and to the significant contribution of vegetation clearing and removal to the overall GHG budget, emissions from land conversion to managed peatlands show a significant increase over the assessment period (Figure 7-4), while emissions from managed peatlands remaining in the same category are relatively stable.

Emissions from managed peatlands are reported under land converted to wetlands for the first 20 years after conversion and under wetlands remaining wetlands thereafter.

FIGURE 7-4: Areas and CO_2 Emissions from Managed Peatlands in 1990–2004 (LWL = land converted to wetlands; WLWL = wetlands remaining wetlands)



7.7.1.2 Methodological Issues

CO_2 is the dominant GHG emitted from commercial peatlands and the only gas reported under this category. The general phases of peat extraction are i) drainage, ii) vegetation clearing, iii) extraction, iv) stockpiling, v) abandonment, and vi) peatland restoration and natural revegetation. The main sources of emissions are vegetation clearing upon conversion, the continuing decay of dead organic matter piled on the sides of peat fields, and the rapid oxidation of exposed peat, resulting in a threefold increase in CO_2 emission rates (Waddington and Warner, 2001). Estimates were developed using a Tier 2 methodology, based on domestic emission factors. They include emissions and removals during all five phases. More information on estimation methodology can be found in Section A3.5 of Annex 3.

Note that the methodology does not include carbon losses from the peat transported off site; should these be included, total emissions from managed peatlands would significantly increase.

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[39] This area includes peatlands that would be classified as forest, cropland, and grassland in the IPCC land classification.

7.7.1.3 Uncertainty and Time-Series Consistency

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 biomass carbon density (20 t C/ha) was assumed, except when suitable information on forest conversion to managed peatlands was received from the CFS, in which case emissions from merchantable biomass were included.

It is very difficult to obtain up-to-date information on the areas of managed peatlands; areas reported here were modelled based on peat production data (Cleary, 2003). This introduces a significant uncertainty, since production is strongly influenced by summer weather conditions; fluctuations in peat production should not in theory modify the commercial peatland area. In addition, the fate of abandoned peatlands is not monitored in Canada; older peat fields could have been converted to other uses. Therefore, the area estimate of abandoned peatlands is probably conservative.

Finally, soil drainage may affect the surrounding peatlands, even though these would not be actively managed. Should this be the case, the impact of peatland drainage should be estimated based on an area larger than the peat extraction sites.

7.7.1.4 QA/QC and Verification

Annex 6 describes the general QA/QC procedures being implemented for Canada's GHG inventory; they apply to this category as well.

7.7.1.5 Recalculations

This is a new reporting category for Canada, and no recalculations have been carried out.

7.7.2 FLOODED LANDS (RESERVOIRS)

Reporting emissions from land conversion to flooded land is a new requirement brought about by the IPCC Good Practice Guidance for LULUCF (IPCC, 2003). Canada is reporting estimates in this category for the first time. Since this is a relatively new reporting area, work is still ongoing, and refinements will be made in consultation with scientists in industry, academia, and government to ensure that the best and most relevant data available are utilized.

Although this category includes in theory all flooded lands regardless of purpose, owing to data limitations, this submission includes only 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 1980, land conversion to flooded lands occurred in reporting zones 4, 5, 8, 10, and 14. The total land area flooded for 10 years or less declined from 883 kha in 1990 to 157 kha in 2004. In 2004, 61% of the 157 kha of reservoirs, or 95 kha, had previously been unmanaged forests.

Emissions declined from a little over 5 Mt in 1990 to less than 1 Mt in 2004.

7.7.2.1 Methodological Issues

Two estimation methodologies were used to account for GHG fluxes from flooded lands, depending on land conversion practices. When there was evidence of forest clearing during reservoir construction, carbon stock changes were estimated as in all forest conversion events, with the CBM-CFS3 (see Section 7.9 below and Section A3.5). In the absence of such evidence, it was assumed that all vegetation was simply flooded. Evidence of forest clearing was restricted to the margins of a few future reservoirs located in reporting zones 4 and 5. The two methodologies are mutually exclusive, since they apply to different areas.

The default approach to estimate emissions from flooding assumes that all forest biomass carbon is emitted immediately (IPCC, 2003). In the Canadian context, this approach would overestimate emissions from reservoir creation, since the largest proportion of any submerged vegetation does not decay for an extended period of time. A domestic approach was developed and used to estimate emissions from reservoirs based on measured CO_2 fluxes above reservoir surfaces, consistent with the descriptions of Tier 2 methodology (IPCC, 2003, 2006). Section A3.5 in Annex 3 contains more detail on this estimation methodology.

In keeping with good practice, only CO_2 emissions are included in the assessment. As recommended in the IPCC Good Practice Guidance for LULUCF (IPCC, 2003) and in the 2006 IPCC Guidelines (IPCC, 2006), the scope of the assessment is also limited to 10 years after flooding, as an attempt to minimize the potential double-counting of carbon lost from managed lands in the watershed in the form of dissolved organic carbon and subsequently emitted from reservoirs. Therefore, only CO_2 emissions are calculated for hydroelectric reservoirs where known flooding occurred from 1980 to 2004.

For each reservoir, the proportion of pre-flooding area that was forest is used to apportion the resulting emissions to the categories forest land converted to wetlands and other land converted to wetlands.

It is important to note that fluctuations in the area of lands converted to wetlands (reservoirs) reported in the CRF tables are not indicative of changes in current conversion rates, but reflect the difference between land areas recently (<10 years ago) converted to reservoirs and older reservoirs (>10 years), whose areas are thus transferred out of the accounting. The reporting system does not encompass all the reservoir areas in Canada, which are monitored separately in the Canadian Reservoir Database.

7.7.2.2 Uncertainties and Time-Series Consistency

For forest land converted to wetlands, please see the corresponding subheading in Section 7.9, Forest Conversion.

Section A3.5 in Annex 3 discusses the uncertainty associated with the Tier 2 estimation methodology.

Owing to current limitations in LULUCF estimation methodologies, it is not possible to fully monitor the fate of dissolved carbon and ensure that it is accounted for under the appropriate land category. The possibility of double-counting in the Wetlands category is, however, limited to watersheds containing managed lands, which would exclude several large reservoirs in reporting zones 4 and 5. Ongoing scientific work will attempt to address this issue more fully, also including a comparative analysis between different estimation approaches.

7.7.2.3 QA/QC and Verification

Annex 6 describes the general QA/QC procedures being implemented for Canada's GHG inventory; they apply to this category as well.

For forest land converted to wetlands, please see also the corresponding subheading in Section 7.9, Forest Conversion.

7.7.2.4 Recalculations

This is a new reporting category for Canada, and no recalculations have been carried out.

7.8 SETTLEMENTS

The Settlements category is very diverse, including all roads and transportation infrastructure; rights-of-way for power transmission and pipeline corridors; residential, recreational, commercial, and industrial lands in urban and rural settings; and land used for resource extraction other than forest (oil and gas, mining).

In settlements remaining settlements, urban trees contribute very little to the national GHG budget. Preliminary estimates indicate modest removals in the order of 0.16 Mt.

For the purpose of this inventory, two types of land conversion to settlement were estimated: forest land conversion to settlements, and non-forest conversion to settlements in the Canadian north. In 2004, 417 kha of lands converted to settlements accounted for emissions of 7 Mt. Forest conversion to settlements represents over 99% of these emissions. The conversion of cropland to settlements is known to occur in Canada; an estimation methodology is under development.

7.8.1 SETTLEMENTS REMAINING SETTLEMENTS

This category includes estimates of carbon sequestration in urban trees. No modification has been made in activity data or methods since the last submission. This component, although approximate, makes a very minor contribution to the LULUCF Sector and represents a low priority for improvement.

7.8.2 LANDS CONVERTED TO SETTLEMENTS

7.8.2.1 Source Category Description

This section covers non-forest conversion to settlements in the Canadian north. Section 7.9, Forest Conversion, summarizes issues and emissions associated with the conversion of forest to settlements.

7.8.2.2 Methodological Issues

Resource development in Canada's vast northern ecumene is the dominant driver of land-use change. An accurate estimation of this direct human impact in northern Canada requires that activities be geographically located and the pre-conversion vegetation known — a significant challenge, considering that the area of interest extends over 359 Mha, intersecting with six reporting zones (2, 3, 10, 13, 17, and 18). A number of information sources were used to identify areas of high land-use change potential and narrow down the geographical domain of interest. These areas were targeted for change detection analysis using 23 Worldwide Reference System Landsat frames from circa 1985, 1990, and 2000. The scenes cover more than 8.7 million hectares (56%) of the potential land-use change area identified using the geographic information system (GIS) data sets. Lack of available imagery prevented the implementation of the system beyond 2000.

The average rate of land-use change between 1985 and 2000 over the assessed area was 666 ha/year; 70% of land-use change areas occurred in reporting zone 13. The same annual rate of land-use change was applied for the years 2001–2004.

A series of aboveground biomass maps in 2000 were developed for the main land-use change areas, using relationships between aboveground biomass and remote sensing data constructed from and calibrated with ground measurements. These maps were used to determine CO_2 emissions from the clearing of aboveground biomass.

7.8.2.3 Uncertainties and Time-Series Consistency

For forest land converted to settlements, please see the corresponding subheading in Section 7.9, Forest Conversion.

The uncertainty about the area of non-forest land converted to settlements in the Canadian north is estimated at 20%; the uncertainty about the pre-conversion standing biomass varies between 35% and 50%. Section A3.5 provides more information.

7.8.2.4 QA/QC and Verification

Annex 6 describes the general QA/QC procedures being implemented for Canada's GHG inventory; they apply to this category as well.

For forest land converted to settlements, please see the corresponding subheading in Section 7.9, Forest Conversion.

7.8.2.5 Recalculations

Tundra conversion to settlements is a new reporting category for Canada, and no recalculations have been carried out. Recalculations of forest conversion are discussed in Section 7.9, Forest Conversion.

7.9 FOREST CONVERSION

Forest conversion is not a reporting category, since it overlaps with the subcategories of lands converted to cropland, wetlands, and settlements; it is nevertheless reported as a memo item. This section will briefly discuss methodological issues specific to this event and outline the general approach taken to estimate its extent, location, and impact. It is worth noting that a consistent approach was applied for all types of forest conversion, minimizing omissions and overlaps, while maintaining spatial consistency as much as possible.

In 2004, forest conversion to cropland, wetlands, and settlements amounted to emissions of about 16 Mt, down from 28 Mt in 1990. This reduction is accounted for by declines of over 6 Mt in emissions from forests converted to cropland and of 4 Mt in forests converted to wetlands (flooded lands).

Care should be taken to distinguish annual deforestation rates (from 64 kha in 1990 down to 47 kha in 2004) from the total area of forest land converted to other uses as reported in the CRF tables for each inventory year. The latter figures encompass all forest land conversion for 20 years prior to the current inventory year (10 years for reservoirs) and hence are significantly higher than the deforestation rates. Similarly, immediate emissions from forest conversion, which occur in the year of conversion, are only a fraction of all emissions due to forest conversion reported in any inventory year (7 Mt versus 16 Mt in 2004).

Conversion to cropland accounts for the largest share of forest losses to other land categories; conversion rates dropped from 42 kha/year in 1990 to 25 kha/year since 1995. In 2004, it represented 53% of all forest area lost. Conversion to settlements is the second most important cause of forest losses. While conversion rates remained stable during the period, at a little over 19 kha/year, the share of forest losses contributed by conversion to settlements increased from 31% to 42% of all forest losses over 15 years.

Geographically, the highest rates of forest conversion occur in the Boreal Plains and Boreal Shield East (reporting zones 10 and 5); these together represent between 33% and 71% of the total forest area converted in any year over the period 1990–2004.

While forest conversion affects both managed and unmanaged forests, the geographical distribution is distinct. Losses of unmanaged forests occur only in reporting zone 4 (Taiga Shield East) and are mostly caused by reservoir impoundment.

7.9.1 METHODOLOGICAL ISSUES

Forest conversion to other land categories is still a prevalent practice in Canada. This phenomenon is driven by a great variety of circumstances across the country, including policy and regulatory frameworks, market forces, and resource endowment. The economic activities causing forest losses are very diverse; they result in heterogeneous spatial and temporal patterns of forest conversion, which, until recently, were not systematically documented. The challenge has been to develop an approach that would integrate a large variety of information sources to capture the various forest conversion patterns across the Canadian landscape, while maintaining a consistent approach in order to minimize omissions and overlaps.

The approach adopted for estimating forest areas converted to other uses — or "deforested areas" — is based on three main information sources: systematic or representative sampling of remote sensing imagery, records, and expert judgement. The methodology is in its first phase of implementation and should be considered as a transition towards a refined and comprehensive system for monitoring forest conversion.

The core method involves remote sensing mapping of deforestation on samples from Landsat images dated circa 1975, 1990, and 2000. For implementation purposes, all permanent forest removal wider than 20 m from tree base to tree base and at least 1 ha was considered forest conversion. This convention was adopted as a guide to correctly label linear patterns in the landscape. The other main information sources consist of databases or other documentation on forest roads, power lines, oil and gas infrastructure, and hydroelectric reservoirs. Expert opinion was called upon when records data were unavailable or of poor quality or the remote sensing sample was insufficient. Expert judgement was also used to scale up local deforestation rates from non-statistical samples, reconcile differences among records and remote sensing information, and resolve large discrepancies between the 1975–1990 and 1990–2000 area estimates. A more detailed description of the approach and data sources is provided in Section A3.5 in Annex 3.

The unavailability of suitable imagery post-2000 prevented the use of this information source for the full time series. Section A3.5.2 also describes the interpolation and extrapolation procedures adopted in such cases.

All estimates of emissions due to forest conversion were generated with the CBM-CFS3, except when forests were flooded without prior clearing. Hence, methods are in general consistent with those used in the forest land remaining forest land category. Section A3.5 summarizes the estimation procedures.

7.9.2 UNCERTAINTIES AND TIME-SERIES CONSISTENCY

Based on expert judgement, an overall uncertainty of ±38% bounds the estimate of the total forest area converted annually in Canada, placing with 95% confidence the true value of this area for 2004 between 29 kha and 65 kha. Care should be taken not to apply the 38% range to the cumulative area of forest land converted to another category over the last 20 years (land areas reported in the CRF). Section A3.5 in Annex 3 describes the main sources of uncertainty about area estimates derived from remote sensing and records.

Consultations with regional experts suggest that there may be a bias, especially in 1975–1990, towards conservativeness. Any such bias would affect the uncertainty range for these and subsequent years.

Work is ongoing to improve uncertainty quantification.

7.9.3 QA/QC AND VERIFICATION

Annex 6 describes the general QA/QC procedures being implemented for Canada's GHG inventory; they apply to this category as well. In addition, detailed QA/QC procedures were carried out during estimate development procedures and documented by the CFS. More information is available in Section A3.5 of Annex 3.

7.9.4 RECALCULATIONS

Previous submissions reported only forest conversion to cropland and grassland and, to a lesser extent, settlements (urbanization only).

Previously reported estimates of forest conversion to cropland consisted of an average conversion rate of 29 kha between 1990 and 2000, with all (and only) forest biomass emitted on the year of conversion, resulting in annual emissions of 18 Mt. The new methodology accounts for both immediate and long-term emissions from all pools; hence, in any inventory year, the estimates of total area of forest land converted to cropland and the associated emissions encompass all land conversion over the two previous decades (20 years). In the current submission, the annual conversion rates show a decreasing trend from 42 kha in 1990 to 25 kha in 1995 and beyond. Pre-1990 rates were higher, and this is reflected in the large land area under forest land converted to cropland in the 1990s. Further, the reporting of long-term emissions from the post-conversion decay of dead organic matter and soils ensures that the prolonged impact of historically higher conversion rates is still felt in the early 1990s (e.g., residual emissions of 18 Mt out of a total of 28 Mt in 1990).

Another discrepancy between the 2005 and 2006 submission estimates results from the modified definitional framework of the Cropland and Grassland categories and the non-occurrence of forest conversion to grassland (see Section 7.3, Land Category Definition and Representation of Managed Lands). Consequently, the previously reported rate of conversion of forest to both cropland and grassland (total of 70 kha/year, annual emissions of 13 Mt) is not strictly comparable with the current estimates.

The 2005 submission reported annual losses of 11 kha of forests due to urbanization, with estimated annual emissions of 4 Mt. The updated estimates of 18 kha/year and 7 Mt reflect the expanded geographical coverage of the methodology, as well as the estimation of the long-term impact of forest losses.

7.9.5 PLANNED IMPROVEMENTS

In addition to the category-specific improvements in methodology and completeness, efforts will be devoted to cross-cutting issues requiring enhanced collaboration among MARS partners, such as the consistent representation of land areas and its impact on uncertainty estimates for the entire sector. More complete and detailed documentation of the GHG inventory is also under preparation.

8 WASTE (CRF SECTOR 6)

8.1 OVERVIEW

This category includes emissions from the treatment and disposal of wastes. Sources include solid waste disposal on land (landfills), wastewater treatment, and waste incineration. The categories evaluated are CH_4 emissions from solid waste disposal on land, CH_4 and N_2O emissions from wastewater treatment, and CO_2, CH_4, and N_2O emissions from waste incineration.

Much of the waste treated or disposed of is biomass or biomass based. CO_2 emissions attributable to such wastes are not included in inventory totals but are reported in the inventory as a memo item. CO_2 emissions from biogenic origin are not reported if they are reported elsewhere in the inventory or the corresponding CO_2 uptake is not reported in the inventory (e.g., annual crops). Therefore, in this circumstance, the emissions are not included in the inventory emission totals, since the absorption of CO_2 by the harvested vegetation is not estimated by the Agriculture Sector and, thus, the inclusion of these emissions in the Waste Sector would result in an imbalance. Also, CO_2 emissions from wood and wood products are not included, because these emissions are accounted for in the LULUCF Sector at the time of tree harvest. On the other hand, CH_4 emissions from anaerobic decomposition of wastes are included in inventory totals as part of the Waste Sector.

If carbon is lost from forests at an unsustainable rate (i.e., faster than annual regrowth), the carbon budget for forest lands will be negative for net emissions.

In 2004, the GHG emissions from the Waste Sector contributed 29 Mt to the national inventory as compared with 25 Mt for 1990, representing an increase of 16%. The emissions from this sector represented 3.8% and 4.2% of the overall Canadian GHG emissions in 2004 and 1990, respectively.

Emissions from the Solid Waste Disposal on Land subsector, which consists of the combined emissions from municipal solid waste (MSW) landfills and wood waste landfills, accounted for 27 Mt or 95% of the emissions for this sector in 2004. The chief contributor to the Waste Sector remains the CH_4 released from MSW landfills, which amounted to 25 Mt (1.2 Mt CH_4) in 2004. This net emission value is determined by subtracting the amount of CH_4 captured from the total estimated CH_4 generated within the landfill by the Scholl Canyon model, then adding the quantity of the captured CH_4 that was uncombusted by the flaring operation, where applicable. Approximately 21% of the CH_4 generated in Canadian MSW landfills in 2004 was captured and combusted.

The increase in the CH_4 generation rate from MSW landfills is directly dependent upon the population growth and the waste generation rate and is mitigated by landfill gas capture programs, provincial/municipal waste diversion projects, and international exportation of MSW. It is expected that as larger and more “state of the art” landfills are constructed, where gas collection systems will be required, a greater portion of landfill gas will be captured in the future, resulting in a greater reduction of emissions from this sector. Waste diversion initiatives began in the early 1990s, and, based upon the most recent national figures, approximately 22% of waste is diverted from disposal (landfill or incineration) (Statistics Canada, 2000, 2003, 2004a).

Table 8-1 summarizes the Waste Sector and subsector GHG contributions for the 1990, 1995, and 2001–2004 inventory years.

TABLE 8-1: Waste Sector GHG Emissions Summary, Selected Years

GHG Source Category	GHG Emissions					
	kt CO_2 eq					
	1990	1995	2001	2002	2003	2004
Waste Sector TOTAL[1]	**25 000**	**26 000**	**28 000**	**28 000**	**29 000**	**29 000**
a. Solid Waste Disposal on Land	23 000	25 000	27 000	27 000	27 000	27 000
b. Wastewater Handling	1 100	1 100	1 200	1 200	1 200	1 200
c. Waste Incineration	400	330	250	230	240	250

Note:

1 Totals may not add due to rounding.

8.2 SOLID WASTE DISPOSAL ON LAND (CRF CATEGORY 6.A)

8.2.1 SOURCE CATEGORY DESCRIPTION

Emissions are estimated from two types of landfills in Canada:

- MSW landfills; and
- wood waste landfills.

In Canada, most, if not all, waste disposal on land occurs in municipally managed or privately owned landfills. Very few, if any, unmanaged waste disposal sites exist. Therefore, it has been assumed that all waste is disposed of in managed facilities. Residential, institutional, commercial, and industrial wastes are disposed of in MSW landfills. In the last 15 years, dedicated construction and demolition landfills were constructed. Typically, these landfills do not require CH_4 collection systems due to the very low organic content in the waste stream. Therefore, these landfills are currently excluded from the analysis.

Wood waste landfills are mostly privately owned and operated by forest industries, such as saw mills and pulp and paper mills. These industries use the landfills to dispose of surplus wood residue, such as sawdust, wood shavings, bark, and sludges. Some industries have shown increasing interest in waste-to-energy projects that produce steam and/or electricity by combusting these wastes. In recent years, what used to be regarded as a waste is now being processed as a value-added product — e.g., wood pellets for residential and commercial pellet stoves and furnaces and hardboard, fibreboard, and particle board. Wood waste landfills have been identified as a source of CH_4 emissions; however, there is a great deal of uncertainty in the estimates. Wood waste landfills are a minor source in comparison with MSW landfills.

The IPCC Guidelines (IPCC/OECD/IEA, 1997) provide two methodologies for estimating emissions from landfills: a default method and a first-order kinetics method, also known as the Scholl Canyon model. The default method relates emissions to the quantity of waste landfilled in the previous year, whereas the Scholl Canyon model relates emissions to the waste that has been landfilled in previous years.

The composition and amount of waste landfilled in Canada have significantly changed over the past several decades, primarily as a result of population growth. For this reason, a static model such as the default method is not felt to be appropriate. Therefore, emissions from MSW landfills and wood waste landfills are estimated using the Scholl Canyon model.

The following is an explanation of both the factors that contribute to landfill gas generation and the Scholl Canyon model that was used to estimate GHG emissions from landfills.

Landfill gas, which is composed mainly of CH_4 and CO_2, is produced by the anaerobic decomposition of organic wastes. The first phase of this process typically begins after waste has been in a landfill for 10–50 days. Although the majority of the CH_4 and CO_2 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. The amount of moisture within a landfill also 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. Temperature variations can affect microbial activity, subsequently affecting their ability to decompose matter (Maurice and Lagerkvist, 2003).
- *pH and Buffer Capacity*: The generation of CH_4 in landfills is greatest when neutral pH conditions exist. The activity of methanogenic bacteria is inhibited in acidic environments.
- *Availability of Nutrients*: Certain nutrients are required for anaerobic digestion. These include carbon, hydrogen, nitrogen, and phosphorus. In general, MSW contains the necessary nutrients to support the required bacterial populations.
- *Waste Density and Particle Size*: The particle size and density of the waste also influence gas generation. Decreasing the particle size increases the surface area available for degradation and therefore increases the gas production rate. The waste density, which is largely controlled by compaction of the waste as it is placed in the landfill, affects the transport of moisture and nutrients through the landfill, which also affects the gas generation rate.

8.2.2 METHODOLOGICAL ISSUES

CH_4 produced from the decomposition of waste in landfills is calculated using the Scholl Canyon model, which is a first-order decay model. This reflects the fact that waste degrades in landfills over many years. Data pertaining to landfill gas capture were obtained directly from the owners/operators of specific landfills with landfill gas collection systems.

CH_4 emissions are determined by calculating the amount of CH_4 generated from landfill waste decomposition through the Scholl Canyon model, subtracting the CH_4 captured through landfill gas recovery systems, then adding the quantity of uncombusted CH_4 emitted by the flares for those locations where a portion or all of the recovered landfill gas is burned without energy recovery. The GHG emissions associated with the combustion of that portion of the landfill gas that is captured and utilized for energy generation purposes are accounted for in the Energy Sector. A more detailed discussion of the methodologies is presented in Annex 3.

8.2.2.1 CH_4 Generation

The Scholl Canyon model was used to estimate the quantity of CH_4 generated. The model is based upon the following first-order decay equation (IPCC/OECD/IEA, 1997):

Equation 8-1:

$$G_i = M_i * k * L_0 * \exp^{-(k \times t_i)}$$

where:

G_i = generation rate from the ith section (kt CH_4/year)
M_i = mass of refuse in the ith section (Mt)
k = CH_4 generation rate constant (/year)
L_0 = CH_4 generation potential (kg CH_4/t of refuse)
t_i = age of the ith section (years)

In order to estimate CH_4 emissions from landfills, information on several of the factors described above is needed. To calculate the net emissions for each year, the sum of G_i for every section of waste landfilled in past years was taken, and the captured gas was subtracted for each province. A computerized model has been developed to estimate aggregate emissions on a regional basis (by province and territory) in Canada. The national CH_4 emission value is the summation of emissions from all regions.

Waste Disposed of Each Year or the Mass of Refuse (M_i)

■ **MSW Landfills**

Two primary sources were used in obtaining waste generation and landfill data for the GHG inventory. The amount of MSW landfilled in the years 1941 through to 1990 was estimated by Levelton (1991). For the years 1998, 2000, and 2002, MSW disposal data were obtained from the Waste Management Industry Survey that is conducted by Statistics Canada on a biennial basis (Statistics Canada, 2000, 2003, 2004a). MSW disposal values, which include both landfilled and incinerated MSW, for the intervening odd years (1999 and 2001) were obtained by taking an average of the corresponding even years. Incinerated waste quantities were subtracted from the Statistics Canada disposal values in order to obtain the amount of MSW landfilled for 1998–2002. For the years 1991–1997 and 2003–2004, with the exception of Prince Edward Island, the Northwest Territories, and the Yukon, a trend analysis was completed by fitting a polynomial to the Levelton (1991) and Statistics Canada (2000, 2003, 2004a) MSW landfill values.

- **Wood Waste Landfills**

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 1999–2004.

CH_4 Generation Rate (k)

The CH_4 kinetic rate constant (k) represents the first-order rate at which CH_4 is generated after waste has been landfilled. The value of k is affected by four major factors: moisture content, temperature, availability of nutrients, and pH. It is assumed that in a typical MSW landfill, the nutrient and pH conditions are attained. In many parts of Canada, subzero conditions exist for up to seven months of the year, with temperatures dropping below –30°C (Thompson *et al.*, 2005); however, evidence suggests that ambient temperature does not affect landfill decay rates (Maurice and Lagerkvist, 2003; Thompson and Tanapat, 2005). In addition, seasonal temperature variations in the waste are minimal when compared with atmospheric temperature variations (Maurice and Lagerkvist, 2003). At depths exceeding 2 m, the landfill temperature is independent of the ambient temperature. It has been shown in Canadian field experiments that an insignificant amount of variation in landfill CH_4 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.

The k values used to estimate emissions from both types of landfills originate from a study conducted by the University of Manitoba. This study employed the provincial precipitation data from 1971 to 2000 (Thompson *et al.*, 2005) to obtain k values from a precipitation versus k value relationship developed by the U.S. EPA. The U.S. k values are related to precipitation, assuming that the moisture content of a landfill is a direct function of the annual precipitation. Based on both the U.S. k values and precipitation data and the average annual precipitation at Canadian landfills surveyed by Levelton (1991), k values were assigned to each of the provinces (Thompson *et al.*, 2005).

- **MSW Landfills**

The k values used to estimate emissions from MSW landfills have been chosen from the range of k value estimates for each province (Thompson *et al.*, 2005). These values are provided in Table 8-2.

- **Wood Waste Landfills**

One k value has been chosen to represent all of the wood waste landfills in Canada. British Columbia, Quebec, Alberta, and Ontario together landfill 93% of the wood waste in Canada (NRCan, 1997). A k value of 0.03/year was chosen to be used in the model to estimate wood products industry landfill CH_4 emissions based upon a report prepared by the National Council for Air and Stream Improvement Inc. (NCASI, 2003).

TABLE 8-2: MSW Landfill k Value Estimates for Each Province/Territory

Provincial/Territorial k Value Estimates (/year)											
NL	PE	NS	NB	QC	ON	MB	SK	AB	BC	NT[1]	YT
0.074	0.058	0.073	0.061	0.054	0.044	0.020	0.014	0.016	0.067	0.007	0.006

Note:

1 NT includes NU.

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). The majority of recycling programs in Canada began in or after 1990; therefore, there was no substantial waste diversion prior to this date. In order to calculate the CH_4 generation potential prior to 1990, Statistics Canada recycling information from the 2002 survey year was used to estimate the percentage of diverted organic materials per province (Statistics Canada, 2000, 2003, 2004a). The 1990–2004 calculated L_0 values were increased by the percentage currently diverted in order to calculate the CH_4 generation potential between 1941 and 1989 (Table 8-3). For provinces where diversion data were not available, the default value (165 kg/t of waste) was used (Thompson *et al.*, 2005). This default value of L_0 was obtained from the U.S. EPA (EPA, 1990). As waste disposal practices in Canada change and as new information is made available, the L_0 value will be adjusted accordingly.

L_0 was determined employing the methodology provided by the IPCC Guidelines (IPCC/OECD/IEA, 1997) (Equation 8-2) using the provincial waste composition data as input to the degradable organic carbon (DOC) calculation.

Equation 8-2:

$$L_0 = MCF * DOC * DOC_F * F * 16/12 * 1000 \text{ kg } CH_4/\text{t } CH_4$$

where:

L_0 = CH_4 generation potential (kg CH_4/t waste)
MCF = CH_4 correction factor (fraction)
DOC = degradable organic carbon (t C/t waste)
DOC_F = fraction DOC dissimilated
F = fraction of CH_4 in landfill gas
16/12 = stoichiometric factor

According to the IPCC Guidelines, the MCF for managed landfill sites has a value of 1.0 (IPCC/OECD/IEA, 1997). The fraction of CH_4 (F) emitted from a landfill ranges from 0.4 to 0.6 and was assumed to be 0.5. The IPCC default DOC_F value of 0.77 was used.

The DOC calculation is derived from the biodegradable portion of the MSW (Equation 8-3).

Equation 8-3:

$$DOC = (0.4 * A) + (0.17 * B) + (0.15 * C) + (0.3 * D)$$

where:

A = fraction of MSW that is paper and textiles
B = fraction of MSW that is garden or park waste
C = fraction of MSW that is food waste
D = fraction of MSW that is wood or straw

TABLE 8-3: **CH_4 Generation Potential (L_0) from 1941 to Present[1]**

Location	2002 Organic Waste Diversion[2]	L_0 Value Following 1990	L_0 Value Prior to 1990
	(%)	*(kg/t of waste)*	
British Columbia	23.3	108.8	134.1
Alberta	16.7	100.0	116.7
Saskatchewan	4.3	106.8	111.3
Manitoba	4.9	92.4	96.5
Ontario	16.4	90.3	105.1
Quebec	13.7	127.8	145.3
New Brunswick	19.8	117.0[3]	140.2
Prince Edward Island	N/A[4]	117.0[3]	165.0[3]
Nova Scotia	29.7	89.8	116.5
Newfoundland and Labrador	N/A[4]	102.2	165.0[3]
Northwest Territories and Nunavut	N/A[4]	117.0[3]	165.0[3]
Yukon	N/A[4]	117.0[3]	165.0[3]

Notes:

1 Source: Thompson *et al.* (2005), except where otherwise noted.
2 Source: Statistics Canada (2002).
3 Default value.
4 N/A = unavailable categorical information.

Wood Waste Landfills

Equation 8-2 generated an L_0 value of 80 kg CH_4/t of wood waste, which was used to estimate emissions from wood waste landfills by the Scholl Canyon model. IPCC defaults were used for the CH_4 correction factor, MCF (unmanaged deep landfills); the fraction of CH_4 in the landfill gas, F (0.5); and the fraction DOC disssimilated, DOC_F (0.5), the lower end of the default range for wastes containing lignin (IPCC/OECD/IEA, 1997). One hundred percent wood or straw waste composition was assumed to calculate the fraction of DOC in Equation 8-3.

Captured Landfill Gas

Some of the CH_4 that is generated in MSW landfills is captured and combusted. Through combustion, this landfill CH_4 converts into CO_2, reducing the CH_4 emissions. In order to calculate the net CH_4 emissions from landfills, the quantity of captured CH_4 that passes through the flare uncombusted must be added to the difference between the quantity of CH_4 estimated by the Scholl Canyon model to have been generated and the amount of CH_4 captured based upon survey data. The captured gas is wholly or partially flared or combusted for electricity or heat generation. GHG emissions affiliated with the use of landfill gas for energy recovery are accounted for in the Energy Sector.

A flaring combustion efficiency for CH_4 in landfill gas of 99.7% was used to determine the quantity of CH_4 that circumvented the flare. This value was obtained from Table 2.4-3 of Chapter 2.4 of EPA AP 42 (EPA, 1995) and is their typical value, although it ranges from 38% to 99% efficiency.

The quantities of landfill gas collected from 1983 to 1996 were obtained from Environment Canada (1998). Since 1997, data on the amount of landfill gas captured are collected directly from individual landfill operators biennially by Environment Canada's National Office of Pollution Prevention (Environment Canada, 2003a). Since the landfill gas capture data are collected every odd year, for the purposes of the national GHG inventory, the landfill gas capture data for the subsequent even years are averaged from the odd years from 1997.

8.2.3 UNCERTAINTIES AND TIME-SERIES CONSISTENCY

The following discussion on uncertainty for the categories within this sector is based upon the results as reported in *Quantitative Assessment of Uncertainty in Canada's National GHG Inventory Estimates for 2001* (ICF, 2004). This Tier 2 evaluation of uncertainty employed values from the 2001 inventory year (2003 submission). However, there have been modifications made to the methodology, emission factors, and sources of information as a consequence of the findings of this uncertainty study. Therefore, although the results of this study may not be an accurate representation of the uncertainty around the emissions from this subsector and the model inputs, in lieu of a follow-up Tier 2 study, it is expected that the improvements made would result in a reduction of the uncertainty for this subsector.

The CH_4 emissions from this key category include the CH_4 emissions from the MSW landfills and from the wood waste landfills. The level of uncertainty associated with the CH_4 emissions from the combined subsectors was estimated to be in the range of −35% to +40%, which closely resembles the uncertainty range of −40% to +35% estimated in this study for the CH_4 emissions from the MSW landfills. The level uncertainty range provided by the ICF (2004) study is only slightly larger than the ± 30% span estimated with a 90% confidence level by a previous study, which used a Tier 1 approach based upon 1990 data (McCann, 1994). However, it should be noted that the ICF (2004) study's uncertainty range is quoted for a 95% confidence interval, which would typically be larger than the range quoted for a 90% confidence interval.

The MSW landfills contributed to over 90% of the total CH_4 emissions from this key category in 2001 (Environment Canada, 2003b). The uncertainty estimates for the CH_4 emissions from the MSW landfills seem to have been largely influenced by the uncertainty in the inventory values for the CH_4 generation potentials (L_0) for 1941–1989 and for 1990–2001 and the CH_4 generation rate constant (k), where the uncertainty for both the k and L_0 were based upon an estimate from one expert elicitation. A simplified model of the Scholl Canyon method was used for the Monte Carlo simulation, which may have had a bearing on relevancy of the uncertainty values. An error was introduced in the calculation of the MSW landfill CH_4 emission uncertainty by the use of the year 2000 value (instead of the 2001 value) for the total CH_4 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 the wood waste landfills was significantly higher (i.e., −60% to +190%) than that for the MSW landfills, its contribution to the uncertainty in the key category was much lower due to its relatively low contribution of emissions (i.e., less than 10%) (Environment Canada, 2003b). The uncertainty estimate for wood waste landfills seems to have been largely influenced by the CH_4 generation rate, carbon content of the waste landfilled, and the biodegradable fraction of the waste, where the uncertainties were assumed by ICF Consultants (ICF, 2004) based upon IPCC Guidelines (IPCC/OECD/IEA, 1997) and/or IPCC Good Practice Guidance (IPCC, 2000) where available.

The estimates are calculated in a consistent manner over time.

8.2.4 QA/QC AND VERIFICATION

A Tier 1 QC review was conducted for this key category. Some transcription errors were detected and corrected accordingly. No significant anomalies were identified.

8.2.5 RECALCULATIONS

Recalculations for total emissions from Solid Waste Disposal on Land resulted in increases of 26.4% and 14.6% in total emissions for 1990 and 2003, respectively, over emissions reported in the 2005 inventory year submission.

The municipal landfill model was improved from the last NIR submission by amendments to three of the Scholl Canyon parameters: CH_4 generation rate constant, k; CH_4 generation potential, L_0; and the calculation of the quantity of waste landfilled in the provinces from 1991 to the present, M_i.

A study conducted by the University of Manitoba and funded by Environment Canada reviewed and verified the model used by Environment Canada to estimate the CH_4 generation from landfills (Thompson *et al.*, 2005). The study found that the k used previously based upon the Levelton (1991) study was underestimated due to the introduction of the temperature influence, which is now understood to not play a significant role in comparison with landfill waste moisture content. In addition, when comparing annual precipitation with the assigned decay values, there was no consistency within the data — i.e., there were many cities with similar annual precipitation levels but differing decay values. Therefore, the present model uses k values recommended by the University of Manitoba for each province based on an average of k values determined from annual precipitation levels at major cities (Thompson *et al.*, 2005). These changes resulted in increases of provincial k values, ranging from 100% to 570%.

A review of Canadian waste composition studies by the University of Manitoba, under the same study described above, provided updated values of province-specific L_0 values. Previously, the L_0 values employed by the model were 165 kg/t of waste from 1941 to 1989 and 117 kg/t of waste from 1990 to 2003. The reduced value reflected a reduction in the organic content of waste landfilled due to recycling initiatives beginning in 1990. The new values of L_0 for the years prior to 1990, calculated following the IPCC Guidelines (IPCC/OECD/IEA, 1997) methodology and based on recent waste audits conducted by the provincial governments or municipalities, gave reductions in provincial values in a range from 0 to 29%. For 1990 to the present, the current L_0 when compared with the previous value recorded a reduction that ranged from 0 to 23%, reflecting the results of the waste diversion programs.

The methodology used to quantify the waste landfilled in provincial landfills in the years following 1990 was modified. In the previous inventories, the quantities were extrapolated from provincial 1992 landfilled quantities per capita data and Statistics Canada Census data, which provided population data over the time series. The current methodology uses the Levelton (1991) study data from 1941 to 1990 and the results from the biennial Statistics Canada surveys on waste management for 1998, 2000, and 2002 to develop a relation derived from a polynomial curve–fitting exercise to interpolate the 1991–1997 data. The Levelton (1991) waste quantities data are the result of surveys made of managed landfills in 1990. The Statistic Canada data provide an ongoing source of activity data following a standardized methodology. The data from the 2000 and 2002 surveys included waste exported to the United States from Ontario. In order to examine only those wastes landfilled in Ontario, the quantities exported for these two years were obtained from the Ontario Ministry of the Environment (2006) and subtracted from the values provided by Statistics Canada (2000, 2003, 2004a). The Statistics Canada data also included the quantity of waste incinerated. Therefore, the quantity of incinerated waste was subtracted from the 1998, 2000, and 2002 data to reflect only the quantity of waste landfilled.

As an improvement to the accuracy of the submission and to better align with the IPCC Guidelines (IPCC/OECD/IEA, 1997) reporting instructions, the emissions associated with the combustion of captured landfill gas are now accounted for in the Energy Sector. This is now possible as a result of more activity data becoming available through the *Inventory of Landfill Gas Recovery and Utilization in Canada* (Environment Canada, 2003a), which allows for the development of a relationship to interpolate values over the complete time series for consistency. In previous years, this CH_4 quantity was simply subtracted, with the flared amount, from the overall CH_4 generated for each province and not reported in the Energy Sector.

A further refinement of the present model is the quantification of the CH_4 that is emitted from the landfill gas flaring operations. This amount was obtained from the quantity of CH_4 flared at each installation, which was interpolated over the time series from known values (Environment Canada, 1996b, 2003a), and the default flare efficiency of 99.7% for the combustion of CH_4 in landfill gas mixtures (EPA, 1995) for each year that the flares operated. These quantities were then summed to provide the annual contribution for each province. Therefore, the net CH_4 emissions from the landfill operations were calculated by subtracting the total CH_4 captured from the total CH_4 generated, estimated by the Scholl Canyon model, and then adding this number to the amount of CH_4 that was released to the atmosphere uncombusted by the flare.

8.2.6 PLANNED IMPROVEMENTS

A multiyear study, being conducted by the University of Manitoba and funded by Environment Canada, was initiated in 2005 and will be completed in the fall of 2006. Some of the results from this study have been used to improve this present submission, such as a review and verification of the Scholl Canyon model used by Environment Canada and the development of new provincial CH_4 generation rate constants and CH_4 generation potentials. The second phase of the study will consist of an inventory of Canadian landfills, which will include a survey of historical data on the amount landfilled on a site-specific basis. Depending on the availability, completeness, and accuracy of these activity data, it may be possible to consider a Tier 3 approach to CH_4 generation estimation.

Another study is being considered to review the quantity of wood waste being placed in Canadian wood and pulp and paper industry landfills.

8.3 WASTEWATER HANDLING (CRF CATEGORY 6.B)

8.3.1 SOURCE CATEGORY DESCRIPTION

Emissions from municipal and industrial wastewater treatment were estimated. Both municipal and industrial wastewater can be aerobically or anaerobically treated. When wastewater is treated anaerobically, CH_4 is produced; however, it is typical that systems with anaerobic digestion in Canada contain and combust the produced CH_4. CH_4 emissions from aerobic systems are assumed to be negligible. Both types of treatment systems generate N_2O through the nitrification and denitrification of sewage nitrogen (IPCC/OECD/IEA, 1997).

CO_2 is also generated by both types of treatment. However, as discussed above, CO_2 emissions originating from the decomposition of food are not to be included with the national total estimates, in accordance with IPCC Guidelines (IPCC/OECD/IEA, 1997).

The emission estimation methodology for municipal wastewater handling is divided into two areas: CH_4 from anaerobic wastewater treatment and N_2O from human sewage.

8.3.2 METHODOLOGICAL ISSUES

A more detailed discussion of the methodologies is presented in Annex 3.

8.3.2.1 CH_4 Emissions

Municipal Wastewater Treatment

The IPCC default method was not used, because the required data were not available. A method developed for Environment Canada (ORTECH Corporation, 1994) was used to calculate an emission factor. Based on the amount of organic matter generated per person in Canada and the conversion of organic matter to CH_4, it was estimated that 4.015 kg CH_4/person per year could potentially be emitted from anaerobically treated wastewater.

CH_4 emissions were calculated by multiplying the emission factors by the population of the respective province (Statistics Canada, 2004b) and by the fraction of wastewater that is treated anaerobically.

Industrial Wastewater Treatment

CH_4 emissions from treatment of industrial wastewater were found to be negligible. The following equation was used to estimate the CH_4 emissions from this source:

Equation 8-4:

$$CH_{4\ (\text{Industry Type})} = V_{(\text{Industry Type})} * COD_{(\text{industry Type})} * EF_{CH_4} * Frac_{(\text{Anaerobic})}$$

where:

$CH_{4\ (\text{Industry Type})}$ = CH_4 emissions generation per industry type (t)
$V_{(\text{Industry Type})}$ = volume of wastewater treated (L/year)
$COD_{(\text{Industry Type})}$ = chemical oxygen demand per industry type (kg/L)
EF_{CH_4} = CH_4 emission factor (t CH_4/kg COD)
$Frac_{(\text{Anaerobic})}$ = fraction of anaerobically treated wastewater

Process effluent volumes were obtained from surveys conducted by Environment Canada for the years 1986, 1991, and 1996 (Environment Canada, 1986, 1991, 1996a). Volumes were then derived for the complete time series using polynomial curve–fitting interpolation for the intervening years between 1990 and 1996 and a growth function to estimate values from 1997 to 2004. Data were available for the following industries: food, beverages, rubber products, plastic products, total textiles, paper allied products, petroleum and coal products, and chemical products. IPCC default values for the chemical oxygen demand (COD) for each industry were then matched to these industrial sectors (IPCC, 2000). An IPCC default value for the CH_4 emission factor of 0.000 25 t CH_4/kg COD was selected. However, through communications with the Ministries of Environment of the provinces (Ontario, Quebec, and British Columbia) where these industries are mainly based and with selected industry associations, it was concluded that on-site anaerobic treatment of industrial wastes was negligible. Pulp and paper process water accounts for approximately 79.6% of the water consumed for industrial processes, and it was confirmed that no anaerobic processes were employed in Canada for treatment of this effluent. One slaughterhouse in Quebec was identified as using anaerobic digestion as a treatment process; however, the biogas is captured and combusted. A follow-up study is being considered to improve the resolution of the information and ensure completeness and accuracy of the data.

8.3.2.2 N_2O Emissions

Municipal Wastewater Treatment

The N_2O emissions were calculated using the IPCC default method (IPCC/OECD/IEA, 1997). This method estimates emissions based on the amount of nitrogen in sewage and the assumption that 0.01 kg N_2O-N/kg sewage nitrogen will be generated.

Estimates of the amount of nitrogen in sewage were based on the following two assumptions: protein is 16% nitrogen; and Canadian protein consumption is 40.15 kg/person per year. This resulted in an emission factor of 0.101 kg N_2O/person per year.

Emissions were calculated by multiplying the emission factor by the population of the respective provinces (Statistics Canada, 2004b).

Industrial Wastewater Treatment

The IPCC Guidelines (IPCC/OECD/IEA, 1997) do not address the methodology for the estimation of N_2O emissions from industrial wastewater treatment.

8.3.3 UNCERTAINTIES AND TIME-SERIES CONSISTENCY

The following discussion on uncertainty for the categories within this sector is based upon the results as reported in *Quantitative Assessment of Uncertainty in Canada's National GHG Inventory Estimates for 2001* (ICF, 2004). This Tier 2 evaluation of uncertainty employed values from the 2001 inventory year (2003 submission). However, there have been modifications made to the methodology, emission factors, and sources of information as a consequence of the findings of this uncertainty study. Therefore, although the results of this study may not be an accurate representation of the uncertainty around the emissions from this subsector and the model inputs, in lieu of a follow-up Tier 2 study, it is expected that the improvements made would result in a reduction of the uncertainty for this subsector.

The overall level uncertainty associated with the wastewater treatment subsector was estimated to be in the range of –40% to +55%. The level uncertainty range provided by the ICF (2004) study is less than the ±60% span estimated with a 90% confidence level by a previous study, which used a Tier 1 approach based on 1990 data (McCann, 1994). This is an improvement to the uncertainty as assessed for this category, since the uncertainty range quoted by ICF (2004) for a 95% confidence interval should typically show a larger value than that quoted for a 90% confidence interval. Based on 2001 data, the trend uncertainty associated with the total GHG emissions (comprising CH_4 and N_2O) 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 2004 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. The CH_4 emissions accounted for about 85% of the total emissions from this subsector category.

Since the methods and data sources have remained unchanged over the time series, the estimates for this category are consistent over time.

8.3.4 QA/QC AND VERIFICATION

A Tier 1 QC review was conducted for this key category. No significant anomalies were identified.

8.3.5 RECALCULATIONS

The recalculations for Wastewater Handling resulted in decreases of 10.8% and 11.6% in total emissions for 1990 and 2003, respectively, from emissions reported in the 2005 inventory year submission.

Recalculations were conducted on CH_4 and N_2O emission values for the complete 1990–2003 time series based upon new sources of information on the type of municipal wastewater treatment processes used (i.e., anaerobic versus aerobic) and, to a lesser extent, data from the 2004 *Annual Demographic Statistics* published by Statistics Canada (2004b).

8.3.6 PLANNED IMPROVEMENTS

Canada is planning to update the wastewater emission data based upon the results from a study that would include an inventory of wastewater treatment plants in Canada, quantification of GHG releases, and an estimation of GHG emission factors.

8.4 WASTE INCINERATION (CRF CATEGORY 6.C)

8.4.1 SOURCE CATEGORY DESCRIPTION

Emissions from both MSW and sewage sludge incineration are included in the inventory. Some municipalities in Canada utilize incinerators to reduce the quantity of MSW sent to landfills and to reduce the amount of sewage sludge requiring land application.

GHG emissions from incinerators vary depending on factors such as the amount of waste incinerated, the composition of the waste, the carbon content of the non-biomass waste, and the facilities' operating conditions.

8.4.1.1 MSW Incineration

A combustion chamber of a typical mass-burn MSW incinerator is composed of a grate system on which waste is burned and is either water-walled (if the energy is recovered) or refractory-lined (if it is not). GHGs that are emitted from MSW incinerators may include CO_2, CH_4, and N_2O.

As per the IPCC Guidelines (IPCC/OECD/IEA, 1997), CO_2 emissions from biomass waste combustion are not included in this section of the inventory. The only CO_2 emissions included in this section are from fossil fuel–based carbon waste, such as plastics and rubber.

CH_4 emissions from MSW incineration are assumed to be negligible and are not calculated due to a lack of underlying emission research.

8.4.1.2 Sewage Sludge Incineration

Two different types of sewage sludge incinerators are used in Canada: multiple hearth and fluidized bed. In both types of incinerators, the sewage sludge is partially de-watered prior to incineration. The de-watering is typically done in a centrifuge or using a filter press. Currently, municipalities in Ontario and Quebec operate sewage sludge incinerators.

CH_4 and N_2O emissions are estimated from sewage sludge incineration.

8.4.2 METHODOLOGICAL ISSUES

The emission estimation methodology depends on waste type and gas emitted. A more detailed discussion of the methodologies is presented in Annex 3.

8.4.2.1 CO_2 Emissions

The IPCC Guidelines (IPCC/OECD/IEA, 1997) do not specify a method to calculate CO_2 emissions from the incineration of fossil fuel–based waste (such as plastics and rubber). Therefore, the following three-step method was developed:

1. *Calculating the Amount of Waste Incinerated*: The amount of waste incinerated each year was estimated based on a regression analysis using data from an Environment Canada (1996b) study, which contains detailed provincial incineration data for the year 1992, and from a study performed by A.J. Chandler & Associates Ltd. for Environment Canada, which provided incineration data for 1999, 2000, and 2001 (Environment Canada, 2003b).
2. *Developing Emission Factors*: Provincial CO_2 emission factors are based on the assumption that carbon contained in waste undergoes complete oxidation to CO_2. The amount of fossil fuel–based carbon available in the waste incinerated has been determined using typical percent weight carbon constants (Tchobanoglous *et al.*, 1993). The amount of carbon per tonne of waste is estimated and converted to tonnes of CO_2 per tonne of waste by multiplying by the ratio of the molecular mass of CO_2 to that of carbon.
3. *Calculating CO_2 Emissions*: Emissions were calculated on a provincial level by multiplying the amount of waste incinerated by the appropriate emission factors.

8.4.2.2 N_2O and CH_4 Emissions

Emissions of N_2O from MSW incineration were estimated using the IPCC default method (IPCC/OECD/IEA, 1997). An average factor was calculated assuming that the IPCC five stoker facility factors were most representative. To estimate emissions, the calculated factor was multiplied by the amount of waste incinerated by each province.

Emissions are dependent on the amount of dried solids incinerated. To calculate the CH_4 emissions, the amount of dry solids incinerated is multiplied by an appropriate emission factor. Estimates of the amount of dried solids in the sewage sludge incinerated in the years 1990–1992 are based on a study completed in 1994 (Fettes, 1994). Data for the years 1993–1996 were acquired through telephone surveys of facilities that incinerate sewage sludge. Data for the years 1997 and 1998 were obtained from a Compass Environmental Inc. study prepared for Environment Canada (Environment Canada, 1999). 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, 2003b). To estimate the amount of sewage sludge incinerated in the years 2002–2004, a regression analysis was completed using the Chandler and Compass Environmental Inc. MSW incineration values.

Emissions of CH_4 are estimated based on emission factors obtained from the U.S. EPA publication *Compilation of Air Pollutant Emission Factors* (EPA, 1995). The emission factors are 1.6 t CH_4/kt of total dried solids for fluidized bed sewage incinerators and 3.2 t CH_4/kt of dried solids for multiple hearth incinerators, both equipped with venture scrubbers. To estimate emissions, the calculated factor was multiplied by the amount of waste incinerated by each province. The national emission values were then determined as the summation of these emissions for all provinces.

Emissions of N_2O from sewage sludge incineration were estimated using the IPCC default emission factor for fluidized beds, 0.8 kg/t of dry sewage sludge incinerated (IPCC, 2000). To estimate emissions, the calculated factor was multiplied by the amount of waste incinerated by each province. The national emission values were then determined as the summation of these emissions for all provinces.

8.4.3 UNCERTAINTIES AND TIME-SERIES CONSISTENCY

The following discussion on uncertainty for the categories within this sector is based upon the results as reported in *Quantitative Assessment of Uncertainty in Canada's National GHG Inventory Estimates for 2001* (ICF, 2004). This Tier 2 evaluation of uncertainty employed values from the 2001 inventory year (2003 submission). However, there have been modifications made to the methodology, emission factors, and sources of information as a consequence of the findings of this uncertainty study. Therefore, although the results of this study may not be an accurate representation of the uncertainty around the emissions from this subsector and the model inputs, in lieu of a follow-up

Tier 2 study, it is expected that the improvements made would result in a reduction of the uncertainty for this subsector.

The overall level uncertainty associated with the waste incineration source category was estimated to be in the range of –12% to +65%. For 2001 inventory estimates, the overall trend uncertainty associated with the total GHG emissions (comprising CO_2, CH_4, and N_2O) from incineration of wastes (comprising MSW and sewage sludge) was estimated to be in the range of about 10% to 11%. The inventory trend was estimated at 10%. The extrapolation of trend uncertainty in 2001 to the 2004 inventory should be made with caution, as the trend uncertainty is more sensitive than level uncertainty to the changes in the inventory estimate values for the more recent years. CH_4 accounted for over 80% of the total GHG emissions from this source category.

8.4.4 QA/QC AND VERIFICATION

A Tier 1 QC review was conducted for this key category. No significant anomalies were identified.

8.4.5 RECALCULATIONS

This year's recalculations resulted in an increase of 26.4% and a decrease of 32.4% in total emissions for 1990 and 2003, respectively, from emissions reported in the 2005 inventory year submission.

The CO_2 emissions from fossil fuel–based waste and N_2O emissions were recalculated for the years 1990–2003 to account for the new activity data and the linear regression approach used to provide consistent methodology over the time series. The data from the recent sources show a continued reduction in the use of incinerators in Canada to destroy MSW.

New data on the quantities of sewage sludge being incinerated were used to update the model, where in previous years, due to lack of information, the emissions were assumed to be constant since 1996. This resulted in a recalculation of the CH_4 emissions from 1990 to 2003. This year's inventory also includes N_2O emissions from the incineration of sewage sludge using an IPCC default emission factor (IPCC, 2000).

8.4.6 PLANNED IMPROVEMENTS

An analysis of the municipal incineration activity data is planned. The study proposal includes a historical compilation of the activity data from 1990 to 2005, a current inventory of all Canadian MSW incinerators, waste composition, annual throughput for each unit, and estimated GHG emission factors.

9 RECALCULATIONS AND IMPROVEMENTS

This chapter presents a summary of the recalculations and improvements performed in this submission and a summary of the planned improvements to the overall inventory. The reader will find in Chapters 3 through 8 the category-specific details of the recalculations, along with a description by GHG category of planned improvements to the methodologies and data.

9.1 EXPLANATIONS AND JUSTIFICATIONS FOR RECALCULATIONS

Each year, Environment Canada reviews and, if necessary, revises and recalculates the emissions and removals estimates for all years in the inventory. This work is carried out as part of continuous improvement efforts to integrate refined data or methods, incorporate new information or additional sources and sinks, implement any new guidance, and correct errors and omissions.

In this submission, a number of important improvements and recalculations have been incorporated for all sectors. These originate from improved allocation of emissions to source sectors, from the use of higher-tier methods or revised emission factors and activity data, and from the inclusion of new emission sources not previously covered.

Notably, CO_2 emissions arising from natural gas reforming to produce hydrogen, in the bitumen and oil refining sectors, previously allocated to the Industrial Processes Sector, are now allocated to the Energy Sector and reported under the Fugitives subsector. Some recalculations in the Energy Sector were triggered by recent detailed studies performed in the Canadian upstream oil and gas and oil refining sectors. Updates to the HFC emission estimation model and incorporation of more recent years' activity data generated recalculations and improvements to the HFC estimates. The inclusion of various mineral uses and semiconductor manufacturing as new sources entailed other recalculations in the Industrial Processes Sector. The use of Tier 2 methods in the Agriculture Sector for direct and indirect N_2O emission sources has significantly revised estimates downward for this sector. The LULUCF Sector implemented important methodological changes as well, involving new data sources and estimation procedures. Finally, recalculations in the Waste Sector, due primarily to changes to the methodology and activity data for CH_4 emission estimations from Solid Waste Disposal on Land, caused a major increase in the emission values for this sector. Changes from the 2005 NIR submission include a 24% increase in the 1990 emission value and a 13% increase in the 2003 emission value for the Waste Sector.

This section provides a summary of the major recalculations performed in each sector, followed by a description of the impacts on GHG levels and trends.

9.1.1 ENERGY

Fuel combustion emission estimates were revised for 2003, since Statistics Canada, the source of the fuel consumption data, revised its recent fuel-use data. This affected the estimates for the Energy Industries, Transport, Manufacturing Industries and Construction, and the Other Sectors subsectors. The primary impact was in the Public Electricity and Heat Production source category.

Transport estimates were also marginally affected by these changes to national statistics for 2003. More importantly, Transport estimates for 1990–2004 now include a preliminary attempt to accommodate fuel ethanol used in Canada. The inclusion of this fuel type in the Transport emissions increases them almost insignificantly. Finally, a regional reallocation of diesel fuel use between adjacent Canadian provinces for 1997 and 1998 has triggered a small shift of emissions between on and off road, with a minor (1 to 5 kt CO_2 eq) change to the Transportation totals for those years.

Fugitive emission estimates for the oil and gas industry were recalculated from 1990 to 2003 based on studies conducted by CAPP and CPPI. The updated 2005 CAPP study, as prepared by Clearstone Engineering Ltd., includes revised activity data and emission factors to account for new sources, changes in technology, and changes in production and process activities. The current study also accounts for the impact of flaring and venting regulations on GHG emissions.

This study improves on the 1999 upstream oil and gas industry study by incorporating additional and updated sources of information, along with the inclusion of an uncertainty assessment and the implementation of QA/QC processes following the IPCC Good Practice Guidance (IPCC, 2000). For the petroleum refining industry, the 2004 CPPI study contributed previously unaccounted-for venting sources from petroleum refining activities. The study also helps increase the transparency of Canada's estimates by allowing the allocation of venting and flaring emissions to the appropriate fugitive categories.

9.1.2 INDUSTRIAL PROCESSES

Several categories in the Industrial Processes Sector were recalculated, mainly because of activity data updates and methodological changes, as described below.

Under Mineral Products, recalculations were made to the 2003 lime production CO_2 emission estimate, since updated 2003 activity data became available. Acquisition of actual clinker production data allowed the revision of 1990–1996 cement production emission estimates. As it was determined in a recent study (AMEC, 2006) that a significant amount of soda ash was consumed in industries other than glass manufacturing, 1990–2003 emissions associated with the use of this mineral were recalculated. For example, soda ash use in flue gas desulphurization can generate considerable amounts of CO_2. CO_2 emissions from limestone use were also recalculated for the years 1990–2003 to take into account emissions coming from application of limestone in pulp and paper mills and other chemical uses not previously reported. One new mineral-related source, namely the use of magnesite in magnesium production, was also introduced into this year's inventory, resulting in other recalculations for the Industrial Processes Sector.

Under Chemical Industry, 1990–2003 emission estimates for ammonia production were revised to exclude all CO_2 that stayed trapped in exported urea.

Under Metal Production, emissions associated with aluminium production as a whole for 1990–2003 were recalculated, as the industry has adjusted the coefficients used to calculate PFC emissions, and SF_6 emissions were added to the inventory. Minor revisions were also done to the CO_2 emission estimates for aluminium production. Since more SF_6 consumption data were gathered from magnesium casting facilities, incorporating these new data resulted in recalculations of SF_6 emissions for 1990–2003.

Under Production and Consumption of Halocarbons, corrections to the activity data used for estimating emissions from fire extinguishers induced recalculations of HFC emissions for 1996–2000. Data on HFC imports and sales by market segment that were gathered through the Cheminfo Services study in 2005 were used to revise the 2001–2003 HFC emission estimates, which had been assumed to stay constant at the 2000 level in the previous inventory.

PFC emissions for 1995–1997 were revised because the estimation method was corrected. Furthermore, 1998–2003 emissions were reestimated based on more recent data obtained from the Chemical Controls Division of Environment Canada.

The inclusion of semiconductor manufacturing as a new source caused upward revisions of emissions coming from the consumption of SF_6 for 1990–2003.

The Other and Undifferentiated Production category was recalculated for 1990–2003 because of reallocation of emissions coming from the use of natural gas to produce hydrogen in oil refining and bitumen upgrading.

9.1.3 SOLVENT AND OTHER PRODUCT USE

In this sector, the revision of demographic statistics led to recalculations for 2002–2003 estimates of N_2O emissions from medical applications and from the use of N_2O as a propellant. These updates had a negligible impact.

9.1.4 AGRICULTURE

This submission incorporates a number of significant changes compared with the 2005 submission as detailed in Chapter 6 on the Agriculture Sector. As a result, many recalculations have been carried out due to methodological upgrades and updates in animal populations.

Inventory methodologies for CH_4 emissions from enteric fermentation and manure management of dairy cattle have been modified to derive a time series of emission factors reflecting changes in milk production over time using the IPCC Tier 2 methods. CH_4 emission factors for dairy and non-dairy cattle from manure management have also been modified using gross energy intake following the IPCC Good Practice Guidance (IPCC, 2000), as well as updates of B_0 and MCFs for all animal categories from the 2006 IPCC Guidelines (IPCC, 2006). Methodologies for estimating direct (synthetic fertilizer nitrogen, animal manure applied as fertilizers, and crop residue decomposition) and indirect N_2O emissions (volatilization of NH_3 and NO_x, and leaching and runoff of nitrogen) from agricultural soils have been upgraded from IPCC Tier 1 to Tier 2 as required for key source categories. Some animal population accounts have been revised based on the latest available updates from Statistics Canada. Manure nitrogen excretion rates for various livestock categories have been revised based on the 2006 IPCC Guidelines (IPCC, 2006). In addition, biological nitrogen fixation by the legume–rhizobium association is no longer included in the inventory. This decision is supported by the conclusion of Rochette and Janzen (2005) (and reflected in the 2006 IPCC Guidelines) that there is no evidence that measurable amounts of N_2O are produced during the nitrogen fixation process. Therefore, Canada decided to report this source as "not occurring." However, the contribution of legume nitrogen to N_2O emissions is included from crop residue decomposition on agricultural soils.

9.1.5 LAND USE, LAND-USE CHANGE AND FORESTRY

Significant enhancements were implemented in the LULUCF Sector, leading to significant recalculations of the whole time series. The 2006 submission incorporates estimates from country-specific Tier 3 methodologies for forest land remaining forest land and all forest land converted to other land uses, which address modelling of carbon transfers between all carbon pools. An advanced Tier 2 methodology was used for cropland remaining cropland (mineral soils). All the new methodologies integrate spatially disaggregated activity data and differ radically from previous approaches.

Estimates are provided for the first time in the wetlands category, for both peatlands and flooded lands. Estimates are also provided this year for the conversion of grassland (tundra) to settlements in the Canadian north. All new estimates were developed with country-specific data.

The definitional framework for all land categories was harmonized, and, as a result, estimates of grassland conversion to cropland were revised using an updated definition. Also as a result of new definitions for cropland and grassland, land conversion to grasslands is deemed not to occur, as managed grasslands/pastures are classified as part of Croplands.

9.1.6 WASTE

Updates to the population statistics generated by Statistics Canada for population estimates from 1997 to 2003 led to recalculations mainly of the CH_4 and N_2O wastewater handling categories, as well as, to a much smaller extent, the CH_4 emissions from MSW landfills, with a minimal effect. A major modification to the methodology to estimate the quantities of waste landfilled and the development of new values for the CH_4 generation potential and the CH_4 generation rate constant resulted in a recalculation of CH_4 landfill emission estimates for 1990–2003. CH_4 and N_2O emissions from wastewater treatment were also recalculated due to the introduction of a new source of activity data for 1990–2003. Finally, implementation of a new methodology and use of new activity data resulted in a recalculation of CO_2 and N_2O emissions from waste incineration for the same period.

9.2 IMPLICATIONS FOR EMISSION LEVELS

Table 9-1 provides a summary, both by sector and for national GHG totals, of the quantitative effects of recalculations.

TABLE 9-1: Recalculations Summary

Sector	GHG Emissions/Removals														
	Mt CO_2 eq														
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
National Total[1]															
Previous	596	589	606	608	630	646	663	675	682	696	720	712	719	740	N/A
Current	599	592	609	611	631	649	667	680	686	698	725	719	726	754	758
% Change	0.5	0.6	0.6	0.4	0.2	0.4	0.5	0.7	0.6	0.4	0.7	1.0	0.9	1.8	–
Energy															
Previous	469	461	478	478	494	508	523	534	543	558	582	576	583	600	N/A
Current	475	467	485	485	502	517	532	545	555	569	596	590	597	622	620
% Change	1.4	1.4	1.4	1.6	1.7	1.7	1.9	2.2	2.3	2.1	2.3	2.5	2.4	3.6	–
Industrial Processes															
Previous	54	55	54	54	57	57	58	58	55	53	52	51	51	52	N/A
Current	53	55	53	53	55	56	57	57	52	50	50	49	48	50	54
% Change	–1.9	–1.0	–0.9	–3.1	–3.6	–3.1	–3.1	–2.4	–5.1	–5.6	–4.9	–4.0	–5.3	–3.6	–
Solvent															
Previous	0.42	0.42	0.43	0.43	0.44	0.44	0.45	0.45	0.45	0.46	0.46	0.47	0.47	0.48	N/A
Current	0.42	0.42	0.43	0.43	0.44	0.44	0.45	0.45	0.45	0.46	0.46	0.47	0.47	0.48	0.48
% Change	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	–
Agriculture															
Previous	52	52	53	54	57	58	60	60	60	61	61	60	59	62	N/A
Current	45	44	45	46	47	49	51	51	51	51	51	51	51	53	55
% Change	–14	–14	–14	–15	–16	–15	–15	–16	–16	–16	–16	–15	–14	–15	–
Waste															
Previous	20	21	21	22	22	22	22	23	24	24	25	24	25	25	N/A
Current	25	25	26	26	26	26	26	27	28	28	28	28	28	29	29
% Change	24	23	22	21	21	20	20	18	17	16	14	15	14	13	–
LULUCF															
Previous	–154	–133	–140	–110	–110	8	–89	–102	–60	–68	–85	–89	–33	–44	N/A
Current	–81	–96	–162	–74	16	195	–77	–124	90	–44	–130	–120	7	–10	82
% Change	–47	–28	16	–32	–114	2476	–14	21	–252	–36	53	34	–122	–77	–

Notes:

1 National totals exclude all gases from the LULUCF Sector.

N/A = not applicable

Emissions have been rounded from the estimated values. Percent differences were calculated based on the non-rounded estimated values.

Overall, changes in emission levels were fairly significant due mainly to recalculations undertaken in the Energy Sector (i.e., fugitive emissions), the Agriculture Sector, and the Waste Sector. Total GHG emissions (excluding the LULUCF Sector) were overall revised upwards. Revisions vary between about +3 Mt (+0.5%) for 1990 and about +14 Mt (+1.8%) for 2003.

For the Energy Sector, recalculations resulted in an increase in reported emissions by between 6.6 Mt (+1.4%, 1990) and 21.8 Mt (+3.6%, 2003).

For the Industrial Processes Sector, recalculations resulted in a decrease in emissions of about 1 Mt for 1990 (or a 1.9% decrease for this sector). The emissions decreased for all years, with the greatest changes in 1998, 1999, and 2002, amounting to 3 Mt (5.1%), 3 Mt (5.6%), and 3 Mt (5.3%), respectively.

For the Solvent and Other Product Use Sector, recalculations resulted in minimal changes.

For the Agriculture Sector, overall recalculations resulted in changes between –14% for 1990 (about –7.4 Mt) and –16% for 2003 estimates (about –9.6 Mt).

For the LULUCF Sector (not included in national totals), the effect of recalculations on the level of estimates is very significant. In particular, net removals in the Forest Land category are much lower than previously reported. A large proportion of these changes are explained by differences in estimation procedures, notably the incorporation of all carbon pools, as opposed to updated activity data. This is particularly apparent in years of severe fire seasons, where large differences can be observed with previously submitted estimates, due to the impact of emissions from the burning of dead organic matter. Conversely, net emissions from cropland are significantly reduced due to a declining emission trend in land converted to cropland, which was not captured by the former approach; and refined estimates associated with changes in cropland management practices.

For the Waste Sector, recalculations resulted in a 24% increase for 1990 and 14% and 13% increases in emissions for 2002 and 2003, respectively.

9.3 IMPLICATIONS FOR EMISSION TRENDS

Overall, the recalculations of the total GHG estimates (excluding the LULUCF Sector) had a medium effect on the long-term trend (1990–2003), amounting to an increase of 2%. The 1990–2003 increase previously reported was 24%; it is now 26%.

For the Energy Sector, the emission trend over 1990–2003 is now +31%, compared with +28% previously reported.

For the Industrial Processes Sector, recalculations resulted in a decrease in emissions for all years between 1990 and 2003. The emissions from this sector decreased from 1990 to 2003 by 6.0% (previously 4.4%).

For the Solvent and Other Product Use Sector, recalculations had very little or no impact on the trends.

For the Agriculture Sector, the increase in GHG emissions over 1990–2003 was revised from 19% (previous submission) to 17%. Changes to the methodologies for N_2O emissions from soils were responsible for most of this impact on the trend.

In the Waste Sector, the increase in emissions over 1990–2003 is now 15%, compared with 27% previously reported. As mentioned previously, the main contributing category to this increase is the CH_4 emissions from MSW landfills. Modifications to the key inputs for the Scholl Canyon model are responsible for this increase, including the adoption of new CH_4 generation potentials and CH_4 generation rate constants as well as the use of a new methodology to estimate the quantity of waste placed in landfills.

In the LULUCF Sector (excluded from national totals), both short- and long-term trends are not particularly meaningful, given that emissions are driven by the forest fire emissions, which are extremely variable from one year to the next.

9.4 PLANNED IMPROVEMENTS

Improvement activities and work plans are developed on a continuous basis to further refine and increase the transparency, completeness, accuracy, consistency, and comparability of the Canadian GHG inventory.

The following is a discussion of current improvement activities and plans based on recommendations provided by the external review process, the UNFCCC ERTs' annual reports, and inventory sector experts. Improvement plans are developed and prioritized based on key category contributions and resource availability. Some improvements span several years.

9.4.1 QUALITY ASSURANCE/QUALITY CONTROL

The design and implementation of a full formal QA/QC plan, building on the existing quality framework (SNC Lavalin, 2004) and the QC Tier 1 procedures implemented on key categories for the current and last submissions, remain a key priority. Owing to budgetary and staffing constraints, QA/QC procedures have not been upgraded or expanded since the previous submission. To enable the full development and implementation of the plan, including upgrading the archiving and documentation system, the Greenhouse Gas Division is in the process of staffing a QA/QC coordinator. For each sector and category, with an initial focus on key categories, QA/QC activity books will be expanded upon and Tier 2 QA and QC plans will be developed, including audits and review plans, as well as verification activities, expanding upon and formalizing current activities. A critical short-term priority consists of the consolidation and expansion of the documentation of the inventory process and of the QA/QC activities, in addition to the development of a GHG archiving system up to standards. QA/QC activities will ultimately be integrated within a continuous and dynamic quality management cycle for the national inventory.

9.4.2 UNCERTAINTIES

Building on the uncertainty study with Tier 2 analysis completed in 2004 (ICF, 2004), further work has been completed to enhance and refine the uncertainty assessment of the GHG inventory (ICF, 2005). These improvements led to a sensitivity analysis to evaluate the degree of sensitivity of the overall uncertainty in the 2001 inventory to the uncertainty of input parameters; the results are reported in this report. Also, the results of the overall inventory trend uncertainty for 2001 have now been reported.

Uncertainty assessments are being conducted for the categories not included in the ICF (2004, 2005) studies and/or for which changes to methods and data have been made or are being implemented. Where available, updates to the 2001 uncertainty estimates are provided in this NIR, in the relevant sector chapters. The implementation of the enhanced methodologies in the LULUCF Sector required an important and concerted effort; uncertainty estimates could not be produced for the categories in this sector in time for the 2006 submission. Work is ongoing to document and quantify uncertainties in each LULUCF category.

A midterm goal is to build internal capacity for uncertainty analysis through the development of an uncertainty quantification system, with linkages to the emissions/removals system, to allow updates to the uncertainty estimates as activities, data, and methods change. A Tier 1 study of the uncertainties for the 2004 emissions will be initiated, followed by acquisition of tools and training to enable continuous in-house updates using a Tier 2 methodology.

9.4.3 KEY CATEGORIES

Future improvement plans also include the development of an IPCC Good Practice Guidance (IPCC, 2000) Tier 2 key category analysis model based on uncertainty analysis results.

9.4.4 DATA MANAGEMENT SYSTEM

The Greenhouse Gas Division has initiated a planning process to develop a data management system for the entire GHG inventory. This has been delayed, but a first step has been planned to define and assess the business requirements, including the option of a multiuser relational inventory database. A second phase of what is anticipated to be a multiyear project will consist of designing, testing, and implementing the system.

9.4.5 ENERGY SECTOR

9.4.5.1 Energy Industries and Fugitive Emissions

As far as the Energy Industries subsector is concerned, a Canadian bitumen industry study has been initiated and is expected to be completed in 2006, with the aim of refining the current combustion, process, and fugitive estimation methods and emission values.

9.4.5.2 Transportation

The current transport model (M-GEM05), upgraded in 2005, continuously evolves to take advantage of the power of the relational database to accommodate an increasing number of higher-resolution data being made available through partnerships and reporting. Future improvements will concentrate on employing better activity data, in particular higher-resolution vehicle population profiles, improved Vkmt estimates, better class-specific fuel consumption patterns, and improved disaggregation of marine activity data to better distinguish domestic and international emissions.

Additionally, and in response to ERT comments, Canada attempted to extract the transportation fuels (gasoline/diesel) used in mining, forestry, and agriculture from transport – off road, and report the associated emissions within their stationary source category counterparts, using current national energy balance data. An initial attempt illustrated the uncertainty embodied in these data with respect to the separation of fuel used by mobile or stationary devices; consequently, this procedure has been postponed until additional knowledge is obtained. As mentioned previously in this NIR, trying to make this change on the basis of current knowledge would reduce the accuracy of the transportation emission estimates and, as such, warrants the “do-nothing” option to prevent an increase in overall uncertainty.

9.4.6 INDUSTRIAL PROCESSES SECTOR

For ammonia production, a study is in progress to obtain the quantity of ammonia production for which the feedstock hydrogen is a by-product of chemical processes that do not involve CO_2 emissions. Another objective of this study is to examine the feasibility of converting to an estimation method based on the consumption of natural gas as input feedstock (versus the current output-based method). For nitric acid, efforts are being made to gather information with respect to the abatement technologies used by the Canadian industry over the years and to assess whether it will be necessary to update the three abatement-specific emission factors currently applied. Other efforts will focus on acquiring more recent data on the consumption of halocarbons and on SF_6 use in electric utilities through the CEA. Finally, the disaggregation of CO_2 emissions included in the Other and Undifferentiated subsector, utilizing industry-reported non-energy fuel use and application-specific emission factors, is also part of the planned improvements for the Industrial Processes Sector.

9.4.7 AGRICULTURE SECTOR

In the current method, the digestible energy for beef and dairy cattle is static over time based on 2001 feed rations. Data on changes in feed ration digestibility over time are being researched to assess the sensitivity of CH_4 emissions. For N_2O soil emissions, the effects of irrigation and soil texture will be investigated. In addition, supplementary efforts will be put into improving the transparency of documentation for the new methodologies used this year, including the publication of empirical data.

9.4.8 LAND USE, LAND-USE CHANGE AND FORESTRY SECTOR

The 2006 submission presents the initial outcome of a multiyear and multiagency effort to substantially improve LULUCF estimates. Efforts were prioritized towards the harmonization across land uses and towards the top key categories — namely, managed forests, cropland, and forest conversion.

Canada has adopted an incremental approach to the implementation of its MARS for LULUCF. Therefore, each inventory submission incorporates improvements as they become available, rather than all at once. Canada continues, through its MARS, to develop a land-use change information system consistent with land reporting requirements described in the IPCC Good Practice Guidance for LULUCF (IPCC, 2003) and quantitative uncertainty estimates for each LULUCF category. The enhanced coverage, complexity, and spatial resolution of data, as well as the specificity of approaches, methods, and data sources, result in enhanced complexity of the inventory preparation. Work is in progress to improve the LULUCF inventory process and infrastructure, from preparation of estimates to documentation. Targeted areas for improvements also include uncertainty quantification for the main LULUCF categories, additional documented QA/QC procedures, and transparency and completeness of documentation.

9.4.9 WASTE SECTOR

A multiyear study supported by Environment Canada, which is being conducted by the University of Manitoba, will be developing an inventory of landfills in Canada. Depending upon the completeness in identifying active, closed, and abandoned landfills and the level of reliable historical information available, this information may be considered to develop a Tier 3 methodology for the estimation of CH_4 emissions from MSW landfills. In addition, studies are being considered for 2006–2007 to improve the muncipal and industrial wastewater emission data and to collect new municipal, clinical, and hazardous waste incineration activity data.

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ANNEX 1: KEY CATEGORIES

A1.1 KEY CATEGORIES — METHODOLOGY

Both the IPCC *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC, 2000) and the IPCC *Good Practice Guidance for Land Use, Land-Use Change and Forestry* (IPCC, 2003) recommend as good practice the identification of key categories of emissions and removals. The intent is to help inventory agencies prioritize their efforts to improve overall estimates. A key category is defined as "one that is prioritized within the national inventory system because its estimate has a significant influence on a country's total inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both" (IPCC, 2000).

This annex describes the key category analysis conducted for Canada's inventory, according to IPCC approaches.

Good practice first requires that inventories be disaggregated into categories from which key sources and sinks may be identified. Source and sink categories are defined according to the following guidelines:

- IPCC categories should be used with emissions specified in CO_2 equivalent units according to standard GWPs.
- A category should be identified for *each* gas emitted by the source, since the methods, emission factors, and related uncertainties differ for each gas.
- Source categories that use the same emission factors based on common assumptions should be aggregated before analysis.

The Canadian analysis of categories for key sources and sinks proceeds according to the Tier 1 Good Practice Guidance approaches of IPCC (2000, 2003). Using the Tier 1 method, key categories are first identified by *quantitative* methods using a predetermined cumulative emissions threshold. Second, Tier 1 key categories are determined by *qualitative* approaches. A more comprehensive Tier 2 approach is recommended if uncertainty estimates are available. In this approach, the results of Tier 1 are multiplied by the relative uncertainty of the source and sink category. Since uncertainty estimates are not available for the LULUCF Sector, Tier 1 methods have been used for key category determination.

The quantitative approach identifies key categories from two perspectives. The first analyzes the emission contribution that each category makes to the national total (with and without LULUCF). The second perspective analyzes the trend of emission contributions from each category to identify where the greatest absolute changes (either increases or decreases) have taken place over a given time (with and without LULUCF). The percent contributions to both levels and trends in emissions are calculated and sorted from greatest to least. A cumulative total is calculated for both approaches. IPCC has determined that a cumulative contribution threshold of 95% for both level and trend assessments is a reasonable approximation of 90% uncertainty for the Tier 1 method of determining key categories (IPCC, 2000). The 95% cumulative contribution threshold has been used in this analysis to define an upper boundary for key category identification. Therefore, when source and/or sink contributions are sorted in decreasing order of importance, those that contribute to 95% of the cumulative total are considered quantitatively to be key.

Level contribution of each source is calculated according to Equation A1-1, which follows IPCC (2000), whereas Equation A1-2 is used to calculate the level contribution from both sources and sinks following IPCC (2003):

Equation A1-1 for source category level assessment:

$$L_{x,t} = E_{x,t}/E_t$$

where:

$L_{x,t}$ = the level assessment for source x in year t

$E_{x,t}$ = the emission (CO_2 eq) estimate of source category x in year t

E_t = the total inventory estimate (CO_2 eq) in year t

Equation A1-2 for source/sink category level assessment:

$$L_{x,t}^* = E_{x,t}^* / E_t^*$$

where:

$L_{x,t}^*$ = level assessment for source or sink x in year t. The asterisk (*) indicates that contributions from all categories (including LULUCF) are entered as absolute values.

$E_{x,t}^*$ = $| E_{x,t} |$: absolute value of emission or removal estimate of source or sink category x in year t

E_t^* = $\sum_x | E_{x,t} |$: total contribution, which is the sum of the absolute values of emissions and removals in year t.

Trend contribution of each source is calculated according to Equation A1-3, which follows IPCC (2000), while Equation A1-4 is used to calculate the trend contribution from both sources and sinks following IPCC (2003):

Equation A1-3 for source category trend assessment:

$$T_{x,t} = L_{x,t} * \left| \{[(E_{x,t} - E_{x,0})/E_{x,t}] - [(E_t - E_0)/E_t]\} \right|$$

where:

$T_{x,t}$ = the contribution of the source category trend to the overall inventory trend (i.e., the trend assessment); the contribution is always recorded as an absolute value

$L_{x,t}$ = the level assessment for source x in year t (derived in Equation A1-1)

$E_{x,t}$ and $E_{x,0}$ = the emission estimates of source category x in years t and 0, respectively

E_t and E_0 = the total inventory estimates in years t and 0, respectively

Equation A1-4 for source and sink category trend assessment:

$$T_{x,t} = E_{x,t}^* / E_t^* \left| \{[(E_{x,t} - E_{x,0})/E_{x,t}] - [(E_t - E_0)/E_t]\} \right|$$

where:

$T_{x,t}$ = trend assessment, which is the contribution of the source or sink category trend to the overall inventory trend. The trend assessment is always recorded as an absolute value, i.e., a negative value is always recorded as the equivalent positive value.

$E_{x,t}^*$ = $| E_{x,t} |$: absolute value of emission or removal estimate of source or sink category x in year t

$E_{x,t}$ and $E_{x,0}$ = real values of estimates of source or sink category x in years t and 0, respectively

E_t and E_0 = $\sum_x E_{x,t}$ and $\sum_x E_{x,0}$ total inventory estimates in years t and 0, respectively. E_t differs from E_t^* in Equation A1-2 in that the removals are not entered as absolute values.

The qualitative approach strengthens the foregoing quantitative analysis by considering more subjective criteria to determine if a category should be listed as key. In most cases, the application of these criteria identifies categories identical to those prioritized by the quantitative analysis. However, additional categories identified as key may be added to the primary list. IPCC Good Practice Guidance (IPCC, 2000) identifies four significant criteria for qualitative analysis. They are as follows:

1. *Mitigation techniques and technologies*: Identify those sources where emissions are being reduced significantly through the use of mitigation techniques or technologies.
2. *High expected emissions growth*: Identify sources with significant growth forecast.
3. *High uncertainty*: Identify most uncertain sources as key to help improve the accuracy of the inventory.
4. *Unexpectedly low or high emissions*: Identify calculation errors and discrepancies by doing order-of-magnitude checks.

This analysis uses three main sources of information to help define qualitative criteria. These published information sources provide valuable insight into qualitative key category assessment:

1. *Canada's First National Climate Change Business Plan* (NCCS, 2000a), *Government of Canada Action Plan 2000 on Climate Change* (Government of Canada, 2000), and *Project Green — Moving Forward on Climate Change: A Plan for Honouring Our Kyoto Commitment* (Government of Canada, 2005), outlining significant mitigation measures under way and planned in a range of sectors;
2. Natural Resources Canada's forecasts of GHG emissions from source categories for a Business-as-Usual (NRCan, 1999) and a Kyoto scenario (NCCS, 2000b); and
3. *Quantitative Assessment of Uncertainty in Canada's National GHG Inventory Estimates for 2001* (ICF, 2004).

The overall purpose of identifying key categories is the institution of best practices in GHG inventory development. The appropriate aggregation of categories is crucial to reflect not only actual sources and sinks but also identical estimation procedures. Thus, while the UNFCCC CRF categories provide a basis for identifying sources and sinks, some aggregation of these sources and sinks can occur when using the same emission factors based on common estimation assumptions. In this analysis, major categories such as fuel combustion, fugitive emissions, industrial processes, agriculture, and waste are in keeping with the CRF. Within these major categories, the aggregation of subcategories occurs when estimates are made based on common assumptions about emission factors and on common activity data. For example, within the fuel combustion category, emissions from residential, commercial, and agriculture subsectors are combined.

In developing source and sink categories, it is also necessary to consider each GHG separately, since estimating methods, emission factors, and related uncertainties differ for each gas. Accordingly, source and sink categories are given for each major GHG — CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6 — where that gas is a contributor to the national inventory.

A complete listing of all source and sink categories for the 2004 inventory is shown in Table A1-1.

A1.1.1 SUMMARY ASSESSMENT

The results of key category assessment in accordance with both IPCC *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC, 2000) and the IPCC *Good Practice Guidance for Land Use, Land-Use Change and Forestry* (IPCC, 2003) are given in Table A1-1.

TABLE A1-1: Key Category Analysis Summary, 2004 Inventory

Source Table	IPCC Category	Direct GHG	Key Source/Sink Category (Yes/No)	If Yes, Criteria for Identification
1-A-1-a	Fuel Combustion – Public Electricity and Heat Production	CO_2	Yes	Level, Trend, and Quality
1-A-1-a	Fuel Combustion – Public Electricity and Heat Production	CH_4	–	–
1-A-1-a	Fuel Combustion – Public Electricity and Heat Production	N_2O	–	–
1-A-1-b	Fuel Combustion – Petroleum Refining	CO_2	Yes	Level, Trend, and Quality
1-A-1-b	Fuel Combustion – Petroleum Refining	CH_4	–	–
1-A-1-b	Fuel Combustion – Petroleum Refining	N_2O	–	–
1-A-1-c	Fuel Combustion – Manufacture of Solid Fuels and Other Energy Industries	CO_2	Yes	Level, Trend, and Quality
1-A-1-c	Fuel Combustion – Manufacture of Solid Fuels and Other Energy Industries	CH_4	Yes	Trend
1-A-1-c	Fuel Combustion – Manufacture of Solid Fuels and Other Energy Industries	N_2O	–	–
1-A-2	Fuel Combustion – Manufacturing Industries and Construction	CO_2	Yes	Level and Trend
1-A-2	Fuel Combustion – Manufacturing Industries and Construction	CH_4	–	–
1-A-2	Fuel Combustion – Manufacturing Industries and Construction	N_2O	–	–
1-A-3-a	Fuel Combustion – Civil Aviation	CO_2	Yes	Level, Trend, and Quality
1-A-3-a	Fuel Combustion – Civil Aviation	CH_4	Yes	Quality
1-A-3-a	Fuel Combustion – Civil Aviation	N_2O	Yes	Quality
1-A-3-b	Fuel Combustion – Road Transportation	CO_2	Yes	Level, Trend, and Quality
1-A-3-b	Fuel Combustion – Road Transportation	CH_4	–	–
1-A-3-b	Fuel Combustion – Road Transportation	N_2O	Yes	Level and Quality
1-A-3-c	Fuel Combustion – Railways	CO_2	Yes	Level and Trend
1-A-3-c	Fuel Combustion – Railways	CH_4	–	–
1-A-3-c	Fuel Combustion – Railways	N_2O	Yes	Quality
1-A-3-d	Fuel Combustion – Navigation	CO_2	Yes	Level
1-A-3-d	Fuel Combustion – Navigation	CH_4	–	–
1-A-3-d	Fuel Combustion – Navigation	N_2O	Yes	Quality
1-A-3-e	Fuel Combustion – Other Transport (Off-Road)	CO_2	Yes	Level, Trend, and Quality
1-A-3-e	Fuel Combustion – Other Transport (Off-Road)	CH_4	Yes	Quality
1-A-3-e	Fuel Combustion – Other Transport (Off-Road)	N_2O	Yes	Quality
1-A-3-e	Fuel Combustion – Pipeline Transport	CO_2	Yes	Level and Trend
1-A-3-e	Fuel Combustion – Pipeline Transport	CH_4	–	–
1-A-3-e	Fuel Combustion – Pipeline Transport	N_2O	–	–
1-A-4	Fuel Combustion – Other Sectors	CO_2	Yes	Level and Trend
1-A-4	Fuel Combustion – Other Sectors	CH_4	Yes	Trend
1-A-4	Fuel Combustion – Other Sectors	N_2O	–	–
1-B-1-a	Fugitive Emissions – Coal Mining	CH_4	Yes	Trend
1-B-2-a	Fugitive Emissions – Oil	CO_2	Yes	Trend
1-B-2-a	Fugitive Emissions – Oil	CH_4	Yes	Level
1-B-2-a	Fugitive Emissions – Oil	N_2O	–	–
1-B-2-b	Fugitive Emissions – Natural Gas	CO_2	Yes	Level and Trend
1-B-2-b	Fugitive Emissions – Natural Gas	CH_4	Yes	Level and Trend
1-B-2-c-1-1	Fugitive Emissions – Oil and Natural Gas – Venting – Oil	CO_2	–	–
1-B-2-c-1-1	Fugitive Emissions – Oil and Natural Gas – Venting – Oil	CH_4	Yes	Level and Trend
1-B-2-c-1-2	Fugitive Emissions – Oil and Natural Gas – Venting – Natural Gas	CO_2	–	–
1-B-2-c-1-2	Fugitive Emissions – Oil and Natural Gas – Venting – Natural Gas	CH_4	Yes	Level and Trend
1-B-2-c-1-3	Fugitive Emissions – Oil and Natural Gas – Venting – Combined	CO_2	–	–
1-B-2-c-1-3	Fugitive Emissions – Oil and Natural Gas – Venting – Combined	CH_4	–	–
1-B-2-c-2-1	Fugitive Emissions – Oil and Natural Gas – Flaring – Oil	CO_2	Yes	Trend
1-B-2-c-2-1	Fugitive Emissions – Oil and Natural Gas – Flaring – Oil	CH_4	–	–
1-B-2-c-2-1	Fugitive Emissions – Oil and Natural Gas – Flaring – Oil	N_2O	–	–
1-B-2-c-2-2	Fugitive Emissions – Oil and Natural Gas – Flaring – Natural Gas	CO_2	–	–
1-B-2-c-2-2	Fugitive Emissions – Oil and Natural Gas – Flaring – Natural Gas	CH_4	–	–
1-B-2-c-2-3	Fugitive Emissions – Oil and Natural Gas – Flaring – Combined	CO_2	Yes	Trend
1-B-2-c-2-3	Fugitive Emissions – Oil and Natural Gas – Flaring – Combined	CH_4	–	–
2-A-1	Industrial Processes – Cement Production	CO_2	Yes	Level
2-A-2	Industrial Processes – Lime Production	CO_2	Yes	Quality

TABLE A1-1: Key Category Analysis Summary, 2004 Inventory (CONTINUED)

Source Table	IPCC Category	Direct GHG	Key Source/Sink Category (Yes/No)	If Yes, Criteria for Identification
2-A-3	Industrial Processes – Limestone and Dolomite Use	CO_2	Yes	Trend
2-A-4	Industrial Processes – Soda Ash Production and Use	CO_2	–	–
2-A-7-2	Industrial Processes – Magnesite Use	CO_2	–	–
2-B-1	Industrial Processes – Ammonia Production	CO_2	Yes	Level, Trend, and Quality
2-B-2	Industrial Processes – Nitric Acid Production	N_2O	–	–
2-B-3	Industrial Processes – Adipic Acid Production	N_2O	Yes	Trend and Quality
2-C-1	Industrial Processes – Iron and Steel Production	CO_2	Yes	Level and Trend
2-C-3	Industrial Processes – Aluminium Production	CO_2	Yes	Level and Trend
2-C-3	Industrial Processes – Aluminium Production	PFCs	Yes	Trend
2-C-4-1	Industrial Processes – Aluminium Production	SF_6	–	–
2-C-4-2	Industrial Processes – Magnesium Production	SF_6	Yes	Trend and Quality
2-C-5	Industrial Processes – Magnesium Casting	SF_6	–	–
2-F	Industrial Processes – Consumption of Halocarbons	HFCs	Yes	Level, Trend, and Quality
2-F	Industrial Processes – Consumption of Halocarbons	PFCs	–	–
2-F-8	Industrial Processes – Consumption of SF_6 for Electrical Equipment	SF_6	Yes	Trend
2-F-7	Industrial Processes – Consumption of SF_6 for Semiconductor	SF_6	–	–
2-G	Industrial Processes – Other (Undifferentiated Processes)	CO_2	Yes	Level, Trend, and Quality
3-D	Solvent and Other Product Use	N_2O	–	–
4-A	Agriculture – Enteric Fermentation	CH_4	Yes	Level and Trend
4-B	Agriculture – Manure Management	CH_4	–	–
4-B	Agriculture – Manure Management	N_2O	Yes	Level
4-D-1	Agriculture – Direct Agricultural Soils	N_2O	Yes	Level, Trend, and Quality
4-D-2	Agriculture – Animal Manure on Pasture, Range, and Paddock	N_2O	Yes	Level
4-D-3	Agriculture – Indirect Agricultural Soils	N_2O	Yes	Level, Trend, and Quality
5-A.1	LULUCF – Forest Land Remaining Forest Land	CO_2	Yes	Level and Trend
5-A.1	LULUCF – Forest Land Remaining Forest Land	CH_4	Yes	Level and Trend
5-A.1	LULUCF – Forest Land Remaining Forest Land	N_2O	Yes	Level and Trend
5-A.2	LULUCF – Land Converted to Forest Land	CO_2	–	–
5-B.1	LULUCF – Cropland Remaining Cropland	CO_2	Yes	Level and Trend
5-B.2	LULUCF – Land Converted to Cropland	CO_2	Yes	Level
5-B.2	LULUCF – Land Converted to Cropland	CH_4	–	–
5-B.2	LULUCF – Land Converted to Cropland	N_2O	–	–
5-D.1	LULUCF – Wetlands Remaining Wetlands	CO_2	–	–
5-D.2	LULUCF – Land Converted to Wetlands	CO_2	Yes	Trend
5-D.2	LULUCF – Land Converted to Wetlands	CH_4	–	–
5-D.2	LULUCF – Land Converted to Wetlands	N_2O	–	–
5-E.2	LULUCF – Settlements	CO_2	Yes	Level and Trend
5-E.2	LULUCF – Settlements	CH_4	–	–
5-E.2	LULUCF – Settlements	N_2O	–	–
6-A	Waste – Solid Waste Disposal on Land	CH_4	Yes	Level, Trend, and Quality
6-B	Waste – Wastewater Handling	CH_4	Yes	Quality
6-B	Waste – Wastewater Handling	N_2O	Yes	Quality
6-C	Waste – Waste Incineration	CO_2	Yes	Quality
6-C	Waste – Waste Incineration	CH_4	–	–
6-C	Waste – Waste Incineration	N_2O	–	–

A1.2 KEY CATEGORY TABLES

A1.2.1 LEVEL ASSESSMENT WITHOUT LULUCF

Table A1-2 shows key categories indicated from level assessment without LULUCF, and Figure A1-1 shows the contribution of key categories to the level assessment.

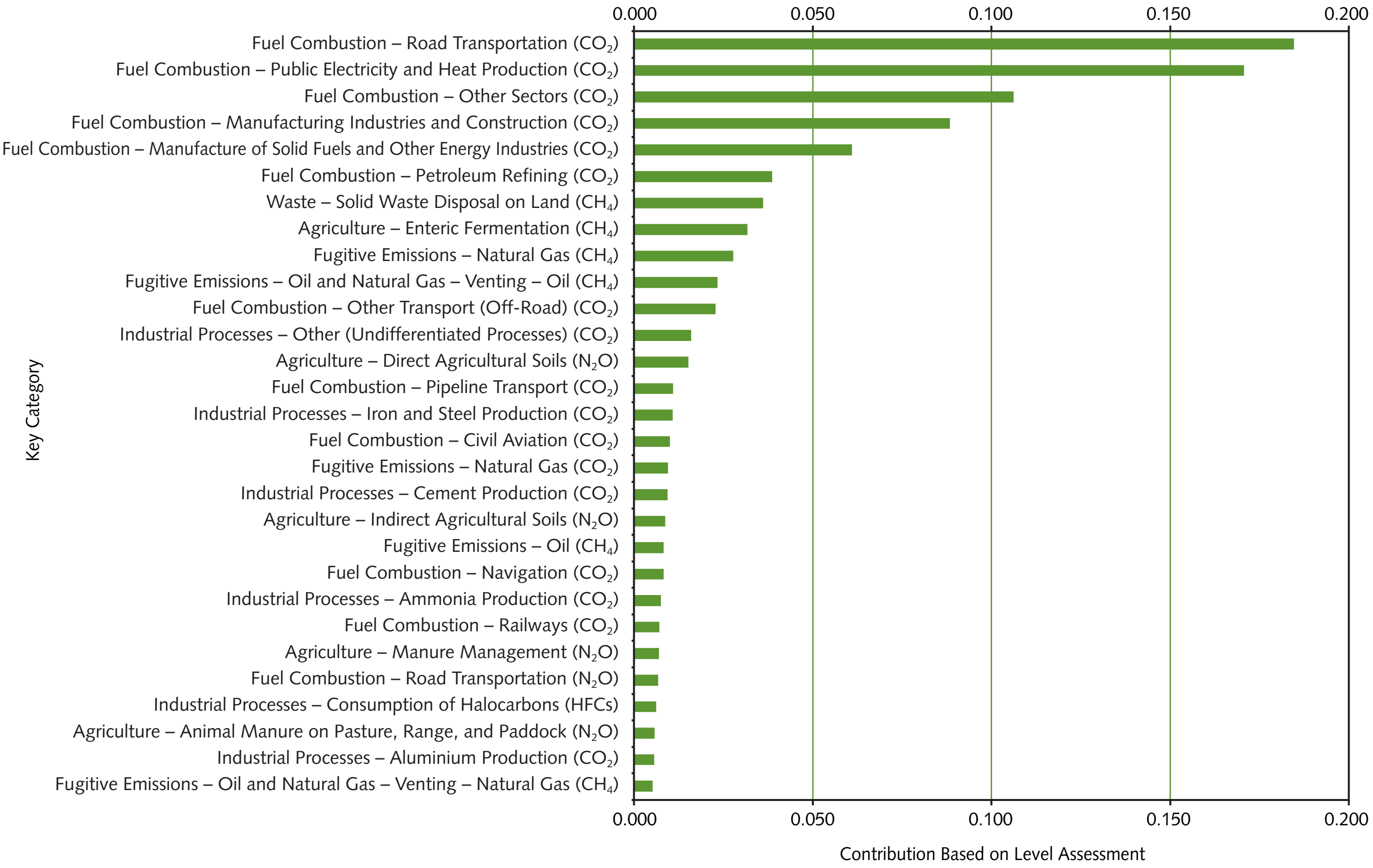
TABLE A1-2: 2004 Key Categories by Level Assessment[1] without LULUCF

Source Table	IPCC Category	Direct GHG	1990 (Base Year) kt CO_2 eq	2004 (Current Year) kt CO_2 eq	Level Assessment	Cumulative Total
1-A-3-b	Fuel Combustion – Road Transportation	CO_2	102 878	139 943	0.185	18%
1-A-1-a	Fuel Combustion – Public Electricity and Heat Production	CO_2	94 745	129 383	0.171	36%
1-A-4	Fuel Combustion – Other Sectors	CO_2	69 415	80 449	0.106	46%
1-A-2	Fuel Combustion – Manufacturing Industries and Construction	CO_2	62 368	66 978	0.088	55%
1-A-1-c	Fuel Combustion – Manufacture of Solid Fuels and Other Energy Industries	CO_2	28 076	46 165	0.061	61%
1-A-1-b	Fuel Combustion – Petroleum Refining	CO_2	22 674	29 239	0.039	65%
6-A	Waste – Solid Waste Disposal on Land	CH_4	23 416	27 373	0.036	69%
4-A	Agriculture – Enteric Fermentation	CH_4	18 423	23 998	0.032	72%
1-B-2-b	Fugitive Emissions – Natural Gas	CH_4	13 418	20 993	0.028	74%
1-B-2-c-1-1	Fugitive Emissions – Oil and Natural Gas – Venting – Oil	CH_4	9 937	17 697	0.023	77%
1-A-3-e	Fuel Combustion – Other Transport (Off-Road)	CO_2	15 086	17 257	0.023	79%
2-G	Industrial Processes – Other (Undifferentiated Processes)	CO_2	8 312	12 052	0.016	81%
4-D-1	Agriculture – Direct Agricultural Soils	N_2O	10 941	11 512	0.015	82%
1-A-3-e	Fuel Combustion – Pipeline Transport	CO_2	6 705	8 281	0.011	83%
2-C-1	Industrial Processes – Iron and Steel Production	CO_2	7 058	8 161	0.011	84%
1-A-3-a	Fuel Combustion – Civil Aviation	CO_2	6 216	7 589	0.010	85%
1-B-2-b	Fugitive Emissions – Natural Gas	CO_2	4 192	7 193	0.009	86%
2-A-1	Industrial Processes – Cement Production	CO_2	5 435	7 099	0.009	87%
4-D-3	Agriculture – Indirect Agricultural Soils	N_2O	5 535	6 624	0.009	88%
1-B-2-a	Fugitive Emissions – Oil	CH_4	4 753	6 294	0.008	89%
1-A-3-d	Fuel Combustion – Navigation	CO_2	4 733	6 261	0.008	90%
2-B-1	Industrial Processes – Ammonia Production	CO_2	3 942	5 660	0.007	91%
1-A-3-c	Fuel Combustion – Railways	CO_2	6 315	5 349	0.007	91%
4-B	Agriculture – Manure Management	N_2O	4 079	5 252	0.007	92%
1-A-3-b	Fuel Combustion – Road Transportation	N_2O	3 649	5 081	0.007	93%
2-F	Industrial Processes – Consumption of Halocarbons	HFCs	0	4 678	0.006	93%
4-D-2	Agriculture – Animal Manure on Pasture, Range, and Paddock	N_2O	3 193	4 306	0.006	94%
2-C-3	Industrial Processes – Aluminium Production	CO_2	2 715	4 224	0.006	94%
1-B-2-c-1-2	Fugitive Emissions – Oil and Natural Gas – Venting – Natural Gas	CH_4	2 655	3 896	0.005	95%

Note:

[1] IPCC *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, Chapter 7, Tier 1 Analysis - Level Assessment - Sorted.

FIGURE A1-1: Contributions of Key Categories to Level Assessment without LULUCF



A1.2.2 LEVEL ASSESSMENT WITH LULUCF

Table A1-3 shows key categories indicated from level assessment with LULUCF, and Figure A1-2 shows the contribution of key categories to the level assessment.

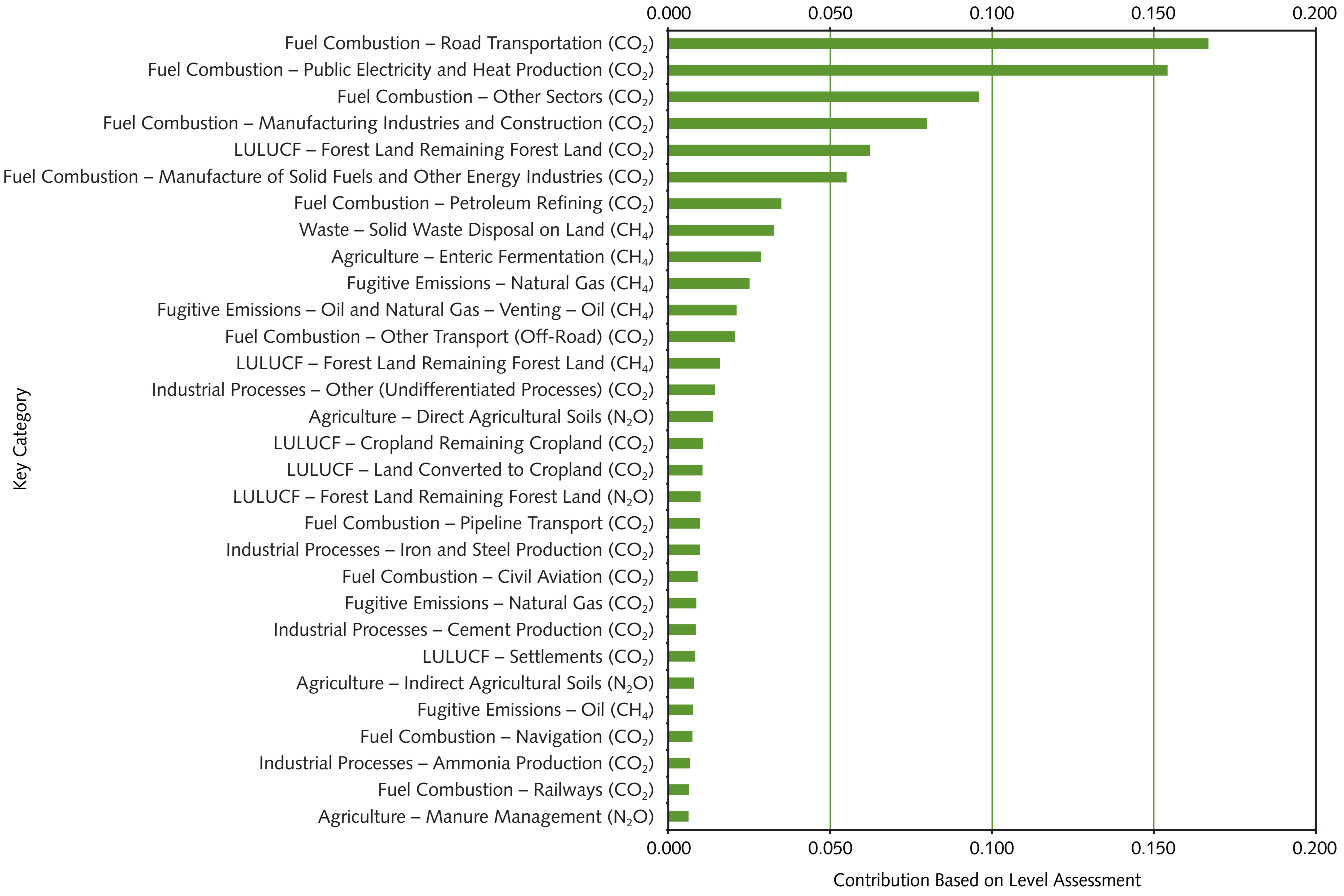
TABLE A1-3: 2004 Key Categories by Level Assessment[1] with LULUCF

Source Table	IPCC Category	Direct GHG	1990 (Base Year)	2004 (Current Year)	Level Assessment	Cumulative Total
			kt CO_2 eq	*kt CO_2 eq*		
1-A-3-b	Fuel Combustion – Road Transportation	CO_2	102 878	139 943	0.167	17%
1-A-1-a	Fuel Combustion – Public Electricity and Heat Production	CO_2	94 745	129 383	0.154	32%
1-A-4	Fuel Combustion – Other Sectors	CO_2	69 415	80 449	0.096	42%
1-A-2	Fuel Combustion – Manufacturing Industries and Construction	CO_2	62 368	66 978	0.080	50%
5-A.1	LULUCF – Forest Land Remaining Forest Land	CO_2	–112 973	52 219	0.062	56%
1-A-1-c	Fuel Combustion – Manufacture of Solid Fuels and Other Energy Industries	CO_2	28 076	46 165	0.055	61%
1-A-1-b	Fuel Combustion – Petroleum Refining	CO_2	22 674	29 239	0.035	65%
6-A	Waste – Solid Waste Disposal on Land	CH_4	23 416	27 373	0.033	68%
4-A	Agriculture – Enteric Fermentation	CH_4	18 423	23 998	0.029	71%
1-B-2-b	Fugitive Emissions – Natural Gas	CH_4	13 418	20 993	0.025	74%
1-B-2-c-1-1	Fugitive Emissions – Oil and Natural Gas – Venting -– Oil	CH_4	9 937	17 697	0.021	76%
1-A-3-e	Fuel Combustion – Other Transport (Off-Road)	CO_2	15 086	17 257	0.021	78%
5-A.1	LULUCF – Forest Land Remaining Forest Land	CH_4	3 209	13 379	0.016	79%
2-G	Industrial Processes – Other (Undifferentiated Processes)	CO_2	8 312	12 052	0.014	81%
4-D-1	Agriculture – Direct Agricultural Soils	N_2O	10 941	11 512	0.014	82%
5-B.1	LULUCF – Cropland Remaining Cropland	CO_2	–2 298	–9 005	0.011	83%
5-B.2	LULUCF – Land Converted to Cropland	CO_2	15 620	8 860	0.011	84%
5-A.1	LULUCF – Forest Land Remaining Forest Land	N_2O	1 992	8 303	0.010	85%
1-A-3-e	Fuel Combustion - Pipeline Transport	CO_2	6 705	8 281	0.010	86%
2-C-1	Industrial Processes – Iron and Steel Production	CO_2	7 058	8 161	0.010	87%
1-A-3-a	Fuel Combustion – Civil Aviation	CO_2	6 216	7 589	0.009	88%
1-B-2-b	Fugitive Emissions – Natural Gas	CO_2	4 192	7 193	0.009	89%
2-A-1	Industrial Processes – Cement Production	CO_2	5 435	7 099	0.008	90%
5-E.2	LULUCF – Settlements	CO_2	8 008	6 923	0.008	91%
4-D-3	Agriculture – Indirect Agricultural Soils	N_2O	5 535	6 624	0.008	91%
1-B-2-a	Fugitive Emissions – Oil	CH_4	4 753	6 294	0.008	92%
1-A-3-d	Fuel Combustion – Navigation	CO_2	4 733	6 261	0.007	93%
2-B-1	Industrial Processes – Ammonia Production	CO_2	3 942	5 660	0.007	94%
1-A-3-c	Fuel Combustion – Railways	CO_2	6 315	5 349	0.006	94%
4-B	Agriculture – Manure Management	N_2O	4 079	5 252	0.006	95%

Note:

[1] IPCC *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, Chapter 7, Tier 1 Analysis - Level Assessment - Sorted.

FIGURE A1-2: Contributions of Key Categories to Level Assessment with LULUCF



A1.2.3 TREND ASSESSMENT WITHOUT LULUCF

Table A1-4 shows key categories indicated from trend assessment without LULUCF, and Figure A1-3 shows the contribution of key categories to the trend assessment.

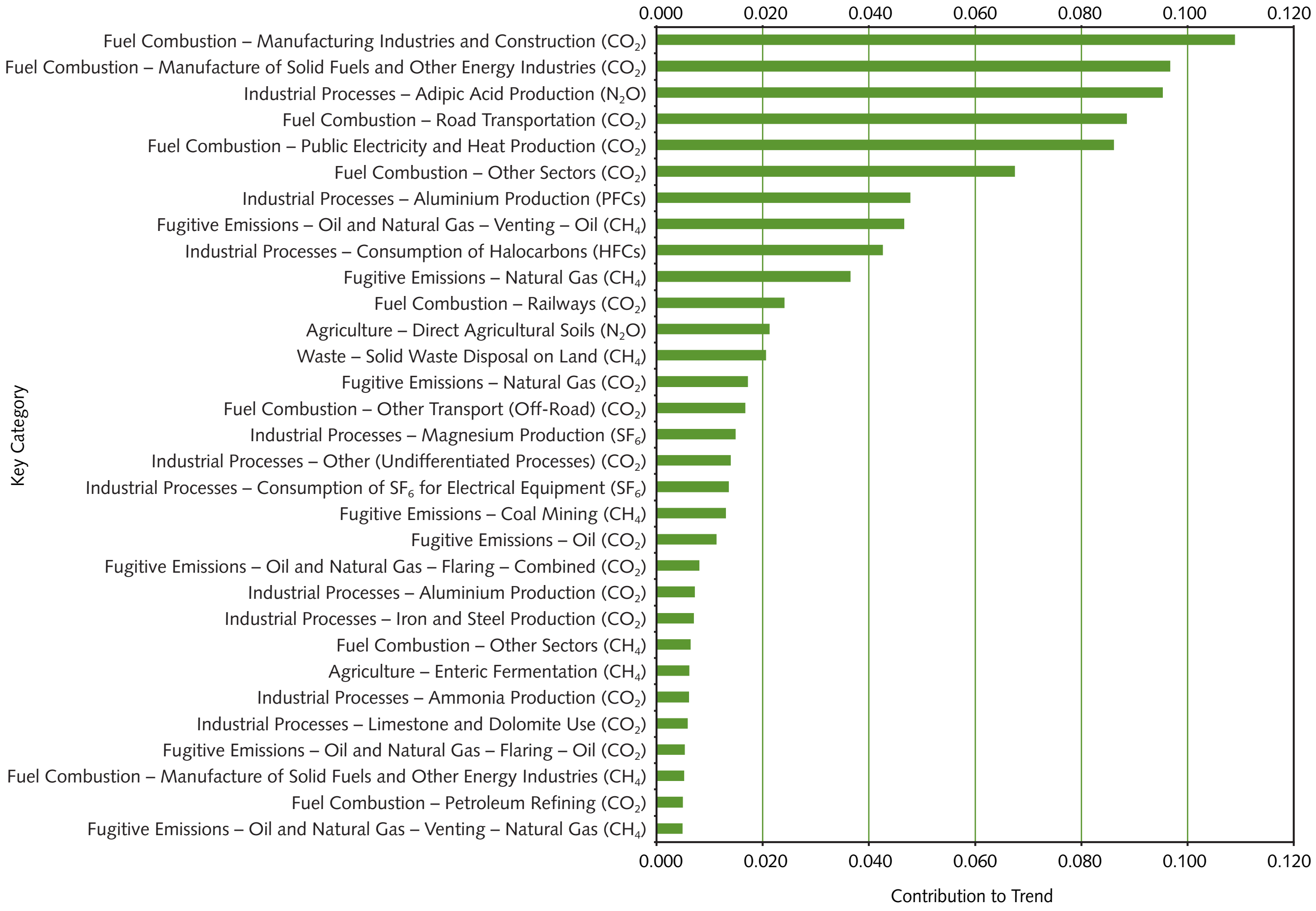
TABLE A1-4: 2004 Key Categories by Trend Assessment[1] without LULUCF

Source Table	IPCC Category	Direct GHG	1990 (Base Year) kt CO_2 eq	2004 (Current Year) kt CO_2 eq	Trend Assessment	Contribution to Trend	Cumulative Total
1-A-2	Fuel Combustion – Manufacturing Industries and Construction	CO_2	62 368	66 978	0.012	0.109	11%
1-A-1-c	Fuel Combustion – Manufacture of Solid Fuels and Other Energy Industries	CO_2	28 076	46 165	0.011	0.097	21%
2-B-3	Industrial Processes – Adipic Acid Production	N_2O	10 718	3 095	0.011	0.095	30%
1-A-3-b	Fuel Combustion – Road Transportation	CO_2	102 878	139 943	0.010	0.089	39%
1-A-1-a	Fuel Combustion – Public Electricity and Heat Production	CO_2	94 745	129 383	0.010	0.086	48%
1-A-4	Fuel Combustion – Other Sectors	CO_2	69 415	80 449	0.008	0.067	54%
2-C-3	Industrial Processes – Aluminium Production	PFCs	6 539	3 027	0.005	0.048	59%
1-B-2-c-1-1	Fugitive Emissions – Oil and Natural Gas – Venting – Oil	CH_4	9 937	17 697	0.005	0.047	64%
2-F	Industrial Processes – Consumption of Halocarbons	HFCs	0	4 678	0.005	0.043	68%
1-B-2-b	Fugitive Emissions – Natural Gas	CH_4	13 418	20 993	0.004	0.036	72%
1-A-3-c	Fuel Combustion – Railways	CO_2	6 315	5 349	0.003	0.024	74%
4-D-1	Agriculture – Direct Agricultural Soils	N_2O	10 941	11 512	0.002	0.021	76%
6-A	Waste – Solid Waste Disposal on Land	CH_4	23 416	27 373	0.002	0.021	78%
1-B-2-b	Fugitive Emissions – Natural Gas	CO_2	4 192	7 193	0.002	0.017	80%
1-A-3-e	Fuel Combustion – Other Transport (Off-Road)	CO_2	15 086	17 257	0.002	0.017	82%
2-C-4-2	Industrial Processes – Magnesium Production	SF_6	2 870	1 997	0.002	0.015	83%
2-G	Industrial Processes – Other (Undifferentiated Processes)	CO_2	8 312	12 052	0.002	0.014	85%
2-F-8	Industrial Processes – Consumption of SF_6 for Electrical Equipment	SF_6	1 796	778	0.002	0.014	86%
1-B-1-a	Fugitive Emissions – Coal Mining	CH_4	1 914	990	0.001	0.013	87%
1-B-2-a	Fugitive Emissions – Oil	CO_2	1 906	3 649	0.001	0.011	88%
1-B-2-c-2-3	Fugitive Emissions – Oil and Natural Gas – Flaring – Combined	CO_2	275	1 233	0.001	0.008	89%
2-C-3	Industrial Processes – Aluminium Production	CO_2	2 715	4 224	0.001	0.007	90%
2-C-1	Industrial Processes – Iron and Steel Production	CO_2	7 058	8 161	0.001	0.007	91%
1-A-4	Fuel Combustion – Other Sectors	CH_4	2 117	1 979	0.001	0.006	91%
4-A	Agriculture – Enteric Fermentation	CH_4	18 423	23 998	0.001	0.006	92%
2-B-1	Industrial Processes – Ammonia Production	CO_2	3 942	5 660	0.001	0.006	92%
2-A-3	Industrial Processes – Limestone and Dolomite Use	CO_2	734	290	0.001	0.006	93%
1-B-2-c-2-1	Fugitive Emissions – Oil and Natural Gas – Flaring – Oil	CO_2	3 303	3 596	0.001	0.005	94%
1-A-1-c	Fuel Combustion – Manufacture of Solid Fuels and Other Energy Industries	CH_4	1 634	2 636	0.001	0.005	94%
1-A-1-b	Fuel Combustion – Petroleum Refining	CO_2	22 674	29 239	0.001	0.005	95%
1-B-2-c-1-2	Fugitive Emissions – Oil and Natural Gas – Venting – Natural Gas	CH_4	2 655	3 896	0.001	0.005	95%

Note:

[1] IPCC *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, Chapter 7, Tier 1 Analysis - Trend Assessment - Sorted.

FIGURE A1-3: Contributions of Key Categories to Trend Assessment without LULUCF



A1.2.4 TREND ASSESSMENT WITH LULUCF

Table A1-5 shows key categories indicated from trend assessment with LULUCF, and Figure A1-4 shows the contribution of key categories to the trend assessment.

TABLE A1-5: 2004 Key Categories by Trend Assessment[1] with LULUCF

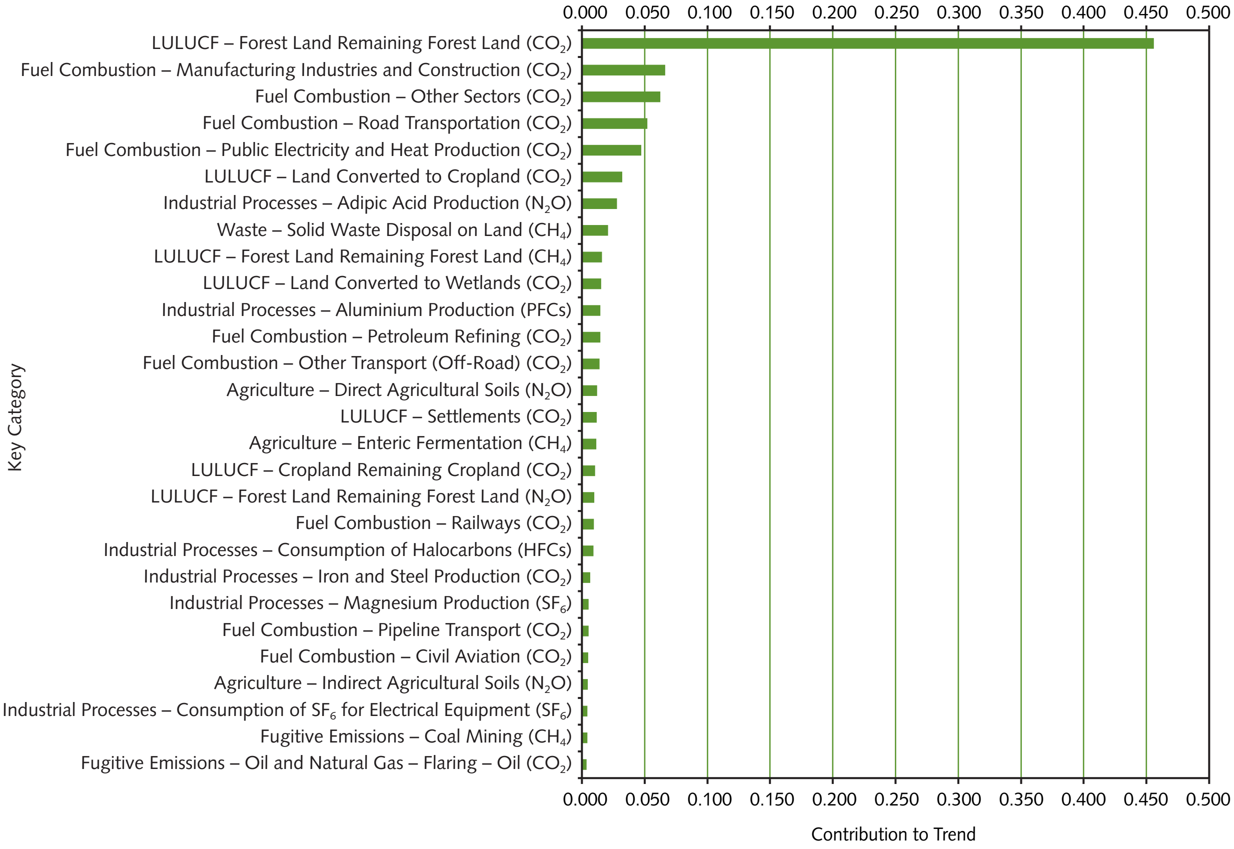
Source Table	IPCC Category	Direct GHG	1990 (Base Year) kt CO_2 eq	2004 (Current Year) kt CO_2 eq	Trend Assessment	Contribution to Trend	Cumulative Total
5-A.1	LULUCF – Forest Land Remaining Forest Land	CO_2	–112 973	52 219	0.173	0.456	46%
1-A-2	Fuel Combustion – Manufacturing Industries and Construction	CO_2	62 368	66 978	0.025	0.066	52%
1-A-4	Fuel Combustion – Other Sectors	CO_2	69 415	80 449	0.024	0.062	58%
1-A-3-b	Fuel Combustion – Road Transportation	CO_2	102 878	139 943	0.020	0.052	64%
1-A-1-a	Fuel Combustion – Public Electricity and Heat Production	CO_2	94 745	129 383	0.018	0.047	68%
5-B.2	LULUCF – Land Converted to Cropland	CO_2	15 620	8 860	0.012	0.032	72%
2-B-3	Industrial Processes – Adipic Acid Production	N_2O	10 718	3 095	0.011	0.028	74%
6-A	Waste – Solid Waste Disposal on Land	CH_4	23 416	27 373	0.008	0.021	76%
5-A.1	LULUCF – Forest Land Remaining Forest Land	CH_4	3 209	13 379	0.006	0.016	78%
5-D.2	LULUCF – Land Converted to Wetlands	CO_2	5 468	970	0.006	0.015	79%
2-C-3	Industrial Processes – Aluminium Production	PFCs	6 539	3 027	0.006	0.015	81%
1-A-1-b	Fuel Combustion – Petroleum Refining	CO_2	22 674	29 239	0.006	0.015	82%
1-A-3-e	Fuel Combustion – Other Transport (Off-Road)	CO_2	15 086	17 257	0.005	0.014	84%
4-D-1	Agriculture – Direct Agricultural Soils	N_2O	10 941	11 512	0.005	0.012	85%
5-E.2	LULUCF – Settlements	CO_2	8 008	6 923	0.004	0.012	86%
4-A	Agriculture – Enteric Fermentation	CH_4	18 423	23 998	0.004	0.011	87%
5-B.1	LULUCF – Cropland Remaining Cropland	CO_2	–2 298	–9 005	0.004	0.010	88%
5-A.1	LULUCF – Forest Land Remaining Forest Land	N_2O	1 992	8 303	0.004	0.010	89%
1-A-3-c	Fuel Combustion – Railways	CO_2	6 315	5 349	0.004	0.009	90%
2-F	Industrial Processes – Consumption of Halocarbons	HFCs	0	4 678	0.003	0.009	91%
2-C-1	Industrial Processes – Iron and Steel Production	CO_2	7 058	8 161	0.002	0.006	92%
2-C-4-2	Industrial Processes – Magnesium Production	SF_6	2 870	1 997	0.002	0.005	92%
1-A-3-e	Fuel Combustion – Pipeline Transport	CO_2	6 705	8 281	0.002	0.005	93%
1-A-3-a	Fuel Combustion – Civil Aviation	CO_2	6 216	7 589	0.002	0.005	93%
4-D-3	Agriculture – Indirect Agricultural Soils	N_2O	5 535	6 624	0.002	0.005	94%
2-F-8	Industrial Processes – Consumption of SF_6 for Electrical Equipment	SF_6	1 796	778	0.002	0.004	94%
1-B-1-a	Fugitive Emissions – Coal Mining	CH_4	1 914	990	0.002	0.004	95%
1-B-2-c-2-1	Fugitive Emissions – Oil and Natural Gas – Flaring – Oil	CO_2	3 303	3 596	0.001	0.003	95%

Notes:

[1] IPCC *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, Chapter 7, Tier 1 Analysis - Trend.

The negative values for LULUCF – Forest Land Remaining Forest Land and LULUCF – Cropland Remaining Cropland indicate a small net removal. The absolute value was used in the assessment, recognizing that this differs slightly from IPCC (2003).

FIGURE A1-4: **Contributions of Key Categories to Trend Assessment with LULUCF**



A1.2.5 QUALITATIVE ASSESSMENT

A1.2.5.1 Mitigation Techniques and Technologies

Mitigation techniques are important for good practices, in particular if they are inclined to produce departures from the norm under which activity data and emission factors are estimated. Table A1-6 shows key categories identified as a result of having significant mitigation techniques and technologies introduced that have had (since 1990), or will have, an impact on emission estimates.

TABLE A1-6: Key Categories by Significant Mitigation Techniques and Technologies

Key Category	GHG	Reference(s)	Comments
Fuel Combustion – Road Transportation	CO_2	Government of Canada, 2000; NCCS, 2000a	Voluntary efficiency standards, increased biofuel use: Voluntary measure
Fuel Combustion – Public Electricity and Heat Production	CO_2	NRCan, 1999; Government of Canada, 2000, 2005; NCCS, 2000a	Utility deregulation opens market to distributed power and reduced barriers to interprovincial trade. Natural gas replaces coal and oil generation: Voluntary measure Wind Power Production Incentive — 4000 MW of wind power by 2010: Budget incentive to displace fuel
Fuel Combustion – Manufacture of Solid Fuels and Other Energy Industries	CO_2	Government of Canada, 2000; NCCS, 2000a	Demonstrate CO_2 capture and storage: Voluntary measure
Waste – Solid Waste Disposal on Land	CH_4	CSA, Online	Landfills are collecting CH_4 emissions for combustion or power generation: Policy measure
Industrial Processes – Adipic Acid Production	N_2O	Lauridson, 2004	An emission abatement system was installed at Canada's only adipic acid production facility in 1997. As a result, emissions from this source decreased by 90% from 1990 to 2003.
Industrial Processes – Magnesium Production	SF_6	NRCan, 1999	Gradual replacement of SF_6 in magnesium casting and smelting by alternative cover gases: Voluntary measure

A1.2.5.2 High Emissions Growth

Table A1-7 shows key categories identified as a result of having emissions growth forecasts of over 20% between 1997 and 2020. Designation as key anticipates significant changes in the sector and indicates a need to establish sound estimating practices.

TABLE A1-7: **Key Categories Identified from Anticipated High Emissions Growth**

Key Source	GHG	Reference(s)	Comments
Fuel Combustion – Manufacture of Solid Fuels and Other Energy Industries	CO_2	NRCan, 1999	Increased heavy oil production
Fuel Combustion – Petroleum Refining	CO_2	NRCan, 1999; NCCS, 2000a	Increased heavy oil use
Fuel Combustion – Petroleum Refining	CO_2	CPPI, 2004	Growth in emissions as a result of desulphurization initiatives for liquid fuels (for gasoline, diesel, and furnace oil)
Fuel Combustion – Transport – Road	CO_2	NRCan, 1999	Growth in road transport use
Fuel Combustion – Transport – Civil Aviation	CO_2	NRCan, 1999	Growth in air travel, passenger and freight
Fuel Combustion – Transport – Civil Aviation	N_2O	NRCan, 1999	Growth in air travel, passenger and freight
Fuel Combustion – Transport – Civil Aviation	CH_4	NRCan, 1999	Growth in air travel, passenger and freight
Fuel Combustion – Transport – Other	CO_2	NRCan, 1999	Growth in off-road use, especially fossil fuel mining
Fuel Combustion – Transport – Road	N_2O	NRCan, 1999	Growth in road transport use
Consumption of HFCs and SF_6	HFCs	NRCan, 1999	Increase due to replacement of CFCs

A1.2.5.3 High Uncertainty

The ICF (2004, 2005) studies of uncertainty associated with 2001 inventory estimates are, with some exceptions, the most current sources of information on uncertainty levels. In these studies, uncertainties are reported following the UNFCCC CRF categories. Table A1-8 shows key categories identified as having a relatively high composite uncertainty (meaning both activity and emission factor uncertainties) compared with the expected norm (see estimates in the tables of Annex 7 and, where relevant, updates in Chapters 3–8).

TABLE A1-8: **Key Categories with a High Composite Uncertainty**

Key Source	GHG	Reference
Fuel Combustion – Manufacturing of Solid Fuels and Other Energy Industries	CO_2	ICF, 2004
Fuel Combustion – Petroleum Refining	CO_2	ICF, 2004
Waste – Solid Waste Disposal on Land	CH_4	ICF, 2004
Waste – Waste Incineration	CO_2	ICF, 2004
Agriculture – Direct Agricultural Soils	N_2O	Hutchinson, 2006
Agriculture – Indirect Agricultural Soils	N_2O	Hutchinson, 2006
Waste – Wastewater Handling	N_2O	ICF, 2004
Waste – Wastewater Handling	CH_4	ICF, 2004
Fuel Combustion – Off-Road: Diesel	N_2O	ICF, 2004
Fuel Combustion – Rail	N_2O	ICF, 2004
Fuel Combustion – Road	CO_2	ICF, 2004
Fuel Combustion – Off-Road: Diesel	CO_2	ICF, 2004
Fuel Combustion – Off-Road: Gasoline	CO_2	ICF, 2004
Fuel Combustion – Marine (Navigation)	N_2O	ICF, 2004
Fuel Combustion – Aviation	N_2O	ICF, 2004
Fuel Combustion – Off-Road: Gasoline	CH_4	ICF, 2004
Industrial Processes – Other and Undifferentiated Production	CO_2	ICF, 2004
Industrial Processes – Ammonia Production	CO_2	ICF, 2004
Industrial Processes – Lime Production	CO_2	ICF, 2004

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ANNEX 2: METHODOLOGY AND DATA FOR ESTIMATING EMISSIONS FROM FUEL COMBUSTION

To estimate emissions from fuel combustion, the following methodology has been adopted. It applies, generally, to all source sectors, although additional refinements and more detailed procedures are often used.

Equation A2-1:

Quantity of Fuel Combusted * Emission Factor per Physical Unit of Fuel = Emissions

For each sector and subsector, the appropriate quantity of each fuel combusted is multiplied by a fuel- and technology-specific emission factor.

The emission factors employed in estimating the emissions for the current GHG inventory are listed in Annex 13:

- *Natural Gas Fuels*: The emission factors vary by fuel type and combustion technology.
- *Refined Petroleum Product Fuels*: The emission factors vary by fuel type and combustion technology.
- *Coal Fuels*: The emission factors for CO_2 vary with the properties of the coal. Therefore, emission factors are assigned for different provinces based upon the origins of the coal used. The emission factors for CH_4 and N_2O vary with the combustion technology.

This is consistent with an IPCC Tier 2–type methodology, as described in the IPCC Guidelines (IPCC/OECD/IEA, 1997).

A2.1 CO_2 EMISSIONS

Fuel combustion CO_2 emissions depend upon the amount of fuel consumed, the carbon content of the fuel, and the fraction of the fuel oxidized (Jaques, 1992). The basis of the CO_2 emission factor derivations has been discussed in previous publications (e.g., Jaques, 1992). The factors have been obtained and developed from a number of studies conducted by Environment Canada, the U.S. EPA, and other organizations, both domestic and international. The methods used to derive the factors are based on the carbon contents of the fuels and the typical fraction of carbon oxidized. Both the hydrocarbons and particulate formed during combustion are accounted for to some extent, but emissions of CO are included in the estimates of CO_2 emissions. It is assumed that CO in the atmosphere undergoes complete oxidation to CO_2 shortly after combustion (within 5–20 weeks of its release).

Emission factors are based upon the physical quantity of fuel combusted, rather than on the energy content of the fuel. They therefore provide a more accurate estimate of emissions, since the number of conversions required to derive the estimates is minimized and since quantity of fuel consumed is commonly reported in physical units to Canada's statistical agency (i.e., Statistics Canada) and is therefore assumed to be more accurate. It is important to note that these Canadian-specific emission factors differ from those of the IPCC in that they relate emissions to the quantity of fuel consumed and not to the energy content of the fuel. The emission factors employed to estimate emissions are subdivided by the type of fuel used.

A2.2 NON-CO_2 GHGs

Emission factors for all non-CO_2 GHGs from combustion activities vary to a lesser or greater degree with:

- fuel type;
- technology;
- operating conditions; and
- maintenance and vintage of technology.

During combustion of carbon-based fuels, a small portion of the fuel remains unoxidized as CH_4. Additional research is necessary to better establish CH_4 emission factors for many combustion processes. Overall factors are developed for sectors based on typical technology splits and available emission factors for the sector. In several sectors, CH_4 emission factors are not known.

During combustion, some of the nitrogen in the fuel or air is converted to N_2O. The production of N_2O is dependent upon the temperature in the boiler/stove and the control technology employed. Additional research is necessary to better establish N_2O emission factors for many combustion processes. Overall factors are developed for sectors based on typical technologies and available emission factors for the sector. In several sectors, N_2O emission factors are not known. Non-CO_2 emission factors in this inventory are listed in Annex 13.

A2.3 BIOMASS COMBUSTION

Some emissions of CO_2 result from the combustion of biomass used to produce energy. However, as per UNFCCC requirements, CO_2 emissions from biomass fuels are not included in the Energy Sector totals. They are accounted for in the LULUCF Sector as a loss of biomass (forest) stocks. CO_2 from biomass combustion for energy purposes is reported as a memo item for information only. CH_4 and N_2O emissions from biomass fuel combustion are reported in the Energy Sector in the appropriate subsectors and included in inventory totals.

A2.4 STATISTICS CANADA ENERGY-USE DATA — RESD

The fossil fuel energy-use data used to estimate combustion emissions are from the RESD (Statistics Canada, #57-003), compiled by Statistics Canada, Canada's national statistics agency. It is the principal source of energy-use data.

The RESD uses a top-down approach to estimate the supply and demand of energy in Canada. The production of fuels in Canada is balanced with the use of fuels in broad categories such as import/export, producer consumption, industry, residential, etc. Industrial energy-use data are divided into broad sectors based on SIC or NAICS codes.

While the RESD also provides fuel-use estimates at a provincial level, the accuracy of these data is not as high as that of the national data. Statistics Canada generally collects the fuel data for the RESD by surveying the suppliers of energy, provincial energy ministries, and some users of energy. The accuracy of the sectoral end-use data is less than that of the total energy supply data. As a result, the total emission estimates for Canada are known with more certainty than the emissions from specific categories. Since 1995, Statistics Canada has been collecting energy-use statistics from end users through the Industrial Consumption of Energy Survey. This bottom-up approach to estimating fuel use by industry (as opposed to the top-down approach used in the RESD) may provide more accurate information at the sectoral level for future inventories.

REFERENCES

IPCC/OECD/IEA (1997), *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, Intergovernmental Panel on Climate Change, Organisation for Economic Co-operation and Development, and International Energy Agency. Available online at: www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm.

Jaques, A.P. (1992), *Canada's Greenhouse Gas Emissions: Estimates for 1990*, Environmental Protection, Conservation and Protection, Environment Canada, Report No. EPS 5/AP/4.

Statistics Canada, *Report on Energy Supply–Demand in Canada* (Annual), Catalogue No. 57-003-XIB.

ANNEX 3: ADDITIONAL METHODOLOGIES

A3.1 METHODOLOGY FOR ENERGY

Readers are referred to Chapter 3 (Energy) and Annex 2 (Methodology and Data for Estimating Emissions from Fuel Combustion).

A3.2 METHODOLOGY FOR INDUSTRIAL PROCESSES

The Industrial Processes Sector covers GHG emissions arising from non-energy-related industrial activities. The processes included in this sector are mineral production and use, chemical production, metal production, consumption of halocarbons and SF_6, and other and undifferentiated production. Each of these can be further divided into various categories — for example, CO_2 emissions from iron and steel production or SF_6 emissions from magnesium casting — as discussed in Chapter 4. The purpose of this section of Annex 3 is to describe in detail the methodologies (i.e., specific equations, activity data, and emission factors) that are used to derive the estimates for the following categories of the Industrial Processes Sector:

- CO_2 from iron and steel production; and
- CO_2 from other and undifferentiated production.

A3.2.1 CO_2 EMISSIONS FROM IRON AND STEEL PRODUCTION

A3.2.1.1 Methodology

The IPCC Tier 2 method is used to estimate, at the national level, CO_2 emissions coming from iron and steel production. This method is based on the tracking of carbon through the process. Emissions from iron production and those from steel production are calculated separately, using the following equations (IPCC, 2000):

Equation A3-1a for emissions from pig iron production:

Emissions$_{\text{pig iron}}$ = (Emission Factor$_{\text{reductant}}$ $*$ mass of reductant) + (mass of carbon in the ore – mass of carbon in pig iron) $*$ 44/12

where:

Emission Factor$_{\text{reductant}}$ = 2.479 t CO_2 / t of coke used (Jaques, 1992). Note that reducing agents used to produce crude iron from iron ore can be coke, coal, charcoal, and petroleum coke. However, it is assumed that the reductant used is 100% metallurgical coke.

mass of reductant = mass of metallurgical coke used in the process

mass of carbon in the ore = zero; according to the IPCC Good Practice Guidance (IPCC, 2000), the carbon content in ore is almost zero.

mass of carbon in pig iron = total pig iron production $*$ carbon content in pig iron (which is about 4%; IPCC, 2000)

44/12 = ratio of the molecular weight of CO_2 to the molecular weight of carbon

Reducing agents used to produce crude iron from iron ore can be coke, coal, charcoal, and petroleum coke. However, it is assumed that the reductant used in the Canadian industry is 100% metallurgical coke. The emission factor for metallurgical coke is 2.479 t CO_2/t coke (Jaques, 1992). According to the IPCC Good Practice Guidance (IPCC, 2000), the carbon content in pig iron is about 4% and that in ore is almost zero. Hence, Equation A3-1a above becomes the simplified Equation A3-1b, which is also shown in Section 4.6.2 of this report:

Equation A3-1b Simplified equation for emissions from pig iron production:

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

To calculate emissions from steel production, the IPCC Good Practice Guidance (IPCC, 2000) suggests the use of a Tier 2–type method, as shown below:

Equation A3-2 for emissions from crude steel production:

$\text{Emissions}_{\text{crude steel}}$ = [(mass of carbon in pig iron used for crude steel – mass of carbon in crude steel) ∗ 44/12] + (Emission $\text{Factor}_{\text{EAF}}$ ∗ steel produced in EAFs)

where:

mass of carbon in pig iron used for crude steel = total pig iron charged to steel furnaces ∗ carbon content in pig iron

mass of carbon in crude steel = total steel production ∗ carbon content in crude steel

44/12 = ratio of the molecular weight of CO_2 to the molecular weight of carbon

Emission $\text{Factor}_{\text{EAF}}$ = emission factor for steel produced in EAFs

steel produced in EAFs = the amount of steel produced in EAFs

According to Equation A3-2, the amount of CO_2 emitted from steel production is estimated based on the difference between the amount of carbon in the iron used to make steel and that in the steel produced. It should be noted that the amount of pig iron fed to steel furnaces (used in Equation A3-2) does not equal the amount of total pig iron production (used in Equations A3-1a and b). The quantity charged to steel furnaces is usually higher than the quantity produced.

For carbon content of the iron used for making steel, the IPCC Good Practice Guidance (IPCC, 2000) suggests a range of 3–5%. The IPCC Good Practice Guidance also provides 0.5–2% as the range of carbon content in steel. Percentages of 4% and 1.25% are applied in the equation as the values of carbon content in iron and steel, respectively. They represent the midpoints of the IPCC default ranges of carbon content. When there is steel produced in EAFs, it is good practice to include the carbon released from consumed electrodes in the estimation of emissions. Electrodes in EAFs are made of carbon (either graphite or Søderberg paste). When they are kept above the steel melt, the electrical arc oxidizes the carbon to CO or CO_2. The IPCC Good Practice Guidance (IPCC, 2000) suggests a carbon emission factor of 1–1.5 kg C/t steel. Multiplying this by the molecular weight ratio of CO_2 to carbon, 44/12, gives 3.67–5.5 kg CO_2 emitted per tonne of steel produced in EAFs. The midpoint of this range, 4.58 kg CO_2/t steel, is chosen to be the EAF emission factor applied in Equation A3-2.

The total emissions from the sector of iron and steel production are the sum of Equations A3-1b and A3-2 above:

Equation A3-3 for emissions from iron and steel production as a whole:

$\text{Total emissions}_{\text{iron \& steel}} = \text{Emissions}_{\text{pig iron}} + \text{Emissions}_{\text{crude steel}}$

CO_2 emissions are estimated, at provincial/territorial levels, based on the percentage of metallurgical consumption attributed to each province and territory.

Equation A3-4 for coke consumption % split:

$$\text{\% split} = \left(\frac{\text{coke consumption in a province}}{\text{total coke consumption in Canada}}\right) * 100\%$$

Equation A3-5 for emission estimates at provincial/territorial levels:

$\text{Provincial/territorial emissions} = \text{Total emissions}_{\text{iron \& steel}} * \text{\% split}$

It should be noted that Ontario is responsible for almost all emissions coming from this category, since the Canadian iron and steel industry is concentrated in this province.

The method described above does not account for additional CO_2 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.

A3.2.1.2 Data Sources

Data on national and provincial/territorial consumption of metallurgical coke for 1990–2004 come from the RESD (Statistics Canada, #57-003). *Primary Iron and Steel* (Statistics Canada, #41-001) provides data at the national level on pig iron production, pig iron charged to steel furnaces, steel production, and quantity of steel produced in EAFs.

A3.2.2 CO_2 EMISSIONS FROM OTHER AND UNDIFFERENTIATED PRODUCTION

A3.2.2.1 Methodology

CO_2 emissions from non-energy use of hydrocarbons are reported under the category of Other and Undifferentiated Production. The fossil fuels can be grouped into three types: gaseous, solid, and liquid. Estimations of emissions coming from each type of fuel are discussed separately in the following sections.

Gaseous Fuels

The only gaseous fuel considered in this category is natural gas used for non-energy purposes. Although it can be used in methanol and thermal carbon black production, a big portion of it actually goes to steam CH_4 reforming for producing the hydrogen needed in ammonia plants. To estimate CO_2 emissions, non-energy use of natural gas in each province/territory is multiplied by an emission factor of 1522 g CO_2 emitted/m^3 (Cheminfo Services, 2005). Summing all the provincial/territorial emissions together gives the national estimate. At the national level, the CO_2 emissions from non-energy use of natural gas are adjusted for the CO_2 emissions associated with ammonia production. More specifically, CO_2 from ammonia production, at the national level, is subtracted from total CO_2 from non-energy use of natural gas to avoid double-counting. It should also be noted that emissions arising from the non-energy use of natural gas to produce hydrogen in the oil refining and bitumen industries are allocated to the Energy Sector of the inventory.

Solid Fuels

Emissions from the following non-energy uses of solid fuels are included in Other and Undifferentiated Production:

- Canadian bituminous coal;
- sub-bituminous coal;
- foreign bituminous coal;
- lignite;
- anthracite; and
- metallurgical coke.

To determine, by province, the CO_2 emissions coming from these solid fuels, fuel-, province-, and year-specific emission factors (Jaques, 1992; McCann, 2000), shown in Table A3-1, are applied to the consumption quantities reported as non-energy use. The national emission estimate for non-energy use of solid fuels is the total of all provincial/territorial emissions.

The emission factors used for estimating releases of CO_2 from non-energy use of coal and coal products are the same as those for combustion, because it is assumed that the carbon in these products will eventually be oxidized and emitted as CO_2.

TABLE A3-1: CO_2 Emission Factors for Coal and Coal Products

Province	CO_2 Emission Factors								
Coals	1990	1991	1992	1993	1994	1995	1996	1997	1998–2004
					(g/kg)				
Newfoundland and Labrador									
Canadian Bituminous[1]	2300[2]	2294	2287	2281	2274	2268	2262	2255	2249[3]
Anthracite	2390[2]	2390	2390	2390	2390	2390	2390	2390	2390[3]
Prince Edward Island									
Canadian Bituminous[1]	2300[2]	2294	2287	2281	2274	2268	2262	2255	2249[3]
Nova Scotia									
Canadian Bituminous	2300[2]	2294	2287	2281	2274	2268	2262	2255	2249[3]
U.S. Bituminous	2330[2]	2325	2320	2314	2309	2304	2299	2293	2288[3]
New Brunswick									
Canadian Bituminous	2230[2]	2201	2172	2142	2113	2084	2055	2026	1996[3]
U.S. Bituminous	2500[2]	2476	2453	2429	2405	2382	2358	2334	2311[3]
Quebec									
Canadian Bituminous[1]	2300[2]	2294	2287	2281	2274	2268	2262	2255	2249[3]
U.S. Bituminous	2500[2]	2480	2461	2441	2421	2402	2382	2362	2343[3]
Anthracite	2390[2]	2390	2390	2390	2390	2390	2390	2390	2390[3]
Ontario									
Canadian Bituminous	2520[2]	2487	2454	2420	2387	2354	2321	2287	2254[3]
U.S. Bituminous	2500[2]	2492	2483	2475	2466	2458	2449	2441	2432[3]
Sub-Bituminous[4]	2520[2]	2422	2323	2225	2126	2028	1930	1831	1733[3]
Lignite	1490[2]	1488	1486	1485	1483	1481	1479	1478	1476[3]
Anthracite	2390[2]	2390	2390	2390	2390	2390	2390	2390	2390[3]
Manitoba									
Canadian Bituminous	2520[2]	2486	2453	2419	2386	2352	2319	2285	2252[3]
Sub-Bituminous	2520[2]	2422	2323	2225	2126	2028	1930	1831	1733[3]
Lignite	1520[2]	1508	1496	1484	1472	1460	1448	1436	1424[3]
Anthracite	2390[2]	2390	2390	2390	2390	2390	2390	2390	2390[3]
Saskatchewan									
Canadian Bituminous[5]	1700[2]	1719	1738	1757	1776	1795	1814	1833	1852[3]
Lignite	1340[2]	1351	1362	1373	1384	1394	1405	1416	1427[3]
Alberta									
Canadian Bituminous	1700[2]	1719	1738	1757	1776	1795	1814	1833	1852[3]
Sub-Bituminous	1740[2]	1743	1746	1749	1753	1756	1759	1762	1765[3]
Anthracite	2390[2]	2390	2390	2390	2390	2390	2390	2390	2390[3]
British Columbia									
Canadian Bituminous	1700[2]	1747	1793	1840	1886	1933	1979	2026	2072[3]
All Provinces									
Metallurgical Coke	2480[2]	2480	2480	2480	2480	2480	2480	2480	2480[3]

Notes:

1 Assumed same source of Canadian bituminous for Newfoundland and Labrador, Prince Edward Island, Nova Scotia, and Quebec.

2 Jaques (1992).

3 Adapted from McCann (2000).

4 Represents both domestic and imported sub-bituminous.

5 Assumed same source of Canadian bituminous for Saskatchewan and Alberta.

Liquid Fuels

In addition to the emissions coming from gaseous and solid fuels mentioned above, CO_2 emitted by the non-energy use of several refined petroleum products and NGLs is also included in the category Other and Undifferentiated Production.

To estimate these emissions at provincial/territorial levels, the non-energy use quantity of each of the refined petroleum products and NGLs is multiplied by its corresponding emission factor, shown in Tables A3-2 and A3-3. The summation of the provincial/territorial estimates gives the national emission estimate.

TABLE A3-2: **CO_2 Emission Factors for Various Refined Petroleum Products**

	Emission factors *(g CO_2/L)*	Sources
Still Gas	2000	Jaques (1992)
Motor Gasoline	2360	Jaques (1992)
Kerosene	2550	Jaques (1992)
Diesel Fuel Oil	2730	Jaques (1992)
Light Fuel Oil	2830	Jaques (1992)
Heavy Fuel Oil	3090	Jaques (1992)
Petroleum Coke Oil	4200	Nyboer (1996)
Aviation Gasoline	2330	Jaques (1992)
Aviation Turbo Fuel	2550	Jaques (1992)

TABLE A3-3: **CO_2 Emission Factors for Natural Gas Liquids**

	Fraction of carbon stored in products	Emission factors *(g CO_2/L)*	Sources
Propane	0.8	303	IPCC/OECD/IEA (1997); McCann (2000)
Butane	0.8	349	IPCC/OECD/IEA (1997); McCann (2000)
Ethane	0.8	197	IPCC/OECD/IEA (1997); McCann (2000)

The non-energy use emission factors shown in Table A3-2 are the same as those used for calculating combustion-related emissions, because it is assumed that the carbon in these refined petroleum products used for non-energy purposes will eventually be oxidized and emitted as CO_2. In the case of non-energy use of NGLs, factors that account for the potential emissions that occur when all the carbon is oxidized are provided in the McCann (2000) study. The IPCC Guidelines (IPCC/OECD/IEA, 1997) show a default value for the fraction of carbon that can be stored in products that are manufactured using propane, butane, or ethane as feedstock. The McCann (2000) potential emission factors are multiplied by the IPCC default fraction of carbon stored of 0.8 to give the non-energy use emission factors of the three NGLs.

Finally, the use of petrochemical feedstocks, naphthas, lubricants, greases, and other petroleum products also results in CO_2 emissions that are accounted for in the category of Other and Undifferentiated Production. These non-energy products can be employed in producer consumption, mining, manufacturing, forestry, construction, transportation, agriculture, public administration, and commercial and institutional sectors. Their carbon factors (mass of carbon emitted per volume of product used) come from Jaques (1992). These factors are then multiplied by the molecular weight ratio between CO_2 and carbon, 44/12, and by (1 – fraction of carbon stored) to give the CO_2 emission factors used to estimate emissions. As in the case of NGLs, the default values of fraction of carbon stored are found in the IPCC Guidelines (IPCC/OECD/IEA, 1997). Derivations of the non-energy use emission factors are shown in Table A3-4. To estimate emissions at national and provincial/territorial levels, the volume of non-energy product used is multiplied by its corresponding emission factor.

A3.2.2.2 Data Sources

The RESD (Statistics Canada, #57-003) is the activity data source for the Other and Undifferentiated Production category. This report presents data by fuel type and area of application (i.e., energy versus non-energy use applications).

TABLE A3-4: CO_2 Emission Factors for Non-Energy Petroleum Products

Non-Energy Products	Carbon Factor (g C/L)	Molecular Weight Ratio between CO_2 and Carbon	Fraction of Carbon Stored (IPCC Default)	Resulting CO_2 Emission Factor (g CO_2/L)
	A	B	C	D = A × B × (1 – C)
Petrochemical Feedstocks	680	44/12	0.8	500
Naphthas	680	44/12	0.75	625
Lubricating Oils and Greases	770	44/12	0.5	1410
Petroleum Used for Other Products	790	44/12	0.5	1450

A3.3 METHODOLOGY FOR SOLVENT AND OTHER PRODUCT USE

Readers are referred to Chapter 5 (Solvent and Other Product Use).

A3.4 METHODOLOGY FOR AGRICULTURE

This section of Annex 3 describes the estimation methodologies, specific equations, models, activity data, and emission factors that are used to derive the GHG estimates for the Agriculture Sector, namely:

- CH_4 emissions from enteric fermentation;
- CH_4 and N_2O emissions from manure management; and
- N_2O emissions from agricultural soils (direct emissions, indirect emissions, and animal manure emissions on pasture, range, and paddock).

Animal population data sources, which are common to those three agricultural source categories, are described in the first section. Agricultural soils also emit/sequester CO_2, but this is reported in the LULUCF Sector. CO_2 methodology description can be found in Section A3.5 of this annex.

A3.4.1 ANIMAL POPULATION DATA SOURCES

Annual livestock population data at a provincial level were used to develop emission estimates. An enhanced single livestock characterization was used for emission sources of enteric fermentation and manure management, since a Tier 2 approach based on IPCC Good Practice Guidance (IPCC, 2000) was adopted. A list of livestock categories and their corresponding data sources are given in Table A3-5.

TABLE A3-5: Data Sources for Animal Populations

Animal Category	Data Source
Cattle	
Bull, Dairy Cow, Beef Cow, Dairy Heifer, Beef Heifer, Beef Heifer for Slaughter, Steer, and Calves	Statistics Canada, Catalogue No. 23-012, Table 1, Cattle on Farms
Swine	
Boar, Sow, Pig <20 kg, Pig 20–60 kg, and Pig >60 kg	Statistics Canada, Catalogue No. 23-010, Table 1, Pigs on Farms
Goat, Horse, and Bison	Statistics Canada, 1991, 1996, and 2001 Census of Agriculture, Catalogue Nos. 93350, 93356, and 95F0301, Table 22.1, Other Livestock and Colonies of Bees, by Province, Census Agricultural Region and Census Division
Poultry	
Chicken, Layer, and Turkey	Statistics Canada, 1991, 1996, and 2001 Census of Agriculture, Catalogue Nos. 93350, 93356, and 95F0301, Table 23.1, Poultry Inventory, by Province, Census Agricultural Region and Census Division
Sheep and Lamb	Statistics Canada, Catalogue No. 23-011, Table 1, Sheep and Lambs on Farms

Livestock population data are expressed on an annual basis, although data collection is on a quarterly (swine) or semiannual basis (cattle, sheep, and lamb) or a five-year Census period basis (horse, goat, bison, and poultry). Therefore, there is a need to annualize these data.

For populations estimated every five years with Census data, data are adjusted through interpolation to avoid large annual changes, especially for years immediately before the Census year, as recommended during the UNFCCC 2003 in-country review. In addition, bison population data were not collected in 1991; thus, bison population was set constant at the 1996 level since 1990.

Cattle, sheep, and lamb data are reported in January and July by Statistics Canada. Average annual populations for these are calculated by taking the simple mean of the two semiannual data sets. The same approach is taken for pig population data, which are collected quarterly.

A3.4.2 CH_4 EMISSIONS FROM ENTERIC FERMENTATION

A3.4.2.1 Methodology

CH_4 emissions from enteric fermentation for dairy and beef cattle are estimated with the IPCC Tier 2 methodology (Table A3-6). For the other animal categories, the IPCC Tier 1 methodology is used (Table A3-7). The release of CH_4 from enteric fermentation from various categories of livestock in Canada is calculated using Equation A3-6.

Equation A3-6:

$$CH_{4EF} = \sum_{T} (N_T * EF_{(EF)T})$$

where:

CH_{4EF} = enteric fermentation emissions for all animal categories

N_T = animal population for the Tth animal category or subcategory in each province

$EF_{(EF)T}$ = emission factor for the Tth animal category or subcategory

See Table A3-6 and Table A3-7.

TABLE A3-6: CH_4 Emission Factors for Enteric Fermentation and Manure Management by Animal Category except Dairy Cows

Animal Category	Emission Factors	
	Enteric Fermentation $EF_{(EF)T}$	Manure Management $EF_{(MM)T}$[1]
	(kg CH_4/head per year)	
Cattle		
Bulls	94[2]	3.2
Beef Cows	90[2]	3.5
Beef Heifers	75[2]	2.8
Dairy Heifers	73[2]	15.4
Heifers for Slaughter	63[2]	1.8
Steers	56[2]	2.0
Calves	40[2]	1.1
Pigs		
Boars	1.5[3]	6.4
Sows	1.5[3]	6.3
Pigs <20 kg	1.5[3]	1.8
Pigs 20–60 kg	1.5[3]	5.1
Pigs >60 kg	1.5[3]	7.9
Other Livestock		
Sheep	8[3]	0.3
Lambs	8[3]	0.2
Goats	5[3]	0.3
Horses	18[3]	2.3
Buffaloes	55[3]	2.0
Poultry		
Chickens	N/A	0.03
Hens	N/A	0.03
Turkeys	N/A	0.08

Notes:

1 Emission factors are derived from Mariner *et al*. (2004) with modifications following the guidance provided by IPCC (2000).

2 Emission factors are derived from Boadi *et al*. (2004) following the guidance provided by IPCC (2000).

3 IPCC Tier 1 default emission factors (IPCC/OECD/IEA, 1997).

N/A = not available

TABLE A3-7: CH_4 Emission Factors for Enteric Fermentation and Manure Management for Dairy Cows from 1990 to 2004

Year	Emission Factors[1]	
	Enteric Fermentation $EF_{(EF)T}$	Manure Management $EF_{(MM)T}$
	(kg CH_4/head per year)	
1990	116.9	25.7
1991	117.7	25.9
1992	120.3	26.5
1993	122.3	26.9
1994	123.0	27.1
1995	123.8	27.3
1996	125.6	27.4
1997	126.1	27.7
1998	128.0	27.9
1999	130.1	28.2
2000	132.1	29.0
2001	132.9	29.3
2002	135.2	29.6
2003	135.3	29.7
2004	134.8	29.6

Note:

1 Dairy cow emission factors are derived from Boadi *et al*. (2004) for enteric fermentation and Marinier *et al*. (2004) for manure management following the guidance provided by IPCC (2000) and IPCC (2006), with modifications.

A3.4.2.2 Determining CH_4 Enteric Emission Factors for Various Categories of Cattle Using the IPCC Tier 2 Methodology

The IPCC Tier 2 method is used to determine enteric CH_4 emission factors for beef and dairy cattle in Canada. To achieve this, the cattle population was characterized by animal type, physiological status, age, sex, weight, rate of gain, level of activity, and production environment. Much of this information was not available in the published literature and was obtained from beef and dairy cattle specialists across the country. This information was used to calculate emission factors associated with various cattle categories based on the IPCC Tier 2 equations, as detailed in the following sections. Many of these data were also used to derive manure CH_4 emission factors for cattle. Since the previous inventory, additional modifications were made to derive a time series of emission factors for dairy cattle emissions to reflect changes in milk production over time.

When available, data from surveys of production and management practices published in scientific journals were utilized to describe the production environment and associated performance of classes of animals. Because the information was not available for all classes of cattle, a survey of dairy and beef production practices was created and administered to regional and provincial cattle specialists. Additional information was obtained from research scientists at universities and federal research institutions, as well as from provincial/national commodity groups and provincial/regional performance recording organizations (Boadi *et al*., 2004). The derived emission factors are assumed to be applicable to the entire time series for all animals with the exception of dairy cows, for which milk production and milk fat since 1990 are factored in. This does not reflect the fact that performance and feeding practices may have changed since 1990, which would require a varying emission factor. However, time series of parameters such as average animal weight for cattle are not available, and consistent data on change in feeding practices since 1990 have not yet been obtained.

Production and Performance of Dairy Cattle

A summary of production performance of Canadian dairy cattle is provided in Table A3-8. A change from the 2005 submission is the estimation of an emission factor time series for dairy cattle to reflect the increase in milk productivity of cows over the 1990s and beyond. Average milk production from 1990 to 2004 and number of milk days per cow per year at the provincial level are provided in Table A3-9.

TABLE A3-8: Characteristics of Dairy Production in Canada

Animal Category/Parameters	Production Characteristics[1]	Data Sources[2]
Dairy Cows		
Average weight, kg	634 (51)	Okine and Mathison, 1991; Kononoff *et al*., 2000; Petit *et al*., 2001
Mature weight, kg	646 (55)	–
Conception rate, %	59.2 (7.3)	–
Calves		
Birth weight, kg	41 (3.3)	–
Average weight, kg	186 (18.5)	–
Mature weight, kg	330.5 (37.6)	–
Daily weight gain, kg/day	0.7 (0.3)	–
Calf crop,[3] %	93 (6)	–
Replacement Heifers		
Average weight, kg	461.6 (24.7)	–
Beginning weight (1 year), kg	327.8 (31.0)	–
Mature weight at calving, kg	602.1 (45.9)	–
Mature weight, kg	646.1 (54.9)	–
Daily weight gain, kg/day	0.77 (0.14)	–
Replacement rate, %	32.3 (3.2)	Western Dairy Herd Improvement, 2002

Notes:

1 The numbers in parentheses are the standard deviation.

2 Values with no reference were obtained from expert consultations (see Boadi *et al*., 2004).

3 Calf crop is the percentage of the overwintering cows that produced a live calf.

Production practices varied across some provinces because of differences in land values, climate, forage availability, and market access. The predominant practices for each province were represented in the IPCC Tier 2 equations.

Milk Yield and Fat Data

Western Dairy Herd Improvement records for milk yield were available for Manitoba, Saskatchewan, Alberta, and British Columbia. Dairy Herd Improvement records were also available for Ontario, Quebec, Nova Scotia, and Prince Edward Island. Average milk production for each province from 1995 to 2004 was drawn from *Dairy Animal Improvement Statistics* (Agriculture and Agri-Food Canada, 2005) and was used to calculate net energy for lactation, or $NE_{lactation}$ (NE_l). For 1990–1994, only the national milk yield data were published. The provincial annual average milk production per day was calculated by dividing the national average production by the number of milking days per year by province (Boadi *et al*., 2004). Milk fat data (%) were also obtained from Agriculture and Agri-Food Canada (2005) and were assumed to be identical across provinces.

Duration of Time in a Production Environment

It was assumed that animals that were dry during the summer months were on pasture; animals that were dry during the remainder of the year were in confinement. Further, replacement heifers were assumed to calve at 24 months, although they may have been more than 24 months of age at calving in some circumstances.

Percentage of Cows Pregnant

An estimate of the percentage of cows pregnant in the herd at any given time was calculated according to J.C. Plaizier (University of Manitoba, personal communication, 2004) using the following formula:

Percent cows pregnant = (gestation length/calving interval ∗ 100)
– percent cows culled due to
reproductive failure

TABLE A3-9: Average Milk Production from 1990 to 2004 and Number of Milking Days at a Provincial Level

Year	NL	PE	NS	NB	QC	ON	MB	SK	AB	BC
	Average Milk Production									
	(kg/cow per day)[1]									
1990	24.2	25.0	24.7	24.5	24.5	24.5	25.3	25.4	25.1	24.6
1991	24.6	25.3	25.1	24.9	24.8	24.8	25.7	25.8	25.5	25.0
1992	25.5	26.3	26.0	25.8	25.7	25.7	26.6	26.7	26.4	25.9
1993	26.1	26.9	26.6	26.5	26.4	26.4	27.3	27.4	27.1	26.5
1994	26.5	27.3	27.0	26.8	26.7	26.7	27.7	27.8	27.5	26.9
1995	26.4	27.2	26.9	26.7	26.2	27.0	28.2	28.5	30.1	30.0
1996	26.6	27.4	27.2	27.0	26.8	27.7	28.7	29.2	30.6	30.3
1997	27.0	27.8	27.5	27.4	27.2	27.9	29.0	29.7	30.9	29.9
1998	27.4	28.3	28.0	27.8	28.2	28.7	29.3	30.6	31.5	30.7
1999	28.4	29.2	28.9	28.7	29.2	29.3	30.1	31.1	32.1	31.5
2000	30.0	29.9	30.6	29.9	30.0	29.7	31.2	31.9	32.8	32.4
2001	30.3	30.3	30.9	30.9	30.5	29.6	32.3	32.8	33.5	32.8
2002	30.3	31.1	30.9	31.2	31.1	30.9	31.8	33.8	34.4	33.9
2003	30.6	31.3	31.2	30.9	31.0	30.8	32.1	34.0	34.7	34.3
2004	30.5	30.9	31.1	30.7	30.9	30.5	32.3	34.0	34.2	34.3
Milk days per year[2]	306	297	300	302	303	303	293	292	295	301

Notes:

1 Agriculture and Agri-Food Canada (2005).

2 Boadi *et al*. (2004).

Production Practices and Performance for All Classes of Beef Cattle

Table A3-10 presents the characteristics of beef cattle collected by Boadi *et al*. (2004) from publications and expert consultations. Values presented represent an average that was drawn for all provinces.

■ Duration of Time in a Production Environment

Calves were assumed to have a non-functional rumen or to consume very small amounts of dry feed (mostly milk) from birth until 2–3 months of age. Therefore, enteric CH_4 emissions in these first few months were assumed to be zero. Replacement heifers over 15 months of age were assumed to be bred or pregnant. All replacement stock (breeding bulls, young and replacement heifers over 12 months of age) was assumed to enter the breeding herd (breeding bulls, mature and beef cows) at 24 months of age.

Characterization of the Feeding Practices for Beef and Dairy

When available, data from surveys examining feeding management strategies or practices that had subsequently been published in scientific journals were utilized to describe the feeding strategies for classes of animals. Additional information was obtained from research scientists at universities and federal research institutions, as well as from provincial/national commodity groups and provincial/regional performance recording organizations.

■ Ration Digestible Energy Calculations for Dairy Cattle

Forage digestible energy (DE) values determined by Christensen *et al*. (1977) for forages grown on the prairies were used to estimate ration DE for Alberta, Saskatchewan, and Manitoba. National Research Council

TABLE A3-10: Characteristics of Beef Production in Canada

Animal Category/Parameters	Production Characteristics[1]	Data Sources[2]
Beef Cows		
Average weight, kg	603 (36)	Kopp *et al*., 2004
Mature weight, kg	619 (52)	AAFRD, 2001
Milk, kg/day	7.3 (1.2)	Kopp *et al*., 2004
Milk fat, %	3.6 (0.6)	Kopp *et al*., 2004
Conception rate, %	93.7 (1.3)	Manitoba Agriculture and Food, 2000; AAFRD, 2001
Replacement Heifers		
Average weight, kg	478 (34)	–
Mature weight, kg	620 (51)	–
Daily weight gain, kg/day	0.64 (0.14)	–
Replacement rate, %	14.4 (3.1)	Manitoba Agriculture and Food, 2000
Bulls		
Yearling weight, kg	541 (18)	–
Average weight, kg	940 (98)	–
Mature weight, kg	951 (112)	–
Daily weight gain, kg/day	1.0 (0.17)	–
Calves (including Dairy Calves)		
Birth weight, kg	40 (3)	AAFRD, 2001
Wean weight, kg	258.4 (19.1)	Small and McCaughey, 1999
Age at weaning, days	215 (15)	–
Daily weight gain, kg/day		
Replacement heifers	0.67 (0.13)	Kopp *et al*., 2004
Backgrounder	0.98 (0.17)	–
Finisher	1.37 (0.12)	–
Calf crop, %	95 (2.3)	–
Heifer and Steer Stockers		
Average weight, kg	411 (47)	Kopp *et al*., 2004
Mature weight, kg	620 (51)	–
Daily weight gain, kg/day	0.98 (0.16)	–
Proportion to feedlot, %	65 (30)	–
Feedlot Animals		
Average weight, kg		
Direct finish	540 (25)	–
Background finish	562 (64)	–
Mature weight, kg	630 (46)	–
Finish weight, kg	609 (28)	–
Daily weight gain, kg/day	1.37 (0.12)	–

Notes:

1 The numbers in parentheses are the standard deviation.

2 Values with no reference were obtained from expert consultations (see Boadi *et al*., 2004).

values (NRC, 2001) were used to estimate ration DE calculations for British Columbia and the eastern provinces. Total mixed rations for cattle were assumed to be mainly forage and grain due to limited information regarding other feed ingredients. It was also assumed that lactating cows on pasture were supplemented with grain; therefore, DE values were assumed to be similar to those of rations fed in confinement.

- **Ration Digestible Energy Calculations for Beef Cattle**

Forage DE values determined by Christensen *et al*. (1977) for forages utilized on the prairies were used to estimate ration DE for Saskatchewan and Manitoba. Values from AAFRD and University of Alberta (2003) were used for Alberta, while NRC (2001) values were used to estimate DE of rations from British Columbia and the eastern provinces.

Calculating Enteric CH_4 Emission Factors

Emission factors were derived using IPCC equations for different categories of cattle (dairy cows, dairy heifers, beef cows, beef heifers, bulls, calves, heifer replacement, heifers >1 year, and steers >1 year) based on stages of production. Dairy cattle emissions, for example, were estimated for two production categories — dry cows and lactating cows. As the duration of time that an animal was in a category was variable for some categories, a weighted emission factor was calculated. Criteria used in the weighting included duration of time in the category and relative percentage of the population in each stage of production. Provincial emission factors for non-dairy cattle weighted on the basis of provincial contribution to the national animal populations in 2001 were used to calculate a national emission factor for each category for the entire time series since 1990 (Table A3-11). For dairy cattle, provincial emission factors weighted on the basis of provincial contribution to the national dairy populations from 1990 to 2004 were used to calculate a national emission factor for each year since 1990 (Table A3-12).

A3.4.3 CH_4 EMISSIONS FROM MANURE MANAGEMENT

A3.4.3.1 Methodology

The IPCC Tier 2 methodology is used to estimate CH_4 emissions from manure management systems that have been developed and outlined in the IPCC *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC, 2000). Equation A3-7 is used to calculate CH_4 emissions from manure management for various categories of livestock in Canada.

Equation A3-7:

$$CH_{4MM} = \sum_{T} \left(N_T * EF_{(MM)T}\right)$$

where:

CH_{4MM} = emissions for all animal categories

N_T = animal population for the Tth animal category or subcategory in each province

$EF_{(MM)T}$ = emission factor for the Tth animal category or subcategory

See Table A3-6 and Table A3-7.

Sources of animal population data are the same as those used in the enteric fermentation estimations (see Table A3-5).

A3.4.3.2 Determining CH_4 Emission Factors for Various Animal Categories Based on Manure Management Practices Using the IPCC Tier 2 Methodology

The IPCC Tier 2 method for estimating CH_4 emissions from manure management used country-specific inputs, taking into account livestock diet, type and distribution of manure storage, and climate.

The following equation represents an IPCC Tier 2 estimate of CH_4 emission factors from manure management systems:

TABLE A3-11: Provincial and National CH_4 Emission Factors Associated with Various Beef Cattle in Canada

Provinces	Emission Factors						
	Dairy Heifers	Beef Cows	Bulls	Calves <1 year	Heifer Replacement	Heifers >1 year	Steers >1 year
				(kg CH_4/head per year)			
NL	93	85	105	45	68	99	91
PE	75	88	88	33	71	48	44
NS	78	90	84	41	68	70	64
NB	77	98	96	39	80	46	42
QC	70	104	96	42	97	41	38
ON	75	105	90	40	90	60	55
MB	72	94	93	33	73	60	55
SK	75	77	87	37	61	55	50
AB	71	93	96	43	76	65	59
BC	72	95	106	37	82	64	59
Range	70–93	77–105	84–106	33–45	61–97	41–70	38–64
Mean[1]	73	90	94	40	75	63	56
Standard Deviation[2]	7 (9%)	8 (9%)	7 (8%)	4 (10%)	11 (14%)	10 (17%)	9 (17%)

Notes:

1 Weighted means for each beef category based on animal population in 2001.

2 Numbers in parentheses expressed as percentage of the mean (Source: Boadi *et al*., 2004).

TABLE A3-12: Provincial and National CH_4 Emission Factors for Dairy Cows from 1990 to 2004

Year	Emission Factors									
	NL	PE	NS	NB	QC	ON	MB	SK	AB	BC	National Mean[1]
					(kg CH_4/head per year)						
1990	123.0	118.1	111.0	116.8	112.6	120.5	122.6	118.9	114.5	126.1	116.9
1991	124.0	118.8	111.9	117.7	113.3	121.1	123.5	119.7	115.4	127.1	117.7
1992	126.6	121.7	114.5	120.4	115.9	123.7	126.2	122.2	117.9	129.8	120.3
1993	128.4	123.5	116.3	122.4	117.9	125.7	128.2	124.0	119.8	131.6	122.3
1994	129.4	124.4	117.2	123.1	118.6	126.3	129.1	124.9	120.7	132.5	123.0
1995	128.7	123.8	116.6	122.5	117.5	127.7	129.1	124.8	125.6	139.8	123.8
1996	129.3	124.4	117.5	123.3	119.5	129.7	130.6	126.6	127.0	141.1	125.6
1997	130.2	125.3	118.1	124.2	120.5	129.3	131.6	127.9	127.4	139.9	126.1
1998	131.1	126.4	119.2	125.0	122.8	131.4	132.1	129.4	128.4	140.9	128.0
1999	133.8	128.8	121.6	127.5	125.3	132.8	134.2	130.8	130.0	143.4	130.1
2000	137.7	131.2	125.7	130.7	127.7	133.7	137.1	133.2	132.1	146.0	132.1
2001	139.0	132.9	127.0	133.6	129.1	133.9	139.3	135.1	133.3	146.7	132.9
2002	138.8	135.1	126.8	134.4	130.9	137.1	138.8	136.9	135.3	149.8	135.2
2003	139.8	135.7	127.8	133.5	130.5	137.2	139.2	137.8	136.0	150.4	135.3
2004	139.4	134.5	127.4	132.6	130.1	136.5	139.6	138.3	135.0	149.5	134.8

Note:

1 Emission factors at the national level are calculated by using each provincial emission factor weighted by its dairy cow population.

Equation A3-8:

$$EF_{(MM)T} = VS_T * 365\ \text{days/year} * B_{0T} * 0.67\ \text{kg/m}^3 * \sum_{ij} (MCF_{ij} * MS_{Tij})$$

where:

$EF_{(MM)T}$ = annual emission factor for defined animal population T, kg

VS_T = daily volatile solids excreted for an animal within the defined population T, kg

B_{0T} = maximum CH_4 producing potential for manure produced by an animal within defined population T, m^3/kg VS

MCF_{ij} = CH_4 conversion factor for each manure management system i in climate region j

MS_{Tij} = system distribution factor, defined as the fraction of animal category T's manure that is handled using manure system i in climate region j

(IPCC 2000, Equation 4.17, p. 4.34)

Tables A3-6 and A3-7 provide a list of emission factors used for this category for both non-cattle and cattle livestock, derived from a study by Marinier *et al*. (2004), with modifications to increase consistency with the enteric fermentation category and updates to incorporate the latest scientific information available from the 2006 IPCC Guidelines (IPCC, 2006). Previously, dry matter intake (DMI) for dairy and non-dairy cattle was derived from expert consultations (Marinier *et al*., 2004). Based on the 2005 ERT recommendations, DMI and volatile solids (VS) for dairy and non-dairy cattle were reestimated using the same method as for enteric fermentation. Another change from the 2005 submission is the estimation of an emission factor time series for dairy cattle to reflect the increase in milk productivity of cows over the 1990s and beyond. In addition, maximum CH_4 production potential (B_0) and CH_4 conversion factors (MCFs) have been updated (IPCC, 2006).

The following sections examine the data sources for estimating VS for major animal categories.

Volatile solids (VS)

VS are the organic fraction of total solids within the manure and can be measured from manure samples, although this is rarely done in Canada. Alternatively, VS can be estimated using the IPCC (2000) methodology based on dietary intake:

Equation A3-9:

$$VS = DMI * (1 - DE/100) * (1 - ASH/100)$$

where:

VS = volatile solids excretion, kg/head per day

DMI = ration dry matter intake, kg/head per day

DE = digestible energy of the ration, %

ASH = mineral content of the manure, %

(IPCC 2000, Equation 4.16, p. 4.31)

Estimating VS based on the IPCC (2000) methodology requires an estimate of ration DMI. Ration DMI in livestock depends on many factors, including body size, lactation stage, and time of year, and can be estimated through calculation of the gross energy (GE) intake:

Equation A3-10:

$$GE = \{[(NE_m + NE_a + NE_l + NE_p)/(NE_m/DE)] + [NE_g/(NE_g/DE)]\}/(DE/100)$$

where:

GE = gross energy, MJ/day

NE_m = net energy required for maintenance, MJ/day

NE_a = net energy required for activity, MJ/day

NE_l = net energy required for lactation, MJ/day

NE_p = net energy required for pregnancy, MJ/day

NE_m/DE = ratio of net energy available in a diet for maintenance to digestible energy

NE_g = net energy net energy needed for growth (MJ/day)

NE_g/DE = ratio of net energy available in a diet for growth to digestible energy consumed

DE = digestible energy of the ration, %

(IPCC 2000, Equation 4.11, p. 4.20)

GE values were converted to DMI using a feed energy factor of 18.45 MJ/kg (IPCC, 2000). The following sections outline the input values for Equation A3-9: DE, ASH, DMI, and VS.

Digestible Energy (DE)

Broad regional differences in ration composition were identified for sheep, horses, and swine. Regional differences were not considered for goats or poultry, since such data were not available. Cattle categories are covered under the enteric fermentation category above.

Generally, rations for grazing livestock consist of grains and roughage. Diet digestibility will vary, with grains having a higher digestibility than roughages.

The distribution of grain-based and roughage-based diets was estimated for sheep and horses in each province. Knowing the approximate DE for grains and roughages for each animal type and the distribution of grain and roughage usage by province, a weighted estimate of DE was obtained (Table A3-13). It should be noted that this method does not account for additives that may increase or decrease digestibility.

TABLE A3-13: Approximate Digestible Energy (DE) for Selected Livestock and Data Sources

Animal Category	DE (%)	Data Sources[1]
Goat	65	W. Whitmore, Manitoba Agriculture and Food
Laying Hen	80	S. Leeson, University of Guelph; D. Korver, University of Alberta
Chicken	80	S. Leeson, University of Guelph; D. Korver, University of Alberta
Turkeys	78	S. Leeson, University of Guelph
Swine	87	C.F. deLange, University of Guelph
Feeding on Grain Diet		
Sheep	74	Weston (2002)
Horse	70	L. Warren, Colorado State University
Feeding on Roughage Diet		
Sheep	65	W. Whitmore, Manitoba Agriculture and Food
Horses	60	L. Warren, Colorado State University

Note:

1 Expert consultations (Marinier *et al*., 2004).

Manure Ash Content (ASH)

ASH is required to obtain an estimate of the organic portion of the manure. Table A3-14 contains the recommended values obtained from various sources.

TABLE A3-14: Manure Ash Content for Selected Livestock and Data Sources

Animal Category	ASH (%)	Data Sources
Cattle	8	IPCC (2000)
Sheep	8	IPCC (2000)
Goat	8	IPCC (2000)
Horse	4	IPCC (2000)
Laying Hen	10	Marinier *et al*. (2004)
Chicken	7	Marinier *et al*. (2004)
Turkey	5	Marinier *et al*. (2004)
Swine	5	Marinier *et al*. (2004)

Dry Matter Intake (DMI)

Ranges for DMI for non-cattle were determined through consultation with experts and published values (Table A3-15). For various cattle categories, DMI values were estimated using Equation A3-9 based on the same variables and parameters used for estimating CH_4 emissions from enteric fermentation (Section A3.4.2).

TABLE A3-15: Dry Matter Intake for Selected Livestock

Animal Category	DMI *(kg/head per day)*	Data Sources
Sheep and Lamb		
Ewes	1.2–2.8	NRC (1985)
Rams	2.1–3.0	Statistics Canada (Catalogue No. 23-011) and W. Whitmore, Manitoba Agriculture and Food
Replacement Lambs	1.2–1.5	NRC (1985)
Market Lambs	1.3–1.6	NRC (1985)
Horses		
Mature Idle Horses	7.4 –11	NRC (1989); L. Warren, Colorado State University
Mature Working Horses	7.4–13.7	NRC (1989); L. Warren, Colorado State University
Weanlings	3.6–6.3	NRC (1989)
Swine		
Starters (5–20 kg)	0.55–0.72	C. Wagner-Riddle, University of Guelph
Growers (20–60 kg)	1.4–2.1	J. Patience, Prairie Swine Centre
Finishers (60–110 kg)	2.1–3.3[1]	M. Nyachoti, University of Manitoba; C. Pomar, Agriculture and Agri-Food Canada
Sows	2.28	C. Wagner-Riddle, University of Guelph
Boars	2.0–2.5	M. Nyachoti, University of Manitoba; NRC (1998)
Goats		
Does	1.2–2.8	NRC (1981)
Bucks	1.4–2.3	CRAAQ (1999)
Kids	1.4	CRAAQ (1999)
Poultry		
Laying Hens	0.072–0.11	S. Leeson, University of Guelph; D. Korver, University of Alberta
Broilers	0.085–0.088	S. Leeson, University of Guelph; D. Korver, University of Alberta
Turkeys	0.023–0.53	Hybrid Turkeys (2001)

Note:

1 Calculated as 3.5% of body weight (20 kg).

VS Calculation and Error Assessment

Values for DMI, DE, and ASH were used to calculate VS for each non-cattle livestock category by province. A Monte Carlo simulation was performed using Crystal Ball® (Decisioneering, 2000), whereby a probability distribution was assigned to each of the inputs DMI, DE, and ASH. Equation A3-9 was calculated 10 000 times using inputs within the assigned distributions to arrive at the mean VS and 95% confidence interval (Table A3-16).

TABLE A3-16: **Mean VS and Associated 95% Confidence Interval Expressed as a Percentage of the Mean for Each Non-Cattle Category in Each Province**

	Mean VS[1]									
	BC	AB	SK	MB	ON	QC	NB	NS	PE	NL
	(kg/head per day)									
Sheep										
Ewes	0.6 (42)	0.62 (42)	0.6 (42)	0.62 (42)	0.6 (41)	0.6 (41)	0.6 (42)	0.6 (42)	0.6 (42)	0.6 (41)
Rams	0.8 (20)	0.8 (20)	0.8 (20)	0.8 (20)	0.8 (20)	0.8 (20)	0.8 (20)	0.8 (20)	0.8 (20)	0.8 (20)
Breeding Lambs	0.4 (20)	0.4 (20)	0.4 (20)	0.4 (19)	0.4 (19)	0.4 (20)	0.4 (19)	0.4 (19)	0.4 (19)	0.4 (19)
Market Lambs	0.5 (13)	0.5 (13)	0.4 (15)	0.5 (13)	0.5 (13)	0.4 (15)	0.5 (13)	0.4 (14)	0.5 (13)	0.5 (13)
Horses										
Mature Horses	3.2 (15)	3.2 (15)	3.3 (16)	3.2 (15)	3.2 (15)	3.1 (16)	3.2 (15)	3.2 (15)	3.2 (16)	3.2 (15)
Swine										
Starters (5–20 kg)	0.08 (80)	0.08 (80)	0.08 (80)	0.08 (100)	0.08 (80)	0.08 (80)	0.08 (80)	0.08 (80)	0.08 (80)	0.08 (80)
Growers (20–60 kg)	0.23 (35)	0.23 (35)	0.23 (35)	0.20 (40)	0.22 (36)	0.22 (36)	0.23 (35)	0.23 (35)	0.23 (35)	0.23 (35)
Finishers (60–110 kg)	0.36 (33)	0.36 (33)	0.36 (33)	0.31 (39)	0.34 (35)	0.34 (35)	0.36 (33)	0.36 (33)	0.36 (33)	0.36 (33)
Sows	0.28 (53)	0.28 (53)	0.28 (53)	0.28 (57)	0.28 (56)	0.28 (56)	0.28 (53)	0.28 (53)	0.28 (53)	0.28 (53)
Boars	0.29 (27)	0.29 (27)	0.29 (27)	0.25 (32)	0.28 (29)	0.28 (29)	0.29 (27)	0.29 (27)	0.29 (27)	0.29 (27)
Goats										
All Goats	0.64 (41)	0.64 (41)	0.64 (41)	0.64 (41)	0.64 (41)	0.64 (41)	0.64 (41)	0.64 (41)	0.64 (41)	0.64 (41)
Poultry										
Laying Hens	0.02 (26)	0.02 (26)	0.02 (26)	0.02 (26)	0.02 (26)	0.02 (26)	0.02 (26)	0.02 (26)	0.02 (26)	0.02 (26)
Chickens	0.02 (16)	0.02 (16)	0.02 (16)	0.02 (16)	0.02 (16)	0.02 (16)	0.02 (16)	0.02 (16)	0.02 (16)	0.02 (16)
Turkeys	0.06 (28)	0.06 (28)	0.06 (28)	0.06 (28)	0.06 (28)	0.06 (28)	0.06 (28)	0.06 (28)	0.06 (28)	0.06 (28)

Note:

1 Numbers in parentheses are 95% confidence interval expressed as a percentage of the mean.

Maximum CH_4 Producing Potential (B_0)

B_0 was determined from several studies examining anaerobic digestion (Hashimoto *et al*., 1981; Safely *et al*., 1992). B_0 is defined as the maximum volume of CH_4 that can be produced from 1 kg of VS loaded into a manure management system and is expressed in m^3/kg VS loaded. Because it is a measure of the maximum CH_4 production, B_0 is not affected by the temperature at which manure is digested (Hashimoto *et al*., 1981). Factors that affect B_0 include diet, age of manure, amount of foreign material, and species. Swine manure has the highest CH_4 producing potential, followed by poultry, beef cattle, and dairy cattle. Very little research has been done to determine the B_0 for horses, and no research could be found on sheep or goat manure. Because of lack of available data in Canada, the IPCC default B_0 values were used (Table A3-17).

TABLE A3-17: Values of Maximum CH_4 Producing Potential (B_0) for Various Livestock Types[1]

Animal Category	Maximum CH_4 Producing Potential (B_o) *(m^3/kg VS)*
Dairy Cattle	0.24
Non-Dairy Cattle[2]	0.19
Sheep	0.19
Goat	0.18
Horse	0.30
Swine	0.48
Hen	0.39
Broiler	0.36
Turkey	0.36

Notes:

1 Data source: IPCC (2006), Volume 4: Agriculture, Forestry and Other Land Uses, Tables 10A-5 to 10A-10.

2 Non-dairy cattle value also used for buffalo.

Methane Conversion Factor (MCF)

MCF is the proportion of B_0 that is realized and is affected by the storage system (for cattle and swine) and climate region. Values are presented in Table A3-18.

TABLE A3-18: CH_4 Conversion Factor (MCF) for Each Animal Type[1]

Animal Type	Liquid	Solid Storage	Pasture and Paddock	Others
Dairy Cattle	0.20	0.02	0.01	0.01
Non-Dairy Cattle[2]	0.20	0.02	0.01	0.01
Swine	0.20	0.02	N/A	0.01
Poultry	–	–	–	0.015
Horse	–	–	–	0.01
Goat	–	–	–	0.01
Sheep	–	–	–	0.01
Lamb	–	–	–	0.01

Notes:

1 Data source: IPCC (2006), Volume 4: Agriculture, Forestry and Other Land Uses, Tables 10A-5 to 10A-10 (cool climate, average annual temperature 12°C).

2 Non-dairy cattle value also used for buffalo.

N/A = not applicable

Manure System Distribution Factor (MS)

MS is the proportional distribution of AWMS within a given area. There is no scientific literature published on the distribution of manure management systems in Canada. While every provincial department of agriculture has information about manure management practices, no consistent and systematic information could be found on the distribution of these practices among provinces.

A survey of expert opinion was conducted in 2003–2004 as part of the Tier 2 study by Marinier *et al*. (2004), and the results are shown in Table A3-19. For beef, dairy, swine, and poultry, these values were calculated using a weighted average based on population. For horses, sheep, and goats, these values were a non-weighted average based on the survey responses. No specific data were available for covered lagoons and biodigesters, but these are assumed to be part of Other Systems.

TABLE A3-19: Percentage of Manure Nitrogen Handled by AWMS[1]

Animal Category	Liquid Systems (N_L)	Solid Storage and Drylot (N_{SSD})	Pasture, Range, and Paddock (N_{PRP})	Other Systems (N_O)
Non-Dairy Cattle	1	47	48	4
Dairy Cattle	42	40	18	0
Poultry	10	88	2	0
Sheep and Lamb	0	38	62	0
Swine	96	3	0	1
Goat	0	42	58	0
Horse	0	42	58	0
Bison	0	42	58	0

Note:

1 Data source: Marinier *et al*. (2004).

A3.4.4 N_2O EMISSIONS FROM MANURE MANAGEMENT

A3.4.4.1 Methodology

The IPCC Tier 1 methodology is used to estimate N_2O emissions from AWMS. Estimates of N_2O emissions from AWMS, excluding those from manure on pasture, range, and paddock systems, are calculated using Equation A3-11. N_2O emissions from the manure on pasture, range, and paddock are reported under Agricultural Soils. Three factors were required for estimating emissions of N_2O resulting from manure management: i) nitrogen excretion rates for various animal types and categories, ii) types of AWMS, and iii) emission factors associated with each manure management system.

Equation A3-11:

$$N_2O_{AWMS} = \sum_{AWMS,T} \left(N_T * N_{AWMS} * N_{EX,T} * EF_{AWMS} \right) * \frac{44}{28}$$

where:

N_2O_{AWMS} = N_2O emissions for all AWMS, excluding manure nitrogen on pasture, range, and paddock

N_T = population for the Tth animal category or subcategory

Refer to Section A3.4.2 for livestock population data sources and calculations.

N_{AWMS} = percentage of nitrogen produced by each AWMS (%)

Refer to Table A3-19.

$N_{EX,T}$ = nitrogen excretion rate for the Tth animal category or subcategory

Refer to Table A3-20.

EF_{AWMS} = N_2O emission factors from manure management for each specific AWMS

Refer to Table A3-21.

44/28 = molecular weight ratio of N_2O to N_2

Manure management systems data for each animal type are the same as those used to derive CH_4 emissions from manure. Animal population data are identical to those used for CH_4 emissions from enteric fermentation and manure.

A3.4.4.2 Nitrogen Excretion Rates for Various Domestic Animals

The IPCC Guidelines (IPCC/OECD/IEA, 1997) provide default rates of nitrogen excretion for various domestic animal categories for North America. There have been very few comprehensive, scientific studies on the rate of nitrogen excretion for various domestic animals in Canada. Nitrogen excretion rate is calculated using the average rate of nitrogen excretion for a specific animal category (IPCC, 2006) multiplied by its average weight (Table A3-20).

TABLE A3-20: Nitrogen Excretion Rate for Each Specific Animal Category

Animal Category	Average Manure Nitrogen Excretion per 1000 kg Live Animal Mass per Day *(kg/1000 kg per day)*	Average Live Weight[1] *(kg)*	Nitrogen Excretion[2] (N_{EX}) *(kg N/head per year)*
Non-Dairy Cattle	0.34	468	58.1
Dairy Cattle	0.45	659	108.2
Poultry	1.02	1.4	0.5
Sheep and Lamb	0.42	27	4.1
Swine	0.52	61	11.6
Goat	0.45	64	10.5
Horse	0.30	450	49.3
Bison[3]	0.34	468	58.1

Notes:

1 Average live weights for non-dairy cattle were taken from Boadi *et al*. (2004); for others, from IPCC (2006).

2 For non-dairy cattle, manure nitrogen excretion rates were calculated by weighting the various non-dairy animal populations in 2001; for poultry, the manure nitrogen excretion rate was calculated by weighting layer, chicken, and turkey populations in 2001.

3 For bison, average manure nitrogen excretion and live weight were assumed to be the same as for non-dairy cattle.

A3.4.4.3 Emission Factors Associated with AWMS

The type of AWMS has a significant impact on N_2O emissions. Less aerated systems, such as liquid systems, generate little N_2O, while drylots or manure on pasture and paddock produce more. However, there is little scientific information in Canada specifying amounts of N_2O emissions associated with manure management systems. Therefore, IPCC default emission factors, as listed in Table A3-21, were used for emission estimates.

TABLE A3-21: Percentage of Manure Nitrogen Lost as N_2O-N for Specific AWMS[1]

Animal Category	Liquid Systems (EF_L)	Solid Storage and Drylot (EF_{SSD})	Pasture, Range, and Paddock (EF_{PRP})	Other Systems (EF_O)
Non-Dairy Cattle	0.1	2.0	2.0	0.5
Dairy Cattle	0.1	2.0	2.0	0.5
Poultry	0.1	2.0	2.0	0.5
Sheep and Lamb	0.1	2.0	1.0[2]	0.5
Swine	0.1	2.0	2.0	0.5
Goat	0.1	2.0	1.0[2]	0.5
Horse	0.1	2.0	1.0[2]	0.5
Bison	0.1	2.0	2.0	0.5

Notes:

1 Data source: IPCC/OECD/IEA (1997).

2 Data source: IPCC (2006), Volume 4, Agriculture, Forestry and Other Land Uses, Table 11.1.

A3.4.5 N_2O EMISSIONS FROM AGRICULTURAL SOILS

This section provides a summary of the methodologies for estimating N_2O emissions from agricultural soils, some of which are new and country-specific, compared with the NIR 2005 submission. Emissions of N_2O from agricultural soils consist of direct and indirect emissions as well as emissions from manure on pasture, range, and paddock. Direct emissions are those occurring on farmland as a result of nitrogen that has entered the soil from synthetic fertilizers, animal manure applied as fertilizer, and crop residue and as a result of adoption of tillage practices, summerfallow, and cultivation of histosols. Emissions from indirect sources are emitted off site following volatilization and leaching of synthetic fertilizer, manure, and crop residue nitrogen.

A3.4.5.1 Direct N_2O Emissions

Synthetic Nitrogen Fertilizers

- **Methodology**

Canada has developed a new Tier 2 country-specific methodology to estimate N_2O emissions from synthetic nitrogen fertilizer application on agricultural soils, which takes into account local climate regimes and topographic conditions. Equation A3-12 is used to estimate N_2O emissions by ecodistrict.[40] Emission estimates at the provincial and national scales are obtained by aggregating estimates at the ecodistrict level.

Equation A3-12:

$$N_2O_{SFN} = \sum \left(N_{FERT,i} * EF_{BASE,i} * RF_{THAW} \right) * \frac{44}{28}$$

where:

N_2O_{SFN} = emissions from synthetic nitrogen fertilizers, kg N_2O/year

$N_{FERT,i}$ = total synthetic fertilizer consumption at the ith ecodistrict, kg N/year. N_{FERT} at an ecodistrict level is estimated using Equation A3-16.

$EF_{BASE,i}$ = a weighted average of emission factors at the ith ecodistrict, which is a function of local climate (precipitation/potential evapotranspiration) and landforms, kg N_2O-N/kg N per year

See "Determining Basic N_2O Emission Factor (EF_{BASE}) for an Ecodistrict" below.

RF_{THAW} = a ratio factor adjusting EF_{BASE} for emissions during spring thaw: for Newfoundland and Labrador, Prince Edward Island, Nova Scotia, New Brunswick, Quebec, and Ontario, $RF_{THAW} = 1.4$; for other provinces, $RF_{THAW} = 1.0$

See "Determining the Effect of Spring Thaw on N_2O Emission (RF_{THAW})" below.

44/28 = molecular weight ratio of N_2O to N_2

Data for mineral nitrogen fertilizer sales are available by province only and needed to be disaggregated to the ecodistrict level. The approach was based on the assumption that the potential amount of mineral nitrogen fertilizers applied (N_{APPLDP}) is equal to the difference between recommended nitrogen rates (N_{RCMD}) and manure nitrogen available for application on cropland ($N_{MAN\text{-}AV,CROPS}$), (see Equation A3.13).

Equation A3-13:

$$N_{APPLDP,i} = N_{RCMD,i} - N_{MAN\text{-}AV,CROPS,i}$$

where:

$N_{APPLDP,i}$ = total nitrogen fertilizer potentially applied in ecodistrict i, kg N/year

$N_{RCMD,i}$ = recommended fertilizer application in ecodistrict i, kg N/year

$N_{MAN\text{-}AV,CROPS,i}$ = available nitrogen from manure applied to crops in ecodistrict i, kg N/year

N_{RCMD} was estimated as the sum of the products of each crop type and the recommended fertilizer application rate for that crop in that ecodistrict (Yang *et al*., 2005):

Equation A3-14:

$$N_{RCMD,i} = \sum \left(CROPA_{ij} * N_{RECRT,j} \right)$$

where:

$CROPA_{ij}$ = area of crop type j in ecodistrict i, ha

$N_{RECRT,j}$ = recommended nitrogen application rate for crop type j in ecodistrict i, kg N/ha per year

$N_{MAN\text{-}AV,CROPS}$ was calculated as the sum of all manure nitrogen from all farm animals in the ecodistrict as follows:

Equation A3-15:

$$N_{MAN\text{-}AV,CROPS,i} = \sum_{jik} \left[(AnimalNo_{ji} * N_{EX,j}) * (1 - FracPRP_j) * (1 - Frac_{(LossMS)jk} - UNAV) \right]$$

where:

$AnimalNo_{ji}$ = animal population of category j in ecodistrict i, number of head

See data sources in Table A3-5.

$N_{EX,j}$ = nitrogen excretion rate for animal category j, kg N/head per year

See Table A3-20.

$FracPRP_j$ = fraction of $N_{EX,j}$ that is deposited on pasture by grazing animals for animal category j

See Table A3-19.

$Frac_{(LossMS)jk}$ = fraction of $N_{EX,j}$ that is lost during manure storage and handling in manure management system k for animal category j

See Table A3-22.

UNAV = fraction of $N_{EX,j}$ that is either in organic form or unavailable for crops: 0.35 (Yang *et al*., 2005).

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[40] Ecodistrict is defined as a subdivision of an ecoregion characterized by a distinctive assemblage of relief, landforms, geology, soil, vegetation, water bodies, and fauna.

TABLE A3-22: Total and NH_3 and NO_x Nitrogen Losses Associated with Various Livestock and Manure Management Systems

Animal Category	Manure Management Systems	Total Manure Nitrogen Loss (%) ($Frac_{(LossMS)}$)	NH_3-N and NO_x-N Loss (%)[1] ($Frac_{GASM}$)
Dairy Cow	Liquid	40 (15–45)	40 (15–45)
	Solid Storage	35 (10–55)	25 (10–40)
	Pasture, Range and Paddock	–	20 (5–50)
Non-Dairy Cattle	Liquid	40 (15–45)	40 (15–45)
	Solid Storage	40 (20–50)	30 (20–50)
	Pasture, Range and Paddock	–	20 (5–50)
Swine	Liquid	48 (15–60)	48 (15–60)
	Solid Storage	50 (20–70)	45 (10–65)
Sheep and Lamb	Solid Storage	15 (5–20)	12 (5–20)
	Pasture, Range and Paddock	–	20 (5–50)
Goat and Horse	Solid Storage	15 (5–20)	12 (5–20)
	Pasture, Range and Paddock	–	20 (5–50)
Poultry	Liquid	50	50
	Solid Storage	53 (20–80)	48 (10–60)
	Pasture, Range and Paddock	–	20 (5–50)

Notes:

1 Numbers in parentheses indicate a range.

Data sources: Hutchings *et al*. (2001); EPA (2004); Rotz (2004).

Because the potential amount of fertilizer needs to be reconciled with the total amount sold in the province (N_{SALES}) to estimate the actual amount applied (N_{FERT}), N_{APPLDP} is adjusted in each ecodistrict as follows:

Equation A3-16:

$$N_{FERT,\,i} = N_{APPLDP,\,i} * \left(\sum_{ip} N_{APPLDPp} / N_{SALESp} \right)$$

where:

$N_{FERT,i}$ = total fertilizer nitrogen actually applied to all crops in ecodistrict i, kg

$N_{APPLDP,i}$ = total fertilizer nitrogen potentially applied to all crops in ecodistrict i, kg

$\sum_{ip} N_{APPLDPp}$ = sum of all fertilizer nitrogen potentially applied in province p, kg

N_{SALESp} = total amount of fertilizer nitrogen sold in province p, kg

In ecodistricts where $N_{MAN\text{-}AV,CROPS}$ exceeded N_{RCMD}, N_{FERT} was set to 0. For years between two consecutive Census years (e.g., 1991 and 1996), N_{RCMD} was linearly interpolated to successively estimate annual values of N_{APPLDP} and N_{FERT} at the ecodistrict level.

Determining Basic N_2O Emission Factor (EF_{BASE}) for an Ecodistrict

The influence of local climatic conditions was assessed by the determination of regional fertilizer-induced emission factors (EF_{BASE}). These factors were estimated using the same approach as for the determination of the IPCC Tier 1 emission factor by Bouwman (1996), i.e., EF_{BASE} = slope of the "N_2O emissions vs. N fertilizer rate" relationship. EF_{BASE} was estimated for the three regions where field N_2O measurements are available: Quebec–Ontario in the east, and Brown-Dark Brown and Black soil zones in the Prairies. The "EF_{BASE} vs. fertilizer N" relationship determined for the Quebec–Ontario region has a similar slope (0.0119 kg N_2O-N/kg N) and fit ($r^2 = 0.43$) as the IPCC Tier 1 default emission factor derived by Bouwman (1996) using global data. In the Prairie region, low and variable N_2O emissions were measured across the range of nitrogen fertilizer rates (Brown-Dark Brown soils = 0.0016 kg N_2O/kg N; Black soils = 0.008 kg N_2O/kg N). These observations suggest that soil N_2O production in the Prairie region is not limited by mineral nitrogen availability but rather by the low denitrification activity under well-aerated dry soil conditions.

N_2O is mostly produced during denitrification and, as a result, is greatly influenced by the soil oxygen status. Accordingly, N_2O emission factors have been shown to increase with increasing rainfall (Dobbie *et al*., 1999), and climate-variable emission factors have been used in soil N_2O inventory (Flynn *et al*., 2005). A similar approach is proposed in this methodology by estimating emission factors at the ecodistrict level as a function of the ratio of the long-term normals (AAFC archived database) of precipitation to potential evapotranspiration (P/PE) from May to October (Figure A3-1). Despite the uncertainty in the determination of emission factors in the Prairie region, this approach appears as a valid option to account for the water-limited N_2O emissions in that region. To account for the topographical effect, an EF_{BASE} was estimated at a P/PE = 1 (0.012 kg N_2O-N/kg N) for the lower sections of the landscapes. The fraction of the landscape to which this condition was applied differs among landscape types.

To derive a basic N_2O emission factor (EF_{BASE}) for an ecodistrict, the following equation was used:

Equation A3-17:

$$EF_{BASE} = EF_{CT,P/PE=1} * F_{TOPO} + EF_{CT} * (1 - F_{TOPO})$$

where:

See Figure A3-1.

$EF_{CT,\ P/PE=1}$ = emission factor estimated at P/PE = 1 in an ecodistrict, 0.012 kg N_2O-N/kg N

F_{TOPO} = fraction of the ecodistrict area in the lower section of the toposequence

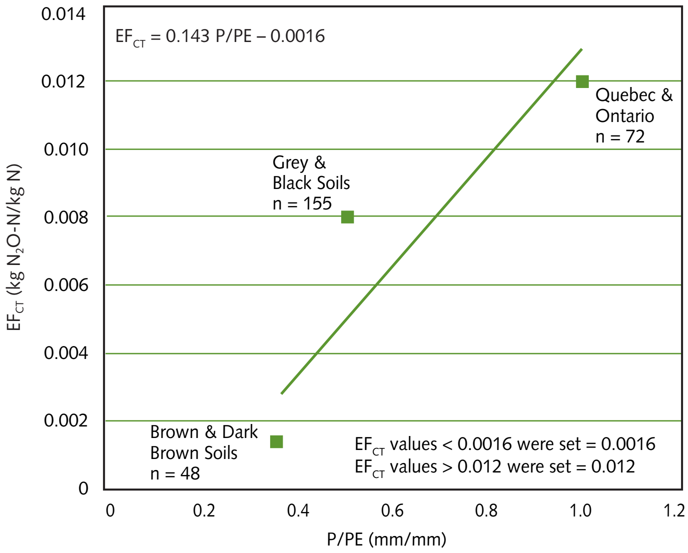
See Table A3-24.

EF_{CT} = emission factor estimated at actual P/PE accounting for climate and topography in an ecodistrict, kg N_2O-N/kg N

P = long-term mean precipitation from May to October in an ecodistrict, mm

PE = long-term mean potential evapotranspiration, mm

FIGURE A3-1: N_2O Emissions as a Function of P/PE



Landscape segmentation data were incorporated into the calculation of the national N_2O emission estimates, based upon the observations that N_2O emissions are greater in lower sections of the Prairie landscape where intermittently saturated soil conditions that are favourable to denitrification occur (Corre *et al*., 1996, 1999; Pennock and Corre, 2001; Izaurralde *et al*., 2004). The fraction of the landscape occupied by such lower sections, or F_{TOPO}, was applied to concave portions of the landscape (i.e., lower and depressional landscape positions) where soils are likely to be saturated for significant periods of time on a regular basis and soils are imperfectly and poorly drained with mottles[41] within 50 cm of the land surface. MacMillan and Pettapiece (2000) used digital elevation models to characterize the areal extent of upper, mid, lower, and depressional portions of the landscape and their associated characteristics (slope and length). Their results were used to determine proportions of landforms in the SLC attribute file, as described in Table A3-23, which was the basis for determining the proportion of the landscape to which to apply F_{TOPO} for deriving N_2O emission estimates (Table A3-24).

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[41] Mottles are the product of intermittent oxidation/reduction cycles of (generally) iron present in the soil profile. Prevalence, size, and colour of mottles are indicative of the soil materials being intermittently saturated for significant periods of time.

TABLE A3-23: Landforms within Soil Landscapes of Canada Polygons[1]

Landform Descriptor		Upper			Mid			Lower			Depression		
Surface Form	Slope Class	Prop	Slope	S_L	Prop	Slope	S_L	Prop	Slope	S_L	Prop	Slope	S_L
Hummocky	B or 4	30	9	50	35	9	50	25	7	35	10	1	15
	C or 10	30	12	50	35	12	50	25	9	35	10	1	20
	D or 16	35	25	70	30	25	60	25	15	50	10	1	20
Level	A or 1	0	N/A	N/A	45	1	450	45	1	450	10	1	100
Ridged	A or 1	20	3	40	55	4	110	20	3	40	5	0.5	10
	B or 4	20	6	40	55	6	110	20	4	40	5	1	20
	C or 10	15	15	60	65	18	180	15	10	60	5	1	20
Undulating	A or 1	20	2	50	50	2	120	15	2	40	15	0.5	40
	B or 4	25	4	60	45	4	115	20	3	50	10	1	25

Notes:

1 Prop – areal extent of landscape segment within SLC landform, Slope – slope (%) for each landscape segment, and S_L – slope length (m) for each landscape segment.

N/A = not applicable

TABLE A3-24: Summary of the Portions of the Landscapes to which F_{TOPO} was Applied[1]

Landform	Positions Associated with F_{TOPO}	Fraction of Cultivated Land Associated with F_{TOPO} (%)
Hummocky + Knoll and Kettle	Depressions + half of lower landscape	16
Inclined + Dissected	None	0
Level	Depressions	6
Ridged	Depressions + half of lower landscape	10
Rolling	Depressions + half of lower landscape	16
Steep	None	0
Terraced	Depressions	10
Undulating	Depressions	8
All Cultivated Land	–	10

Note:

1 Data source: Soil Landscape Database of Canada; A. Brierley and B. McConkey, expert opinion.

■ Determining the Effect of Spring Thaw on N_2O Emission (RF_{THAW})

Average annual snowfall in eastern Canada varies between 1 and 4.5 m (Environment Canada, 2002). Snowmelt water in the spring creates wet soil conditions that favour N_2O production. Accordingly, results from micrometeorological studies show that significant N_2O emissions can occur during spring thaw in Ontario (Wagner-Riddle *et al*., 1997; Wagner-Riddle and Thurtell, 1998; Grant and Pattey, 2003) and that estimating emissions only in the snow-free period underestimates total annual emissions of N_2O. For reasons including lower annual snowfall, spring thaw emissions are usually smaller in the Prairies than in eastern Canada (Lemke *et al*., 1999).

Gregorich *et al*. (2005) summarized field measurements of N_2O emissions from agricultural soils under various conditions in Quebec and Ontario. Based on these data reported on annual crops, the ratio factor for spring thaw (RF_{THAW}) was defined as the ratio of the mean N_2O emissions during spring thaw (1.19 kg N_2O-N/ha; n = 10 site-years) to emissions during the snow-free season (2.82 kg N_2O-N/ha; n = 58 site-years) (Gregorich *et al*., 2005). Thus, RF_{THAW} was estimated at 1.4 (1 + 1.19/2.82) for eastern Canada.

Chamber flux measurements used to estimate EF_{CT} in the Prairies include spring thaw emissions, because low snow accumulation in that region allows chamber deployments during that period. Cumulative snow-free-season N_2O emissions include spring thaw emissions (R. Lemke, personal communication). Therefore, no adjustment to the EF_{CT} for the spring thaw emissions is required in the Prairies (RF_{THAW} = 1).

■ Data Source

Accounting in agriculture relies on data from the Census of Agriculture, a self-administered questionnaire that all farmers are required by law to complete every five years (1991, 1996, and 2001). Data include the type of operating arrangement, the legal location of the farm headquarters, the area of each crop, summerfallow, tillage practices, improved and unimproved pasture, idle agricultural land and “other” land, such as forest, wetlands, and building sites, the area of manure, fertilizer, and pesticide application, individual and total income, and expenses.

The Farm Input Markets Unit of the Farm Income and Adaptation Policy Directorate of AAFC collected annual fertilizer nitrogen consumption data at the provincial level and published *Canadian Fertilizer Consumption, Shipments and Trade* from 1990 to 2002 (Korol, 2003).[42] For 2003 and 2004, fertilizer nitrogen data were obtained from the Canadian Fertilizer Institute.[43] The data sources for fertilizer consumption are the regional fertilizer associations that conduct surveys of all principal companies engaged in fertilizer retailing at a provincial level.

There are 958 weather stations in the AAFC archived weather database. These stations (80°00'N–41°55'N, 139°08'W–52°40'W) across Canada (758 stations) and the United States (200 stations) were used to interpolate monthly precipitation and potential evapotranspiration from May to October from 1951 to 1991 to the ecodistrict centroids. AAFC archived weather data were provided by the Meteorological Service of Canada, Environment Canada, and the data were quality controlled.

Manure Applied as Fertilizer

■ Methodology

Emissions of N_2O from manure applied as fertilizer include N_2O produced from the application of manure from drylot or solid storage, liquid, and other waste management systems on agricultural soils. Similarly to synthetic fertilizer N_2O emissions, a new country-specific methodology is developed to estimate N_2O emissions from manure applied as fertilizer. The methodology is based on the quantity of manure nitrogen produced by domestic animals and country-specific EF_{BASE} taking into account regional climate moisture and topographic conditions (at the ecodistrict level). N_2O emission estimates from this source are calculated using Equation A3-18.

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[42] Available online at: www.agr.ca/policy/cdnfert/text.html.

[43] Available online at: www.cfi.ca/Publications/Statistical_Documents.asp.

Equation A3-18:

$$N_2O_{MAN,i} = \sum \left(N_{MAN,\ CROPS,i} * EF_{BASE,i} * RF_{THAW} \right) * \frac{44}{28}$$

where:

$N_2O_{MAN,i}$ = emissions from animal manure applied to cropland as fertilizers in ecodistrict i, kg N_2O/year

$N_{MAN,CROPS,i}$ = total amount of animal manure nitrogen applied as fertilizer to cropland in ecodistrict i, kg N/year, (see Equation A3-19).

$EF_{BASE,i}$ = a weighted average emission factor for ecodistrict i accounting for climate and topography, kg N_2O-N/kg N per year

See "Determining Basic N_2O Emission Factor (EF_{BASE}) for an Ecodistrict."

RF_{THAW} = a ratio factor adjusting EF_{BASE} for emissions during spring thaw: for Newfoundland and Labrador, Prince Edward Island, Nova Scotia, New Brunswick, Quebec, and Ontario, $RF_{THAW} = 1.4$; for other provinces, $RF_{THAW} = 1.0$

See "Determining the Effect of Spring Thaw on N_2O Emission (RF_{THAW})."

44/28 = molecular weight ratio of N_2O to N_2

Equation A3-19:

$$N_2O_{MAN,CROPS,i} = \sum_T [(N_T * N_{EX,T}) * (1 - N_{PRP,T}) * (1 - Frac_{(LossMS,T)})]$$

where:

$N_2O_{MAN,CROPS,i}$ = emissions from animal manure applied as nitrogen fertilizers on cropland in ecodistrict i, kg N_2O/year

N_T = population for the Tth animal category or subcategory

Refer to Section A3.4.2 for livestock population data sources and calculations.

$N_{EX,T}$ = nitrogen excretion rate for the Tth animal category or subcategory

Refer to Table A3-20.

$N_{PRP,T}$ = fraction of manure nitrogen on pasture, range, and paddock for each animal category T in ecodistrict i

See Table A3-19.

$Frac_{(LossMS,T)}$ = fraction of total losses of manure nitrogen for each animal category T excluding pasture, range, and paddock in ecodistrict i

See Table A3-22.

■ Data Source

Animal population data sources and population adjustments are the same as those used for CH_4 emissions from enteric fermentation and manure.

Biological Nitrogen Fixation

Biological nitrogen fixation by the legume–rhizobium association, a major source of N_2O in the IPCC Guidelines methodology (IPCC/OECD/IEA, 1997), is not included in the 2006 IPCC Guidelines (IPCC, 2006). This decision is supported by the conclusion of Rochette and Janzen (2005) that there is no evidence that measurable amounts of N_2O are produced during the nitrogen fixation process itself. Therefore, Canada decided to report this source as "not occurring." However, the contribution of legume nitrogen to N_2O emissions is included as a source of N_2O emissions from crop residue decomposition on agricultural soils (N_{RES}).

Crop Residues

■ Methodology

The transformations (nitrification and denitrification) of the nitrogen released during the decomposition of crop residues returned to fields result in N_2O emissions into the atmosphere. A new country-specific methodology similar to that for fertilizer and manure applied as fertilizer is used to estimate N_2O emissions from crop residues, based on Equation A3-20, Equation A3-21, and Equation A3-22.

Equation A3-20:

$$N_2O_{RES} = \sum \left(N_{RES,i} * EF_{BASE,i} * RF_{THAW} \right) * \frac{44}{28}$$

where:

N_2O_{RES} = emissions from crop residue decomposition, kg N_2O-N/year

$EF_{BASE,i}$ = a weighted average of emission factors for ecodistrict i, kg N_2O-N/kg N per year

See "Determining Basic N_2O Emission Factor (EF_{BASE}) for an Ecodistrict."

RF_{THAW} = a ratio factor adjusting EF_{BASE} for emissions during spring thaw: for Newfoundland and Labrador, Prince Edward Island, Nova Scotia, New Brunswick, Quebec, and Ontario, $RF_{THAW} = 1.4$; for other provinces, $RF_{THAW} = 1.0$

See "Determining the Effect of Spring Thaw on N_2O Emission (RF_{THAW})."

44/28 = molecular weight ratio of N_2O to N_2

$N_{RES,i}$ = total amount of crop residue nitrogen that is returned to the cropland annually for ecodistrict i, kg N/year, calculated as follows:

Equation A3-21:

$$N_{RES,i} = \sum_{T} [P_{T,i} \ast Frac_{Renew,T,i} \ast (R_{AG,T} \ast N_{AG,T} + R_{BG,T} \ast N_{BG,T})]$$

where:

$Frac_{Renew,T,i}$ = fraction of total area under crop T that is renewed annually in ecodistrict i

$R_{AG,T}$ = ratio of aboveground residues to harvested yield for crop T, kg dry matter (DM)/kg

$N_{AG,T}$ = nitrogen content of aboveground residues for crop T, kg N/kg DM

$R_{BG,T}$ = ratio of belowground residues to harvested yield for crop T, kg DM/kg

$N_{BG,T}$ = nitrogen content of belowground residues for crop T, kg N/kg DM

T = crop/forage type

$P_{T,i}$ = total production of the Tth crop type that is renewed annually in ecodistrict i, as calculated below (Equation A3-22), kg DM/year

Equation A3-22:

$$P_{T,i} = \frac{A_{T,i} \ast Y_{T,i}}{\sum_{i=1}^{N} (A_{T,i} \ast Y_{T,i})} \ast P_{T,p} \ast H_2O_T$$

where:

$A_{T,i}$ = area under crop type T in ecodistrict i, ha

$Y_{T,i}$ = average crop yield for crop type T in ecodistrict i, kg/ha per year

H_2O_T = water content of harvested crop T, kg/kg

$P_{T,p}$ = total crop production for crop type T in province p, kg DM/year

■ Data Source

Estimates of N_2O emissions from crop residue decomposition rely on crop production data from the Census of Agriculture and crop yield surveys of Statistics Canada. Both areas and yields are available at all levels of ecostratification (SLC, ecodistrict, ecoregion, ecozone), provincially and nationally; area seeded to each crop is available for the Census years (1991, 1996, 2001), and yields of select crops are available annually. Specific parameters for each crop type are listed in Table A3-25.

Statistics Canada (#22-002) collects and publishes annual field crop production data. Crops include wheat, barley, corn/maize, oats, rye, mixed grains, flax seed, canola, buckwheat, mustard seed, sunflower seed, canary seeds, fodder corn, sugar beets, tame hay, dry peas, soybean, dry white beans, coloured beans, chick peas, and lentils. Area and production of each crop are reported at the Census Agricultural Region and provincial levels, and yields have been allocated to SLC polygons through area overlays by AAFC.

Cultivation of Histosols

■ Methodology

Cultivation of organic soil (histosols) for annual crop production produces N_2O. The IPCC Tier 1 methodology is used to estimate N_2O emissions from cultivated organic soils as shown in Equation A3-23.

Equation A3-23:

$$N_2O_H = \sum \left(A_{OS,i} \ast EF_{HIST}\right) \ast \frac{44}{28}$$

where:

N_2O_H = N_2O emissions from cultivated histosols

$A_{OS,i}$ = total area of cultivated organic soils in each province, ha

EF_{HIST} = IPCC default emission factor for mid-latitude organic soils, 8.0 kg N_2O-N/ha per year (IPCC, 2000)

44/28 = molecular weight ratio of N_2O to N_2

■ Data Source

Areas of cultivated histosols at a provincial level are not collected as part of the Census of Agriculture. Consultations with numerous soil and crop specialists across Canada indicate that the total area of cultivated organic soils from 1990 to 2004 in Canada is 16 540 ha (G. Padbury and G. Patterson, AAFC, personal communication).

Reduced N_2O Emissions as a Result of Adoption of No-Tillage and Reduced Tillage on the Canadian Prairies

■ Methodology

This is a new category in Canada's inventory of direct N_2O emissions from soils. It does not derive from additional nitrogen input (such as fertilizer, manure, and crop residue nitrogen) but is rather like a "modifier" to several factors affecting N_2O production and emission when tillage practices are modified. For example,

TABLE A3-25: Water Content (H_2O), Ratios of Aboveground (R_{AG}) and Belowground (R_{BG}) Residues to Yield, Renewal Interval ($Frac_{Renew}$), and Nitrogen Content of Crop (N_{AC}), Aboveground (N_{AG}), and Belowground (N_{BG}) Residues[1]

Crop (T)	H_2O content (%)	R_{AG}	R_{BG}	$Frac_{Renew}$	N_{AC} (g N/kg)	N_{AG} (g N/kg)	N_{BG} (g N/kg)
Wheat	12	1.5	0.4	1	26	6	10
Oat	12	1.4	0.6	1	18	6	10
Barley	12	1.2	0.4	1	19	7	10
Rye	12	1.5	0.4	1	18	6	10
Flax	8	2.3	0.6	1	35	7	10
Canola	9	2.3	0.6	1	35	8	10
Corn (Grain)	15	0.8	0.3	1	15	5	7
Soybean	14	1.5	0.8	1	67	6	10
Mixed Grains	12	1.4	0.6	1	22.3	6.3	10
Buckwheat	12	2.3	0.8	1	18	6	10
Peas, Dry	13	1.8	0.7	1	37	18	10
Beans, Dry Field	13	0.7	0.4	1	42	10	10
Mustard Seed	9	2.3	0.6	1	40	8	10
Sunflower Seed	2	2.0	0.7	1	24	10	10
Lentils	13	1.9	0.7	1	44	10	10
Corn (Silage)	70	0.1	0.3	1	13	13	7
Canary Seed	12	3.0	1.0	1	25	7	10
Summerfallow	0	–	–	1	0	0	0
Tame Hay (Other)	13	0.7	3.9	0.2	16	16	10
Tame Hay (Alfalfa & Mix)	13	0.3	1.3	0.2	26	15	15
Safflower	2	2.0	0.7	1	24	10	10
Potatoes	75	0.3	0.1	1	15	20	10
Sugar Beets	80	0.3	0.1	1	10	29	10
Triticale	12	1.5	0.6	1	22	6	10
Forage for Seed	13	4.0	3.3	0.2	30	15	13
Tame/Seeded Pasture	0	0.7	2.5	0.1	15	15	15

Note:

1 Data source: Janzen *et al*. (2003).

compared with conventional or intensive tillage (IT), direct seeding or no-tillage (NT) as well as reduced tillage (RT) affect the decomposition of soil organic matter, soil carbon and nitrogen availability, soil bulk density, and water content.

Reduced emissions of N_2O resulting from the adoption of NT and RT can be expressed as follows:

Equation A3-24:

$$N_2O_{TILL} = \sum\{[N_{FERT,i} + N_{MAN,CROPS,i} + N_{RES,i}] * [EF_{BASE,i} * FRAC_{NT\text{-}RT,i} * (F_{TILL} - 1]\} * \frac{44}{28}$$

where:

N_2O_{TILL} = reduced N_2O resulting from the adoption of NT and RT, kg N_2O/year

$N_{FERT,i}$ = total synthetic fertilizer nitrogen consumption in ecodistrict i, kg N/year

$N_{MAN,CROPS,i}$ = total amount of animal manure nitrogen applied as fertilizer to cropland in ecodistrict i, kg N/year

$N_{RES,i}$ = total amount of crop residue nitrogen that is returned to the cropland annually for ecodistrict i, kg N/year

$EF_{BASE,i}$ = a weighted average of emission factor for ecodistrict i, kg N_2O-N/kg N per year

$FRAC_{NT\text{-}RT,i}$ = fraction of cropland on NT and RT in ecodistrict i, %

F_{TILL} = a ratio factor adjusting EF_{BASE} (*see "Determining Basic* N_2O *Emission Factor* (EF_{BASE}) *for an Ecodistrict"*) due to the adoption of NT and RT: F_{TILL} = 1.0 in eastern Canada and British Columbia; F_{TILL} = 0.8 in the Prairies (see below)

44/28 = molecular weight ratio of N_2O to N_2

The ratio factor (the ratio of mean N_2O fluxes on NT or RT to mean fluxes on IT, N_2O_{NT}/N_2O_{IT}) represents the effect of NT or RT on N_2O emissions (F_{TILL}). Field studies in Quebec and Ontario comparing emissions between NT and mouldboard plowing (Gregorich *et al*., 2005) provided an F_{TILL} of 1.0 (1.55 kg N/ha / 1.54 kg N/ha) for Quebec and Ontario (Table A3-26). A similar exercise for the Prairie region yielded an F_{TILL} of 0.8 (0.44/0.53) for the Brown, Dark Brown, Grey, and Black soil zones (Table A3-27). F_{TILL} affects only the cultivated areas under NT and RT. Consequently, an F_{TILL} of 1 was used for all soils other than the Brown, Dark Brown, Grey, and Black soil zones on the Prairies.

Data Source

The fraction of cropland on NT and RT ($FRAC_{NT\text{-}RT}$) for each ecodistrict within the Brown, Dark Brown, Black, and Grey soil zones of the Prairies originated from the Census of Agriculture (Statistics Canada, #93350, #93356, #95F0301) and is identical to that used in the LULUCF cropland remaining cropland category for NT and RT practices. These data are published at the Census Agricultural Region, Census Division, provincial, and national level. Annual $FRAC_{NT\text{-}RT}$ between the two consecutive Census years is adjusted through interpolation.

N_2O Emissions Resulting from Summerfallowing

Methodology

Summerfallowing is a farming practice typically used in the Prairie region to conserve soil moisture by leaving the soil unseeded for an entire growing season in a crop rotation. During the fallow year, several factors may stimulate N_2O emissions relative to a cropped situation, such as higher soil water content, temperature, and available carbon and nitrogen (Campbell *et al*., 1990). Experimental studies have shown that N_2O emissions in fallow fields are similar to emissions from continuously cropped fields (Table A3-28). Therefore, the following country-specific methodology is used to estimate the effect of summerfallowing on N_2O emissions.

During a crop year, direct N_2O emissions from a given field are summarized as follows:

Equation A3-25:

$$N_2O_{CROP} = N_2O_{SFN} + N_2O_{MAN} + N_2O_{RES}$$

where:

N_2O_{SFN}, N_2O_{MAN}, and N_2O_{RES} were defined above.

TABLE A3-26: N_2O Emissions from Soils under Mouldboard Plow (MP) and No-Till (NT) in Quebec and Ontario

Location	Year	Cropping System	Soil Texture	Nitrogen Applied	Emissions		Ref.[1]
					MP	NT	
				(kg N/ha)	*(kg N_2O-N/ha per year)*		
Québec, QC	2001	Barley	Loamy Sand	60	1.24	1.23	1
Québec, QC	2001	Barley	Clay	60	20.62	44.24	1
Québec, QC	2002	Barley	Loamy Sand	60	0.93	1.52	1
Québec, QC	2002	Barley	Clay	60	6.12	12.12	1
Québec, QC	2003	Barley	Loamy Sand	60	0.81	0.61	1
Québec, QC	2003	Barley	Clay	60	12.16	38.92	1
Ottawa, ON	2002	Soybean	Sandy Loam	0	1.51	1.15	2
Ottawa, ON	2002	Corn	Sandy Loam	190	0.71	1.06	2
Ottawa, ON	2003	Soybean	Sandy Loam	0	0.42	0.29	2
Ottawa, ON	2003	Corn	Sandy Loam	190	0.37	0.27	2
Ottawa, ON	2004	Soybean	Sandy Loam	0	1.34	1.13	2
Ottawa, ON	2004	Corn	Sandy Loam	190	1.54	4.35	2
Montréal, QC	1994	Corn + Soybean	Heavy Clay	180	2.1	1.8	3
Montréal, QC	1994	Corn + Soybean	Silt Clay Loam	180	3.5	2.2	3
Montréal, QC	2003	Soybean	Loamy Sand	0	0.9	1.44	4
Montréal, QC	2004	Corn	Loamy Sand	0	0.75	0.55	4
Montréal, QC	2004	Corn	Loamy Sand	80	1.5	1.25	4
Montréal, QC	2004	Corn	Loamy Sand	160	1.95	1.55	4
Woodslee, ON	1995	Corn	Clay Loam	155	1.29	0.96	5
Woodslee, ON	1995	Corn + Red Clover	Clay Loam	155	1.07	1.04	5
Woodslee, ON	2000	Corn	Clay Loam	182	8.99	7.55	6
Woodslee, ON	2001	Corn	Clay Loam	182	1.49	1.57	6
Woodslee, ON	2002	Corn	Clay Loam	182	3.95	2.00	6
Woodslee, ON	2002	Corn	Clay Loam	180	0.64	0.57	7
Woodslee, ON	2002	Soybean	Clay Loam	0	0.75	0.31	7
Woodslee, ON	2003	Corn	Clay Loam	180	0.84	0.46	7
Woodslee, ON	2003	Soybean	Clay Loam	0	0.66	0.73	7
Woodslee, ON	2004	Corn	Clay Loam	160	1.28	2.40	7
Mean ± Standard Deviation[2]					**2.84 ± 4.41**	**4.76 ± 10.71**	
Mean ± Standard Deviation[3]					**1.54**	**1.55**	

Notes:

1 References: 1. Rochette *et al*. (unpublished); 2. Gregorich *et al*., 2004 (unpublished); 3. MacKenzie *et al*., 1997; 4. MacKenzie *et al*., 1998; 5. Kaharabata *et al*., 2003; 6. Drury *et al*., 2006; 7. Drury (unpublished).

2 Mean of raw data.

3 Mean of log-transformed (to the base 10) data to account for log-normal distribution of the field data.

TABLE A3-27: N_2O Emissions from Soils under Intensive Till (IT) and No-Till (NT) in the Prairie Region

Location	Year	Crop	Nitrogen Applied	Emissions		Ref.[1]
				IT	NT	
			(kg N/ha)	*(kg N_2O-N/ha per year)*		
Breton, AB	1993	Fallow	0	0.34	0.30	1
Breton, AB	1993	Wheat	0	0.13	0.17	1
Breton, AB	1993	Wheat	56	0.39	0.19	1
Breton, AB	1993	Wheat	Manure	0.22	0.33	1
Breton, AB	1993	Wheat	Pea Residue	0.36	0.50	1
Ellerslie, AB	1993–1994	Fallow	0	1.77	1.08	1
Ellerslie, AB	1993–1994	Wheat	0	1.51	0.50	1
Ellerslie, AB	1993–1994	Wheat	56	2.10	1.22	1
Ellerslie, AB	1993–1994	Wheat	Manure	0.77	0.58	1
Ellerslie, AB	1993–1994	Wheat	Pea Residue	0.17	1.59	1
Swift Current, SK	1999–2004	Fallow	0	0.14	0.06	2
Swift Current, SK	1999–2004	Field Pea	5	0.14	0.08	2
Swift Current, SK	1999–2004	Wheat	50	0.19	0.17	2
Three Hills, AB	2000–2002	Fallow	0	3.38	1.73	3
Three Hills, AB	2000–2002	Field Pea	5	1.72	0.94	3
Three Hills, AB	2000–2002	Wheat	75	1.88	1.42	3
Arithmetic Mean ± Standard Deviation[2]				**0.95 ± 0.98**	**0.68 ± 0.57**	
Geometric Mean[3]				**0.53**	**0.44**	

Notes:

1 References: 1. Lemke *et al*., 1999; 2. Lemke (unpublished); 3. Goddart (unpublished).

2 Mean of raw data.

3 Geometric mean (log-transformed data) to account for log-normal distribution of the field data.

During a fallow year, no fertilizer or manure is applied. In the absence of external nitrogen inputs, N_2O emissions during the fallow year (N_2O_{FALLOW}) can be seen as consisting of i) "background" emissions that would have occurred regardless of fallow (N_2O_{BACK}) and ii) emissions due to the modifications to the soil environment by fallow ($N_2O_{FALLOW\text{-}EFFECT}$):

Equation A3-26:

$$N_2O_{FALLOW} = N_2O_{BACK} + N_2O_{FALLOW\text{-}EFFECT}$$

Since N_2O emissions are assumed equal during fallow and cropped years:

Equation A3-27:

$$N_2O_{SFN} + N_2O_{MAN} + N_2O_{RES} = N_2O_{BACK} + N_2O_{FALLOW\text{-}EFFECT}$$

Assuming that background emissions during the fallow year are approximately equal to those associated with previous-year crop residue decomposition ($N_2O_{BACK} = N_2O_{RES}$), $N_2O_{FALLOW\text{-}EFFECT}$ is estimated as the sum of emissions resulting from fertilizer and manure nitrogen applications during the crop year of the rotation:

Equation A3-28:

$$N_2O_{FALLOW\text{-}EFFECT} = N_2O_{SFN} + N_2O_{MAN}$$

At the ecodistrict level, the emissions due to the practice of summerfallow were then calculated by summing emissions from fertilizer and manure application to annual crops for the ecodistrict and multiplying the sum by the proportion of the area under annual cropping in that ecodistrict that is under summerfallow, as follows:

Equation A3-29:

$$N_2O_{FALLOW-EFFECT,i} = (N_2O_{SFN,i} + N_2O_{MAN,i}) * Frac_{FALLOW,i}$$

where:

$N_2O_{SFN,i}$ = N_2O_{SFN} in annual crops in ecodistrict i, kg N_2O-N

$N_2O_{MAN,i}$ = N_2O_{MAN} in annual crops in ecodistrict i, kg N_2O-N

$Frac_{FALLOW,i}$ = fraction of cropland in ecodistrict i that is under summerfallow, %

Thus, total national emissions of N_2O resulting from the practice of summerfallow ($N_2O_{FALLOW-EFFECT}$) can be calculated as:

Equation A3-30:

$$N_2O_{FALLOW-EFFECT,i} = \sum [N_2O_{SFN,i} + N_2O_{MAN,i}) * Frac_{FALLOW,i}]$$

- **Data Source**

Estimates of N_2O_{SFN} and N_2O_{MAN} at an ecodistrict level are those derived from the synthetic fertilizer and manure as fertilizer source categories (see above). $Frac_{FALLOW}$ is derived from the Census of Agriculture for each ecodistrict (Statistics Canada, #93350, #93356, #95F0301) and is identical to that used in the LULUCF cropland remaining cropland category for the summerfallow practice. Annual $Frac_{FALLOW}$ between the two consecutive Census years is adjusted through interpolation.

A3.4.5.2 Manure on Pasture, Range, and Paddock from Grazing Animals

Methodology

The IPCC Tier 1 default methodology is used to estimate N_2O emissions from manure on pasture and paddock from grazing animals. The IPCC methodology is based on the quantity of manure nitrogen produced by domestic animals on pasture and paddock. N_2O emissions from manure on pasture, range, and paddock are calculated using Equation A3-31. Note that N_2O emissions from manure on pasture and paddock are reported under Agricultural Soils, not under Manure Management.

TABLE A3-28: N_2O Emissions in Crop–Fallow Rotations in the Prairie Region

Location	N_2O Emissions	
	Continuous Wheat	Fallow
	(kg N/ha)	
Three Hills, AB	0.7	1.3
Three Hills, AB	0.9	0.6
Three Hills, AB	2.0	3.3
Swift Current, SK	0.1	0.0
Swift Current, SK	0.3	0.2
Swift Current, SK	0.1	0.0
Swift Current, SK	0.6	0.0
Three Hills, AB	1.5	1.6
Three Hills, AB	2.0	1.6
Swift Current, SK	0.1	0.1
Swift Current, SK	0.4	0.5
Swift Current, SK	0.1	0.0
Swift Current, SK	0.2	0.1
Ellerslie, AB	1.7	1.3
Ellerslie, AB	0.6	0.5
Ellerslie, AB	0.9	1.1
Breton, AB	0.2	0.4
Ellerslie, AB	2.1	1.2
Ellerslie, AB	0.9	0.4
Ellerslie, AB	2.4	3.0
Breton, AB	0.5	0.7
Breton, AB	0.8	0.3
Cooking Lake, AB	1.5	0.7
Cooking Lake, AB	1.0	0.8
Mean	0.89	0.82

Source:
Unpublished data compiled by R. Lemke, AAFC.

Equation A3-31:

$$N_2O_{MPRP} = \sum_{T} \left(N_T * N_{EX,T} * FRAC_{GASM,T} * N_{PRP,T} * EF_{PRP,T} \right) * \frac{44}{28}$$

where:

N_2O_{MPRP} = N_2O emissions from manure on pasture, range, and paddock from grazing animals, kg N_2O/year

N_T = animal population of the animal category T in a province, head

Refer to Section A3.4.2 for livestock population data sources and calculations.

$N_{EX,T}$ = nitrogen excretion rate for the animal category T, kg N/head per year

See Table A3-20.

$Frac_{GASM,T}$ = fraction of manure nitrogen available for N_2O emissions on pasture, range, and paddock for the animal category T

See Table A3-19.

$N_{PRP,T}$ = fraction of manure nitrogen excreted on pasture, range, and paddock by animal category T

See Table A3-19.

$EF_{PRP,T}$ = emission factor for manure nitrogen deposited by animals on pasture, range, and paddock: 0.02 kg N_2O-N/kg N for dairy cattle, non-dairy cattle, bison, swine, and poultry, and 0.01 kg N_2O-N/kg N for sheep, lamb, goat, and horse (IPCC, 2006)

See Table A3-21.

44/28 = molecular weight ratio of N_2O to N_2

Data Source

Animal population data and data sources are the same as those used for CH_4 emission estimates from enteric fermentation.

A3.4.5.3 Indirect N_2O Emissions

Volatilization and Redeposition of Nitrogen

■ Methodology

The IPCC Tier 1 methodology is used to estimate indirect N_2O emissions due to volatilization and redeposition of fertilizer and manure nitrogen applied to agricultural soils. The emission calculation is shown in Equation A3-32.

Equation A3-32:

$$N_2O_{VD} = \sum \left[\left(N_{FERT,i} * VOLAT_{FERT} \right) + N_{MAN\text{-}VOLAT,i} \right] EF_{VD} * \frac{44}{28}$$

where:

N_2O_{VD} = indirect N_2O emissions due to volatilization and redeposition, kg N_2O/year

$N_{FERT,i}$ = synthetic nitrogen fertilizer consumption in ecodistrict i, kg N/year

$VOLAT_{FERT}$ = fraction of synthetic fertilizer nitrogen applied to soils that volatilizes as NH_3-N and NO_x-N: 0.1 kg (NH_3-N + NO_x-N)/kg N (IPCC/OECD/IEA, 1997)

EF_{VD} = emission factor due to volatilization and redeposition: 0.01 kg N_2O-N/kg N (IPCC/OECD/IEA, 1997)

44/28 = molecular weight ratio of N_2O to N_2

$N_{MAN\text{-}VOLAT,i}$ = total manure nitrogen lost as NH_3-N and NO_x-N from livestock excretion in ecodistrict i, kg N, calculated as follows:

Equation A3-33:

$$N_{MAN\text{-}VOLAT} = \sum_{m,T} \left(N_T * N_{EX,T} * AWMS_{m,T} * Frac_{GASMm,T} \right)$$

where:

N_T = animal population for animal category T, head

$N_{EX,T}$ = nitrogen excretion from animal category T, kg N/year

Refer to Section A3.4.4 methodology for calculation and data source (Table A3-20).

$AWMS_{m,T}$ = fraction of manure nitrogen from animal category T managed under manure management system m

See Table A3-19.

$Frac_{GASMm,T}$ = fraction of manure nitrogen excreted by animal category T and managed under manure management system m that volatilizes as NH_3-N and NO_x-N

See Table A3-22.

■ Data Source

Data sources for estimating N_{FERT} and $N_{MAN\text{-}VOLAT}$ at an ecodistrict level are provided in the previous sections.

Leaching, Runoff, and Erosion

■ Methodology

A modified IPCC Tier 1 methodology is used to estimate indirect N_2O emissions from leaching, runoff, and erosion of fertilizer nitrogen, manure nitrogen, and crop residue nitrogen from agricultural soils:

Equation A3-34:

$$N_2O_L = \sum [(N_{FERT,i} + N_{MAN,i} + N_{PRP,i} + N_{RES,i}) * Frac_{LEACH,i} * EF_{LEACH}] * \frac{44}{28}$$

where:

N_2O_L = indirect N_2O emissions due to leaching and runoff, kg N_2O/year

$N_{FERT,i}$ = synthetic nitrogen fertilizers applied for ecodistrict i, kg N

$N_{MAN,i}$ = manure nitrogen applied as fertilizers for ecodistrict i, kg N

$N_{PRP,i}$ = manure nitrogen on pasture, range, and paddock for ecodistrict i, kg N

$N_{RES,i}$ = crop residue nitrogen for ecodistrict i, kg N

$Frac_{LEACH,i}$ = fraction of nitrogen that is lost through leaching and runoff for ecodistrict i, as defined below

EF_{LEACH} = leaching/runoff emission factor: 0.0125 kg N_2O-N/kg N (IPCC, 2006)

44/28 = molecular weight ratio of N_2O to N_2

Determining the Fraction of Nitrogen that is Leached ($Frac_{LEACH}$) at the Ecodistrict Level in Canada

In Canada, leaching losses of nitrogen vary widely among regions. High nitrogen inputs in humid conditions may lead to losses greater than 100 kg N/ha per year in some farming systems of southern British Columbia (Paul and Zebarth, 1997; Zebarth *et al*., 1998). Such losses, however, represent only a small fraction of Canadian agroecosystems. In Ontario, Goss and Goorahoo (1995) predicted leaching losses of 0–37 kg N/ha, accounting for 0–20% of nitrogen inputs from seed, feed, fertilizer, manure, animals, nitrogen fixation, and atmospheric deposition. Leaching losses in most of the Prairie region may be smaller due to lower precipitation and lower nitrogen inputs on an areal basis. Based on a long-term experiment in central Alberta, Nyborg *et al*. (1995) suggested that leaching losses were minimal, and Chang and Janzen (1996) found no evidence of nitrogen leaching in non-irrigated, heavily manured plots, despite large accumulations of soil nitrate in the soil profile.

The default value for $Frac_{LEACH}$ in the IPCC Guidelines (IPCC/OECD/IEA, 1997) was 0.3. $Frac_{LEACH}$ can reach values as low as 0.05 in regions where rainfall is much lower than potential evapotranspiration (IPCC, 2006), such as in the Prairie region of Canada. Accordingly, it was assumed that $Frac_{LEACH}$, depending on the ecodistrict, would vary from a low of 0.05 to a high of 0.3.

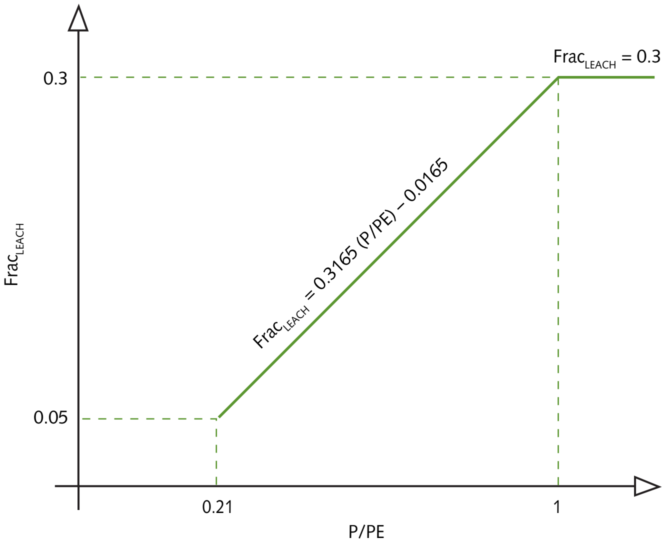
For ecodistricts with a P/PE value for the growing season (May through October) greater than or equal to 1, the maximum $Frac_{LEACH}$ value recommended by the 2006 IPCC Guidelines of 0.3 was assigned. For ecodistricts with the lowest P/PE value (0.21), a minimum $Frac_{LEACH}$ value of 0.05 was assigned. For ecodistricts with a P/PE value that ranged between 0.21 and 1, $Frac_{LEACH}$ was estimated by the linear function that joins the points (P/PE, $Frac_{LEACH}$) = (1, 0.3; 0.21, 0.05) (Figure A3-2).

Data Source

Data sources for N_{FERT}, N_{MAN}, N_{PRP}, and N_{RES} at an ecodistrict level are provided in the previous sections.

Long-term normals of monthly precipitation and potential evapotranspiration from May to October, 1951–2001 (AAFC archived database), were used to calculate $Frac_{LEACH}$ at an ecodistrict level (see Synthetic Nitrogen Fertilizers under Section A3.4.5.1).

FIGURE A3-2: **Determination of the Ecodistrict $Frac_{LEACH}$ Values**



A3.5 METHODOLOGY FOR LAND USE, LAND-USE CHANGE AND FORESTRY

In the current submission, the LULUCF Sector of the inventory includes the GHG emissions/removals associated with managed lands and with land conversion to different land categories.

As in Chapter 7, the structure of this annex attempts to maintain the land-based reporting categories, while grouping related data collection, creation, and estimate development methodologies. Section A3.5.1 summarizes the spatial framework for estimate development and area reconciliation. The general approach for estimating carbon stock changes, emissions, and removals in all forest-related categories, including managed forests, forest conversion to other lands, and lands converted to forests, is briefly described in Section A3.5.2. Sections A3.5.3 to A3.5.6 provide similar information for Cropland, Grassland, Wetlands, and Settlements.

Several approaches to the estimation of delayed emissions due to carbon storage in HWPs are briefly described in Section A3.5.7, along with implications for Canada.

A3.5.1 SPATIAL FRAMEWORK FOR LULUCF ESTIMATE DEVELOPMENT AND AREA RECONCILIATION

The enhanced complexity of estimate development and active participation of several groups of scientists and experts create a complex institutional framework within which close collaboration is essential. At the same time, the approaches, methods, tools, and data that are available and most suitable to monitor one land activity are not always appropriate for another. Important differences exist in the spatial framework used by each group, with the risk that activity data and estimates become spatially inconsistent. A hierarchical spatial framework was agreed upon by all partners of the LULUCF MARS, to ensure the highest possible consistency and spatial integrity of the GHG inventory.

At the finest level of spatial resolution are "analysis units," which are specific to each estimation system. In managed forests, the analysis units are the management units found in provincial and territorial forest inventories. For the purpose of this assessment, managed forests were classified into some 1441 analysis units across 12 provinces and territories (Table A3-29). Analysis units typically result from the intersection of administrative areas used for timber management and ecological boundaries.

Analysis units for estimating the areas of forest converted to other uses were based on expected deforestation rates and characteristics, as well as administrative boundaries. The most suitable spatial framework for GHG monitoring of agricultural lands (Cropland and Grassland) is the National Soil Database of the Canadian Soil Information System (CanSIS)[44] and its underlying Soil Landscapes of Canada (SLC). The full array of attributes that describe a distinct type of soil and its associated landscapes, such as surface form, slope, typical soil carbon content under native and dominant agricultural land use, water table depth, etc., is called a soil landscape. SLC polygons (the "analysis units") may contain one or more distinct soil landscape components and may also contain small but highly contrasting components. The SLC polygons are in the order of 1000 – 1 000 000 ha and are appropriate for mapping at the scale of 1:1 million. Note that the precise locations of particular soil landscapes within a polygon, of particular forest stands within a forest management analysis unit, or of forest conversion events within a deforestation analysis unit are not defined or spatially explicit; by convention, the expression "spatially referenced" refers to locational information associated with the boundaries of such spatial units.

SLC polygons are the basic units of Canada's National Ecological Framework, a hierarchical, spatially

TABLE A3-29: Spatial Analysis Units of Managed Forests

	Canada	NL	PE	NS	NB	QC	ON	MB	SK	AB	BC	YT	NT
No. of Analysis Units	1441	39	1	12	1	138	319	74	39	69	688	13	48

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[44] http://sis.agr.gc.ca/cansis

consistent national context within which ecosystems at various levels of generalization can be described, monitored, and reported on (Marshall and Schut, 1999). The 12 500 SLC polygons are nested in the next level of generalization (1021 ecodistricts), which are further grouped in 194 ecoregions and 15 ecozones.

The LULUCF Sector of the GHG inventory reports information in 18 "reporting zones" (Chapter 7, Figure 7-2). These reporting zones are essentially the same as ecozones, with three exceptions: the Boreal Shield and Taiga Shield ecozones are split into their east and west components to form four reporting zones; and the Prairies ecozone is divided into a semiarid and a subhumid component. These subdivisions were made along the lines of existing ecoregion boundaries and hence do not alter the hierarchical nature of the spatial framework. Table A3-30 provides the land and water areas of each reporting zone. Methods and data sources used for developing this information are described in McGovern (2006).

TABLE A3-30: **Land and Water Areas of Reporting Zones**

Reporting Zone Number	Reporting Zone Name	Total Area of Land *(ha)*	Total Area of Fresh Water *(ha)*
1	Arctic Cordillera	23 991 965	285 935
2	Northern Arctic	142 849 760	8 626 750
3	Southern Arctic	75 772 411	10 159 949
4	Taiga Shield East	65 827 941	9 175 965
5	Boreal Shield East	99 129 131	11 927 579
6	Atlantic Maritime	19 747 728	1 202 125
7	Mixedwood Plains	11 014 617	5 766 280
8	Hudson Plains	36 393 778	977 306
9	Boreal Shield West	71 111 613	12 839 461
10	Boreal Plains	67 185 834	6 426 116
11	Subhumid Prairies	21 603 974	743 835
12	Semiarid Prairies	23 494 899	472 671
13	Taiga Plains	58 415 062	7 588 078
14	Montane Cordillera	47 226 428	1 244 416
15	Pacific Maritime	20 487 877	322 057
16	Boreal Cordillera	46 064 255	947 007
17	Taiga Cordillera	26 373 796	156 579
18	Taiga Shield West	52 606 707	11 119 644

Activity data originating from different sources cannot be harmonized at the level of analysis units, since analysis units used in different land categories often overlap, and the exact location of events, stands, or activities within a unit is not known. The spatial reconciliation is conducted within 60 "reconciliation units," which are derived from the spatial intersection of reporting zones with provincial and territorial boundaries. QC and QA procedures are conducted at the levels of analysis units (during estimate development) and of reconciliation units (at the estimate compilation stage).

A3.5.2 FOREST LAND AND FOREST-RELATED LAND-USE CHANGE

A3.5.2.1 Carbon Modelling

The estimation of carbon stock changes, emissions, and removals from managed forests, forest conversion to other land uses, and land converted to forests was conducted with version 3 of the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3), the most recent of a family of models whose development goes back to the late 1980s (Kurz *et al*., 1992). The model integrates forest inventory information (forest age, area, and species composition), growth rates, natural and anthropogenic disturbances, and ecosystem processes to simulate carbon transfers between ecosystem carbon pools, exchanges with the atmosphere, and losses to HWPs.

Processes and events modelled by the CBM-CFS3 to generate the estimates submitted here are growth, litterfall, natural tree mortality, decomposition, management activities, natural disturbances, and forest conversion. Management activities represented are commercial thinning (since 2000), clear-cutting, partial cutting, and salvage cutting.[45] Natural disturbances in the managed forests include wildfires, defoliators, and wood borers. Different practices of forest conversion are also modelled, including controlled burning.

Table A3-31 matches the representation of forest carbon pools in the CBM-CFS3 with the IPCC forest carbon pools (IPCC, 2003). Living biomass pools are further subdivided into two sets, for each of hardwood

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[45] Salvage cutting is the removal of merchantable timber left after a natural disturbance. Whenever possible, salvage logging is distinguished from conventional harvesting operations so as not to overstate the total area affected by the combination of natural and anthropogenic disturbances.

TABLE A3-31: Forest Carbon Pools in IPCC and CBM-CFS3

IPCC Carbon Pools		Pool Names in CBM-CFS3	Comments
Living Biomass	Aboveground biomass	Merchantable stemwood Other (submerchantable stemwood, tops, branches, stumps, non-merchantable trees) Foliage	– Merchantable stemwood is defined to provincial standards, e.g., top and bottom diameter limits. – Submerchantable stemwood is currently included in the "other" pool.
	Belowground biomass	Fine roots Coarse roots	– Fine roots are included here because fine root biomass is modelled rather than measured.
Dead Organic Matter (DOM)	Dead wood	Aboveground fast Belowground fast Medium Softwood stem snag Softwood branch snag Hardwood stem snag Hardwood branch snag	– Each pool is characterized by the biomass component added to it and by the turnover rates of the pool.
	Litter	Aboveground very fast Aboveground slow	
Soils	Soil organic matter	Belowground very fast Belowground slow Black carbon Peat	– Belowground very fast pool includes dead and decaying fine roots, which in practice cannot be separated from soil. – Black carbon and peat are currently not represented.

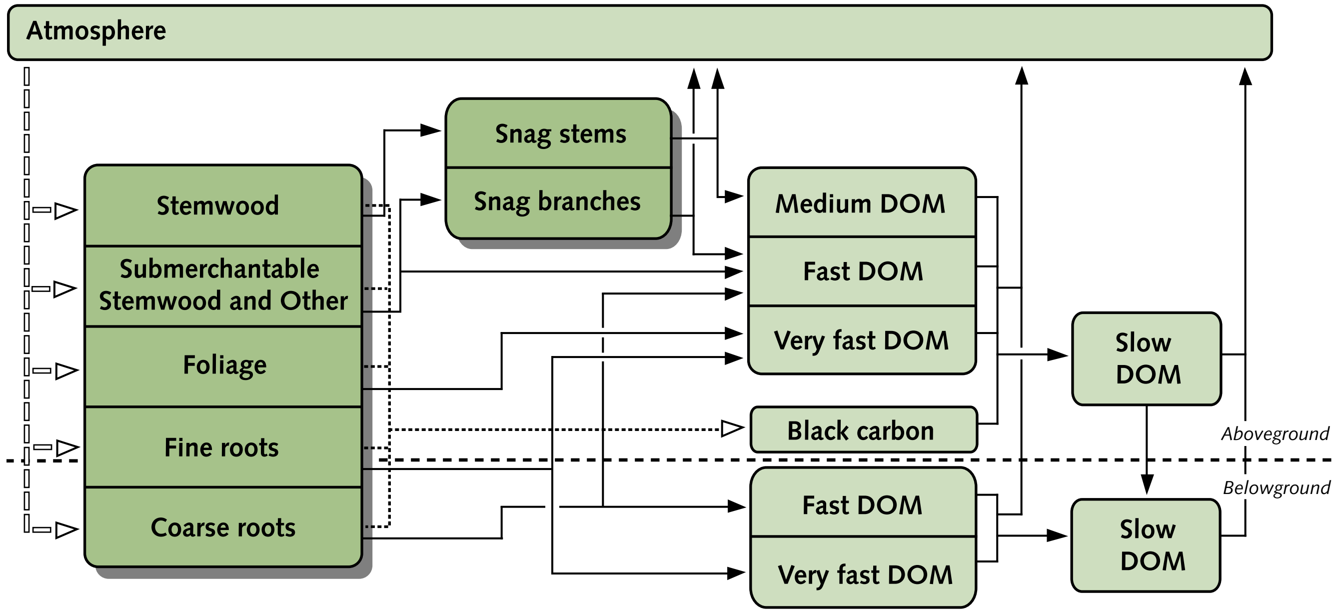
and softwood tree species. The first 16 carbon pools were implemented for the national estimation.

Carbon transfers between pools as shown in Figure A3-3 are simulated as two distinct processes: annual processes and disturbance events. Annual processes comprise growth, litterfall, mortality, and decomposition, as well as simultaneous carbon transfers executed at each time step (annually), in every inventory record.

Rates of carbon transfer are defined for each pool, based on pool-specific turnover rates (for biomass pools) or decay rates (dead organic matter [DOM] and soil pools). Turnover rates can be very high (e.g., 95% for hardwood foliage) or very slow (e.g., <1% for stemwood). Annual decay rates are defined for a reference mean annual temperature of 10°C; they vary between 50% (for the very fast DOM pools, such as dead fine roots) and 0.0032% (for slow soil pools). During annual processes, carbon in biomass pools is typically transferred to DOM pools; carbon in DOM pools is transferred to another DOM pool (e.g., stem snags to medium deadwood pool), to a slow soil pool, or to the atmosphere. More information on pool structure and decay rates is available in Kurz *et al*. (in preparation).

Disturbances trigger different combinations of carbon transfers, based on the disturbance type and severity, the forest ecosystem affected, and the ecological region. For modelling purposes, land-use changes are also implemented as disturbances. The impact of a disturbance is defined in a disturbance matrix, which specifies for each disturbance type the proportion of each pool in the ecosystem that is transferred to other pools, released to the atmosphere (in different GHGs), or transferred to HWPs. Figure A3-4 illustrates one such matrix, simulating forest conversion in the Boreal Shield West, during which the wood is harvested and residues (slash) are burned. The impact of wildfires and insect infestations was simulated with up to 14 different disturbance matrices. Management activities and deforestation practices were each represented in 15 disturbance matrices. In total, 59 different disturbance matrices were used to represent the various disturbance types (including land-use change). The

FIGURE A3-3: **Carbon Transfers between Pools at Each Annual Time Step as Modelled in CBM-CFS3**



number of different disturbance matrices is dependent on the availability of activity data (e.g., the spatial and temporal resolution of data sources used to document disturbances) and the knowledge required to parameterize the disturbance matrices.

Growth is simulated as an annual process. Every record in the forest inventory used in each of the 1441 analysis units is associated with a growth curve that defines the dynamics of merchantable volume over time. Assignment of an inventory record to the appropriate growth curve is based on a classifier set that includes province, ecological stratum, leading species, site productivity class, and several other classifiers that differ between provinces and territories. Growth curve libraries for each province and territory in Canada are derived from permanent or temporary sample plots or from forest inventory information.

Conversion of merchantable volume curves to aboveground biomass curves is performed with a set of equations developed for Canada's National Forest Inventory (Boudewyn *et al*., in preparation). These equations are developed for each province/territory, ecozone, leading species, or forest type, and they estimate aboveground biomass of each component from merchantable stemwood volume (per hectare). Finally, belowground biomass pools are estimated using regression equations (Li *et al*., 2003). Mean annual increments are not used in the estimation. Figure A3-5 shows the resulting total biomass per hectare in each 20-year age class for each ecozone. The average biomass in each age class can be interpreted as the mean yield curve across all forest types, leading species, and site productivity classes, by reporting zone.

There are no CO_2 emission factors applicable to all fires, as the proportion of CO_2-C emitted for each pool, documented in each disturbance matrix, can be specific to the pool, the types of forest and disturbance, and the ecological zone. With a few exceptions, the proportion of total carbon emitted in each carbon-containing GHG (CO_2, CO, and CH_4) is constant: 90% of carbon is emitted as CO_2, 9% as CO, and 1% as CH_4 (B. Stocks, personal communication to W. Kurz).

While the CBM-CFS3 can model carbon fluxes at various spatial scales, generating national estimates involved harmonizing, integrating, and ingesting vast quantities of data from a great diversity of sources (Figure A3-6). The next section documents the key data sources used for this submission.

FIGURE A3-4: Disturbance Matrix Simulating the Carbon Transfers Associated with Forest Conversion with Harvest and Slash Burning, Applied to Forest Conversion in Reporting Zone 9 (Boreal Shield West)

	Softwood merchantable	Softwood foliage	Softwood others	Softwood submerchantable	Softwood coarse roots	Softwood fine roots	Hardwood merchantable	Hardwood foliage	Hardwood others	Hardwood submerchantable	Hardwood coarse roots	Hardwood fine roots	Aboveground Very Fast DOM C	Belowground Very Fast DOM C	Aboveground Fast DOM C	Belowground Fast DOM C	Medium DOM C	Aboveground Slow DOM C	Belowground Slow DOM C	Softwood Stem Snag	Softwood Branch Snag	Hardwood Stem Snag	Hardwood Branch Snag	Black C	Peat
Softwood merchantable																									
Softwood foliage																									
Softwood others																									
Softwood submerchantable																									
Softwood coarse roots																									
Softwood fine roots																									
Hardwood merchantable																									
Hardwood foliage																									
Hardwood others																									
Hardwood submerchantable																									
Hardwood coarse roots																									
Hardwood fine roots																									
Aboveground Very Fast DOM C		0.32				0.401		0.32				0.401	0.8												
Belowground Very Fast DOM C						0.401						0.401		0.8											
Aboveground Fast DOM C			0.32	0.6	0.5				0.32	0.6	0.5				0.8						0.8		0.8		
Belowground Fast DOM C					0.5						0.5					0.8									
Medium DOM C	0.027						0.027										0.9			0.9		0.9			
Aboveground Slow DOM C	0.003	0.01	0.01				0.003	0.01	0.01									1							
Belowground Slow DOM C																			1						
Softwood Stem Snag																									
Softwood Branch Snag																									
Hardwood Stem Snag																									
Hardwood Branch Snag																									
Black C																								1	
Peat																									1
CO_2	0.15	0.6	0.6	0.35		0.18	0.15	0.6	0.6	0.35		0.18	0.18	0.18	0.18	0.18	0.09			0.09	0.18	0.09	0.18		
CH_4	0.018	0.064	0.064	0.045		0.018	0.018	0.064	0.064	0.045		0.018	0.018	0.018	0.018	0.018	0.009			0.009	0.018	0.009	0.018		
CO	0.002	0.006	0.006	0.005			0.002	0.006	0.006	0.005			0.002	0.002	0.002	0.002	0.001			0.001	0.002	0.001	0.002		
N_2O																									
Products	0.8						0.8																		

FIGURE A3-5: Average Biomass (t C/ha) in Each Age Class, by Ecozone

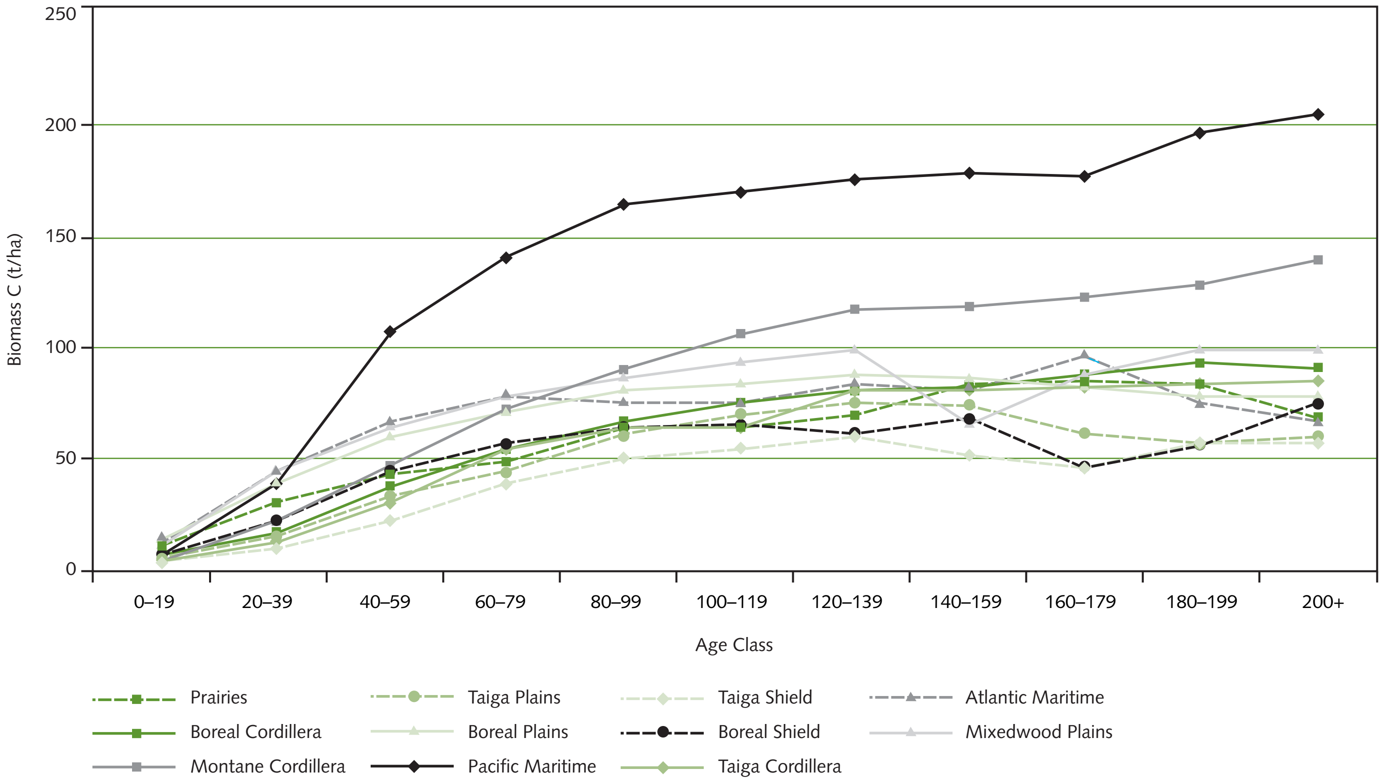
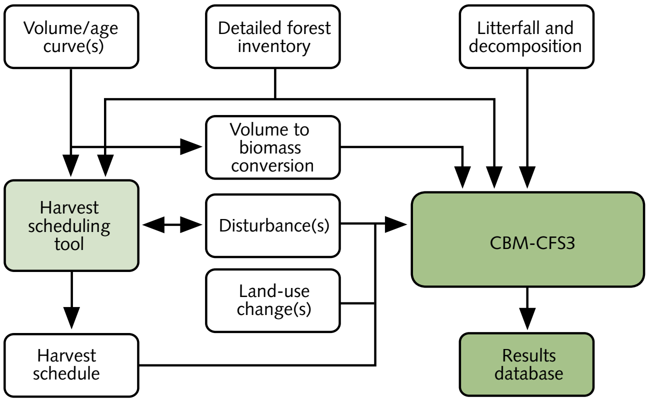


FIGURE A3-6: Generic Data Inputs to the CBM-CFS3



A3.5.2.2 Data Sources

Data sources for managed forest land, forest conversion, and land converted to forest land are provided below.

Managed Forest Land

The Canadian provincial and territorial governments, whose jurisdiction includes natural resource management, provided essential information, notably detailed forest inventory data and, when available, details on forest management activities and practices, disturbances and disturbance prevention or control, regional yield tables (volume/age curve) for dominant tree species and site indices, as well as regional expertise (Table A3-32). The forest inventory data in Canada's Forest Inventory (CanFI, 2001) were used for Labrador, Nova Scotia, New Brunswick, Manitoba, Saskatchewan, Alberta, Yukon, and the Northwest Territories. More recent and higher-resolution inventory data were provided by Prince Edward Island, Quebec, Ontario, British Columbia, and Newfoundland. Considerable efforts were necessary to harmonize, format, and compile the detailed inventory information into input data for the CBM-CFS3.

TABLE A3-32: Main Sources of Information and Data, Managed Forests

Description	Source	Spatial Resolution	Temporal Coverage	Reference
Fire data	Canadian Wildland Fire Information System	Spatially explicit	2004	Expert http://cwfis.cfs.nrcan.gc.ca/
	Canadian Large Fire Database	Spatially referenced	1959–2003	http://fire.cfs.nrcan.gc.ca/research/climate_change/lfdb_e.htm
Forest inventories	Canadian Forest Inventory (CanFI)	CanFI grid cell	1949–2004	http://nfi.cfs.nrcan.gc.ca/canfi/index_e.html
	Alberta	Analysis units	N/A	Growth curves from provincial expert
	British Columbia	Analysis units	2000	Provincial expert
	Newfoundland and Labrador	Analysis units	2000	Provincial expert
	Ontario	Analysis units	2000	Provincial expert
	Prince Edward Island	Analysis units	2000	Provincial expert
	Quebec	Analysis units	2000	Provincial expert
Harvest data	National Forestry Database	Provincial boundaries	1990–2002	http://nfdp.ccfm.org/
	Alberta	Analysis units	2003–2004	Provincial expert
	British Columbia	Analysis units	2003–2004	Provincial expert
	Newfoundland and Labrador	Analysis units	1990–2004	Provincial expert
	Manitoba	Analysis units	2003–2004	Provincial expert
	New Brunswick	Analysis units	2003–2004	Provincial expert
	Northwest Territories	Analysis units	2003–2004	Territorial expert
	Nova Scotia	Analysis units	2003–2004	Provincial expert
	Ontario	Analysis units	2000–2004	Provincial expert
	Prince Edward Island	Analysis units	2000–2004	Provincial expert
	Quebec	Analysis units	2000–2004	Provincial expert
	Saskatchewan	Analysis units	2003–2004	Provincial expert
	Yukon	Analysis units	2003–2004	Territorial expert
Insect data	Forest Insect and Disease Survey	Spatially explicit	1990–2000	Atlantic Forestry Centre
	Spruce Budworm Decision Support System	Reconciliation units	1970–2003	Expert
	British Columbia	Spatially explicit	1990–2004	Provincial expert
	Saskatchewan	Spatially explicit	1990–2002	Provincial expert
Climate data	Canadian Forest Service (CFS)	Reconciliation units	1961–1990 normals	McKenney (2005)

Note:
N/A = not available

The estimation of the managed forest area required the spatial delineation and combination of three forest management zones:

- forests used to determine the annual allowable cut;[46]
- forests where harvesting may occur but that are outside the area used for long-term timber supply analysis (primarily in private forests); and
- forests subject to fire control but not to harvesting (e.g., some parks and protected areas).

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[46] The *Glossary of Forestry Terms* defines annual allowable cut as the amount of timber that is permitted to be cut annually from a particular area. Available online at: http://nfi.cfs.nrcan.gc.ca/terms/terminology_e.html

Figure A3-7 illustrates these three areas, which together represent managed forests in Canada for the purpose of GHG estimation and reporting. In 2004, the total area of managed forests was 255 131 kha, of which 74% lie in the five reporting zones Boreal Shield East, Montane Cordillera, Boreal Plains, Boreal Shield West, and Taiga Plains. Table A3-33 provides the breakdown of the managed forests into reporting zones.

TABLE A3-33: Distribution of Managed Forests in Reporting Zones

Reporting Zone Number	Reporting Zone Name	Distribution of Managed Forests (%)
1	Arctic Cordillera	0.0
2	Northern Arctic	0.0
3	Southern Arctic	0.0
4	Taiga Shield East	1.9
5	Boreal Shield East	22.1
6	Atlantic Maritime	6.2
7	Mixedwood Plains	1.1
8	Hudson Plains	0.0
9	Boreal Shield West	11.3
10	Boreal Plains	14.2
11	Subhumid Prairies	0.7
12	Semiarid Prairies	0.0
13	Taiga Plains	11.4
14	Montane Cordillera	14.9
15	Pacific Maritime	5.8
16	Boreal Cordillera	7.4
17	Taiga Cordillera	0.4
18	Taiga Shield West	2.7

Forest management activities are documented in the National Forestry Database (Table A3-32); additional information on specific activities was obtained directly from provincial and territorial forest management agencies.

Historical data on areas disturbed by wildfires were extracted from the Canadian Large Fire Database. These were supplemented by provincial and territorial data for the years 1990–2003 and by the Canadian Wildland Fire Information System for the year 2004 (Table A3-32).

Insect disturbances are monitored on aerial surveys (Table A3-32). The gross annual areas are converted into effective impact areas, which represent the area disturbed net of unaffected forested areas (non-treed areas or treed areas with non-host species). Effective impact areas are assigned to analysis units and are further broken down by impact severity: stand-replacing mortality, partial mortality, and growth reduction.

Forest Conversion

In order to account for the long residual effects of forest conversion, conversion rates were estimated starting in 1970. The approach for estimating forest areas converted to other uses — or "deforested areas" — is based on three main information sources: systematic or representative sampling of remote sensing imagery, records, and expert judgement/opinion. While the basic methods have been tested in several pilot projects (CFS, 2006a), the methodology is in its first phase of implementation and should be considered as a transition towards a refined and comprehensive system for monitoring forest conversion. Constraints of time, resources, and data availability have prevented a full method implementation.

The core method involves remote sensing mapping of deforestation on samples from Landsat images dated circa 1975, 1990, and 2000. Change enhancements between two dates of imagery are produced to help highlight areas of forest clearing and identify possible deforestation events (i.e., candidate events). The imagery is then interpreted to determine if the land cover of the candidate event was forest initially (at Time 1) and is a land-cover change or land-use change at Time 2 (Leckie *et al*., 2002; Paradine *et al*., 2004). This deforestation interpretation process was strongly supported by other remote sensing data, including digitized aerial photographs; snow-covered, leaf-off, winter Landsat imagery; secondary Landsat images from other dates and years; ancillary data, such as maps of road networks, settlements, wetlands, woodland coverage, and mine and gravel pit locations; and specialized databases giving locations of oil and gas pipelines and well pads (Table A3-34). When readily available, detailed forest inventory information was also used.

FIGURE A3-7: **Three Types of Forest Management Zones Constituting Managed Forests in Canada**

Each deforestation event identified in the images as greater than 1 ha was manually delineated. The broad forest type prior to deforestation was interpreted[47] and the post-deforestation land use recorded ("post-class"). Confidence ratings on the land use at Time 1 and Time 2 were used in subsequent QC and field validation procedures.

Resources and time limited the size of the remote sensing sample used for the deforestation estimates submitted in 2006. The forested areas of Canada were broadly stratified into regions of expected forest conversion level and dominant cause, which dictated the sampling intensity (Figure A3-8).

Depending on the expected spatial pattern and rates of forest conversion events, sampling approaches ranged from complete mapping to systematic sampling over the entire spatial unit of interest to representative selection of sample cells within a systematic grid. For example, in populated areas of southern Ontario and Quebec and in the northern prairie fringe, a 12.3% sampling rate was generally achieved, with 3.5 × 3.5 km sample cells on a 10-km grid (Figure A3-9). The total areas either fully mapped or sampled (Figure A3-9) cover approximately 135 million hectares, of which 14.8 million hectares were mapped for 1975–1990 and 36.8 million hectares for 1990–2000.

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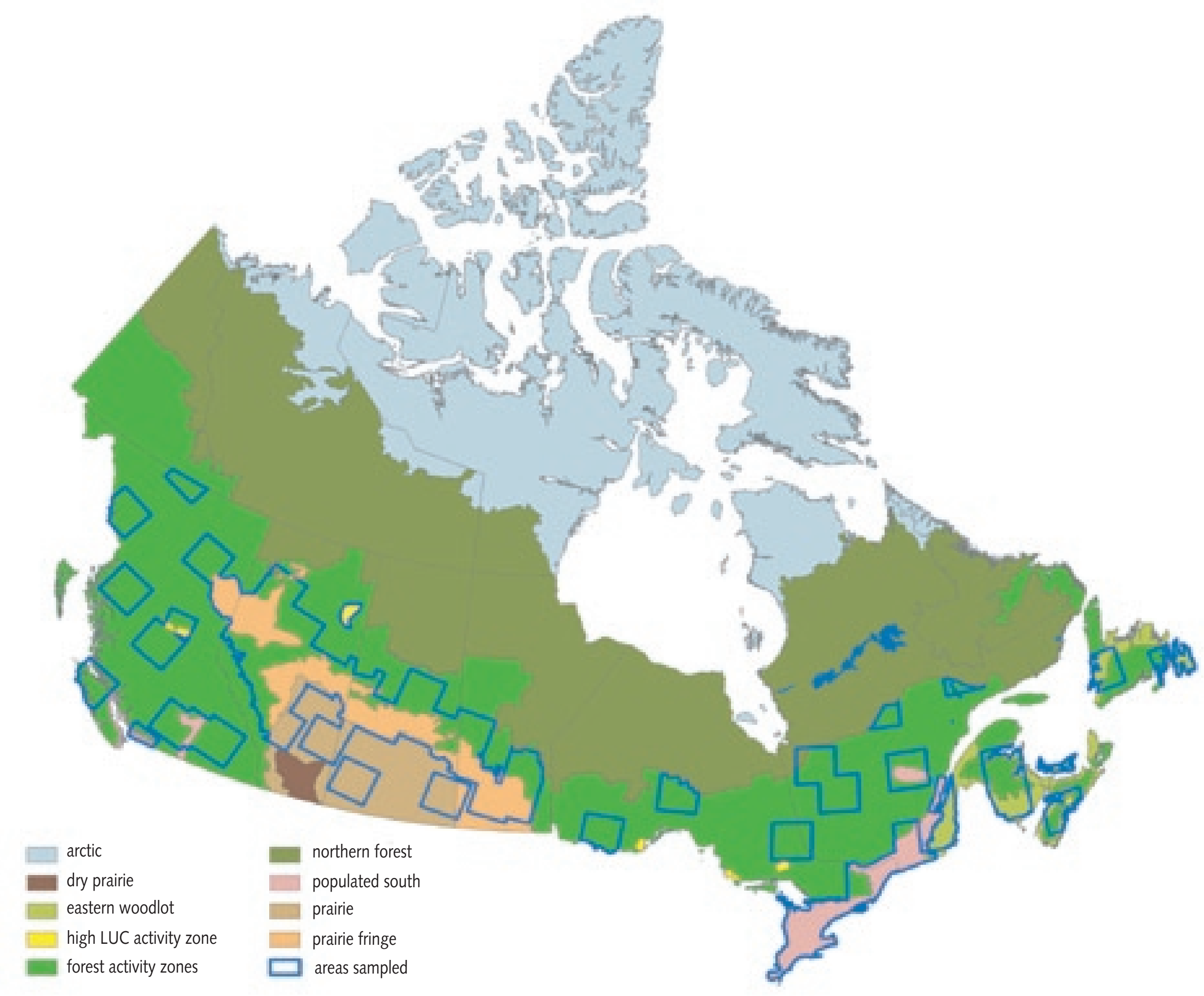
[47] See Chapter 7 for the definitional parameters of "forest."

FIGURE A3-8: **Deforestation Strata and Areas Sampled for the 2006 Submission Estimate (LUC = land-use change)**



Representative samples were used in areas of moderate expected deforestation (e.g., eastern woodlots in the Maritimes; the Eastern Townships in Quebec; the lower mainland of British Columbia; the south agriculture zone of the Prairies). The forest activity stratum is a large region of Canada with a low population density; the main economic activities consist of forestry and other resource extraction. Again, a representative sampling approach was used, augmented in Quebec, Ontario, and British Columbia with additional samples (e.g., pilot studies). Special cases of known, localized, and large deforestation activities were also identified, such as hydroelectric reservoirs and the Alberta oil sands developments. These were handled as single events, with spatially complete mapping.[48] The extent of forests affected by land submersion was estimated by multiplying the area of land flooded by the proportion of forest cover in the region surrounding the reservoir, determined by a Landsat image classification forest-cover map (Wulder *et al*., 2004).

Records were gathered when available (Table A3-34). They mostly consisted of information on forest roads, power lines, oil and gas infrastructure, and hydroelectric reservoirs. Temporal coverage, availability, and appropriateness were the criteria used to make decisions as to the data sources (records or imagery) on which to ultimately rely. Records from six provinces

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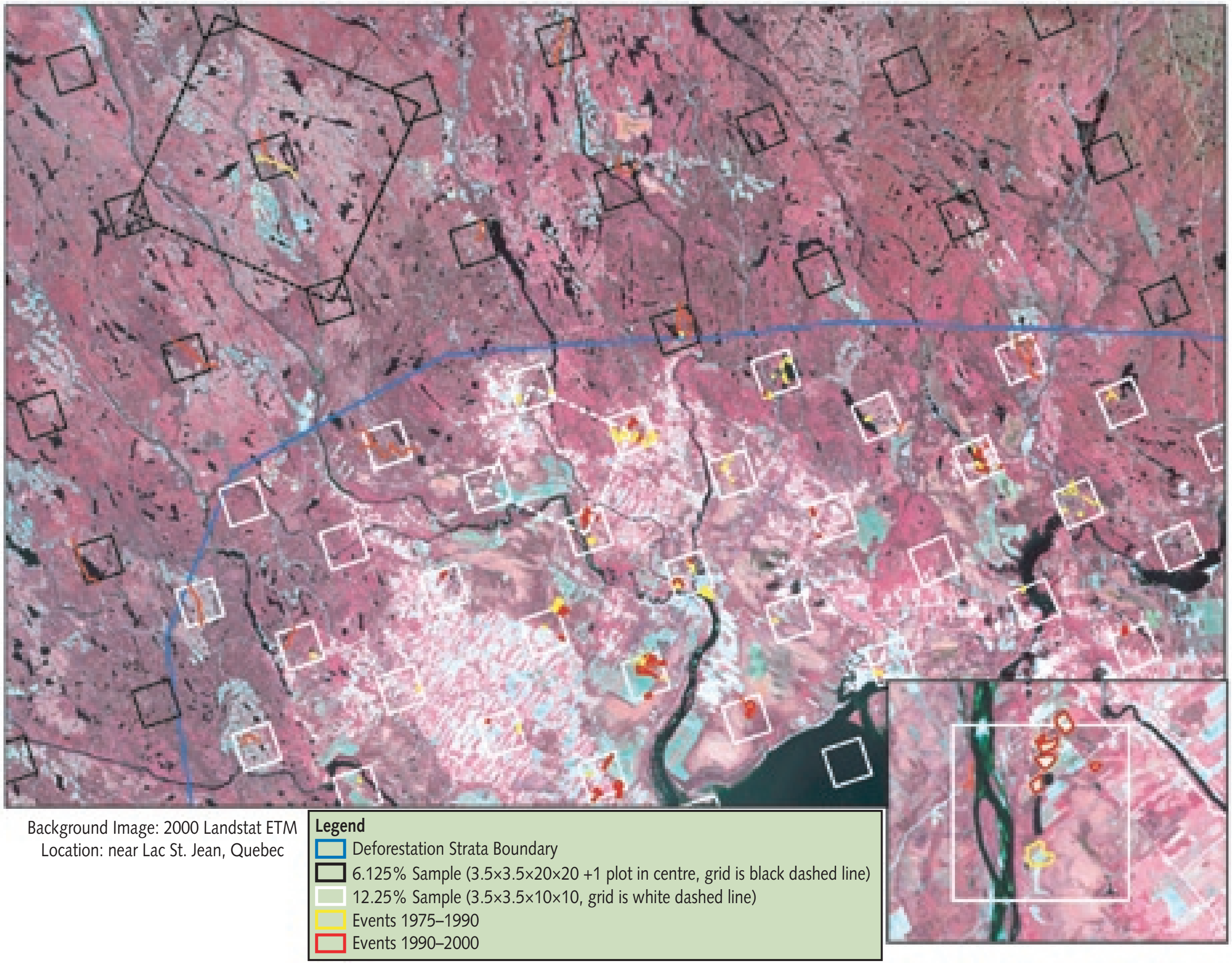
[48] In the case of hydroelectric reservoirs, records were also used to determine flooded area.

FIGURE A3-9: Sampling Grids over Imagery for Forest Conversion Mapping and Delineated Forest Conversion Events



Background Image: 2000 Landstat ETM
Location: near Lac St. Jean, Quebec

were used for forestry roads and from three provinces for power lines. The assessment of forest conversion in Alberta[49] due to oil and gas infrastructure was based on a commercial GIS database of pipelines and well pads and a separate database on the width of pipeline corridors. Approximately 95% of pipelines are less than 20 m wide, and most are 14–16 m wide; the remainder are 20 m wide or slightly more. In most cases, records provide only the total area of land converted to pipelines, regardless of the pre-conversion land category. To obtain consistent estimates, all pipeline rights-of-way were assigned a 20-m width; 5% of the area thus obtained was determined as potential forest conversion area. When pre-conversion land use was missing, records from Canada's National Forest Inventory (CanFI, 1991) were used to determine the proportion of land converted to pipelines that was forest.

Expert opinion was called upon when records data were unavailable or of poor quality or the remote sensing sample was insufficient. Expert judgement was also used to scale up local deforestation rates from non-statistical samples, reconcile differences among records and remote sensing information, and resolve large discrepancies between the 1975–1990 and 1990–2000 area estimates. In such cases, available expert opinion and data sources were brought together, remote sensing and records data were reviewed, and decisions were made (CFS, 2006b). Most estimates, certainly those for the land-use change categories that had the largest impacts, were derived directly from remote sensing samples.

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[49] In British Columbia and Saskatchewan, where oil and gas development is also significant, the basic remote sensing method was used because of poor record quality.

TABLE A3-34: Main Sources of Information for Forest Conversion Mapping

Type of Information	Source
Remote sensing	1975 Landsat (Earthsat) 1990 Landsat (Earthsat) 2000 Landsat (Earth Observation for Sustainable Development of Forests and Earthsat) 1990 winter Landsat Additional Landsat images Other satellite imagery of selected site or regions (e.g., SPOT, IRS) National Air Photo Library digitized (8340 photos throughout populated regions of Canada; generally 1:50 000 black and white 1985–1992; some 1:30 000) Provincial photos digitized [Ontario: 65 416 photos CIR 1:10 000 1995–2004 and 633 black and white 1:40 000; Prince Edward Island: photomosaics 1990 and 2000; Nova Scotia: 872 black and white 1:50 000; plus others (e.g., Saskatchewan 477 photos, Alberta 1110 photos, and British Columbia near Prince George and Vancouver)] Google Maps (circa 2000–2005 images), mainly Landsat and some high-resolution satellite imagery (e.g., Quickbird)
Ancillary data for remote sensing interpretation (not all listed items were available or used for all regions of the country)	NTS or provincial base maps (main layers used were roads, woodlands, wetlands, pits, and quarries) Forest management area boundaries Forest inventory (used in only a few areas) Pipeline and well pad geospatial database (IHS Energy Ltd.)
Records	Provincial data on length and class of forestry road constructed, generally by year from annual reports Provincial data on roads determined by comparison of inventories and GIS analysis Highways: selected events from maps and provincial records Power lines from provincial utility boards or from power companies (sometimes summaries by regions, sometimes GIS database); usually length and kilovolt capacity with standard widths by kilovolt Pipelines and well pads GIS database for the country from IHS Energy Ltd. Pipelines provincial records Hydro reservoirs (Hydro-Québec)

The deforestation data were compiled and summarized on the basis of deforestation strata and reconciliation units. All “deforestation events” were assembled into a large “deforestation event database.” A compilation system summarized events for each deforestation stratum and aggregated deforestation rates to reconciliation units. Compilation also involved insertion of records data and expert judgement. In the course of these procedures, each deforestation event was compiled to yield a local deforestation rate (ha/year) based on the time interval between the images. Since the available imagery was not necessarily dated 1975, 1990, or 2000, the deforestation rates covered different time periods. At the data compilation phase, each forest conversion event was assigned to one of two time periods (1975–1990 or 1990–2000), and the corresponding deforestation rate was assigned to that period. For example, a 7.0-ha event encountered on imagery from the period 1975–1989 would yield a 0.5 ha/year rate (7.0 ha/14 years) and then be assigned to the period 1975–1990. The total area interpreted in a stratum for that time period was then used to determine a relative deforestation rate ((ha/year)/km^2 interpreted) for all events of the same type. Data were grouped by post-class (e.g., the rate for agricultural crop or rural residential). These, in turn, were summarized by broader categories when recompiled by reconciliation unit.

The remote sensing data were derived using the circa 1975, 1990, and 2000 imagery, while records data were annual or summarized over time periods. As explained above, the remote sensing core method provided two distinct forest conversion rates, for 1975–1990 and for

1990–2000, but no annual estimates of these rates. The preparation of annual forest conversion rates for 1970–2004 required the simultaneous application of two procedures: i) extrapolation of annual rates prior to 1975 and beyond 2000; and ii) reconciliation of potential discontinuities circa 1990. In the absence of documented and tested procedures, the simplest approach was to assign the 1975–1990 rate to each year from 1970 to 1983 and the 1990–2000 rate to each year from 1995 to 2004 (the extrapolation). A linear interpolation was applied between the two temporal anchor points (1983 and 1995), which resulted in an estimate of the annual deforestation rate for each intervening year. The procedure is illustrated in Figure A3-10. Noted exceptions to this procedure are individual large events like hydroelectric reservoirs, for which year of flooding was known, and a few records-based events.

Figure A3-11 displays the annual rates of forest conversion by selected end uses. Note that these figures differ from the ones reported in the CRF tables, which are cumulative areas in the "land converted to" categories.

■ QA/QC

Great care was taken in understanding the records data, their suitability, and their limitations. Documentation of the records data was examined, personnel involved in managing and implementing the data collection and storage were interviewed, and, where available, numbers were checked against independent data sources and the expectations of experts.

The remote sensing interpretation was completed following defined practices (Paradine *et al*., 2004) by a variety of organizations, including provincial government forestry or geomatics groups, remote sensing or mapping companies, research and development organizations, and in-house expertise in the CFS. The basic QC process included internal QC within the mapping agency or company by a senior person; "real-time" QA by CFS specialists during interpretation, with feedback provided within days of an interpretation of an area; and a final QA or vetting of the interpretation by the CFS. Field checking was undertaken on established pilot projects. Each QC point and revision were documented within the GIS databases of deforestation event data. Owing to time limitations, not all QC steps were followed; however, at a minimum, one independent QA was completed on a large sample of interpretations.

Records of decision as to data used, expert judgement applied, and resolution of contradictory data were documented (CFS, 2006b). Data sources and limitations were recorded, and remote sensing data and interpretations were archived. Calculations and expert judgement are traceable through the compilation system.

FIGURE A3-10: Procedure to Develop a Consistent Time Series of Rates of Forest Conversion

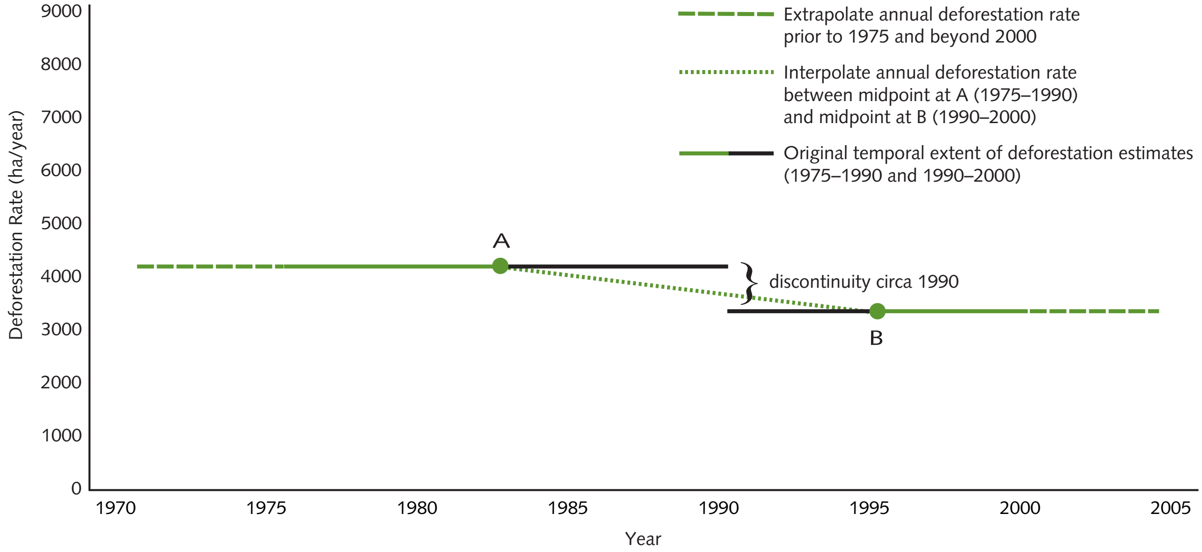
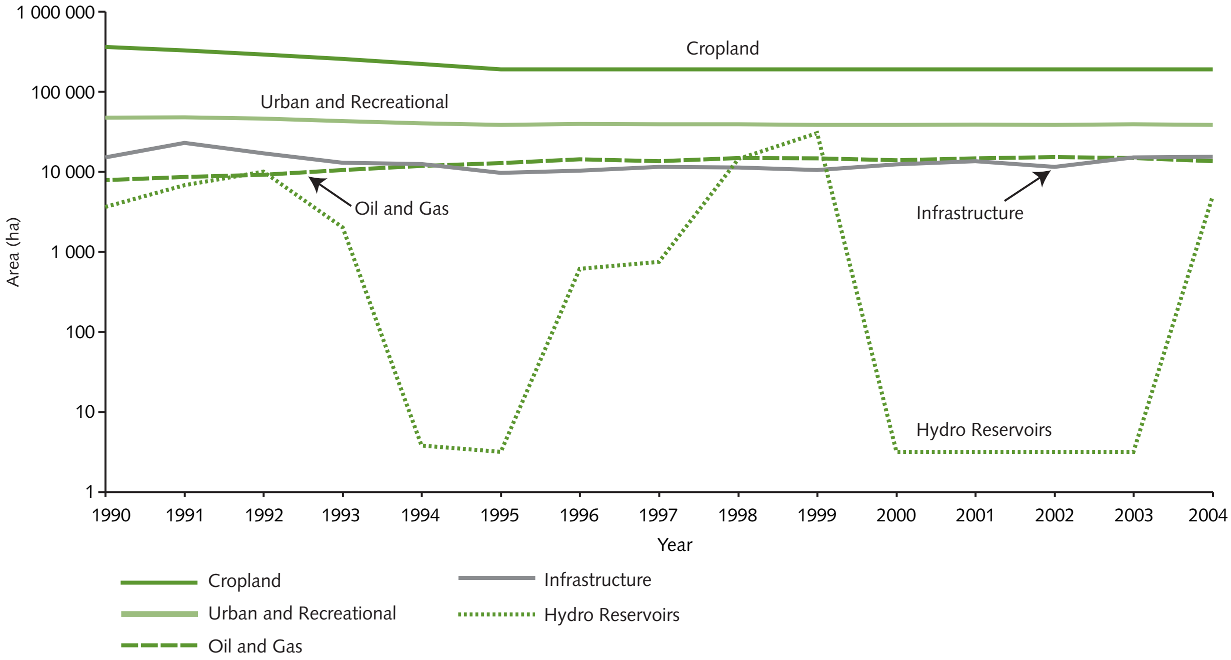


FIGURE A3-11: Annual Rates of Forest Conversion in Canada, by Selected End Uses[1]



Note:

1 Note the log scale.

Uncertainty

There are three main sources of uncertainty in the estimates of forest area converted to other land categories:

1. omission and commission;
2. sampling error; and
3. boundary delineation error.

The deforestation mapping process also involves three additional sources of uncertainty impacting the emission estimates:

4. forest type being removed;
5. post-conversion land category; and
6. event timing.

This section will discuss the first three uncertainty sources. Ongoing work to estimate emission uncertainties will include the last three factors. Complete results will be presented in future submissions.

In estimates derived from remote sensing, the quantification of omission errors (missing forest conversion events) and commission errors (including events that are not forest conversion) takes into account the entire mapping process, including image interpretation, QC, field validation, and other vetting activities. Key uncertainty sources in the 1975–1990 forest conversion events stem from the lower resolution and poorer quality of 1975 imagery and lack of ancillary information. Over the entire time series, there is a tendency for omissions to be small in size, while commission errors are usually from a misinterpretation rather than an oversight and thus are less size dependent. Commission errors arise either from mistakenly calling an area forest at Time 1 (e.g., if the vegetation cover prior to change did not meet the forest definition) or mistakenly labelling as "non-forest" the Time 2 land category (e.g., after a harvest). Over the entire process, commission errors are more likely than omission errors; hence, the estimate of total forest area converted derived from image interpretations is more likely to be overestimated than underestimated. Records, used mostly for roads and power lines, are more likely to omit events than to misattribute them. Expert judgement concluded that a ±20% range was an acceptable and conservative estimate of the total uncertainty due to omission/commission errors.

Sampling for the NIR 2006 deforestation estimates is a mixture of wall-to-wall mapping, systematic samples completely covering regions, samples from representative areas, and complete mapping of selected local areas. In some areas, the sample coverage and design differed between 1975–1990 and 1990–2000. Uncertainty due to the sampling is therefore regionally variable, and, since some types of forest conversion are more prevalent in different regions, the uncertainty by type is also complex and variable. The sampling uncertainties were not estimated by region or type of forest conversion, but rather on a global basis by expert judgement, taking into account regional differences in forest conversion activities and sampling intensity. The sampling error for the total forest area converted was estimated at ±25%.

Boundary delineation error is the displacement of the boundary outline from the true boundary, resulting in incorrect area estimation. Both area overestimation and underestimation can occur, depending on the landscape spatial patterns. In the absence of quantitative evidence, it was assumed that delineation errors did not cause either positive or negative bias and that a ±20% range best represented the uncertainty associated with this type of error.

The overall uncertainty is a combination of the delineation, omission and commission, and sample errors. The simplified estimates of uncertainty made for each one were combined using a simple error propagation method: $(0.2^2 + 0.2^2 + 0.25^2)^{1/2} = 0.38$. The ±38% uncertainty about the estimate of the total forest area converted annually in Canada places with 95% confidence the true value of this area for 2004 between 29 kha and 65 kha.

Consultations with regional experts suggest that there may be a bias, especially in 1975–1990, towards conservativeness. Any such bias would affect the uncertainty range for these and subsequent years. Caution should also be exerted in applying the 38% range to the cumulative area of forest land converted to another category over the last 20 years (land areas reported in the CRF). This issue will be considered in the future.

■ Planned Improvements

Generally, improvements will be incremental, with an emphasis on their efficiency in reducing uncertainties and improving specific estimates. Improvement strategies will combine a greater remote sensing coverage, expanded records compilation, more complete QC, and field verification. Acquiring a complete set of imagery every year is cost-prohibitive, and planning a complete update in the short term would be unrealistic. Target dates are under consideration for complete updates.

Land Converted to Forest Land

Records of land conversion to forest land in Canada were available for 1990–2002 from the Feasibility Assessment of Afforestation for Carbon Sequestration (FAACS) initiative[50] (White and Kurz, 2005). Conversion activities for 1970–1989 and 2003–2004 were estimated based on activity rates observed in the FAACS data. Additional information from the Forest 2020 Plantation Demonstration Assessment[51] was included for 2004. Each event, regardless of date, source, type, or location, was converted to an inventory record for the purposes of carbon analysis. All events were compiled in a single data set of afforestation activity in Canada from 1970 to 2004.

For 1990–2002, the area planted was stratified by ecozone, province, and species. Total area planted by province and ecozone, in conjunction with the proportion of species planted for each province, was used to calculate area planted by species, resulting in estimates of the area converted to forest, by species, for each reconciliation unit.

Yield curves were not always available for some plantation species or growing conditions (stocking level or site history); those used to estimate growth increments were taken from a variety of sources, most often directly from provincial experts. Where species did not have their own yield curve, they were given the yield curve of another species with similar growth characteristics or the species most likely to have been planted in that area. Changes in soil carbon stocks are highly uncertain, because of difficulties in locating data about the carbon stocks prior to plantation. It was assumed that the ecosystem would generally accumulate soil carbon at a slow rate; the limited time frame of this analysis and the scale of the activity relative to other land-use and land-use change activities suggest that the impact of this uncertainty, if any, is minimal.

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[50] www.nrcan.gc.ca/cfs-scf/national/what-quoi/afforestation/carb_seq_e.html

[51] www.nrcan-rncan.gc.ca/cfs-scf/national/what-quoi/afforestation/f2020_e.html

A3.5.2.3 Estimation of Carbon Stock Changes, Emissions, and Removals

At the beginning of each annual time step, the CBM-CFS3 first assigns land-use change activities to inventory records and redistributes these records to ensure that the impacts of land-use change (conversion to forests and conversion of forests) are reported in the new land category. Disturbances are processed only after the land-use conversions have been completed.

The selection of forest stands affected by land-use change and non–land-use change disturbances is based on documented eligibility rules (Kurz *et al*., in preparation). Estimates of the immediate impact of these disturbances are computed for the managed forests and the converted forests.

The third step consists of applying the sets of carbon transfers associated with annual processes to all forest areas (managed forest, land converted to forest, and land converted from forest), including both stocked and non-stocked stands. As explained above, annual processes combine growth, turnover, and decay processes, applied to the entire area of managed forests. The outputs consist of net GHG balance of managed forests, including growth; immediate emissions due to disturbances (carbon stock changes, carbon losses to atmosphere and to forest products); and decay of both DOM and soil organic matter, which occurs as an annual process, including on stands affected by disturbances. During this stage, inventory records that have been in a "land converted to" category for 20 years are converted into the final category.

The same data output is available on converted forest lands (except growth), but is reported in the new land category — e.g., land converted to cropland (CRF Table 5.B Row 2), to wetlands (CRF Table 5.D Row 2), and to settlements (CRF Table 5.E Row 2). Estimates of soil organic matter emissions on forest land converted to cropland were developed separately; methods are described in Section A3.5.3.2. Likewise, estimation methods for emissions (as opposed to carbon stock changes) from forest land converted to flooded lands are described in Section A3.5.5.2.

Note that the immediate effect of disturbances is identifiable in the output data sets for the year of the disturbance. In subsequent years, post-disturbance emissions and removals are simulated as annual processes. The CBM-CFS3 does not distinguish decomposition releases from DOM accumulated prior to or during a disturbance; hence, long-term impact of disturbances cannot be fully identified.

Table A3-35 gives 2004 estimates of the broad components of the GHG balance in managed forests generated by the CBM-CFS3. The largest fluxes are carbon uptake by biomass and DOM decay. The first is largely influenced by the age-class distribution of the managed forests; organic matter decay is controlled by input from litterfall, mortality, and the disturbances that occurred prior to the inventory year. Insect disturbances have very limited immediate impact; however, depending on the severity of infestations and insect damage, they may result in large carbon transfers from biomass to DOM and influence the long-term trend of organic matter decay. Emissions from the DOM pool account for 74% of all wildfire emissions.

TABLE A3-35: GHG Balance of Managed Forests, 2004

Process/Event	GHG Balance				
	Biomass	DOM	Soil	N_2O	Ecosystem Net Balance
			(Gg CO_2 eq)		
Annual processes	–3 190 883	2 091 466	835 926	0	–263 491
Harvesting	132 453	9 878	0	0	142 331
Wildfires	41 788	144 923	0	8 303	195 015
Insects	46	0	0	0	46
Total	**–3 016 596**	**2 246 267**	**835 926**	**8 303**	**73 901**

Note:
Carbon in CH_4 and CO emissions are included in each pool's assessment, but N_2O emissions are computed separately, from total CO_2 emissions (see also Annex 13). Figures include land converted to forest lands.

A3.5.2.4 Uncertainties

Constraints of time and resources prevented the timely development of formal uncertainty estimates for the forest land category in this submission. Important sources of uncertainty about forest land remaining forest land estimates are discussed below.

Area of Managed Forests

The most important reduction in the uncertainty about managed forest estimates stems from the use of detailed forest inventory data sets. However, despite important efforts to obtain, harmonize, and integrate the most accurate forest inventory information available across the country, significant uncertainties remain. A generic cause of this uncertainty is the fact that forest inventories are prepared for purposes other than for GHG estimation and reporting. The forest inventory data used for this submission were collected over several decades from a variety of primary sources, ranging from high-resolution air photography to low-resolution, basic reconnaissance mapping. The different inventory techniques and procedures used across the country are not well documented, nor are they necessarily compatible, because of inconsistent standards and definitions. Hence, the quality and reliability of forest inventory data are highly variable. There is also uncertainty associated with inventory completeness. The methods used to reconcile and compile forest inventory data in support of GHG estimate development do not at present allow a quantification of the uncertainties about managed forest areas. Based on expert judgement, the likelihood of underreporting the area of managed forests is greater than the likelihood of overreporting it.

Key Model Parameters and Assumptions

The sensitivity of emissions and removals to the age-class distribution of managed forests can be high but difficult to quantify, because of complex interactions within the modelling framework. For example, the uncertainty about the age class of a forest stand may affect the simulated stand productivity, depending on the shape of the growth curve and the particular location of a given age category along that curve. Likewise, the age class (or the uncertainty about it) of a stand killed by a fire disturbance may influence the quantity of biomass and DOM affected (or its uncertainty) and the resulting emissions.

Soil and slow-decaying DOM pools contain a considerable amount of carbon. Even though the rates of soil organic matter decay modelled by the annual processes are very small, they do, by virtue of the pool size and forest areas, strongly influence emissions from annual processes. Similarly, the transfers of DOM carbon to the atmosphere modelled in the disturbance matrices, applied over the vast areas affected by disturbances, amount to significant emissions.

Both the current age-class distribution and the initial soil and DOM pool sizes are in turn sensitive to assumptions about historic disturbance regimes. Work is under way to improve the ability to quantify the sensitivity of DOM dynamics in CBM-CFS3 to assumptions about historic disturbances and to refine the assumptions themselves.

A3.5.3 CROPLAND

The following is a summary of methodologies used to estimate CO_2 emissions and removals from cropland management, soil carbon stock change from forest and grasslands conversion to cropland, as well as N_2O emissions from soil disturbance upon conversion to cropland. The estimation methodology for carbon stock changes and GHG emissions from the biomass and DOM pools upon conversion of forest land to cropland are provided in Section A3.5.2.3.

A3.5.3.1 Cropland Remaining Cropland

Change in Carbon Stocks in Mineral Soils

- **Changing Management Practices**

The amount of organic carbon retained in soil represents the balance between the rate of primary production (CO_2 transfer from the atmosphere to the soil) and SOC decomposition (CO_2 transfer from the soil to the atmosphere). How the soil is managed determines whether the amount of organic carbon stored in a soil is increasing or decreasing. The IPCC approach, which guided the development of the CO_2 estimates methodology, is based on the premise that changes in soil carbon stocks over a certain period occur following changes in soil management that influence the rates of either carbon additions to or carbon losses from the soil. If no change in management practices has occurred, the carbon stocks are assumed at equilibrium, and hence the change in carbon stocks is deemed to be zero.

A number of management practices are known to increase SOC in cultivated cropland, such as reduction in tillage intensity, intensification of cropping systems, adoption of yield-promoting practices, and reestablishment of perennial vegetation (Janzen *et al*., 1997; Bruce *et al*., 1999). Adoption of practices with reduced tillage (RT) or no-tillage (NT) can result in significant accumulation of SOC compared with conventional tillage practices (Campbell *et al*., 1995, 1996a,b; Janzen *et al*., 1998; McConkey *et al*., 2003). Many cropping systems can be intensified by increasing the duration of photosynthetic activity through a reduction of summerfallow (Campbell *et al*., 2000, 2005; McConkey *et al*., 2003) and greater use of perennial forage (Biederbeck *et al*., 1984; Bremer *et al*., 1994; Campbell *et al*., 1998). Intensification of cropping systems not only increases the amount of carbon entering the soil, but may also reduce decomposition rates by cooling the soil through shading and by drying the soil. Conversely, switching from conservative to conventional or from intensive to extensive cropping systems will reduce carbon input and increase the decomposition, thereby reducing SOC.

VandenBygaart *et al*. (2003) compiled published data from long-term studies in Canada to assess the effect of agricultural management on SOC. This compendium, as well as availability of activity data (time series of management practices) from the Census of Agriculture (see Data Sources), provided the basis for identifying the key management practices and management changes used to estimate changes in soil carbon stocks. Emissions and removals in mineral soils were estimated for the following land management changes (LMC):

1. Change in mixture of cropland type:
    1.1. Increase in perennial crops
    1.2. Increase in annual crops
2. Change in tillage practices:
    2.1. Intensive tillage (IT) to reduced tillage (RT)
    2.2. IT to no-tillage (NT)
    2.3. RT to IT
    2.4. RT to NT
    2.5. NT to IT
    2.6. NT to RT
3. Change in area of summerfallow
    3.1. Increase in area of summerfallow
    3.2. Decrease in area of summerfallow

Other land management practices can also affect SOC. Although manure application has positive local effects on SOC, the actual amount of carbon stock change is small to non-existent when considering the total carbon input in feed and/or bedding from which the manure carbon is derived (Schlesinger, 1999). Where nutrients are greatly limiting, proper fertilization can increase SOC; in such conditions, however, fertilizer or other nutrient enhancing practice is generally already applied. Losses or gains of irrigated land in semiarid areas can affect SOC, but the impact is unclear, and the area of irrigated land has been relatively constant. Therefore, it was assumed that the selected LMC represented the most important and consistent influences affecting SOC in mineral soils.

Carbon Emission/Removal Factor

To estimate carbon emissions and removals, a carbon emission/removal factor specific to each combination of SLC polygon and management change was multiplied by the area of change. A carbon emission/removal factor is the rate of SOC change per year and per unit of area of LMC.

Equation A3-35:

$$\Delta C = F * A$$

where:

ΔC = change in soil carbon stock, Mg C

F = average annual change in SOC subject to LMC, Mg C/ha per year

A = area of land management change, ha

Areas of LMC (i.e., changes in tillage, crop type, or fallow) were obtained from the Census of Agriculture. Census data provide information on the net change in area during five-year Census periods. In practice, land probably both enters and leaves a land management practice, and combinations of management change occur. However, because only net change data are available, two assumptions were made: additivity and reversibility of carbon factors. Reversibility assumes that the factor associated with an LMC from A to B is the opposite of that associated with the LMC from B to A. Additivity assumes that the carbon changes from each individual LMC occurring on the same piece of land are independent and therefore additive. This assumption is supported by the findings of McConkey *et al*. (2003), who reported that the impact of tillage and crop rotations on SOC is generally additive.

There is a relatively large set of Canadian observations of long-term changes in SOC for LMC such as adoption of NT and reduced frequency of summerfallow (VandenBygaart *et al*., 2003; Campbell *et al*., 2005). However, even this large data set does not cover the whole geographical extent of Canadian agriculture. In addition, i) treatments often vary among research sites, which make comparisons difficult; ii) it is difficult to determine duration of effect; iii) it is difficult to estimate full uncertainty from range of interactions with initial soil state and combination of different practices; and iv) it is difficult to determine the variability of carbon change without management change.

Because of these limitations, a well-calibrated and validated model of soil carbon dynamics, the CENTURY model (Parton *et al.*, 1987, 1988), was used to derive carbon factors for changes between NT and IT, RT and IT, RT and NT, annual and perennial crops, and area of summerfallow. The CENTURY model has been used widely to simulate SOC for Canadian conditions (Voroney and Angers, 1995; Liang *et al*., 1996; Monreal *et al*., 1997; Campbell *et al*., 2000, 2005; Pennock and Frick, 2001; Carter *et al*., 2003; Bolinder, 2004).

Smith *et al.* (1997, 2000, 2001) developed an approach using the CENTURY model to estimate carbon change on agricultural land in Canada. The model underwent an extensive calibration and validation process. To estimate carbon change, it was necessary to develop a generalized description of land use and management from 1910 onwards on cropland for a sample of soil types and climates across Canada. These scenarios were generated from a mixture of expert knowledge and agricultural statistics of land management, including crop types, fallow, and fertilizer applied, following closely the work of Smith *et al.* (1997, 2000). These have been used for the first comprehensive assessments of soil carbon change on agricultural land within a broader assessment of soil health (McCrae *et al.*, 2000).

Initial SOC in 1910 was estimated as 1.25 times the SOC in the SLC polygon soil attribute database. These database SOC values were derived from measurements made for soil surveys and land resource studies (Tarnocai, 1997) and were assumed to represent the SOC in 1985. On average, the simulated SOC from the initialization in 1985 was within a few percent of the database values.

Carbon factors were estimated using the difference in soil carbon stocks over time between simulation of a generalized land use and management scenario with and without the LMC of interest (Smith *et al.*, 2001). The main rationale of the method is that estimating the SOC difference for an LMC and multiplying by the area of that LMC are less sensitive to description of management than predicting absolute SOC change occurring on that area involving the LMC in combination with various current and past land managements.

A 10-year crop-and-tillage system (CTS) was developed for each SLC and Census year, using data from the Census of Agriculture. The CTS focused on seven crops and crop types (grain, oilseeds, pulses, alfalfa, root crops, perennial crops, and summerfallow) and three tillage practices (IT, RT, and NT). Essentially, each CTS represents a mix of crops and tillage practices in space as a mix of crops and tillage practices in time. Under this scheme, a polygon with 20% of cropland area in grain and 20% of cropland area in NT, for example, has 2 of 10 years in grain and 2 of 10 years in NT. Temporal sequences of crop and tillage practices were developed from expert-defined rule-sets, such as "summerfallow never follows summerfallow" and "wheat typically follows soybeans." The construction allows a base CTS and substitutions of LMCs in the CTS to be readily input to the CENTURY model.

The carbon factor was determined as:

Equation A3-36:

Factor = (C for CTS with LMC substitutions – C for base CTS)/[(fraction of CTS substituted with the LMC) * (duration considered)]

If a land management system is defined as a particular mix of crops and tillage practices on a specified land area, a change in carbon due to an LMC (ΔC_{LMC}) can be estimated as the difference in carbon between two land management systems divided by the proportionate amount of LMC between the two land management systems:

Equation A3-37:

$$\Delta C_{LMC}(t) = \Delta C / p_{LMC}$$

where $\Delta C_{LMC}(t)$ is the difference in carbon between land management systems from year to year, and p_{LMC} is the proportion of area of land management system that received the LMC. This proportion can be derived as the proportion of the particular LMC in the base system less the amount of the LMC in the new system after LMC. That is,

Equation A3-38:

$$p_{LMC} = p_{LMbase} - p_{LMnew}$$

where p_{LMbase} is the proportion of the base land management and p_{LMnew} is the proportion of the new land management system.

The following provides an example of CENTURY runs for a Lethbridge Loam (Orthic Dark Brown Chernozem) in the Semiarid Prairies reporting zone. A base model run was made using a 10-year base mix of crops based on the 1996 Census of Agriculture and weather based on that for 1951–2001. CENTURY simulations of SOC were made by substituting perennial crops for the seven annual crops in the base mixture. As a separate exercise, NT was substituted for four years of IT in the base mixture (Figure A3-12). The next step was to calculate the $\Delta C_{LMC}(t)$ function by subtracting the simulated SOC values for the base mix values from those imposed by the LMC (Figure A3-13). Finally, the $\Delta C_{LMC}(t)$ was calculated as the proportion of area of farming system by dividing by the p_{LMC} (Equation A3-37). The respective values of p_{LMC} for the IT to NT reduction and for the addition of perennial crops were 4/10 (4 substitutions in 10-year base mixture) and 7/10.

Soil carbon dynamics are believed to be governed by first-order kinetics. Therefore, carbon change can be expressed as:

Equation A3-39:

$$\Delta C_{LMC}(t) = \Delta C_{LMCmax} * [1 - \exp^{(-k * t)}]$$

where ΔC_{LMCmax} is the maximum carbon change induced by the LMC, k is the rate constant, and t is year.

In practice, the exponential equations are fit statistically using standard statistical analysis software by methods of least squares. The slope of the exponential equation has units of Mg C/ha per year and is the instantaneous factor value. The equation for the slope of the function is:

Equation A3-40:

$$F_{SLOPE}(t) = \Delta C_{LMCmax} * k * \exp^{(-k * t)}$$

Since the accounting is based on annual changes, the equation used for estimating the factor for annual change from the previous year (i.e., from year Y–1 to Y) is:

Equation A3-41:

$$F_{LMC}(t) = \Delta C_{LMCmax} * [\exp^{(-k * (t-1))} - \exp^{(-k * t)}]$$

Since perfect steady-state conditions are never reached, the exponential equation should theoretically apply forever. In practice, however, the exponential equation was truncated when the $F_{LMC}(t)$ dropped to 25 kg C/ha per year. This rate was below a practical measurement limit (Figure A3-14).

■ Estimating Mean k and ΔC_{LMCmax} for Practical Factor Calculations

The ΔC_{LMCmax} and k parameters were determined for all 11 602 soil components. These soil components represented a wide range of initial SOC states and combinations of base crop mixtures and amounts of substitutions. The parameter values were estimated for each reporting zone as the mean across these soil components, weighted by area of agriculture on each component (Table A3-36). The geometric mean was used for k, since its distribution was positively skewed. These means were calculated by three general soil texture classes (sandy, loamy, and clayey) and applied to each soil component based on its textural class. Occasionally, k values less than zero or greater than 0.15 resulted from the fit to ΔC_{LMC}; the k and ΔC_{LMCmax} from these fits were excluded from the reporting zone means.

FIGURE A3-12: **Soil Carbon for a Base Crop Mix and for Perennial (Alfalfa) Substituted for Annual Crops (Wheat) and for No-Till (NT) Substituted for Intensive Till (IT) Based on CENTURY Runs for a Lethbridge Loam**

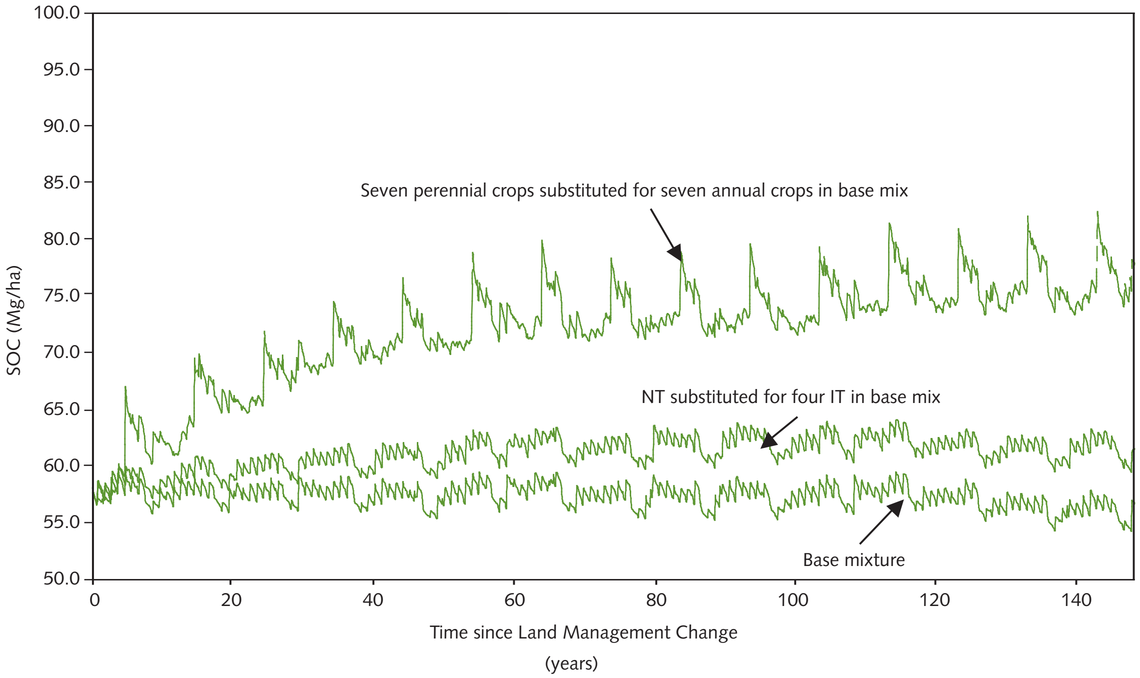

FIGURE A3-13: **Change in SOC for Simulations with Substitutions Relative to Simulations with Base Crop Mix**

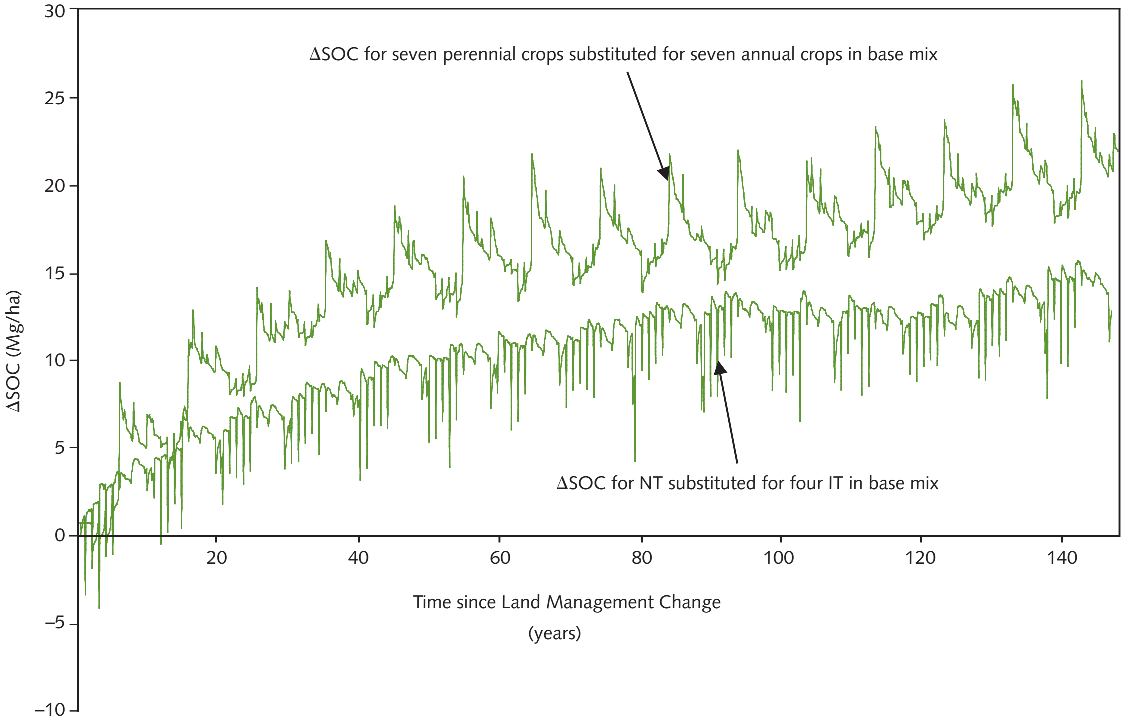

FIGURE A3-14: Estimating ΔC_{LMCmax} and k by Fitting an Exponential Equation to ΔC_{LMC}

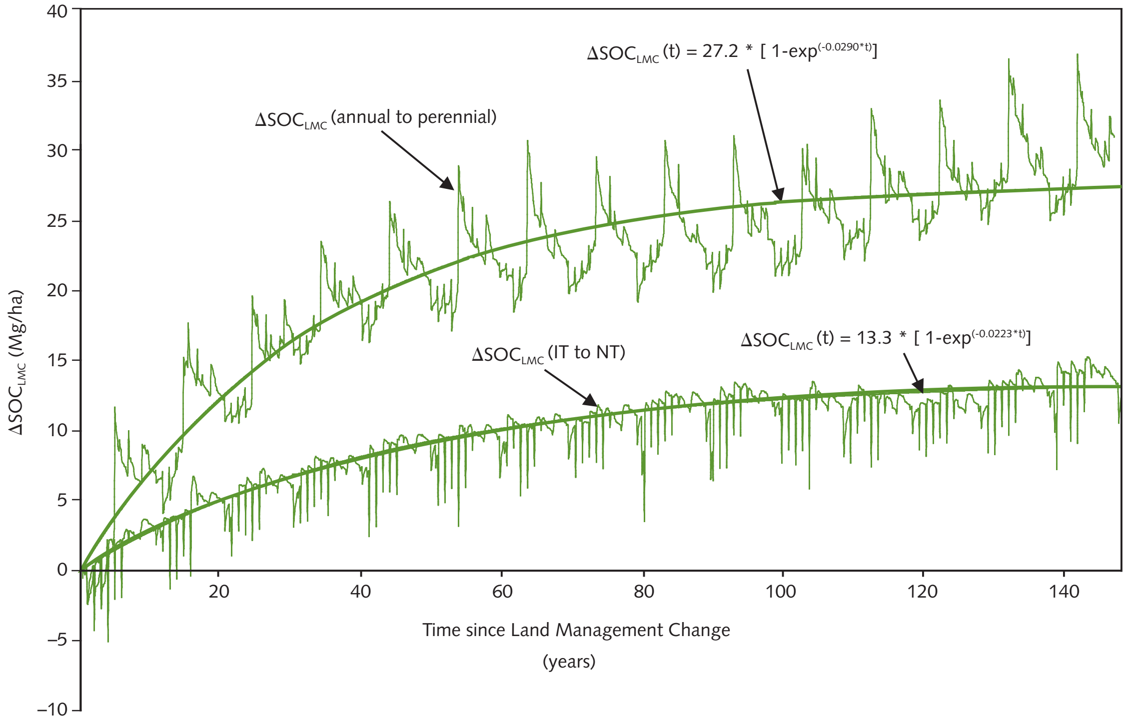

FIGURE A3-15: F_{LMC} from Exponential Equation

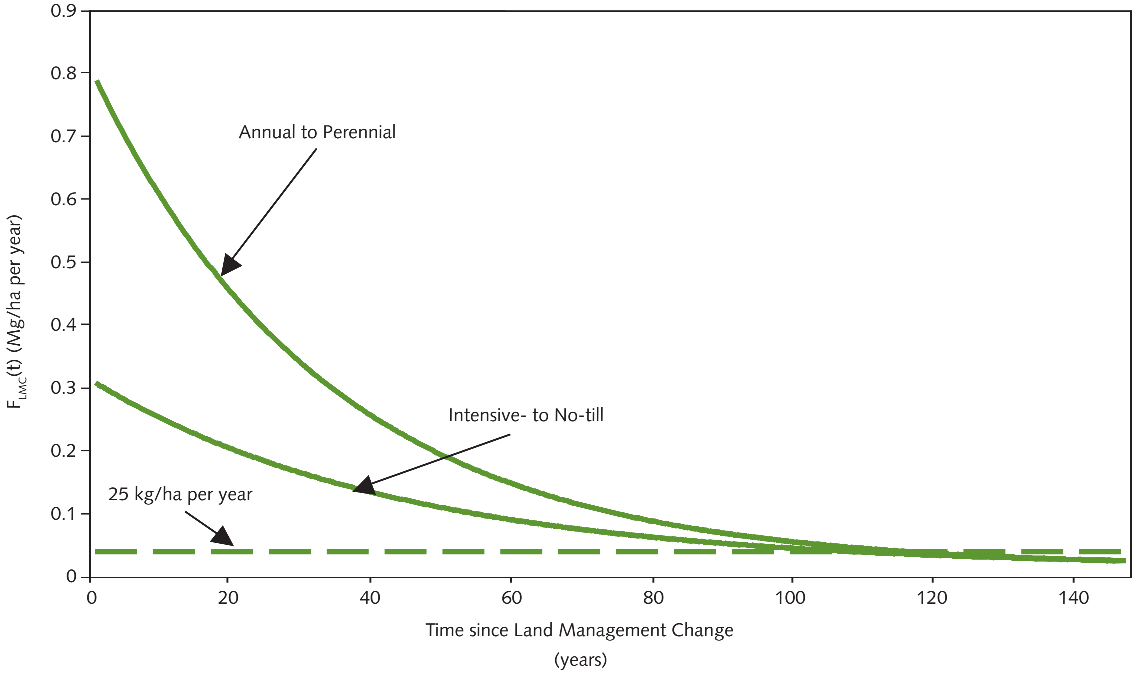

TABLE A3-36: Generalized Values of Parameters for $F_{LMC}(t) = \Delta C_{LMCmax} * [1 - exp^{(-k * t)}]$ to Predict Change from Land Management Change (LMC) and Effective Linear Coefficients of SOC Change

Zone[1]	LMC[2]	k	ΔC_{LMCmax}	Final Year of Effect after LMC[3]	Linear Coefficient for Duration of Effect of LMC	Linear Coefficient for First 20 Years after LMC
		(/year)	*(Mg/ha)*		*(Mg/ha per year)*	*(Mg/ha per year)*
East Atlantic	IT to NT	0.0216	3.5	52	0.05	0.06
	IT to RT	0.0251	2.4	36	0.04	0.05
	RT to NT	0.0233	1.1	1	0.03	0.00
	Decrease fallow	0.0305	13.1	91	0.14	0.30
	Increase perennial	0.0217	43.4	167	0.25	0.77
East Central	IT to NT	0.0250	5.0	65	0.06	0.10
	IT to RT	0.0261	1.9	25	0.04	0.04
	RT to NT	0.0255	3.2	46	0.05	0.06
	Decrease fallow	0.0305	13.1	91	0.14	0.30
	Increase perennial	0.0247	38.2	147	0.25	0.74
Parkland	IT to NT	0.0286	6.5	70	0.08	0.14
	IT to RT	0.0242	2.8	41	0.04	0.05
	RT to NT	0.0263	3.7	51	0.05	0.07
	Decrease fallow	0.0305	13.1	91	0.14	0.30
	Increase perennial	0.0233	29.4	142	0.20	0.55
Semiarid Prairies	IT to NT	0.0261	4.9	63	0.06	0.10
	IT to RT	0.0188	2.3	30	0.03	0.04
	RT to NT	0.0222	2.5	37	0.04	0.05
	Decrease fallow	0.0305	13.1	91	0.14	0.30
	Increase perennial	0.0281	26.1	120	0.21	0.56
West	IT to NT	0.0122	4.8	69	0.04	0.05
	IT to RT	0.0116	0.8	0	0.00	0.00
	RT to NT	0.0119	3.9	53	0.03	0.04
	Decrease fallow	0.0305	13.1	91	0.14	0.30
	Increase perennial	0.0155	34.4	198	0.17	0.46

Notes:

1 Area-weighted summary: East Atlantic is the Atlantic Maritime reporting zone plus the Boreal Shield reporting zone in Newfoundland and Labrador, East Central is the Mixedwood Plains reporting zone plus the Boreal Shield East reporting zone in Ontario and Quebec, Parkland is the Subhumid Prairies, Boreal Shield West, and Boreal Plains reporting zones plus those parts of Montane Cordillera reporting zones with agricultural activity contiguous to agricultural activity within the rest of the Parkland zone, and West is the Pacific Maritime reporting zone plus Montane Cordillera reporting zone excepting that portion of the latter that is included in the Parkland zone as described above.

2 For LMCs in the opposite direction listed, the F_{LMCmax} will be the negative of the value listed.

3 No further carbon change once the absolute value of the rate of change is less than 25 kg C/ha per year.

The dynamics of carbon change for changes in fallow have been well studied in Canada. Therefore, rather than using the value for ΔC_{LMCmax} from the CENTURY simulations, the ΔC_{LMCmax} value was set so that F was 150 C/ha per year (Campbell *et al*., 2005) at 20 years based on a p_{LMC} of 0.5 (i.e., no fallow from 50% fallow). The k was derived from the CENTURY simulations as discussed above.

Generally, rates of SOC losses may be expected to be greater upon an LMC than rates of SOC gain upon the reverse LMC. However, this effect depends greatly on the relative SOC amount at time of the LMC. In particular, if the SOC amount is relatively high, rates of SOC gain will be low when practices are adopted that would be expected to increase SOC (e.g., from annual to perennial crops), while rates of SOC loss will be large when practices are adopted that would be expected to decrease SOC (e.g., from perennial to annual crops). The converse occurs if SOC is relatively low. In the simulations, generally, but not consistently, the rates of carbon gain for an LMC in one direction were predicted to be larger than rates of loss for the LMC in the opposite direction. This behaviour would suggest that many Canadian soils are relatively low in SOC. Detailed knowledge of the exact initial SOC conditions would be needed to determine how direction of LMC affects rates of change, but a reasonable estimate would be that rates of gain for an LMC in one direction are the negative of the rates of loss for the LMC in the opposite direction. There is a major advantage if F_{LMC} for an LMC in one direction is the negative of the rate for the LMC in the opposite direction (e.g., from perennial to annual crops). The advantage is that concurrent LMCs in opposite directions cancel each other out. Therefore, it was decided to make the factors reversible. Reversibility requires that the SOC effect of an LMC in one direction is exactly the negative of the SOC effect of the practice change in the opposite direction.

Estimates of Change in Soil Carbon Stocks

Estimate development was based on processing relational databases of LMCs for which an estimate of carbon change was required. Soil carbon changes as a result of LMC were reported for 1990–2004 based on soil carbon simulations initiated in 1851; because the effect of LMCs declines over time, a vintage or time when change was deemed to have occurred is maintained for each LMC. The carbon change factor was multiplied by the area of LMC and summed across soil components to produce an estimate of carbon change for the SLC polygon. This is the smallest georeferenced unit of carbon stocks and carbon stock changes, with accounting using an IPCC Tier 2 approach as follows:

Equation A3-42:

$$\Delta C_{LMC,t} = \sum_{t1,t2} \sum_{ALL\ SLC} (\Delta C_{TILL} + \Delta C_{SF} + \Delta C_{CROPPING})$$

where:

$\Delta C_{LMC,t}$ = change in soil carbon stocks due to LMC for a specific year (t2) since 1951 (t1)

ΔC_{TILL} = change in soil carbon stocks due to change in tillage practices from each SLC, since each particular tillage change

ΔC_{SF} = change in soil carbon stocks due to the change in summerfallow in each SLC

$\Delta C_{CROPPING}$= change in soil carbon stocks due to the change of annual and perennial crops in each SLC

Land management data from the Census of Agriculture were available in 1951, 1961, 1971, 1976, 1981, 1986, 1991, 1996, and 2001. Land management data for years between Census years were estimated using linear interpolation. From 2002 to 2004, land management data were set at the same level as in 2001.

Data Sources

There are two types of data used, for either deriving carbon factors (modelling) or computing the actual estimates of carbon stock change. The data mainly used for modelling carbon factors include SLC, CTS derived from the Census of Agriculture data, and crop yields, climate data, and activity data from other surveys and databases.

Land Information and Activity (SLC)

The SLC is a national-scale spatial database describing the types of soils associated with landforms, displayed as polygons at an intended scale of representation of 1:1 million.[52] The advantage of using SLC Version 3.0 for the LULUCF inventory is that all SLC polygons are “nested” within the 1995 National Ecological Framework, making it possible to scale up or scale down data and estimates, as required.

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[52] Available online at: http://sis.agr.gc.ca/cansis/nsdb/slc/v1/intro.html.

In all provinces within the agricultural region of Canada, detailed soil survey information (map scales greater than 1:1 million) was used to delineate the SLC polygons and compile the associated database files. The SLC Component Soil Names Files and Soil Layer Files provided specific input data (soil carbon content, soil texture, pH, bulk density, and soil hydraulic properties) for modelling carbon factors with CENTURY. The SLC polygon provides the spatial basis for allocating land management practices (tillage practices, cropping systems from the Census of Agriculture) and cropland converted from forest and grassland to modelled carbon factors.

Analysis Units

There are 3264 SLC polygons that have agricultural activities. Since the SLC polygons have several soil landscape components, the finest spatial resolution for analysis for agricultural activities is 11 602 unique combinations of soil components within SLC polygons. These unique combinations represent the basic analysis units. The location of land management and soil components is not spatially explicit but rather spatially referenced to SLC polygons.

The soil components have different inherent properties that make them more or less likely to have different types of agricultural activities. Each soil component within the SLC attribute file has a suitability rating of "high," "moderate," or "low" likelihood for being under annual crop production. Agricultural activities were linked to specific components. Annual crop production is linked to those components with a high rating of likelihood of being under annual crop production. If there was insufficient area with high likelihood of being under annual cropland for area of annual crops, the remaining annual crop production was linked to components with moderate likelihood of being under annual crop production and, if required, to "low" ranked components. After linking the annual crop production area, perennial forages and seeded pasture area were linked to the remaining components in the same manner, starting with components with the highest likelihood of being in annual crops and ending with components with the lowest likelihood of being cropped.

Tillage Practices

Data for tillage practices were taken from the Census according to the following categories: i) IT – tillage that incorporates most of the crop residue into the soil, ii) RT – tillage that retains most of the crop residue on the surface, and iii) NT – no-till seeding or zero-till seeding. For summerfallow, the categories were i) NT – the area on which "chemicals only" were used for weed control, ii) IT – the area on which tillage only was used, and iii) RT – the area on which a combination of tillage and chemicals was used.

There are two limitations with the Census data pertaining to tillage practices that resulted in uncertainties: i) Statistics Canada and expert opinion indicate that the conservation components tend to be underestimated, and ii) tillage distributions as reported for a region must be applied equally to all crops within that region.

Crop Yields

Crop yields at an ecodistrict level were developed from Statistics Canada surveys. Statistics Canada conducts annual surveys of up to 31 000 farmers, stratified by region, to compile estimates of the area, yield, production, and stocks of the principal field crops grown in Canada. Eight publications are released at strategic points in the crop year; the first area report contains the planting intentions of producers, while the June estimates are made after most of the seeding has been completed. Yields and levels of production by province are estimated twice, based on expectations to the end of harvest, while the November estimate is released after the harvest. The data are released at the Census Agricultural Region level, providing crop yields for approximately 70 spatial units in the country. Census Agricultural Region boundaries were overlain on SLC boundaries in a GIS, and a yield value for each crop in each soil polygon was assigned based on majority proportion. Data used for accounting included 1975–2004 yield data for wheat, barley, oats, corn, soybeans, potatoes, and canola. These yields were used to calibrate the CENTURY crop growth submodel.

Climatic Data

There are 958 weather stations in the AAFC archived weather database. Long-term normals of monthly maximum and minimum temperatures (°C) and precipitation (mm) from 1951 to 2001 for all ecodistricts were used for modelling carbon factors. AAFC archived weather data were provided by the Meteorological Service of Canada, Environment Canada.

Census of Agriculture

Activity data for accounting in cropland remaining cropland rely mainly on data from the Census of

Agriculture, a self-administered questionnaire that all farmers are required by law to complete every five years (Statistics Canada, 1992, 1997, 2002). The smallest area for which Statistics Canada will release data externally for confidentiality reasons is the Dissemination/Enumeration Area level (approximately 52 000 in Canada). AAFC has "reconfigured" Census data for 1981, 1986, 1991, 1996, and 2001 from Dissemination Area units to SLC polygons (and higher-level ecostratification units) using a procedure involving geographic overlays of the relevant boundary files.

Uncertainties

Uncertainty analysis follows an IPCC Tier 2 method based on a Monte Carlo simulation approach that derives a population of possible values for the inventory of carbon emissions/removals estimates. Both error propagation approaches and separate Monte Carlo analyses were used to derive the uncertainty of the various terms in the accounting methodology. Accounting based on a Monte Carlo simulation approach is similar to those used by VandenBygaart *et al*. (2004) and Ogle *et al*. (2003).

The basic analysis unit for uncertainty was the ecodistrict (group of SLC polygons sharing a distinctive assemblage of relief, landforms, geology, soil, vegetation, water bodies, and fauna). There are 436 ecodistricts with agricultural activities. The primary reason for choosing the ecodistrict is that it is the smallest spatial unit where LMC was assumed to be independent from LMC in other ecodistricts and therefore did not require the difficulty of including spatial dependence in area of LMC that would have been necessary if SLC polygons had been used. The latter dependence arises because the allocation of Census data to several spatially contiguous SLC polygons essentially ensures that if the area of a land management is overestimated for one SLC polygon, it must be underestimated in a spatially contiguous SLC polygon. Therefore, the area of LMC could not be assumed to be independent among SLC polygons. However, for larger ecodistricts, there was no compelling reason that the area of LMC is related to the area of LMC in adjacent ecodistricts.

Basically, uncertainties of area of LMC on an ecodistrict scale were estimated to decrease from ±20% (95% confidence limits) where amount of the LMC represented a small proportion of total agricultural area (e.g., 5%) to ±5% (95% confidence limits) where LMC represented half of the agricultural area. These uncertainties were corroborated where possible by comparing Census data with results from earth observation or other independent data sources.

Uncertainties in carbon change factors were estimated from i) variability in factors predicted by the CENTURY-based procedure described previously over ecozones and ii) variability in empirical results when there were numerous experiments within an ecozone. The uncertainties of carbon stock change factors were typically in the range of ±100% (99% confidence limits). Much of this variability was due to varying effects of LMC given various initial carbon stock levels that reflect different historical management and interactions of specific LMCs with other current management practices.

Crystal Ball®, a commercially available add-on for Microsoft Excel, is used to implement and conduct the uncertainty quantification for the inventory, as was suggested in the IPCC report on quantifying uncertainties in practice (IPCC, 2000). This was used to estimate uncertainty of components, such as the uncertainty of area of change from underlying uncertainties of area of specific land management practices at different times. The final combining of uncertainties across LMCs and ecodistricts to derive uncertainties at reporting zone and national scales was done using Crystal Ball®.

CO_2 Emissions from Agricultural Lime Application

Lime is applied to raise the alkalinity and pH of acidic soils. The breakdown of lime releases CO_2 into the atmosphere. Limestone ($CaCO_3$) or dolomite ($CaMg(CO_3)_2$) is often used to neutralize acidic soils, increase the availability of soil nutrients, in particular phosphorus, reduce the toxicity of heavy metals, such as aluminium, and improve the crop growth environment. During this neutralization process, CO_2 is released in the following bicarbonate equilibrium reactions that take place in the soil:

$CaCO_3 + 2H^+ = CO_2 + Ca^{2+} + H_2O$

$CaMg(CO_3)_2 + 4H^+ = 2CO_2 + Ca^{2+} + Mg^{2+} + 2H_2O$

The rate of release varies with soil conditions and the types of compounds applied. In most cases where lime is applied, applications are repeated every few years. Thus, for the purposes of the inventory, it is assumed that the addition rate of lime is in near equilibrium with the consumption of lime applied in previous years. Emissions associated with use of lime are calculated from the amount and composition of the lime applied annually.

Method

The amount of carbon released as a result of limestone application is calculated using the default IPCC Tier 1 approach:

Equation A3-43:

$$C = \sum A_i * \frac{12}{100}$$

where:

A_i = annual limestone consumption in province i (t/year)

12/100 = ratio of molecular weight of carbon to molecular weight of limestone

Similarly, the amount of carbon released as a result of dolomite application is calculated as:

Equation A3-44:

$$C = \sum A_i * \frac{12}{184.3}$$

where:

A_i = annual consumption of dolomitic lime in province i (t/year)

12/184.3 = ratio of molecular weight of carbon to molecular weight of dolomite

If the type of lime was not known, the lime was assumed to be composed of 50% calcitic lime and 50% dolomitic lime.

There is no single source of data for lime application on agricultural soils. The quantity of lime used for agricultural purposes is not collected by Statistics Canada or by the Canadian Fertilizer Association. Lime usage data were retrieved from the Western Canada, Atlantic, Ontario, and Quebec fertilizer associations.

CO_2 Emissions and Removals from Woody Biomass

This section summarizes the approach used to estimate changes in biomass carbon stocks on Canadian cropland with vineyards, fruit orchards, and Christmas tree farms.

Vineyards, fruit orchards, and Christmas tree farms are intensively managed for sustained yields. Vineyards are pruned each year, leaving only the trunk and one-year-old stems. Similarly, fruit trees are pruned annually to maintain the desired canopy shape and size. Old plants are replaced on a rotating basis, for disease prevention, stock improvement, or introduction of new varieties. Typically, Christmas trees are harvested at about 10 years of age. For all three crops, it was assumed that, because of these rotating practices and the requirements for sustained yield, a uniform age-class distribution is generally found on production farms. Hence, there would be no net increase or decrease in biomass carbon within existing farms, as carbon lost from harvest or replacement would be balanced by gains due to new plant growth. The approach was therefore limited to detecting changes in areas under vineyards, fruit orchards, or Christmas tree plantations and estimating the corresponding carbon stock changes in total biomass.

There are no Canadian studies on the aboveground or belowground carbon dynamics of vineyards or fruit trees. However, results from other studies are considered valid inasmuch as varieties, field production techniques, and even root stocks are often the same. Canadian literature on Christmas tree plantations is used whenever suitable.

Based on work by Mailvaganam (2002), it was assumed that, on average, vines are replaced at 28 years of age and that the average vine is therefore 14 years old. Carbon accumulation in biomass was calculated within that time horizon. Because of intensive pruning, the biomass of shoots and leaves is set at the constant value of 4 Mg/ha, while linear rates of aboveground and belowground biomass accumulation in trunks and roots were 0.4 and 0.3 Mg/ha per year, respectively (Nendel & Kersebaum, 2004). These were converted to carbon values using a 50% carbon content in biomass. Upon a decrease of vineyard areas, an instantaneous loss of 6.9 Mg C/ha is assumed, equal to the average standing biomass for 14-year-old vines.

The approach to estimate biomass carbon stocks on fruit orchards used a general allometric equation (Fournier *et al.*, 2003) and published average diameters of peach, nectarine, and apple trees from 6 to 16 years of age, planted at standard spacings (Jimenez and Diaz, 2003, 2004). While the average biomass of a mature tree ranged between 18 kg for an apple tree to 72 kg for a peach tree, because of different standard planting densities, the range of standing biomass per area was narrower, between 36 and 40 Mg/ha. This similarity is expected since, regardless of tree size and planting density, the tree shapes and canopies are manipulated to maximize net photosynthesis per area. An annual rate of carbon sequestration was calculated over a 12-year growth period, at 1.6 Mg C/ha per year. The same rate, multiplied by a root:shoot ratio of 0.40 (Bartelink, 1998), was used to estimate carbon sequestration in belowground biomass. It was assumed that, on new orchard areas, trees accumulate biomass at a linear rate for 10 years (the average tree age on a plantation). Instantaneous carbon loss upon a decrease of orchards was equal to 50% of the total biomass of a 10-year-old tree (22.4 Mg C/ha).

Typically, Christmas trees are marketed at about 10 years of age (Leuty, 1999; Agriculture and Agri-Food Canada, 2003); the average age of farm-grown Christmas trees is therefore estimated at about five years. Wood accounts for approximately 70% of Christmas tree biomass (Hinesley and Derby, 2004), and fresh wood has a moisture content of 60–80%. With typical spacing and an expected market mass of 10 kg, a plantation of marketable trees is estimated to have an aboveground biomass density of 17.1 Mg/ha. With a root:shoot ratio of 0.3 (Bartelink, 1998; Litton *et al*. , 2003; Xiao and Ceulemans, 2004), the total biomass carbon of a marketable tree plantation is estimated at 11.1 Mg C/ha. Carbon sequestration in biomass of new Christmas tree plantations is calculated for five years at rates of 0.85 and 0.26 Mg C/ha for aboveground and belowground biomass, respectively. A decrease of plantation area would result in the immediate loss of 5.6 Mg C/ha.

■ Uncertainties

Uncertainty of the carbon stock change in woody biomass of vineyards, fruit trees, and Christmas tree farms was not estimated.

Cultivation of Organic Soils

Cultivation of histosols for annual crop production usually involves drainage, tillage, and fertilization. All these practices increase decomposition of SOC and, thus, release of CO_2 to the atmosphere.

■ Methods

The IPCC Tier 1 methodology is based on the rate of carbon released per unit land area:

Equation A3-45:

$$C = \sum A_i * EF$$

where:

A_i = area of organic soils that is cultivated for annual crop production in province i

EF = carbon emission factor, t C loss/ha per year. A country-specific EF of 5.7 Mg C/ha per year was used (IPCC, 2006).

■ Data Sources

Areas of cultivated histosols at a provincial level are not included in the Census of Agriculture, which is conducted regularly at five-year intervals by Statistics Canada. In the absence of these data, consultations with numerous soil and crop specialists across Canada were undertaken. Based on these consultations, the total area of cultivated organic soils in Canada was 16 154 ha (G. Padbury and G. Patterson, AAFC, personal communication).

A3.5.3.2 Grassland Converted to Cropland

Conversion of native grassland to cropland generally results in losses of organic carbon and nitrogen and in turn leads to emissions of CO_2 and N_2O to the atmosphere.

A number of studies on changes of SOC and soil organic nitrogen in grassland converted to cropland have been carried out on the Brown, Dark Brown, and Black soil zones of the Canadian Prairies, and these results are summarized in Table A3-37. With the exception of the study of Doughty *et al*. (1954), which involved repeated observation on the same fields, all studies were based on paired comparisons.

Losses of Soil Organic Carbon

The average loss of SOC, weighted for number of locations across landscape positions, was 22%. Many of the studies involved comparisons within 30 years of breaking, while others were 70 or more years from breaking. Since many of these studies did not specify the period since breaking, it is assumed that the 22% SOC loss would refer to about 50–60 years after breaking.

Soil translocation by wind, water, and tillage has played a major role in determining the amounts of SOC and soil organic nitrogen in the cultivated soils relative to

TABLE A3-37: Changes in SOC and Soil Organic Nitrogen Resulting from Grassland Converted to Cropland on the Canadian Prairies

References	Site	Landscape	Years Since Breaking[1]	Soil Depth	ΔC		ΔN		Soil Bulk Density-Adjusted?[2]	Carbon Loss due to Soil Erosion
				(cm)	*(Mg C/ha)*	*(%)*	*(Mg N/ha)*	*(%)*	*(Mg/ha per year)*	*(Mg N/ha)*
Slobodian *et al*. (2002)	St-Denis, SK	Upper	49	0–60	–45.4	–43	–	–	Yes	–
		Foot	49	0–60	–19	–17	–	–	Yes	–
		Lower	19	0–60	–9.1	–10	–	–	Yes	–
Tiessen *et al*. (1982)	SK		90	A&B Horizon	–44	–51	–3.8	–44	Yes	–
			70	A&B Horizon	–29	–27	–0.8	–9	Yes	–
			65	A&B Horizon	–17	–19	–1.8	–20	Yes	–
Pennock *et al*. (1994)	Lanigan, SK	Upper	12	0–45	–21	–18	–2.6	–24	Yes	14
		Foot			–34	–26	–2.4	–21	Yes	9
		Upper	22		–36	–31	–3.9	–36	Yes	19
		Foot			–25	–19	–1.6	–14	Yes	2
		Upper	80		–64	–55	–4.6	–43	Yes	45
		Foot			–45	–35	–3.6	–31	Yes	18
		Level			–31	–29	–2.8	–27	Yes	–
Bergstrom *et al*. (2001)	Minnedosa, MB		NR	A Horizon	–19	–32	–	–	Yes	–
				A&B Horizon	–24	–27	–	–	Yes	–
				A Horizon	–26	–43	–	–	Yes	–
				A&B Horizon	–42	–52	–	–	Yes	–
Mermut *et al*. (1983)	Central SK		70	A&B Horizon	–45.5	–41	–4.6	–35	Yes	–
Gregorich and Anderson (1985)	SK		74	A&B Horizon	–56	–44	–4.4	–40	Yes	39
			54	A&B Horizon	–47	–37	–2.9	–26	Yes	36
			23	A&B Horizon	–68	–54	–3.7	–34	Yes	15
Gregorich *et al*. (1998)	SK	Upper	NR	A&B Horizon	–24	–51	–	–	Yes	–
		Mid	NR	A&B Horizon	+7	+9	–	–	Yes	–
		Lower	NR	A&B Horizon	+30	+19	–	–	Yes	–
	SK	Upper	NR	A&B Horizon	–60	–71	–	–	Yes	–
		Mid	NR	A&B Horizon	–37	–43	–	–	Yes	–
		Lower	NR	A&B Horizon	–33	–26	–	–	Yes	–
	SK	Upper	NR	A&B Horizon	–32	–41	–	–	Yes	–
		Mid	NR	A&B Horizon	–30	–23	–	–	Yes	–
		Lower	NR	A&B Horizon	+15	+11	–	–	Yes	–
Anderson (1995)	SK		NR	Profile	+3.1	+3	–	–	Yes	Minimal
			NR	Profile	–43.1	–43	–	–	Yes	Much
			NR	Profile	–13.6	12	–	–	Yes	Minimal

Notes:

1 NR = not reported.

2 Only data subjected to soil bulk density adjustments are listed. Data without soil bulk density adjustment include Newton *et al*. (1945), Doughty *et al*. (1954), Voroney *et al*. (1981), and Martel and Paul (1974).

those under native grassland where such translocation is minimal. The studies of Pennock *et al*. (1994) and Gregorich and Anderson (1985) used soil erosion rates estimated from abundance of ^{137}Cs in cultivated compared with undisturbed sites to separate carbon loss due to mineralization of SOC after breaking from that due to soil translocation. For these studies, about one-half of SOC loss was attributed to soil translocation. However, many of the studies in Table A3-37, such as that of Newton *et al*. (1945), selected level sampling areas to try to minimize the effect of erosion on SOC loss. Therefore, it is assumed that the 22% SOC loss was primarily from mineralization of SOC.

The CENTURY model (Version 4.0) is used to estimate the SOC dynamics from breaking of grassland to cropland for the Brown and Dark Brown Chernozemic soils (Figure A3-16). Shortly after breaking, there is an increase in soil organic matter, as belowground biomass of the grass becomes part of SOC. After a few years, SOC declines below the amount of SOC that existed under grassland. The rate of SOC decline gradually decreases with time. Neglecting the initial SOC increase due to carbon added from recently killed roots, these SOC dynamics are described by the following equation:

Equation A3-46:

$$\Delta SOC(t) = \Delta SOC_{Bmax} * [1 - \exp^{(-k_B * (t - t_{lag}))}]$$

where ΔSOC(t) is the change of SOC over time, ΔSOC_{Bmax} is the maximum ultimate change in SOC from grassland to cropland, k_B is the rate constant for describing the decomposition, t is the time since breaking of grassland, and t_{lag} is the time lag before ΔSOC becomes negative. The fit of this equation to the grassland simulation is shown in Figure A3-17; using an average k_B of 0.12, 92% of carbon is lost within 25 years of breaking the grassland.

It was assumed that the 22% loss corresponded to about 50–60 years after initial breaking and represented 100% of total loss. Therefore, the ΔSOC_{Bmax} is 0.22/(1–0.22) = 28% of the SOC under agriculture. Given the uncertainty of actual dynamics, we assumed no time lag in SOC loss from breaking grassland, so that soil carbon starts to decline immediately upon breaking. With these assumptions, the general equation for predicting SOC loss from breaking grassland becomes:

Equation A3-47:

$$\Delta SOC(t) = 0.28 * SOC_{agric} * [1 - \exp^{(-0.12 * t)}]$$

where ΔSOC(t) is the change of SOC over time, t is the time (years) since breaking, and SOC_{agric} is the 0- to 30-cm SOC from the National Soil Database within CanSIS for the soil profile under an agricultural land use (cropland). Thus, the total losses of SOC in grassland converted to cropland were calculated using an IPCC Tier 2 approach:

Equation A3-48:

$$\Delta C_{GL\text{-}CL} = \sum_{1951\text{–}2004} \sum_{ALL\ SLC} \sum_{t} (\Delta SOC_t * AERA_{GL\text{-}CL})$$

where:

$\Delta C_{GL\text{-}CL}$ = losses of SOC subject to conversion of grassland to cropland since 1951, Mg C

ALL SLC = all soil polygons that contain grassland

t = time after grassland conversion, years

ΔSOC_t = rate of carbon change at a particular time (t) after breaking, Mg C/ha per year

$AREA_{GL\text{-}CL}$ = area of grassland converted to cropland, ha

Losses of Soil Organic N and N_2O Emissions

From the data in Table A3-37, where changes in both soil organic nitrogen and SOC were determined, the average change in soil organic nitrogen was 0.06 kg N lost/kg C lost. Thus, the emissions of N_2O in grassland converted to cropland were calculated using an IPCC Tier 2 approach as:

Equation A3-49:

$$N_2O_{GL\text{-}CL} = \sum_{1951\text{–}2004} \sum_{ALL\ SLC} \sum_{t} (\Delta SOC_t * AERA_{GL\text{-}CL} * 0.06 * EF_{BASE}) * \frac{44}{28}$$

where:

$N_2O_{GL\text{-}CL}$ = emissions of N_2O subject to conversion of grassland to cropland since 1951, kt

ALL SLC = all soil polygons that contain grassland

t = time after grassland conversion, years

ΔSOC_t = rate of carbon change at a particular time (t) after breaking, Mg C/ha per year

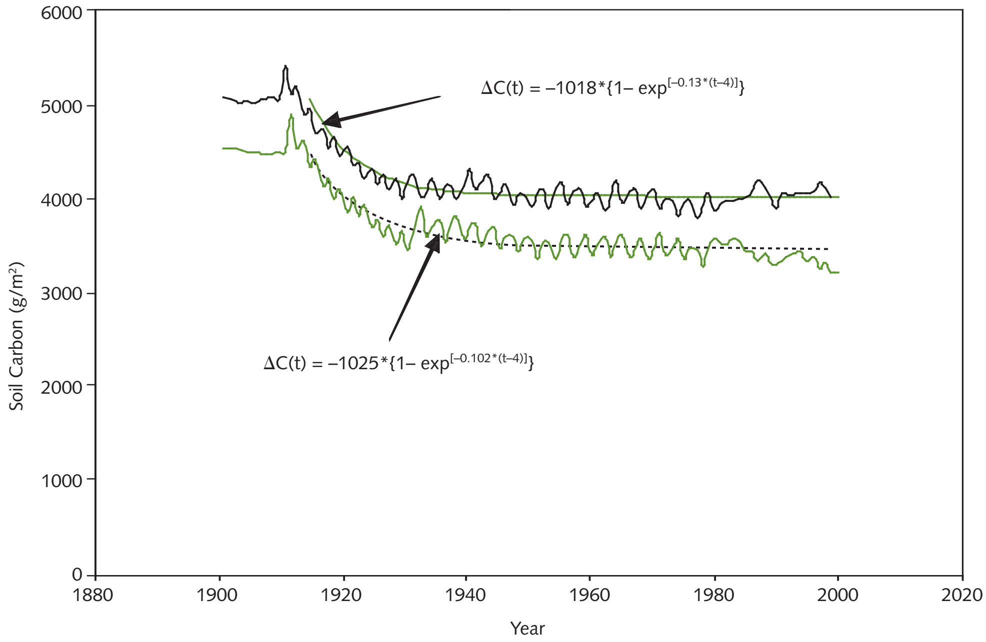
$AREA_{GL\text{-}CL}$ = area of grassland converted to cropland, ha

0.06 = conversion of carbon to nitrogen

EF_{BASE} = emission factor, defined as a function of P/PE at an ecodistrict level (refer to Section 6.4)

44/28 = molecular weight ratio of N_2O to N_2

FIGURE A3-16: **Soil Carbon Change since Breaking of Grassland to Cropland**



Data Sources

For the Census years of 1981, 1986, 1991, 1996, and 2001, unimproved pasture areas at the SLC level were obtained from the "reconfigured" Census of Agriculture database. For 1951, 1961, and 1971, provincial totals for unimproved pasture were disaggregated to SLCs based on the distribution in 1981. Within an SLC, unimproved pasture was allocated to soil components identified as "low" for "likelihood of being cropped." Once allocated to SLC polygons, area totals for unimproved pasture were aggregated to an ecodistrict or reporting unit level as required in each year from 1990.

SOC_{agric} is the 0- to 30-cm soil for each SLC that contains grassland derived from the National Soil Database within CanSIS for the soil profile under an agricultural land use.

A3.5.3.3 Forest Converted to Cropland

CO_2 and N_2O Emissions from Soils

Clearing forest to increase agricultural land is a declining but still significant practice in Canada. This section describes the methodology for estimating change in soil carbon and N_2O emissions associated with the soil disturbance. The method for estimating emissions from biomass upon conversion is presented in Section A3.5.2.3. For SOC change, there is a need to differentiate between the eastern and the western parts of the country.

Eastern Canada

Eastern Canada, generally all land in the provinces of Ontario, Quebec, New Brunswick, Prince Edward Island, Nova Scotia, and Newfoundland and Labrador, was forested before its land use changed to agriculture. There are many observations that compare SOC for land under forest with adjacent land under agricultural purposes in eastern Canada. The mean loss of carbon was 20.3% for a depth of approximately 30 cm (Table A3-38).

Comparing SOC for the existing soil database in CanSIS (Table A3-39) shows that, on average, SOC for the uppermost 30 cm of soil under agriculture was 20.5% less than under forest.

Although the SOC for forested land in Table A3-39 accounts for carbon in the litter layer above mineral soil, in practice, there is always uncertainty in quantifying the litter layer carbon and carbon within soil debris (Paul *et al*., 2002). Soil erosion, which is

TABLE A3-38: Summary of SOC and Soil Organic Nitrogen Changes from Forest Conversion to Agriculture[1]

References	Location	Vegetation Type		Time Frame	Depth	ΔC		ΔN		Soil Bulk Density-Adjusted?
		Pre	Post							
				(years)	*(cm)*	*(Mg C/ha)*	*(%)*	*(Mg C/ha)*	*(%)*	
Carter *et al*. (1998)	Eastern Canada	Coniferous forests with some deciduous species	Annual crops	>35	0–30	26	24	3.2	38	Yes
			Annual crops	>35	0–30	30	31	2.6	33	Yes
			Annual crops	>35	0–30	16	19	2.5	41	Yes
			Annual crops	>35	0–30	–50	–54	–3.9	–49	Yes
			Annual crops	>35	0–30	–10	–12	1.8	30	Yes
			Annual crops	>35	0–30	–23	–29	0.4	7	Yes
			Forage	>35	0–30	11	21	1.0	18	Yes
			Annual crops	>35	0–30	–7	–11	–0.6	–10	Yes
			Forage	>35	0–30	10	17	2.4	41	Yes
			Annual crops	>35	0–30	–44	–45	–1.1	–17	Yes
			Forage	>35	0–30	–27	–28	1.9	29.7	Yes
Coote and Ramsey (1983)	Ontario	Tree/grass/pasture	Cereal	>35	0–30	17	20.9	–	–	No
			Cereal	>35	0–30	–1.3	–1.7	–	–	No
			Cereal	>35	0–30	–37.3	–15	–	–	No
Ellert and Gregorich (1996)	Ontario	Pine	Cereal, soybeans	68	0–30	–22	–24	–1.2	–16	Yes
		White pine	Corn, forage	21	0–30	–28	–20	0.9	17	Yes
		White pine	Corn, forage	40	0–30	47	35	4.2	82	Yes
		Maple, beech	Oats, tobacco	50	0–30	–30	–55	–0.8	–38	Yes
		Hemlock, white pine	Cereal, forage	50	0–30	–91	–68	–1.6	–33	Yes
		Oak, ironwood	Cereal, soybean	50	0–30	–36	–38	–0.7	–12	Yes
		Red oak, white pine	Forage, cereal	50	0–30	–19	–23	0.4	7	Yes
		Maple, beech	Corn, soybean	50	0–30	–15	–8	0.3	2	Yes
		Pine, black spruce	Forage, cereal	53	0–30	–3	–4	0.3	7	Yes
		Pine	Corn, soybean	50	0–30	–24	–31	–0.2	–4	Yes
		Pine	Corn, soybean	20	0–30	–23	–28	–0.4	–8	Yes
		Jack pine	Forage, cereal	145	0–30	–20	–24	–1	–15	Yes
		Maple, beech	Forage, cereal	91	0–30	–42	–40	–1.9	–26	Yes
		Sugar maple	Forage, cereal	85	0–30	–37	–34	–2.1	–26	Yes
		Cherry orchard	Peaches, ryegrass	145	0–30	–17	–29	–1.7	–33	Yes
		Maple, beech	Corn, soybean	105	0–30	–62	–49	–3.7	–36	Yes
		Shagbark hickory	Corn, forage	50	0–30	–68	–47	–5.6	–43	Yes
		Maple, hemlock	Pasture	91	0–29	6	5	0.7	10	Yes
		Shagbark hickory	Pasture	50	0–25	–2	–15	–1.3	–15	Yes
		Shagbark hickory	Pasture	50	0–26	–4	–26	–2.9	–22	Yes
Gregorich *et al*. (1995)	Ontario	Mixed hardwood	Forage, corn	25	0–75	–28.6	–20	–	–	No
Martel and MacKenzie	Quebec	Forest	Cereal-hay	>50	0–30	–55	–28	–0.7	–8	No
						–36	–36	–2.4	–31	No
						–29	–25	–1.3	–22	No
Wanniarachchi *et al*. (1999)	Ontario	Forest	Corn	>50	0–50	–59.9	–45	–	–	No
Gregorich *et al*. (2001)	Ontario	Deciduous forest	Cereal, forage	90–100	0–20	–51.4	–48	–	–	No
Izaurralde *et al*. (2001)	Alberta	Trembling aspen	Cereal, forage	71	0–18	–22.1	–36	0.9	31.1	Yes
Ellert and Bettany (1995)	Saskatchewan	Native aspen	Annual crops	2	0–25	4.6	8.6	0.1	4.2	Yes
			Annual crop	81	0–25	–7.3	–14	0.4	12	Yes
			Pasture	85	0–25	–0.6	–1.1	0.9	26.7	Yes
Fitzsimmons *et al*. (2004)	Central Saskatchewan	Mixed wood	Annual crops	>60	0–30	–10.0	–13	–	–	Yes
			Pasture	>60	0–30	–23	–30	–	–	Yes
			Annual cereals	>60	0–45	–9	–11	–	–	Yes
			Pasture	>60	0–45	–18	–23	–	–	Yes
Pennock and van Kessel (1997)	Central Saskatchewan	Mixed wood	Small grains	>70	0–45	6	14	–	–	No
			Small grains	>70	0–45	–23	–19	–	–	Yes
			Small grains	80	0–45	–41	–35			Yes

Note:

1 Adapted from Murty *et al*. (2002).

generally assumed to increase under agriculture, also reduces measured SOC on agricultural land, and differing erosion rates between sites add to variability.

The CENTURY model (Version 4.0) was used to estimate the SOC dynamics from forest conversion for two locations in Ontario (Figure A3-17). In the first years after deforestation, there is an increase in soil organic matter, as litter and aboveground and belowground DOM become part of SOC. After a few years, SOC declines below the amount of SOC that existed before deforestation. The rate of SOC decline gradually decreases with time.

Neglecting the initial SOC increase, these SOC dynamics were described by the following equation:

Equation A3-50:

$$\Delta SOC(t) = \Delta SOC_{Dmax} * [1 - \exp^{(-k_D * (t - t_{lag}))}]$$

where $\Delta SOC(t)$ is the change in SOC over time, ΔSOC_{Dmax} is the maximum ultimate change in SOC from deforestation to agriculture, k_D is the rate constant for describing the decomposition, t is the time since deforestation, and t_{lag} is the time lag before ΔSOC becomes negative. For the example shown in Figure A3-17, 25% of carbon is lost within 20 years of deforestation and 90% within 100 years.

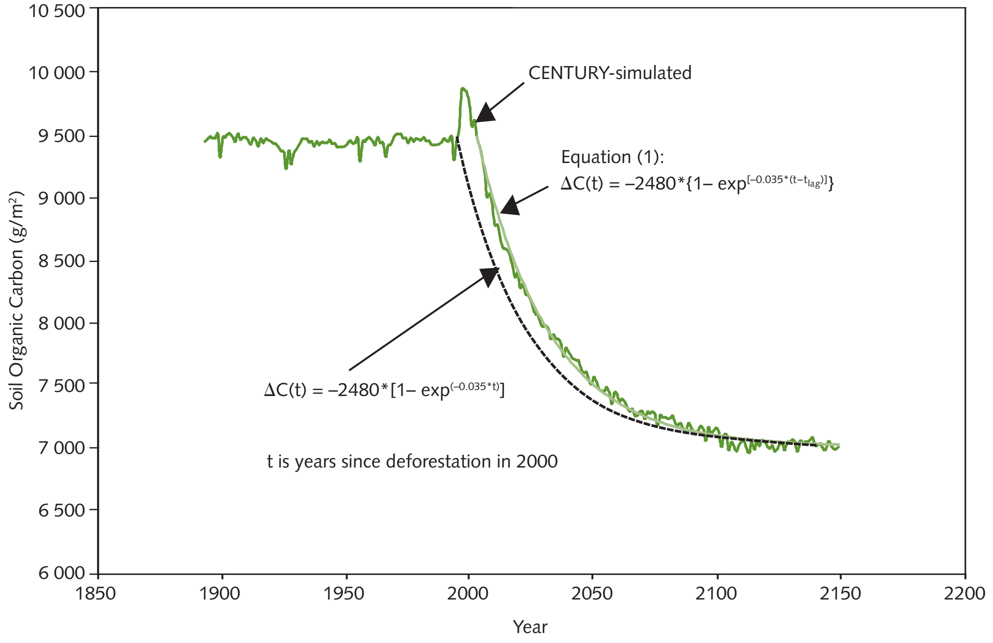
TABLE A3-39: SOC for Forested and Agricultural Land in Eastern and Western Canada from the Canadian Soil Information System Database (0- to 30-cm soil depth)

Soil Texture	Soil Organic Carbon		
	Forested Land	Cropland	Difference
	(Mg C/ha)		(%)
Eastern Canada			
Coarse	85 (26)[1]	68 (42)	–19
Medium	99 (38)	77 (35)	–22
Fine	99 (58)	78 (36)	–21
Western Canada			
Coarse	73 (39)	74 (38)	0
Medium	66 (30)	73 (30)	4
Fine	74 (38)	77 (25)	1

Note:

[1] Standard deviation in parentheses.

FIGURE A3-17: CENTURY-Simulated SOC Following Deforestation of Long-Term Deciduous Forest to Cropland



Note:
Equation (1) was fitted to the SOC after the SOC dropped below the amount present immediately before deforestation.

Given the uncertainty of actual dynamics, it was assumed that there is no time lag in SOC loss from deforestation, so that soil carbon starts to decline immediately upon deforestation: i.e., the fitted SOC loss (i.e., Equation A3-50) is used to estimate SOC loss with time lag set to 0 after fitting. Fitting Equation A3-50 to the simulations shown in Figure A3.17 produces a mean k_D of 0.0262/year. Using this value, 92.7% of SOC loss would occur by 100 years after deforestation. The result of these assumptions is conservative with regard to carbon loss after deforestation, as it is, arguably, more likely to overestimate than to underestimate SOC loss from deforestation to agriculture.

It was decided to use the mean loss of 20.5% of SOC resulting from deforestation to agriculture for eastern Canada based on CanSIS information. This value is similar to the mean value of 20.3% for the upper 30 cm depth based on specific field comparisons for this region (Table A3-38). It was assumed that the 20.5% value corresponded to about 100 years after deforestation, so the ΔSOC_{Dmax} is 1/0.927 times this value, or 22.1% of SOC under long-term forest. As the CanSIS soil database has more data on SOC for conditions under long-term agriculture than of SOC under long-term forest in areas where agriculture exists, we chose to estimate this loss from SOC under agriculture (i.e., loss = 0.221/(1–0.221) × SOC or loss = 0.284 × SOC under agriculture). Therefore, the final equation for estimating SOC loss for deforestation to agriculture in eastern Canada is:

Equation A3-51:

$$\Delta SOC(t) = 0.284 * SOC_{agric} * [1 - \exp^{(-0.0262 * t)}]$$

where $\Delta SOC(t)$ is the change of SOC over time, SOC_{agric} is the 0- to 30-cm SOC from CanSIS for a soil profile under an agricultural land use (cropland), k_D (0.0262) is the rate constant for describing the decomposition, and t is the time since deforestation. Thus, the total amount of SOC lost from forest land converted to cropland is estimated to be:

Equation A3-52:

$$\Delta C_{FL\text{-}CL} = \sum_{ALL\ SLC} \sum_{t1,t2} \sum_{t1+1,t2} (\Delta SOC_t * AERA_{FL\text{-}CL,t})$$

where $\Delta C_{FL\text{-}CL}$ is the total carbon loss in forest land converted to cropland annually since 1970 (t1), t2 is the most recent year, ΔSOC_t is defined in Equation A3-50, and $AREA_{FL\text{-}CL,t}$ is the area of forested land converted to cropland annually since 1970. Note that the SOC loss predicted by Equation A3-50 is in addition to carbon released from removal of carbon in above- and belowground tree biomass and from removal or decay of other above- and belowground coarse woody DOM that existed in the forest at the time of deforestation.

From Table A3-38, average nitrogen change in eastern Canada was –5.2%, representing 0.4 Mg N/ha. For those comparisons where both nitrogen and carbon loss was determined, the corresponding carbon loss was 19.9 Mg C/ha, and carbon loss was 50 times nitrogen loss. For simplicity, it was assumed that nitrogen loss was a constant 2% of carbon loss. Thus, N_2O emissions from forest land converted to cropland are estimated as:

Equation A3-53:

$$N_2O = \Delta C_{FL\text{-}CL} * 0.02 * \frac{44}{28}$$

■ Western Canada

Much of the current agricultural soil in western Canada (Manitoba, Saskatchewan, Alberta, and British Columbia) was grassland prior to cultivation. Hence, deforestation has been primarily of forest that adjoins grassland areas. There is also limited deforestation of secondary forest that has grown on former grassland since the suppression of wildfires with agricultural development. Since deforestation has been less important than in eastern Canada, there are fewer comparisons of SOC under forest and agriculture in the literature.

The CanSIS data provide the most numerous comparisons of SOC under forest with that under agriculture (Table A3-39). On average, these data indicate that there is no loss of SOC from deforestation. This indicates that, in the long term, the balance between carbon input and SOC mineralization remains similar under agriculture as it was under forest.

It is important to recognize that the northern fringe of western Canadian agricultural areas, where most deforestation is occurring, is marginal for arable agriculture, and this pasture and forage crops are the primary agricultural uses after clearing. From Table A3-38, generally, loss of carbon from forest to agriculture is least where agricultural land contains forages and pastures. In fact, frequently, SOC was found to be greater under forages than under forest. Fuller and Anderson (1993) determined that after 40–50 years under forest, SOC was about 40% less than under native grass at an upland site and about 15% less at a lowland site in central Saskatchewan. Similarly, for afforestation of pasture, Paul *et al*. (2002) reported that, on average, there is a slight loss in SOC, whereas there is generally a gain when afforesting land in annual crops.

Some of the paired comparisons do show less SOC under agriculture than under forest. Similar to the situation described for eastern Canada, some of this variability may be due to differential erosion rates for paired comparisons. In comparisons involving upland landform elements, agricultural soils can have much less SOC than adjacent uncultivated soils, but most of that apparent SOC loss is redistribution of SOC within the landscape rather than net loss (Pennock *et al*., 1994; Gregorich *et al*., 1998). Consequently, paired comparisons between forest and agriculture that do not include the entire landform will tend to underestimate carbon in the agricultural land. Also, as discussed for eastern Canada, variability in carbon mass in litter and other detritus can produce variability in SOC comparisons.

For western Canada, no loss of SOC over the long term was assumed from deforestation to agriculture. Therefore, the carbon loss from deforestation in western Canada would be from losses of carbon in above- and belowground tree biomass and coarse woody DOM that existed in the forest at the time of deforestation. Similarly, from Table A3-38, average nitrogen change in western Canada for sites at least 50 years from breaking was +52%, reflecting substantial added nitrogen in agricultural systems compared with the situation in forests. However, recognizing the uncertainty about actual carbon–nitrogen dynamics for deforestation, for purposes of N_2O accounting, forest land converted to cropland was assumed not to be a source of N_2O.

Data Sources

The approach used to estimate the area of forest land converted to cropland is described in Forest Conversion under Section A3.5.2.2. The annual forest conversion by reconciliation unit was disaggregated to SLC polygons on the basis of concurrent changes in the area of cropland within SLC polygons. Only polygons that showed an increase in cropland area for the appropriate time period were allocated deforestation, and the amount allocated was equivalent to that polygon's proportion of the total cropland increase within the reconciliation unit.

Uncertainties

Conversion of grassland to cropland was determined from information in the Census, so the basic method of estimating the uncertainty of carbon change is similar to that outlined for LMC on cropland. The exception was that error propagation was not used, because it was assumed that uncertainty of carbon loss from conversion of grassland to cropland was skewed, so that there is more likelihood of larger carbon losses than small carbon losses. The mean loss was assumed as outlined previously, but the distribution was assumed to be lognormal with a standard deviation of 50% of mean loss. This uncertainty reflects the fact that there are no instances where there has not been an observed loss of carbon from the conversion of grassland to cropland and several instances of large relative losses.

A3.5.4 GRASSLANDS

Agricultural grassland is defined as "unimproved pasture" used for grazing domestic livestock in geographical areas where grassland would not naturally revert to forest if abandoned: southern Saskatchewan and Alberta and a small area of southern British Columbia. These grasslands developed under millennia of grazing by large animals such as bison and periodic burning. Essentially, agricultural grassland as defined is extensively managed native range. This grassland in Canada is ecologically similar to grassland in adjacent areas of the United States, including much high-elevation grasslands in mountainous western states.

The primary direct human activities on agricultural grassland in Canada are burning, adding new plant species into the grassland, and the amount, duration, and timing of grazing by domestic livestock.

A3.5.4.1 Data Sources

The activity data are developed from various data sources, including the Census of Agriculture, which enumerates all farms every five years, and other data collected by governments and industry associations.

The amount of "managed grassland" is identified as that land that farmers in the identified SLC polygons call "unimproved pasture" when participating in the Census. The existence of native grassland remaining grassland areas within SLC polygons outside of the Prairies ecozone is based on the presence of certain soil types by expert knowledge. The occurrence of Chernozems, Sombric Brunisols, and Melanic Brunisols under native conditions in the SLC component file, primarily within British Columbia, was assumed to indicate areas of native grassland.

For 1981, 1986, 1991, 1996, and 2001, unimproved pasture values at the SLC level were obtained from the Census of Agriculture database. For 1951, 1961, and 1971, provincial totals of unimproved pasture were disaggregated to SLCs based on the distribution in 1981. Within an SLC, unimproved pasture was allocated to soil components identified as "low" for "likelihood of being cropped." Once allocated to SLC polygons, area totals for unimproved pasture were aggregated to an ecodistrict or reporting zone level as required in each year from 1990.

A3.5.4.2 General Approach and Methods

State of Grassland

The Prairie Farm Rehabilitation Administration (2000) conducted an assessment of range in the Prairies ecozone from public land agencies and from expert opinion of rangeland professionals and reported that about one-half of range in Canada was in poor condition. They also noted that range management systems had improved over past several decades, and the major challenge is to improve range in poor to good condition as opposed to preventing further decline of range condition. The advantages of good condition are better productivity in terms of grazing and improved biodiversity. However, there is no clear relationship between range condition and SOC. Henderson *et al*. (2004) compared ungrazed enclosures rated in excellent condition with adjacent grazed pastures in poor to good condition. They found no consistent effect of range conditions on SOC. Dormaar and Willms (1990) found significantly more SOC in range in poor than in good condition because range in poor condition was dominated by grass species that provide greater root input of carbon to the soil.

Invasion of grassland with tame grass species is an important problem for Canadian grassland (Prairie Farm Rehabilitation Administration, 2000) because of negative effects on biodiversity (Bai *et al*., 2001). Soils that have been cultivated and then seeded to tame grasses have lower SOC than undisturbed soil remaining in native range (Dormaar *et al*., 1995; Christian and Wilson, 1999). However, SOC is not affected by invasion of tame grasses into native range (Henderson and Naeth, 2005) or intentionally seeded directly into native range without prior cultivation of the native range (Broersma *et al*., 2000).

According to the IPCC Good Practice Guidance for LULUCF (IPCC, 2003), grassland in temperate/boreal regions in degraded conditions has 95% of the SOC of that in non-degraded conditions, indicating opportunity to change SOC by changing conditions of the grass. However, this estimate includes mostly grassland types, especially seeded pastures, not representative of Canadian grassland as defined for GHG inventory purposes. Much of the potential SOC gain from grazing management on rangeland has been from increasing grazing on grassland that has previously been ungrazed or lightly grazed (Conant *et al*., 2001; Schuman *et al*., 2002; Liebig *et al*., 2005), but that opportunity is small in Canada, as its agricultural grassland is already well grazed (Lynch *et al*., 2005). In a modelling study, Lynch *et al*. (2005) estimated a negligible 0.060–0.180 Mg/ha increase in SOC over 30 years from improved grazing management of rangeland compared with the traditional season-long grazing regime in southern Saskatchewan. Bruce *et al*. (1999) estimated that there was no opportunity to increase SOC from grazing management improvements on extensively managed rangeland in North America.

Effect of Grassland Management on SOC

There are a number of studies of the effects of grazing versus no grazing on SOC. The effects of grazing compared with those of no grazing are inconsistent. Studies have shown increased SOC from grazing compared with no grazing (Dormaar *et al*., 1994; Wienhold *et al*., 2001), no effect (Willms *et al*., 2002), and decreased SOC (Bauer *et al*., 1987; Dormaar *et al*., 1997). Dormaar *et al*. (1977) showed that there was no consistent effect of grazing, but that the apparent effect depended greatly on season of sampling and timing of sampling relative to grazing pressure.

Grazing has not been shown to affect annual CO_2 fluxes (LeCain *et al*., 2002).

Reeder and Schuman (2002) showed that SOC was greater for heavy grazing pressure than for moderate grazing pressure. Schuman *et al*. (1999) and Frank *et al*. (1995) found similar results, but later sampling at those same sites showed that SOC for heavy grazing was not greater than that for moderate grazing (Wienhold *et al*., 2001; Ganjegunte *et al*., 2005). Naeth *et al*. (1991) found that there was no effect of grazing on total SOC but that early-season (before July) grazing was more detrimental to carbon inputs to soil than late-season (after July) grazing. Manley *et al*. (1995) found no effect of grazing regime, including rotational grazing, on SOC.

Although the productivity of heavily grazed pasture is lower, which may lead to a decline in range conditions, this was not related to declines in SOC (Biondini and Manske, 1996). The effect of grazing regime is complex, because of the effects of grazing on plant community and effects on carbon input to soil from both above- and belowground plant growth (Schuman *et al*., 2002; Liebig *et al*., 2005). An additional influence of grazing regime is the increased return of carbon in fecal matter as stocking rate increases (Baron *et al*., 2002). Dormaar *et al*. (1997) concluded that soil under native grassland is very resilient to grazing pressure with regard to total SOC.

Prior to agricultural development, the grassland burned regularly, but burning is now aggressively suppressed. Burning of range increased SOC in Canada (Anderson and Bailey, 1980). This effect has been widely observed globally through the production of relatively stable "black carbon" (Gonzalez-Perez *et al*., 2004). However, because of the stability of such black carbon, which is responsible for net SOC increases from periodic burning, current suppression of fire may be preventing further increases in SOC. Nevertheless, there is no reason to conclude that fire suppression is producing significant decreases in SOC. Annual CO_2 fluxes indicate that grazed grassland with no burning does not appear to be either a source or sink of CO_2 in the long term (Frank, 2002).

The addition of organic amendments and inorganic fertilizer will increase the productivity of native grassland (Smoliak, 1965), suggesting that these practices could increase SOC through greater carbon inputs. However, such practices are basically of academic interest, as the only economically practical management options for semiarid grasslands are altering grazing regime, burning, and introducing new plant species (Liebig *et al*., 2005).

There are no detailed comprehensive activity data on management change for Canadian agricultural grassland. However, even if there were such data, there is no indication that this grassland is or will be losing or gaining SOC in response to direct human activity. Therefore, Canada has chosen not to estimate carbon change on its agricultural grassland.

A3.5.5 WETLANDS

A3.5.5.1 Peatlands

Approximately 14 kha of peatlands are currently managed in Canada for the production of horticultural peat. The cumulative area of peatlands ever managed for this purpose amounts to 18 kha, the difference being peatlands that are no longer under production. Canada does not produce peat as a fuel.

Virtually all peat extraction in Canada relies on the vacuum harvest technology. However, many abandoned peat extraction fields were once exploited with the cut-block method; this influences the post-abandonment dynamics of vegetation regrowth. Owing to the extraction technology and desired properties of sphagnum peat, at the time of site selection, preference is given, among other factors, to peatlands with little woody vegetation (Canadian Sphagnum Peat Moss Association).[53]

General Approach and Methods

Only CO_2 emissions from lands converted to wetlands (peatlands) and peatlands remaining peatlands were estimated. The estimation included the following sources: vegetation clearing and subsequent decomposition and decay of organic soils on sites drained during the inventory year, fields under

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[53] Available online at: www.peatmoss.com/pm-harvest.php.

production, peat stockpiles, abandoned peat fields, and restored peatlands. Occasionally, the vegetation cleared for peat extraction meets the definition of forest. In these instances, estimates of merchantable wood removal were produced separately, using the same approach as for forest-related land-use change (see Section A3.5.2).

In any inventory year, emissions from land converted (being drained) for peat extraction are expressed by Equation A3-54 (Waddington *et al*., in preparation):

Equation A3-54:

$$CO_2\text{-}C_{L\_Peat} = CO_2\text{-}C_{\text{DOM current}} + CO_2\text{-}C_{\text{DOM residual}} + CO_2\text{-}C_{\text{SOILS drained}} + CO_2\text{-}C_{\text{SOILS extraction}} + CO_2\text{-}C_{\text{SOILS stockpiles}}$$

where:

$CO_2\text{-}C_{L\_Peat}$ = total carbon emissions as CO_2 from land converted to wetlands (for peat extraction)

$CO_2\text{-}C_{\text{DOM current}}$ = carbon emissions as CO_2 from the decay of vegetation cleared in the current inventory year

$CO_2\text{-}C_{\text{DOM residual}}$ = carbon emissions as CO_2 from the decay of vegetation cleared on previous years (but no more than 20 years prior to the inventory year)

$CO_2\text{-}C_{\text{SOILS drained}}$ = carbon emissions as CO_2 from the oxidation of soil organic matter on peatland drained during the inventory year

$CO_2\text{-}C_{\text{SOILS extraction}}$ = carbon emissions as CO_2 from the oxidation of soil organic matter on productive peatlands converted for 20 years or less

$CO_2\text{-}C_{\text{SOILS stockpiles}}$ = carbon emissions as CO_2 from the oxidation of stockpiled peat on productive peatlands converted for 20 years or less

Pre-conversion biomass is estimated at an average 20 t C/ha (unless the original vegetation forest is cover, in which case average forest stand characteristics of the area were used by the CFM-CFS3). Upon clearing, all biomass carbon is transferred to DOM, which begins to decay on the same year, following an exponential decay curve.

On productive peat fields, emissions are expressed as in Equation A3-55:

Equation A3-55:

$$CO_2\text{-}C_{\text{Peat}} = CO_2\text{-}C_{\text{DOM residual}} + CO_2\text{-}C_{\text{SOILS extraction}} + CO_2\text{-}C_{\text{SOILS stockpiles}} + CO_2\text{-}C_{\text{SOILS abandoned}} + CO_2\text{-}C_{\text{SOILS restored}}$$

where:

$CO_2\text{-}C_{\text{DOM residual}}$ = carbon emissions as CO_2 from the decay of remaining vegetation cleared on previous years

$CO_2\text{-}C_{\text{SOILS extraction}}$ = carbon emissions as CO_2 from the oxidation of soil organic matter on peatlands converted for more than 20 years

$CO_2\text{-}C_{\text{SOILS stockpiles}}$ = carbon emissions as CO_2 from the oxidation of stockpiled peat on peatlands converted for more than 20 years

$CO_2\text{-}C_{\text{SOILS abandoned}}$ = carbon emissions/removals as CO_2 resulting from the net ecosystem production of abandoned peatlands

$CO_2\text{-}C_{\text{SOILS restored}}$ = carbon emissions/removals as CO_2 resulting from the net ecosystem production of restored peatlands

Soil emissions from a productive peat field "$CO_2\text{-}C_{\text{SOILS extraction}}$" are estimated with a single emission factor reflecting peat oxidation rates. Emissions from peat stockpiles are calculated as an exponential decay.

Abandoned peat fields remain a persistent source of atmospheric CO_2 (Waddington and McNeil, 2002), until carbon uptake by regrowing vegetation exceeds soil and DOM decay. In the current model, the emission factor on abandoned fields is reduced by a fixed annual amount to reflect the effect of gradual vegetation establishment and the slow decrease of emissions over several decades.

Current restoration practices consist of blocking drainage ditches, sowing the field with fresh moss spores, and spreading a layer of straw on abandoned peat fields (to prevent desiccation). In the initial years of restoration, straw decomposition may further increase CO_2 emissions, until vegetation is reestablished. Net carbon sequestration on restored peat fields is assumed to occur after five years (Waddington *et al*., in preparation), and its rate is subsequently maintained constant.

It is assumed that the non-growing season is six months long. In that period, emissions represent 15% of the annual total ecosystem CO_2 respiration, and gross ecosystem production is zero during the non-growing season. Table A3-40 lists the main parameter values applied in estimate development. Uncertainty estimates were obtained from expert judgement.

TABLE A3-40: Parameters and Emission Factors for Estimating CO_2-C Emissions from Wetlands (Peatlands)

Emission Factor/Parameter	Unit	Value	Uncertainty (%)
Biomass cleared	t C/ha	20	100
Exponential decay constant, DOM	–	0.05	75
Emission factor on newly drained fields	g CO_2-C/m^2 per year	351	75
Emission factor on productive fields	g CO_2-C/m^2 per year	1019	75
Exponential decay constant, stockpiles	–	0.05	75
Annual decrease in emission factor, abandoned fields	–	–	–
Vacuum-harvested	g CO_2-C/m^2 per year	15	75
Block-cut	g CO_2-C/m^2 per year	35	75
Emission factor, restored peatlands	–	–	–
First year	g CO_2-C/m^2 per year	1753	75
>Five years	g CO_2-C/m^2 per year	–84	75

Data Sources

Little information on the area of peat production is available in Canada. For the purpose of this submission, current and historical areas were estimated and extrapolated from the results of a questionnaire to the Canadian peat industry (Cleary, 2003). The annual area drained for peat extraction was assumed to be equal to the difference in total production areas between successive years, less abandoned and restored peatlands. With the vacuum harvest technology, the average lifetime of a productive peat field is assumed to be 35 years (Cleary, 2003). By default, land converted for more than 20 years is reported in the category "wetlands (peatlands) remaining wetlands (peatlands)."

Uncertainties

Emission factors were derived from flux measurements made mostly over abandoned peatlands, which introduces significant uncertainty when applied to actively managed peatlands, and peat stockpiles. All measurements were conducted in eastern Canada, adding uncertainties to estimates in western Canada. A single estimate of pre-conversion biomass carbon density (20 t C/ha) was assumed, except when suitable information on forest conversion to managed peatlands was received from the CFS, in which case emissions from merchantable biomass were added.

It is very difficult to obtain up-to-date information on the areas of managed peatlands; areas reported here were modelled based on peat production data (Cleary, 2003). This introduces a significant uncertainty, since production is strongly influenced by summer weather conditions; fluctations in peat production should not, in theory, modify the area under management. In addition, the fate of abandoned peatlands is not monitored in Canada; older peat fields could have been converted to other uses. Therefore, the area estimate of abandoned peatlands is probably conservative.

Finally, soil drainage may affect the surrounding peatlands, even though these would not be actively managed. Should this be the case, the impact of peatland drainage should be estimated based on an area larger than the peat extraction sites.

A3.5.5.2 Flooded Lands

General Approach and Methods

Following IPCC Good Practice Guidance for LULUCF (IPCC, 2003), emissions from land converted to wetlands (creation of flooded lands, namely reservoirs) were estimated for all known reservoirs flooded for 10 years or less. Only CO_2 emissions are reported. An IPCC Tier 2 method was used, whereby country-specific CO_2 emission factors were developed based on measurements, as described below. It is believed that the default approach, assuming that all biomass carbon would be emitted upon flooding, would overestimate emissions from reservoir creation, because the majority of submerged vegetation does not decay for an extended period of time

Two estimation methodologies were used to account for GHG fluxes from flooded lands, depending on land conversion practices. When there was evidence of forest clearing during reservoir construction, carbon stock changes were estimated as in all forest conversion events, with the CBM-CFS3 (see Section A3.5.5.2 above). In the absence of such evidence, it was assumed that all vegetation was simply flooded. Evidence of forest clearing was restricted to the margins of future reservoirs located in reporting zones 4 and 5. The two methodologies are mutually exclusive, since they apply to different land areas.

The estimation of CO_2 emissions from the surface of reservoirs is described below. The proportion of the area flooded that was previously forested was used to attribute emissions to either "forest land converted to wetlands" or "other land converted to wetlands."

Since 1993, measurements of CO_2 fluxes have been made above some 57 hydroelectric reservoirs in four different provinces: Quebec, Manitoba, British Columbia, and Newfoundland and Labrador (Duchemin, 2006). In most studies, the reservoirs were located in watersheds little affected by human activities, with the notable exception of Manitoba. In almost all cases, only diffusive fluxes of CO_2, CH_4, or N_2O (in order of frequency) were measured. Studies on ebullition, degassing emissions, and winter emissions are rare and insufficient to support the development of domestic emission factors. Out of these measured reservoirs, a subset of 25 was selected to develop two separate regional emission curves for the 20-year period following impoundment. The emission curve for the Montane Cordillera (reporting zone 14) was developed from 16 reservoirs and a total of 16 measurements. For the Taiga/Boreal region (reporting zones 4, 5, 8, and 10), the emission curve was developed from nine reservoirs and a total of 17 measurements (Figure A3-18). It is important to note that each of these measurements (data points in Figure A3-18) represents on average the integration of between 8 and 28 flux samples per reservoir.

Non-linear regression analysis was used to parameterize the emission curves, of the form:

Equation A3-56:

$$CO_{2\ rate\ L\_reservoir} = b0 + b1 * \ln(t)$$

where:

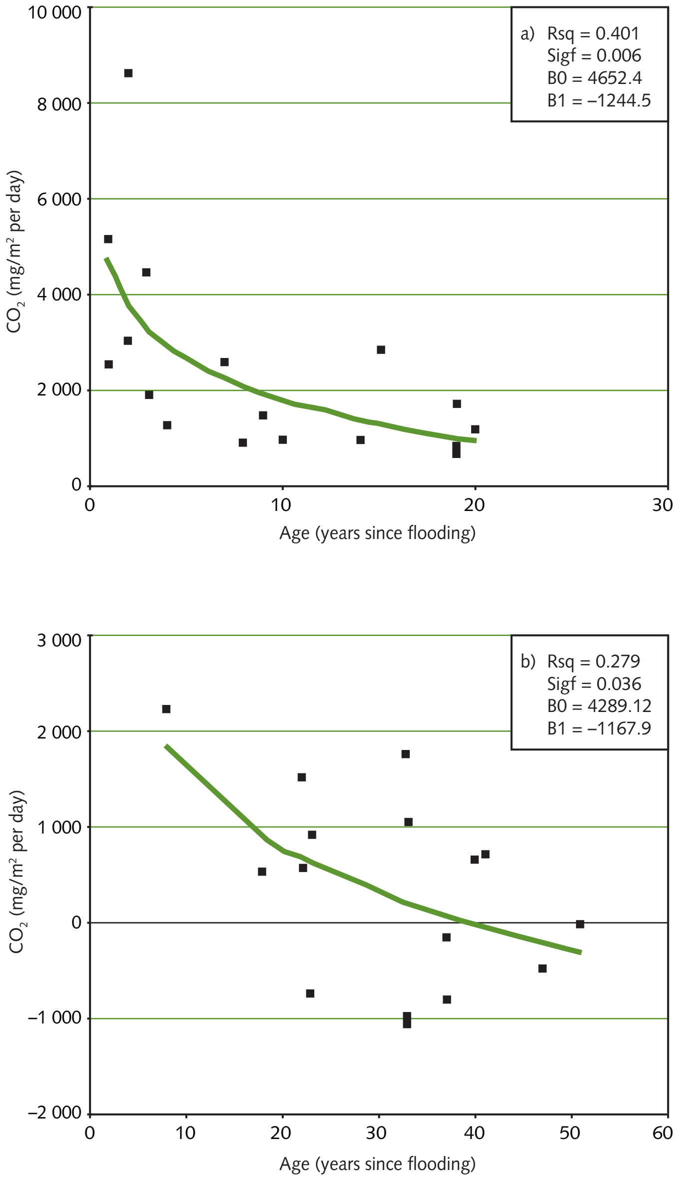
$CO_{2\ rate\ L\_reservoir}$ = rate of CO_2 emissions from land converted to wetlands (reservoirs), mg/m² per day

b0, b1 = curve parameters, unitless

t = time since flooding, years

The relations between diffuse CO_2 flux and age of reservoir were weaker and less significant for the Montane Cordillera. Of particular note is that there were only two sample flux measurements less than 20 years of age in the model fit for the Montane Cordillera.

FIGURE A3-18: Logarithmic Curve Fits for (a) Taiga/Boreal Reservoirs and (b) Cordillera Reservoirs



Note:
Curve parameters are provided, as well as the coefficients of determination and their significance.

Total CO_2 emissions from reservoirs were estimated as the sum of all emissions from reservoirs flooded for 10 years or less:

Equation A3-57:

$$CO_{2\ L\_reservoirs} = \sum_{reservoirs} (CO_{2\ rate\ L\_reservoir} * A_{reservoir} * Days_{ice\ free} * 10^{-8})$$

where:

$CO_{2\ L\_reservoirs}$ = emissions from lands converted to flooded lands (reservoirs), Gg CO_2/year

$CO_{2\ rate\ L\_reservoir}$ = rate of CO_2 emissions for each reservoir, mg/m^2 per day

$A_{reservoir}$ = reservoir area, ha

$Days_{ice\ free}$ = number of days without ice, days

Ice-free period was defined as the average number of days between the observed freeze date and the breakup date of ice cover on a body of water (Magnuson *et al*., 2000). In the case of hydroelectric reservoirs, locations were mapped and estimates of the ice-free period were generated from the lakes–ice-free period isoline map of Canada (Natural Resources Canada, 1974).

Following the guidance in IPCC Good Practice Guidance (Section 3a.3 of IPCC (2003)), $A_{reservoir}$ was used as the best available estimate of the land-use change area.

Emissions were calculated starting from the year that flooding to fill the reservoir is complete. Reservoirs take a minimum of one year to fill following dam completion, unless otherwise confirmed.

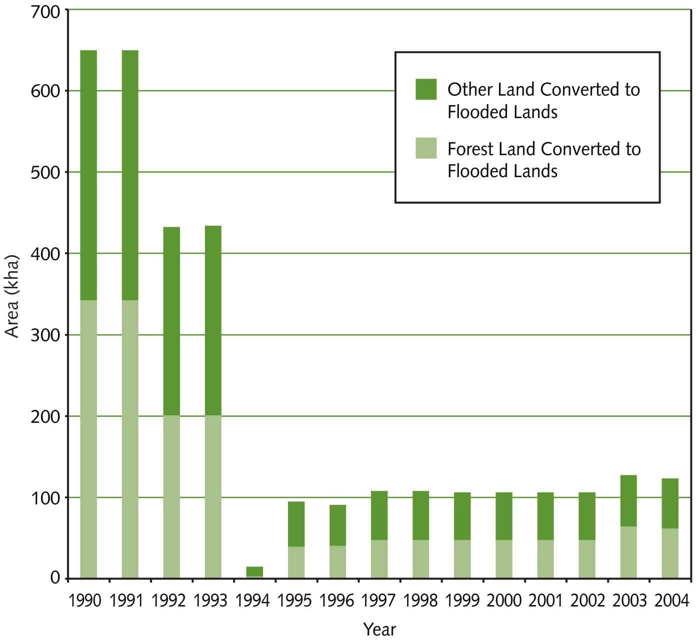
Data Sources

The two main data sources used to develop area estimates were i) information received on forest conversion due to reservoir impoundment in reporting zones 4 and 5 (see Section A3.5.2.2); and ii) the Canadian Reservoir Database (Duchemin, 2002). The database contains 421 records of hydro reservoirs dating back to 1876. Of these reservoirs, 110 have a known surface area totalling 3 452 786 ha. The average reservoir size is 31 388 ha. The distribution of reservoir area is skewed, with 25% of the largest reservoirs representing over 95% of all reservoir area in Canada.

Since CO_2 emissions are reported only for the 10 years following impoundment, all hydroelectric flooding events since 1980 were identified. Information from provincial and private hydroelectric utilities was accessed to update the database and cross-check the date of reservoir construction and the total reservoir area for all these reservoirs. In some instances, the database reported as new facilities some small, refurbished hydroelectric generation sites in the province of Quebec that entered into production under a new ownership. As a result, a separate category was added to the database to document both the original construction and commissioning of a dam and the date when a hydroelectric facility was refurbished but no changes occurred to the reservoir area.

The trend in area flooded is characterized by two distinct periods (Figure A3-19). The first, prior to 1994, was marked by large-scale flooding, which occurred in the early 1980s and still appeared as land converted to wetlands in the 1990–1993 inventory years. After 10 years, these reservoirs were removed from the accounting, and there was a corresponding decrease in the area to a low in 1994. From 1994 to 2004, there was a small but consistent increase in new reservoir areas, with the occurrence of several small to medium-scale flooding events. For comparison, in 2004, eight reservoirs were included in the assessment, for a total of 123 kha, versus six reservoirs and 650 kha in 1990.

FIGURE A3-19: **Cumulative Areas in the Category "Lands Converted to Wetlands (Flooded Lands)"**



It is important to note that fluctuations in the area of lands converted to wetlands (reservoirs) reported in the CRF tables are not indicative of changes in current conversion rates, but reflect the difference between land areas recently (<10 years ago) converted to reservoirs and older reservoirs (>10 years), whose areas are thus transferred out of the accounting. The reporting system does not encompass all the reservoir areas in Canada, which is monitored separately in the Canadian Reservoir Database.

Uncertainty

A temporal curve better reflects the decreasing trends of emission rates after impoundment than a unique emission factor. Hence, the domestic approach is believed to reduce the uncertainty in estimation factors. However, important remaining sources of uncertainty are:

1. The use of two emission curves to represent all recently flooded reservoirs in Canada. While in eastern Canada the time since flooding explains approximately 80% of inter-reservoir variability in CO_2 emissions, in the west, the same parameter accounts for only 50% of the variability (Duchemin, 2006). However, the relative contribution of western reservoirs to the total emissions represents less than 2% of total emissions during the reporting period.
2. Seasonal variability. Some reservoirs display marked seasonal variability in CO_2 fluxes, which are not taken into account in estimate development. Anecdotal evidence suggests that algal bloom in the spring could be associated with this variability, especially in reservoirs subjected to anthropogenic nutrient inputs.
3. The omission of potentially important CO_2 emission pathways, e.g., degassing.

Planned Improvements

As mentioned in Chapter 7 (Section 7.7.2.2), the possibility of double-counting carbon emissions in the wetlands and other land categories is not fully eliminated. Planned improvements include refining the methodology to further minimize the potential double-counting of carbon emissions; improving, in partnership with industry, the activity data on reservoirs; and including flooded lands other than hydroelectric reservoirs as appropriate.

A3.5.6 SETTLEMENTS

Emissions and removals in this category comprise urban tree growth (settlements remaining settlements) and emissions from land conversion to settlements. This submission reports emissions from the conversion of forest land to settlements and of tundra to settlements. Approaches, methods, and data sources for estimating emissions from the conversion of forest land to settlements are covered in Section A3.5.2. This section describes estimate development for the conversion of non-forest land to settlements in the Canadian Arctic and sub-Arctic.

A3.5.6.1 General Approach and Methods

The Canadian northern regions (Arctic and sub-Arctic) cover nearly half of Canada's landmass and include five land categories (sensu IPCC, 2003) except cropland. This assessment covered an area of about 359 million hectares and included reporting zones 1, 2, 3, and 17 as well as, reporting zones 13 and 18 north of 60°N latitude. The challenge was to capture land-use change and estimate associated emissions in this vast and remote landscape. An approach was developed specifically for this task and included the following components:

1. Map non-forest land-use change in Canada's Arctic/sub-Arctic prior to and including 1990 and between 1990 and 2000.
2. Estimate annual GHG emissions (aboveground biomass only) from non-forest land-use change in Canada's Arctic/sub-Arctic for the period 1990–2000.

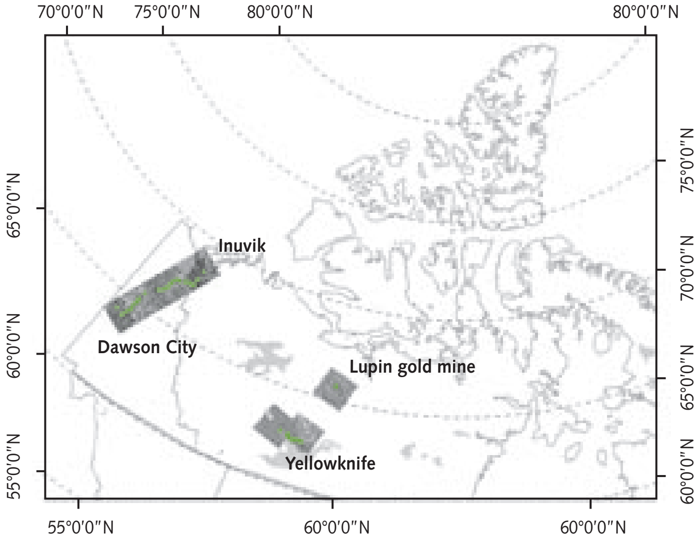
A comprehensive, wall-to-wall analysis over this area was clearly impractical, as this would require on the order of 400 Landsat satellite scenes for each date. Similarly, random sampling would likely not capture enough land-use change events to allow a reliable assessment. Instead, GIS data sets denoting the occurrence of cultural, mining, and other human development were used to reduce and optimize the domain of investigation, by flagging areas with high probability of occurrence of land-use changes. These areas of concentrated land-use change potential were targeted for change detection analysis (change vector analysis; Johnson and Kasischke, 1998) using 23 Worldwide Reference System Landsat frames from circa 1985, 1990, and 2000. The scenes cover more than 8.7 million hectares, 56% of the potential land-use change area identified using the GIS data sets, or 70% of potential land-use change area if seismic survey lines are not included.[54] All 23 frames were located in the western Arctic and sub-Arctic regions.

The Land Use Change Mapping System for Canada's North was devised (Butson and Fraser, 2005), which can be described as a hybrid change detection method based on two separate techniques: change vector analysis for identifying changed areas and constrained signature extension for labelling those changes (Olthof *et al*., 2005). A detailed description of how the Land Use Change Mapping System for Canada's North was used for the purpose of capturing non-forest land-use change in Canada's north is available in Fraser *et al*. (2005). The average rate of land-use change between 1985 and 2000 over the assessed area was 666 ha/year, and 70% of land-use change areas occurred in reporting zone 13. Lack of available imagery prevented the implementation of the system beyond 2000; therefore, the same annual rate of land-use change was applied for the years 2001–2004.

Estimation of aboveground biomass affected by these land-use changes relied on a series of aboveground biomass maps for 2000, derived from actual aboveground biomass measurements conducted at two study areas (Figure A3-20) along the Dempster Highway transect from Dawson City, Yukon, to Tuktoyaktuk, Northwest Territories (summer 2004), and around Yellowknife, Northwest Territories, and the Lupin gold mine, Nunavut (summer 2005). These study areas coincide with the regions where most land-use changes in Canada's north have occurred during the last decades. The dominant land cover types in both study areas are rock, lichen, low–high shrub, grass, and sparse woodland.

Multiple regressions were conducted between $\ln_{(\text{aboveground biomass})}$ and a combination of image signals for all vegetation covers combined (grass, shrub, sparse woodland). The best least-square approximation had an $r^2 = 0.72–0.78$, dependent on approaches used, a relative mean square error of 75–80%, and a median value of the absolute percentage error of 33–53%. Biomass regressions were applied to the pre-conversion imagery for all land-use change areas to yield an estimate of the biomass cleared. All land-use change activities involved conversion of tundra vegetation to settlements, and all pre-conversion biomass carbon was deemed emitted upon clearing.

FIGURE A3-20: Study Areas for the Determination of Aboveground Biomass



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[54] Recent, low-impact seismic lines have a narrow swath of approximately 2 m width, as opposed to conventional ones, which were much larger (~8 m). Low-impact seismic lines were widely adopted over the past decade and considerably reduce the environmental impact of seismic exploration.

When only the aboveground biomass component is considered, land-use change activities over Canada's north released an estimated 41± 6.2 kt CO_2/year during 1990–2000 (up from 29 ± 4.3 kt during 1985–1990).

A3.5.6.2 Uncertainty

The uncertainty in land-use change area covered by the 23 Landsat scenes is estimated to be within 20% (Fraser *et al*., 2005). The biomass equations developed from field measurements in the Dawson City study area were validated on the other study areas of Yellowknife and the Lupin mine. The median values of the absolute percentage error in aboveground biomass estimation for both study areas are 33–53%.

A Monte Carlo simulation method was used to quantify the overall error in carbon emissions caused by uncertainties in land-use change area and biomass estimation. At the 95% confidence level, the percentage error varies from 218% if there is only one land-use change site within a reporting zone to 15% if a reporting zone has 75 or more land-use change sites. The error in the total aboveground biomass carbon stock change estimate, if considered as one reporting area, is about 15%. A full discussion of uncertainty can be found in Chen *et al*. (2005).

A3.5.7 ESTIMATION OF DELAYED CO_2 EMISSIONS FROM HARVESTED WOOD PRODUCTS (HWPs)

In addition to the default method, four alternative approaches for carbon accounting in HWPs have been proposed: stock change, production, atmospheric flow, and simple decay. Box A3-1 provides a brief description of each approach. Although these approaches would yield the same net carbon exchange with the atmosphere if applied at the global level, they differ on a national level in the way in which they account for the time and place of emissions.

As a basis for comparison, the annual emissions of carbon in harvested wood are estimated using the default and three alternative approaches. When warranted, the delayed emissions from domestic wood consumption (stock change and atmospheric flow) or domestic production (production and decay) since 1960 are included. These harvest emissions (HE) are calculated as follows:

IPCC Default:

$HE_{Default}$ = RW + Firewood

Stock Change:

$HE_{Stock\ Change}$ = RW + Firewood – Domestic Long-Lived Commodity + Inherited Emissions from Long-Lived Commodity Consumption

Production:

$HE_{Production}$ = Firewood – Long-Lived Commodity Production + Inherited Emissions from Long-Lived Commodity Production

Atmospheric Flow:

$HE_{Atm.\ Flow}$ = Firewood + Processing Wastes + Inherited Emissions from Long-Lived Commodity Consumption

where:

HE = carbon emitted outside of the managed forests during the inventory year from material harvested and/or consumed in previous and current years
RW = carbon in industrial roundwood and fuelwood harvested in the current inventory year
Firewood = carbon in residential firewood consumed in the current inventory year
Consumption = production + imports – exports
Production = domestic production
Processing Wastes = total industrial wood biomass consumption – commodity production

For Canada, CO_2 emissions outside of managed forests in 2004, resulting from either domestically consumed or domestically produced HWP, vary from 149 Mt (IPCC default) to 91 (atmospheric flow), 107 (production), or 135 Mt (stock change), depending on the approach selected.

Note that delay in carbon emissions due to storage in HWPs is taken into account only for long-lived (>5 years) commodities. The carbon stored in short-lived commodities, including fuelwood and firewood, is assumed to be emitted upon harvest. To date, the calculations have included only semiprocessed commodities (e.g., sawnwood, pulpwood, wood-based panels, paper and paperboard, and other industrial roundwood). It is not feasible at present to develop a system that would monitor the paths of carbon stored in HWPs (HWP-C) from harvest to consumer products.

Further elaboration of these approaches is planned, based on the IPCC Good Practice Guidance for LULUCF (IPCC, 2003).

Box A3-1: Overview of Approaches to Account for Carbon Storage in Harvested Wood Products

In the **IPCC default approach**, only the net change in forest carbon stocks is accounted for. Emissions from harvests are treated as though they are 100% released as CO_2 to the atmosphere in the year and country of harvest. Carbon storage in wood products is not considered.

The **atmospheric flow** approach tracks carbon emissions and removals associated with the harvest, manufacturing, and consumption of wood products within national boundaries. Its intent is similar to the general methodology for estimating fossil fuel emissions and provides a more accurate reflection of when and where harvest emissions actually occur.

The **stock change** approach accounts only for the net carbon stock change in the domestic wood product reservoir, e.g., HWP-C in all long-lived commodities within the national territory, after imports and exports. The difference between the stock change and atmospheric flow accounting lies in the treatment of exported products (which are significant in Canada). In the stock change approach, carbon in all exported wood products and commodities exits the domestic stock and hence is considered an emission to the atmosphere.

The **production** approach accounts for the changes in carbon stocks of domestically harvested wood and commodities derived from this domestic wood, regardless of their actual location. The accounting boundaries hence encompass the entire export market.

The **simple decay** approach also accounts for the delayed emissions from all HWP-C from domestically harvested wood, but in a simplified way, by applying decay curves standardized by product categories.

A3.6 METHODOLOGY FOR WASTE

The Waste Sector generates three sources of emissions: solid waste disposal on land (landfills), wastewater treatment, and waste incineration. This section of Annex 3 describes the detailed accounting methodologies that are used to describe the GHG emission estimates for the following sources from the Waste Sector:

- CH_4 emissions from solid waste disposal on land;
- CH_4 and N_2O emissions from wastewater treatment; and
- CO_2, CH_4, and N_2O emissions from waste incineration.

A3.6.1 CH_4 EMISSIONS FROM SOLID WASTE DISPOSAL ON LAND

A3.6.1.1 Methodology

Emissions are estimated from two types of landfills in Canada:

- municipal solid waste (MSW) landfills; and
- wood waste landfills.

The Scholl Canyon model was used to estimate CH_4 generation from landfills using the following first-order decay equation (IPCC/OECD/IEA, 1997):

Equation A3-58:

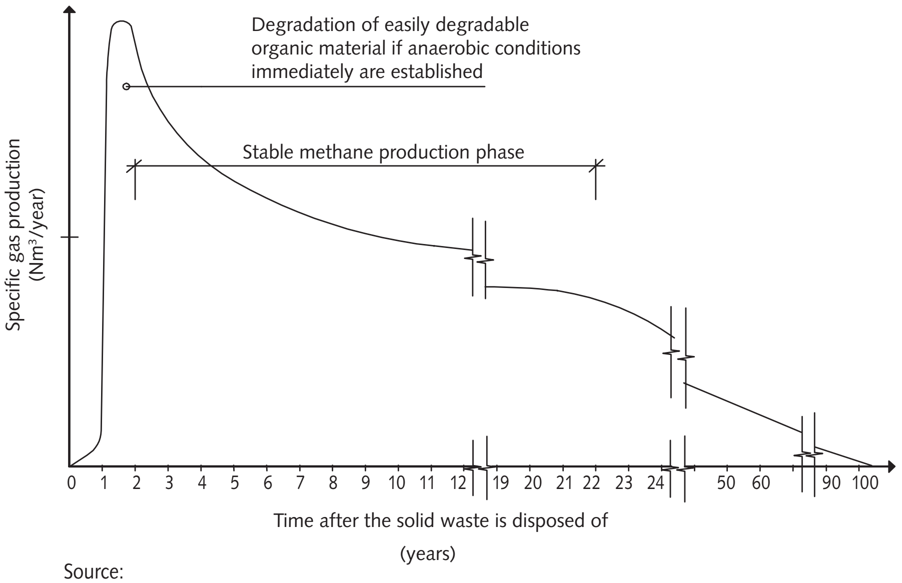
$$G_i = M_i * k * L_0 * \exp^{(-k * t_i)}$$

where:

G_i = generation rate from section i, kt CH_4/year
M_i = mass of refuse in section i, Mt
k = CH_4 generation constant, /year
L_0 = CH_4 generation potential, kg CH_4/t refuse
t_i = age of section i, years

The Scholl Canyon model assumes that CH_4 production is highest in the early phase, followed by a slow steady decline in annual production rates. The Canadian model assumes that the initial lag time where anaerobic conditions are established is negligible, as shown in Figure A3-21.

FIGURE A3-21: **Scholl Canyon Model Representation of Landfill Degradation**



Source:
Jensen and Pipatti (2003).

In order to estimate CH_4 emissions from landfills, information on several of the factors described above is needed. To calculate the net emissions each year, the sum of G_i for every section of waste landfilled in past years was taken, the captured gas was subtracted, and the CH_4 emitted from the combustion of the flared portion of captured gas was added. A computerized model has been developed to estimate aggregate emissions on a regional basis in Canada.

Waste Disposed of Each Year, or the Mass of Refuse (M_i)

■ MSW Landfills

Two primary sources were used in obtaining waste generation and landfill data for the GHG inventory. The amount of MSW landfilled in the years 1941 through to 1990 was estimated by Levelton (1991). For the years 1998, 2000, and 2002, MSW disposal data were obtained from the Waste Management Industry Survey, which is conducted by Statistics Canada on a biennial basis (Statistics Canada, 2000, 2003, 2004a). MSW disposal values for the subsequent odd years (1999 and 2001) were obtained by taking an average of the corresponding even years. Disposal refers to the combination of waste incineration and waste sent to landfill. Therefore, in order to obtain the amount of waste landfilled, incinerated waste was subtracted from the Statistics Canada disposal values for 1998–2002. As well, exported waste was subtracted from the 2000 and 2002 Statistics Canada disposal data, since the amount of waste exported was included in the waste disposal values for these two years (Environment Canada, 2006a). For the years 1991–1997 and 2003–2004, with the exception of Prince Edward Island, the Northwest Territories, and the Yukon, MSW landfill values were estimated by fitting a polynomial to the Levelton (1991) and Statistics Canada (2000, 2003, 2004a) MSW landfill values. To estimate the coefficients in the polynomial, an application of a multiple linear regression (Microsoft Excel LINEST statistical tool for an array) was used. The choice of how many coefficients to use for the polynomial function depended on how well the data fit the lower-order polynomials. Generally, the polynomial fit was improved with increasing number of coefficients. A polynomial of the order 13 was used in the inventory MSW estimates. This multiple linear regression method of estimation is consistent with the IPCC interpolation method (IPCC, 2000). Table A3-41 shows the polynomial coefficients generated by the multiple linear regression method for each of the provinces.

TABLE A3-41: Multiple Linear Regression Polynomial Coefficients Used in Estimating the Amount of MSW Landfilled for 1991–1997 and 2003–2004

	NL	NS	NB	QC	ON	MB	SK	AB	BC
C	1.89E+11	2.85E+11	2.60E+11	7.16E+10	1.89E+12	–3.23E+10	2.11E+11	3.89E+11	6.59E+11
C_1	9.04E+07	1.38E+08	1.25E+08	2.71E+07	9.16E+08	1.71E+07	1.02E+08	1.91E+08	3.22E+08
C_2	5.60E+04	8.49E+04	7.71E+04	1.81E+04	5.64E+05	1.03E+04	6.28E+04	1.17E+05	1.98E+05
C_3	2.560180	3.317993	3.462092	4.566619	21.34639	0.360360	2.653341	2.921053	5.650481
C_4	0.002328	0.003751	0.003247	0.000594	0.025115	0.000729	0.002705	0.005763	0.009481
C_5	–1.21E–05	–1.84E–05	–1.67E–05	3.75E–06	0.000121	–2.25E–06	–1.36E–05	–2.54E–05	–4.29E–05
C_6	–3.10E–09	–4.66E–09	–4.28E–09	1.34E–09	–3.09E–08	–4.96E–10	–3.47E–09	–6.29E–09	–1.07E–08
C_7	2.04E–12	3.15E–12	2.81E–12	–2.69E–13	2.10E–11	4.61E–13	2.31E–12	4.54E–12	7.58E–12
C_8	–3.92E–17	–5.57E–17	–4.84E–17	–9.23E–18	–3.94E–16	–1.13E–17	–4.01E–17	–9.62E–17	–1.55E–16
C_9	6.95E–19	1.06E–18	9.61E–19	–2.10E–19	7.03E–18	1.31E–19	7.83E–19	1.47E–18	2.48E–18
C_{10}	8.56E–23	1.28E–22	1.18E–22	–3.99E–23	8.48E–22	1.30E–23	9.55E–23	1.71E–22	2.92E–22
C_{11}	–1.77E–25	–2.70E–25	–2.44E–25	4.78E–26	–1.79E–24	–3.46E–26	–1.99E–25	–3.77E–25	–6.34E–25
C_{12}	–1.31E–29	–2.05E–29	–1.76E–29	–4.71E–30	–1.40E–28	–4.32E–30	–1.47E–29	–3.32E–29	–5.41E–29
C_{13}	1.29E–32	2.00E–32	1.76E–32	2.18E–34	1.34E–31	3.32E–33	1.46E–32	2.99E–32	4.95E–32

Note:
Coefficients have been rounded and may not result in the correct totals for MSW landfilled.

The amounts of MSW landfilled for the years 1991–1997 and 2003–2004 were calculated according to the following equation:

Equation A3-59:

$$M_X = (C_{13} * x^{13}) + (C_{12} * x^{12}) + (C_{11} * x^{11}) + (C_{10} * x^{10}) + (C_9 * x^9) + (C_8 * x^8) + (C_7 * x^7) + (C_6 * x^6) + (C_5 * x^5) + (C_4 * x^4) + (C_3 * x^3) + (C_2 * x^2) + (C_1 * x) + C$$

where:

M_X = MSW landfilled in year x, t
C_i = coefficient of the ith order
x = year of interest

Statistics Canada MSW disposal data were unavailable for Prince Edward Island, the Northwest Territories, and the Yukon. Thus, MSW landfill values for the period 1991–2004 were obtained by trending the Levelton 1950–1990 MSW landfill values (Levelton, 1991) with the national population for 1950–2004 (Statistics Canada, 2004b). This is a conservative estimate, as waste diversion was negligible during the period 1950–1990, and trending based on these values would result in higher than actual values for the period 1991–2004.

Table A3-42 shows the amount of MSW landfilled for the period 1990–2004.

Wood Waste Landfills

The amount of wood waste landfilled in the years 1970 through to 1992 has been estimated at a national level based on the 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 1993–1997 and from 1999 to 2004. This interpolation method was selected as it was most suitable for the data distribution.

The breakdown in the amount of wood residue landfilled for the solid wood operations and the pulp and paper industries was estimated based on information in a study of pulp and paper mill waste (MWA Consultants Paprican, 1998). The breakdown in wood waste disposal was estimated at 80% for solid wood operations and 20% for pulp and paper mills. This breakdown was assumed to be also true for the years 1970–2004. Table A3-43 shows the amount of wood waste disposed of and landfilled for the period 1990–2004.

TABLE A3-42: MSW Landfilled for 1990–2004

Year	Waste Landfilled											
	NL	PE	NS	NB	QC	ON	MB	SK	AB	BC	NT & NU	YT
						(t)						
1990[1]	366 004	51 293	493 010	462 391	3 699 833	5 957 104	696 174	638 942	1 577 585	1 760 621	34 493	16 608
1991	400 159	57 243	540 341	489 539	4 073 027	6 287 557	741 706	720 035	1 790 701	1 990 162	34 931	16 799
1992	402 670	58 011	533 426	488 826	4 152 266	6 390 940	755 034	729 362	1 837 539	2 012 191	35 770	17 181
1993	403 918	58 732	523 456	485 805	4 230 976	6 479 872	767 869	736 993	1 881 860	2 028 235	36 558	17 540
1994	403 775	59 458	510 179	480 262	4 309 123	6 552 824	780 167	742 752	1 923 350	2 037 746	37 352	17 902
1995	402 110	60 152	493 335	471 972	4 386 673	6 608 214	791 881	746 453	1 961 687	2 040 161	38 110	18 247
1996	398 783	60 859	472 655	460 706	4 463 598	6 644 405	802 966	747 906	1 996 538	2 034 895	38 882	18 599
1997	393 651	61 537	447 861	446 225	4 539 872	6 659 708	813 373	746 914	2 027 558	2 021 350	39 624	18 937
1998	366 280	62 109	421 339	425 626	4 631 317	5 946 885	855 666	780 700	1 874 276	1 795 107	40 249	19 222
1999	369 650	62 674	364 825	387 656	4 830 715	6 410 886	875 695	741 743	2 006 801	1 846 776	40 867	19 503
2000[2]	373 020	63 327	308 311	349 685	5 030 113	6 874 887[3]	895 724	702 786	2 139 327	1 898 445	41 580	19 828
2001	364 808	64 087	307 779	354 002	4 915 833	6 773 268	857 145	711 293	2 193 015	1 965 511	42 412	20 207
2002[2]	356 595	64 891	307 246	358 318	4 801 553	6 671 648[3]	818 566	719 801	2 246 704	2 032 577	43 291	20 607
2003	316 239	65 550	196 137	277 503	4 982 866	6 211 426	858 877	677 779	2 112 755	1 730 360	44 011	20 935
2004	294 000	66 205	134 081	233 189	5 054 168	6 028 654	863 170	653 623	2 106 505	1 640 563	44 726	21 261

Notes:

1 Levelton (1991) data.

2 Statistics Canada disposal data (Statistics Canada, 2000, 2003, 2004a).

3 Exported MSW subtracted from the Statistics Canada disposal data (Environment Canada, 2006d).

The data represented above were chosen from selected years. MSW landfill data from 1941 to 1990 (Levelton, 1991) were used in the multiple linear regression method for estimation of MSW landfilled for 1990–2004.

TABLE A3-43: Wood Waste Generated and Landfilled in Canada for 1990–2004

Year	Wood Waste Disposed of		Wood Waste Landfilled		
	Pulp & Paper	Solid Wood Industry	Pulp & Paper	Solid Wood Industry	Total
		(bone dry tonnes)			
1990	1 811 062	7 244 248	1 566 324	1 086 637	2 652 961
1991	1 811 062	7 244 248	1 566 324	1 086 637	2 652 961
1992	1 811 062	7 244 248	1 566 324	1 086 637	2 652 961
1993	1 537 557	6 150 226	1 329 779	922 534	2 252 313
1994	1 447 245	5 788 981	1 251 672	868 347	2 120 019
1995	1 356 934	5 427 736	1 173 565	814 160	1 987 725
1996	1 266 623	5 066 491	1 095 457	759 974	1 855 431
1997	1 176 311	4 705 246	1 017 350	705 787	1 723 137
1998	1 080 000	4 320 000	934 054	648 000	1 582 054
1999	995 689	3 982 755	861 136	597 413	1 458 550
2000	905 378	3 621 510	783 029	543 227	1 326 256
2001	815 066	3 260 265	704 922	489 040	1 193 962
2002	724 755	2 899 020	626 815	434 853	1 061 668
2003	634 444	2 537 775	548 708	380 666	929 374
2004	547 561	2 190 244	473 566	328 537	802 103

TABLE A3-44: Mean Annual Precipitation and MSW Landfill k Value Estimates for Provincial Landfill Sites

Region	Mean Annual Precipitation *(mm)*	Kinetic Rate Constant k *(/year)*
Newfoundland and Labrador		
Carbonear	N/A	N/A
Corner Brook	1270.8	0.066
St. John's	1513.7	0.081
Average	1392.3	0.074
Prince Edward Island		
Charlottetown	1173.3	0.060
Summerside	1078.0	0.055
Average	1125.7	0.058
Nova Scotia		
Dartmouth	N/A	N/A
Halifax	1452.2	0.077
Lunenburg	N/A	N/A
New Glasgow	N/A	N/A
Sydney	1504.9	0.080
Truro	1202.1	0.062
Average	1386.4	0.073
New Brunswick		
Bathurst	1058.6	0.054
Campbellton	N/A	N/A
Edmundston	N/A	N/A
Fredericton	1143.3	0.059
Moncton	1143.5	0.059
Saint John	1390.3	0.073
Average	1184.0	0.061
Quebec		
Montréal	1064.6	0.054
Québec	1230.3	0.064
Rimouski	915.0	0.045
Saint-Étienne	N/A	N/A
Saint Tite-des-Caps	N/A	N/A
St. Cecile	N/A	N/A
St. Sophie	N/A	N/A
Average	1070.0	0.054
Ontario		
Barrie	938.5	0.046
Belleville	891.6	0.043
Brantford	892.3	0.044
Brockville	983.4	0.049
Cornwall	1002.0	0.050
Guelph	923.2	0.045
Hamilton	910.1	0.045
Kingston	968.4	0.048
Kitchener	N/A	N/A
London	987.1	0.049
North Bay	1007.7	0.050
Oshawa	877.9	0.043
Ottawa-Hull	N/A	N/A
Peterborough	840.3	0.040
Ontario (cont'd)		
St. Catharines	873.6	0.042
Sarnia	846.8	0.041
Sudbury	899.3	0.044
Thunder Bay	711.6	0.033
Timmins	831.3	0.040
Toronto	834.0	0.040
Windsor	918.3	0.045
Average	902.0	0.044
Manitoba		
Brandon	472.0	0.018
Portage la Prairie	514.5	0.021
Thompson	517.4	0.021
Winnipeg	513.7	0.021
Average	504.4	0.020
Saskatchewan		
Moose Jaw	365.1	0.012
Prince Albert	424.3	0.015
Regina	388.1	0.013
Saskatoon	350.0	0.011
Swift Current	377.1	0.013
Yorkton	450.9	0.017
Average	392.6	0.014
Alberta		
Calgary	412.6	0.015
Edmonton	482.7	0.019
Fort McMurray	455.5	0.017
Lethbridge	386.3	0.013
Medicine Hat	333.8	0.010
Red Deer	487.2	0.019
Average	426.4	0.016
British Columbia		
Campbell River	1451.5	0.077
Chilliwack	1501.3	0.080
Courtney	N/A	N/A
Kamloops	305.1	0.008
Matsqui	N/A	N/A
Port Alberni	1910.7	0.105
Prince Rupert	2593.6	0.146
Vancouver	1199.0	0.062
Vemon	409.9	0.015
Victoria	883.3	0.043
Average	1280.7	0.067
Yukon		
Whitehorse	267.4	0.006
Average	267.4	0.006
Northwest Territories & Nunavut		
Yellowknife	280.7	0.007
Average	280.7	0.007

Note:
N/A = not available

CH_4 Generation Constant (k)

The CH_4 generation rate constant k represents the first-order rate at which CH_4 is generated after waste has been landfilled. The value of k is affected by four factors: moisture content, availability of nutrients, pH, and temperature. In calculating provincial decay rates, however, the ambient temperature should not be considered, as the landfill temperature is independent of the ambient temperature at depths exceeding 2 m. The moisture content should be the sole parameter considered (Maurice and Lagerkvist, 2003; Thompson and Tanapat, 2005).

The k values used to estimate emissions from MSW landfills originate from a study conducted by the University of Manitoba that employed the provincial precipitation data from 1971 to 2000 (Thompson *et al.*, 2005). The provincial locations estimating the average annual precipitation were based on those chosen by Levelton (1991). The EPA (2001) default decay values were used in conjunction with the Environment Canada annual precipitation data, and a graph was plotted showing a linear relationship between annual precipitation and decay rate. The U.S. EPA assigns a default decay value of 0.02/year to areas with an annual precipitation less than 635 mm and 0.04/year to areas with an annual precipitation greater than 635 mm. Using this relationship, provincial landfill decay rates were calculated (Thompson *et al.*, 2005).

Table A3-44 shows the mean annual precipitation and decay values assigned for each of the provincial landfill sites chosen by Levelton (1991).

■ MSW Landfills

The k values used to estimate emissions from MSW landfills have been chosen from the average of k value estimates for each province (Thompson *et al.*, 2005). These values are provided in Table A3-45.

■ Wood Waste Landfills

The k value for wood waste landfills has been estimated on a national level based on a report prepared by the National Council for Air and Stream Improvement, Inc. (NCASI, 2003). The recommended default value for k (0.03/year) was chosen for estimating wood product landfill CH_4 emissions.

CH_4 Generation Potential (L_0)

■ MSW Landfills

The CH_4 generation potential (L_0) represents the amount of CH_4 that could be theoretically produced per tonne of waste landfilled. The following equation, as presented in the IPCC Guidelines, was used to calculate the CH_4 generation potential for MSW landfills (IPCC/OECD/IEA, 1997):

Equation A3-60:

$$L_0 = MCF * DOC * DOC_F * F * \frac{16}{12} * 1000 \frac{kg\ CH_4}{t\ CH_4}$$

where:

L_0 = CH_4 generation potential, kg/t waste
MCF = CH_4 correction factor, fraction
DOC = degradable organic carbon, t C/t waste
DOC_F = fraction of DOC dissimilated
F = fraction of CH_4 in landfill gas
16/12 = stoichiometric factor to convert CH_4 to carbon

The CH_4 correction factor (MCF) accounts for the difference between managed and unmanaged solid waste disposal sites. Unmanaged solid waste disposal sites produce less CH_4, since a larger fraction of waste decomposes aerobically in the top layers of the site. The IPCC default value for MCF for managed landfill sites was chosen to represent the MCF for MSW landfills, since it is assumed that all landfills covered by the data

TABLE A3-45: MSW Landfill k Value Estimates for Each Province

Provincial/Territorial k Value Estimates (/year)											
NL	PE	NS	NB	QC	ON	MB	SK	AB	BC	NT[1]	YT
0.074	0.058	0.073	0.061	0.054	0.044	0.020	0.014	0.016	0.067	0.007	0.006

Note:
1 NT includes NU.

collected are engineered landfills. The IPCC default values for MCF are shown in Table A3-46 (IPCC/OECD/IEA, 1997).

TABLE A3-46: Solid Waste Disposal Site CH_4 Correction Factors

Type of Site	MCF Default Values
Managed	1.0
Unmanaged: deep (≥5 m waste)	0.8
Unmanaged: shallow (<5 m waste)	0.4
Default value: uncategorized solid waste disposal sites	0.6

The IPCC default value for the fraction of CH_4 in landfill gas (F) ranges between 0.4 and 0.6. It can vary based on certain factors, including waste composition and potential air dilution effects, that can lower the actual concentration of CH_4 in the landfill gas. The value 0.5 was chosen for the fraction of CH_4 in landfill gas.

The fraction of degradable organic carbon dissimilated (DOC_F) represents the amount of organic carbon that is ultimately degraded and released from the solid waste disposal site. DOC_F accounts for the fact that some of the organic carbon does not degrade or degrades very slowly. The IPCC default value (0.77) for DOC_F for landfill sites excluding lignin was used in the calculation for the CH_4 generation potential (IPCC/OECD/IEA, 1997).

The fraction of degradable organic carbon (DOC) represents the amount of organic carbon that is accessible to biochemical decomposition. It is based on the composition of the waste. Waste audit percentages from across Canada were used to calculate the provincial DOC values according to the following equation (IPCC/OECD/IEA, 1997):

Equation A3-61:

$$DOC = (0.4 * A) + (0.17 * B) + (0.15 * C) + (0.3 * D)$$

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

Provincial waste consumption data and CH_4 generation potentials for 1990–2003 are shown in Table A3-47 (Thompson *et al.*, 2005). For cases where audit data

TABLE A3-47: Canadian CH_4 Generation Potential (L_0) Values Derived from Waste Audit Data for 1990–2003[1]

Location	Paper and Textiles	Garden and Park Waste	Food Waste	Wood and Straw Waste	DOC	CH_4 Generation Potential
			(% by wet weight)			(kg/t of waste)
Vancouver, BC	40.6	17.5	11.7	0.3	21.2	108.8
AB	35.0	11.0	12.0	6.0	19.5	100.0
Regina, SK	33.2	17.0	30.7	N/A[2]	20.8	106.8
Winnipeg, MB	31.0	6.6	26.1	2.3	18.1	92.4
ON	27.0	13.0	25.0	2.9	17.6	90.3
QC	59.0	N/A	2.7	2.9	24.9	127.8
NB	–[3]	–	–	–	–	–
PE	–	–	–	–	–	–
NS	27.7	15.4	25.3	N/A	17.5	89.8
NL	37.0	N/A	30.0	N/A	19.9	102.2
NT & NU	–	–	–	–	–	–
YT	–	–	–	–	–	–

Notes:
1 Data source: Thompson *et al*. (2005).
2 N/A = unavailable categorical information.
3 – = unavailable provincial/territorial data.

were not available, a default value of 117 kg/t of waste has been used (ORTECH Corporation, 1994).

For CH_4 generation prior to 1990, Statistics Canada recycling data (Statistics Canada, 2002) were used to estimate the amount of organic waste diversion per province. The 1990–2003 L_0 values were increased by the percentage currently diverted per province in order to calculate the 1941–1989 L_0 values. For cases where provincial diversion data were not available, a default value of 165 kg/t of waste has been used (EPA, 1990).

Provincial waste consumption data and CH_4 generation potentials for 1941–1990 are shown in Table A3-48 (Thompson *et al.*, 2005).

TABLE A3-48: CH_4 Generation Potential (L_0) from 1941 to Present[1]

Province/ Territory	2002 Organic Waste Diversion	L_0 Value Following 1990	L_0 Value Prior to 1990
	(%)	*(kg/t of waste)*	*(kg/t of waste)*
BC	23.3	108.8	134.1
AB	16.7	100.0	116.7
SK	4.3	106.8	111.3
MB	4.9	92.4	96.5
ON	16.4	90.3	105.1
QC	13.7	127.8	145.3
NB	19.8	117.0[2]	140.2
PE	N/A[3]	117.0[2]	165.0[2]
NS	29.7	89.8	116.5
NL	N/A	102.2	165.0[2]
NT & NU	N/A	117.0[2]	165.0[2]
YT	N/A	117.0[2]	165.0[2]

Notes:

1 Data source: Thompson *et al*. (2005), except for 2002 organic waste diversion, which is from Statistics Canada (2002).

2 Default value.

3 N/A = unavailable categorical information.

■ Wood Waste Landfills

Equation A3-60, as presented in the IPCC Guidelines, was used to calculate the CH_4 generation potential for wood waste landfills (IPCC/OECD/IEA, 1997). The IPCC default value for MCF for unmanaged – deep landfill sites (0.8) was chosen to represent the MCF, as it best represents industry practices.

The IPCC default value for the fraction of CH_4 in landfill gas (F) ranges between 0.4 and 0.6. The value 0.5 was chosen for the fraction of CH_4 in landfill gas.

The fraction of degradable organic carbon dissimilated (DOC_F) represents the amount of organic carbon that is ultimately degraded and released from the solid waste disposal sites. DOC_F accounts for the fact that some of the organic carbon does not degrade or degrades very slowly. The IPCC Guidelines provide default values in the order of 0.5–0.6 for waste sites that include lignin. The value 0.5 was used in the calculation of the CH_4 generation potential (IPCC/OECD/IEA, 1997).

The fraction of degradable organic carbon (DOC) represents the amount of organic carbon that is accessible to biochemical decomposition. Equation A3-61 was used to calculate the national wood waste DOC value, assuming 100% wood or straw composition (IPCC/OECD/IEA, 1997).

Based on these considerations, an L_0 of 80 kg CH_4/t of wood waste was calculated.

■ Captured Landfill Gas

Some of the CH_4 that is generated in MSW landfills is captured. A portion of the CH_4 that is captured is combusted for electricity or heat generation. The remaining portion of captured landfill gas is flared. In order to calculate the net CH_4 emissions from landfills, the amount of captured CH_4 is subtracted from the estimate generated by the Scholl Canyon model, and the portion of CH_4 emitted from flare is added to the estimate of CH_4 generated. GHG emissions affiliated with the use of landfill gas for energy recovery are accounted for in the Energy Sector. The net CH_4 emissions calculation is shown in the following equation:

Equation A3-62:

$$CH_{4(NET)} = CH_{4(generated)} - CH_{4(captured)} + CH_{4(flared)}$$

where:

$CH_{4(NET)}$ = net CH_4 emissions from MSW landfills, t

$CH_{4(generated)}$ = CH_4 emissions generated from MSW landfills, t

$CH_{4(captured)}$ = CH_4 emissions captured from MSW landfills, t

$CH_{4(flared)}$ = CH_4 emissions emitted from flaring of captured MSW landfill gas, t

In order to determine the amount of CH_4 emitted from flaring, a flaring emission control efficiency of 99.7% was used. This value was obtained from Table 2.4-3 of Chapter 2.4 of EPA AP 42 (EPA, 1995). The amount of CH_4 emitted from flaring of landfill gas was calculated as follows:

Equation A3-63:

$$CH_{4(flared)} = LG_{(flared)} * (1 - Eff_{(flare\text{-}control)})$$

where:

$CH_{4(flared)}$ = CH_4 emissions from flaring of MSW CH_4 gas, t/year

$LG_{(flared)}$ = CH_4 gas flared, t/year

$Eff_{(flare\text{-}control)}$ = flare emission control efficiency, fraction

The quantities of landfill gas collected from 1983 to 1996 were obtained from Environment Canada (1998). Since 1997, data on the amount of landfill gas captured are collected directly from individual landfill operators biennially by Environment Canada's National Office of Pollution Prevention (Environment Canada, 2003a). Since the landfill gas capture data are collected every odd year, for the purposes of the national GHG inventory, the landfill gas capture data for the subsequent even years are averaged from the odd years from 1997. The amount of landfill gas captured for the year 2004 was assumed to be constant from the 2003 values. Table A3-49 shows the amount of CH_4 captured and flared from 1983 to 2004.

TABLE A3-49: Estimated MSW CH_4 Captured and Flared for 1983–2004

Year	CH_4 Captured (t)	CH_4 Flared (t)
1983	2 950	0
1984	2 950	0
1985	38 628	22
1986	81 678	4 877
1987	81 678	5 271
1988	192 379	11 090
1989	198 922	13 770
1990	209 000	23 614
1991	213 931	27 175
1992	223 928	35 291
1993	228 966	44 461
1994	244 244	56 729
1995	266 201	69 355
1996	289 282	78 672
1997	267 803	81 001
1998	271 816	90 518
1999	275 830	100 593
2000	294 286	117 192
2001	312 742	135 214
2002	312 560	136 889
2003	312 378	138 911
2004	312 378	138 911

A3.6.1.2 Data Sources

Waste disposal, diversion, and generation data are collected from a biennial waste survey conducted by Statistics Canada (2000, 2003, 2004a). The Statistics Canada data for 1998, 2000, and 2002 waste disposal, diversion, and generation were used in developing its MSW estimates for the national GHG inventory.

Landfill gas capture and flare data are collected directly from individual landfill operators biennially by Environment Canada's National Office of Pollution Prevention (Environment Canada, 2003a).

A3.6.2 CH_4 EMISSIONS FROM WASTEWATER TREATMENT

A3.6.2.1 Methodology

Municipal Wastewater Treatment

The IPCC default method was not used, because the required data were not available. A method developed for Environment Canada (ORTECH Corporation, 1994) was used to calculate an emission factor. This method assumed that the CH_4 generation rate from the anaerobic decomposition of organic matter in wastewater was 0.22 kg CH_4/kg BOD_5 (the five-day biochemical oxygen demand), and the daily per capita BOD_5 loading rate was 0.050 kg BOD_5/person per day.

Based on these two assumptions, it was estimated that 4.015 kg CH_4/person per year could potentially be emitted from anaerobically treated wastewater. The derivation of the CH_4 emission factor is shown below.

Equation A3-64:

$$\mathbf{EF_{CH_4}\ (kg\ CH_4/capita\ per\ year) = (per\ capita\ BOD_5\ loading\ rate) * (CH_4\ generation\ rate)}$$

$$= \left(\frac{0.05\ \text{kg BOD}_5}{\text{capita} * \text{day}}\right) * \left(365\,\frac{\text{days}}{\text{year}}\right) * \left(0.22\,\frac{\text{kg CH}_4}{\text{kg BOD}_5}\right)$$

$$= \left(4.015\,\frac{\text{kg CH}_4}{\text{capita} * \text{year}}\right)$$

The percentage of wastewater that is treated aerobically (primary and secondary wastewater treatment) and anaerobically (waste stabilization pond treatment) was obtained from the Municipal Water Use Data Base for the following years: 1983, 1986, 1989, 1991, 1994, 1996, and 1999 (Environment Canada, 1983–1999). Given that municipal effluent volumetric flow rates are strongly correlated with population, the corresponding missing years for the period 1983–1999 were estimated by trending the water use values (Environment Canada, 1983–1999) with the provincial populations for 1983–1999 (Statistics Canada, 2004b). This method of estimation is consistent with the IPCC surrogate method (IPCC, 2000). The percentage of wastewater treated for 2000–2004 was estimated by applying a growth function to the 1983–1999 water use database values using the provincial populations for 1983–2004 (Statistics Canada, 2004b). This method of estimation is consistent with the IPCC method of extrapolation (IPCC, 2000).

Emissions are calculated by multiplying the emission factors by the population of the respective province (Statistics Canada, 2004b) and the fraction of wastewater that is anaerobically treated.

Equation A3-65:

$$\mathbf{CH_{4(x)} = EF_{CH_4} * P_x * Frac_{AN(x)}}$$

where:

$CH_{4(x)}$ = CH_4 emissions from wastewater treatment for province x, t/year
EF_{CH_4} = CH_4 emission factor for wastewater treatment, t/capita per year
P_x = population of province x
$Frac_{AN(x)}$ = fraction of wastewater treated anaerobically for province x

CH_4 emissions were also calculated using the IPCC check method for CH_4 emissions from domestic wastewater treatment (IPCC, 2000). The check method calculation is shown below:

Equation A3-66:

$$\mathbf{WM = P * D * SBF * EF * FTA * 365 * 10^{-12}}$$

where:

WM = annual CH_4 emission per country, from domestic wastewater, Tg
P = population of country
D = organic load in biochemical oxygen demand per person, g BOD/person per day: 60 g BOD/person per day was used (Table 6.5 of the IPCC Guidelines; IPCC/OECD/IEA, 1997)
SBF = fraction of BOD that readily settles: default = 0.5
EF = emission factor, g CH_4/g BOD: default = 0.6
FTA = fraction of BOD in sludge that degrades anaerobically: default = 0.8

The IPCC check method states that for countries that employ exclusively aerobic processes, the fraction of BOD in sludge that degrades anaerobically (FTA) would be significantly lower or zero. In these cases, IPCC recommends using the full IPCC Guidelines method (IPCC, 2000). Canada falls into this category. However, due to the lack of required data, the check method was used to check the accuracy of the method developed by ORTECH Corporation (1994). The FTA was determined by taking a weighted average of the percentage of people served by anaerobic treatment as follows:

Equation A3-67:

$$FT_i = \sum_x \frac{\%AN_{x,i} * P_{x,i}}{P_{tot,i}}$$

where:

FT_i = fraction of BOD in sludge that degrades anaerobically for year i

$\%AN_{x,i}$ = percentage of the population served by anaerobic wastewater treatment for province x in year i

$P_{x,i}$ = population of province x for year i

$P_{tot,i}$ = population of Canada for year i

The difference in CH_4 emissions between the IPCC check method and the method developed by ORTECH Corporation (1994) is primarily due to the choice of emission factor. The IPCC default emission factor is shown as 0.6 g CH_4/g BOD. The emission factor used in the method developed by ORTECH Corporation (1994) (0.22 g CH_4/g BOD) was obtained from a study performed by Thorneloe (1993).

There may be some anaerobic treatment within the category of secondary wastewater treatment. However, although the percentage of wastewater in secondary treatment that is treated anaerobically was not quantified within the Municipal Water Use Data Base (Environment Canada, 1983–1999), it is not expected to be significant.

Table A3-50 shows the percentage of wastewater treated aerobically (primary and secondary wastewater treatment) and anaerobically (waste stabilization ponds) for 1983–2004. Waste stabilization ponds (facultative lagoons) were assumed to be anaerobic, since they are primarily anaerobic systems with an aerobic top layer that reverts to anaerobic conditions during the night (Rich, 2005).

Industrial Wastewater Treatment

The IPCC default value of 0.25 kg CH_4/kg COD was used in the estimation of CH_4 emissions from industrial wastewater treatment (IPCC, 2000). The volume of industrial wastewater treated was obtained

TABLE A3-50: Percentage of Wastewater Treated by Aerobic and Anaerobic Wastewater Treatment (by Province)

Year	Wastewater Treatment (% Aerobic / % Anaerobic)										
	NL	PE	NS	NB	QC	ON	MB	SK	AB	BC	NT & NU	YT
1983	97.6/2.4	81.4/18.6	83.2/16.8	62.8/37.2	89.8/10.2	97.9/2.1	89.1/10.9	77.4/22.6	79.2/20.8	91.0/9.0	0/100	53.6/46.4
1986	97.7/2.3	86.4/13.6	83.1/16.9	62.9/37.1	91.5/8.5	97.8/2.2	88.9/11.1	79.1/20.9	79.4/20.6	91.6/8.4	0/100	57.0/43.0
1989	96.2/3.8	88.8/11.2	90.4/9.6	58.5/41.5	87.0/13.0	96.9/3.1	88.8/11.2	80.3/19.7	86.6/13.4	91.2/8.8	0/100	16.3/83.7
1990	97.3/2.7	85.1/14.9	89.9/10.1	58.1/41.9	86.7/13.3	96.8/3.2	88.8/11.2	78.2/21.8	89.8/10.2	91.3/8.7	0/100	28.9/71.1
1991	87.1/12.9	84.2/15.8	95.2/4.8	67.5/32.5	89.9/10.1	97.3/2.7	89.9/10.1	78.8/21.2	87.5/12.5	90.4/9.6	0/100	4.4/95.6
1992	92.3/7.7	84.9/15.1	93.9/6.1	62.3/37.7	87.6/12.4	96.9/3.1	89.2/10.8	78.3/21.7	92.1/7.9	90.7/9.3	0/100	18.1/81.9
1993	92.4/7.6	84.9/15.1	95.0/5.0	62.3/37.7	87.3/12.7	96.8/3.2	89.2/10.8	78.5/21.5	93.9/6.1	90.6/9.4	0/100	25.2/74.8
1994	89.0/11.0	84.2/15.8	85.7/14.3	70.5/29.5	86.2/13.8	97.6/2.4	90.1/9.9	81.2/18.8	87.8/12.2	94.4/5.6	0/100	2.5/97.5
1995	94.6/5.4	84.8/15.2	93.2/6.8	64.4/35.6	86.7/13.3	96.9/3.1	89.5/10.5	79.2/20.8	94.2/5.8	92.2/7.8	0/100	19.3/80.7
1996	80.2/19.8	86.2/13.8	88.4/11.6	71.1/28.9	83.7/16.3	97.8/2.2	90.8/9.2	80.0/20.0	87.3/12.7	93.9/6.1	8.8/91.2	2.3/97.7
1997	80.3/19.7	84.9/15.1	92.8/7.2	65.8/34.2	85.7/14.3	97.0/3.0	89.9/10.1	79.5/20.5	94.8/5.2	93.0/7.0	2.3/97.7	7.6/92.4
1998	74.7/25.3	84.9/15.1	92.7/7.3	65.5/34.5	85.5/14.5	97.0/3.0	90.0/10.0	79.5/20.5	96.9/3.1	93.1/6.9	2.0/98.0	13.7/86.3
1999	60.0/40.0	87.7/12.3	86.6/13.4	60.9/39.1	81.7/18.3	97.8/2.2	89.0/11.0	82.4/17.6	88.4/11.6	94.2/5.8	9.6/90.4	2.3/97.7
2000	63.7/36.3	85.2/14.8	92.1/7.9	64.9/35.1	84.4/15.6	97.1/2.9	89.9/10.1	79.1/20.9	97.0/3.0	93.5/6.5	10.5/89.5	0.5/99.5
2001	60.8/39.2	85.2/14.8	91.9/8.1	64.8/35.2	84.1/15.9	97.0/3.0	90.0/10.0	78.5/21.5	98.2/1.8	93.6/6.4	14.0/86.0	0/100
2002	59.6/40.4	85.2/14.8	92.2/7.8	64.9/35.1	83.6/16.4	97.0/3.0	90.1/9.9	78.2/21.8	99.7/0.3	93.7/6.3	13.9/86.1	0/100
2003	59.1/40.9	85.2/14.8	92.4/7.6	64.9/35.1	83.2/16.8	97.0/3.0	90.1/9.9	78.1/21.9	100/0	93.8/6.2	9.2/90.8	0/100
2004	58.5/41.5	85.2/14.8	92.5/7.5	65.0/35.0	82.8/17.2	97.0/3.0	90.3/9.7	78.2/21.8	100/0	93.9/6.1	4.8/95.2	0/100

from surveys conducted by Environment Canada for the years 1986, 1991, and 1996 (Environment Canada, 1986, 1991, 1996). The volume of industrial wastewater treated for 1997–2004 was forecasted by applying a growth function to the 1986, 1991, and 1996 water use database values using the survey years for 1986–2004. This forecasting method is consistent with the IPCC trend extrapolation method (IPCC, 2000). The corresponding missing years for the period 1987–1996 were estimated by fitting a polynomial to the Environment Canada data (1986, 1991, 1996) and the forecasted data (1997–2004). To estimate the coefficients in the polynomial, a multiple linear regression method was used. A polynomial of the order 6 provided the best fit. Table A3-51 shows the polynomial coefficients generated by the multiple linear regression method for each of the industry groups.

The amounts of industrial wastewater treated for the years 1987–1990 and 1992–1995 were calculated according to the following equation:

Equation A3-68:

$$V_x = (C_6 * x^6) + (C_5 * x^5) + (C_4 * x^4) + (C_3 * x^3) + (C_2 * x^2) + (C_1 * x) + C$$

where:

V_x = volume of industrial wastewater treated in year x, million cubic metres

C_i = coefficient of the ith order

x = year of interest

Table A3-52 shows the amount of industrial wastewater treated per industry group for 1986–2004.

CH_4 emissions were calculated by multiplying the volume of wastewater treated per industry type by the corresponding COD value, followed by the default emission factor of 0.25 kg CH_4/kg COD (IPCC, 2000) and the fraction of wastewater that was treated anaerobically. Although one slaughterhouse in Quebec was reported to employ anaerobic digestion, where the collected biogas was combusted for energy generation purposes, it was assumed that there was no anaerobic treatment of industrial wastewater in Canada based on communications with the Ministère de l'Environnement du Québec and the British Columbia Ministry of Environment (Environment Canada, 2006b, 2006c). IPCC COD default values (IPCC, 2000) were used where possible (i.e., where IPCC industry sectors matched the industry sectors included in the Environment Canada surveys). The industry groups shown in Table A3-52 were selected from the total group of industry waste streams provided in the Environment Canada report (Environment Canada, 1986, 1991, 1996) due to the availability of COD values for a select number of industry groups (IPCC, 2000). Table A3-53 shows the industry sectors included within the Environment Canada surveys (Environment Canada, 1986, 1991, and 1996) and the corresponding IPCC default COD values that were chosen to represent the industry sectors (IPCC, 2000).

CH_4 emissions for industrial wastewater treatment were calculated on a national level as follows:

Equation A3-69:

$$CH_{4(IndustryType)} = V_{(IndustryType)} * COD_{(IndustryType)} * EF_{CH_4} * Frac_{(Anaerobic)}$$

where:

$CH_{4(IndustryType)}$ = CH_4 emissions generated per industry type, t/year

$V_{(IndustryType)}$ = volume of wastewater treated, L/year

$COD_{(IndustryType)}$ = chemical oxygen demand per industry type, kg/L

EF_{CH_4} = CH_4 emission factor: IPCC default value = 0.000 25 t CH_4/kg COD

$Frac_{(Anaerobic)}$ = fraction of anaerobically treated wastewater

A3.6.3 N_2O EMISSIONS FROM WASTEWATER TREATMENT

A3.6.3.1 Methodology

The N_2O emissions were calculated using the IPCC default method (IPCC/OECD/IEA, 1997). This method estimates emissions based on the amount of nitrogen in sewage and the assumption that 0.01 kg N_2O-N/kg sewage nitrogen will be generated.

Estimates of the amount of nitrogen in sewage were based on the following two assumptions: protein is 16% nitrogen (IPCC/OECD/IEA, 1997); and Canadian protein consumption is 40.15 kg/person per year. This resulted in an emission factor of 0.101 kg N_2O/person per year. Emissions were calculated by multiplying the emission factor by the population of the respective provinces (Statistics Canada, 2004b).

TABLE A3-51: Multiple Linear Regression Polynomial Coefficients Used in Estimating the Amount of Industrial Wastewater Treated for 1987–1990 and 1992–1995

	C	C_1	C_2	C_3	C_4	C_5	C_6
Food	2.03E+08	1.26E+05	3.88E+01	6.463E–03	1.577E–05	1.624E–10	–1.63E–12
Beverages	1.46E+07	9.106E+03	2.81E+00	4.654E–04	1.138E–06	1.133E–11	1.175E–13
Rubber Products	4.77E+06	2.967E+03	–9.12E–01	1.523E–04	3.708E–07	3.936E–12	3.850E–14
Plastic Products	9.68E+05	6.011E+02	–1.85E–01	3.077E–05	7.515E–08	7.659E–13	7.776E–15
Total Textiles	7.79E+07	4.855E+04	1.48E+01	2.496E–03	6.065E–06	6.568E–11	6.309E–13
Paper & Allied Products	4.30E+08	2.685E+05	8.20E+01	1.385E–02	3.352E–05	3.813E–10	3.503E–12
Petroleum & Coal Products	2.55E+07	1.587E+04	4.87E+00	8.162E–04	1.983E–06	2.140E–11	2.062E–13
Chemical Products	7.79E+07	4.856E+04	1.49E+01	2.496E–03	6.066E–06	6.592E–11	6.312E–13

Note:
Coefficients have been rounded and may not result in the correct totals for the volume of industrial wastewater treated.

TABLE A3-52: Volume of Wastewater Treated per Industry Type for 1986–2004

Year	Volume of Wastewater Treated							
	Food	Beverages	Rubber Products	Plastic Products	Total Textiles	Paper & Allied Products	Petroleum & Coal Products	Chemicals & Chemical Products
	(million cubic metres)							
1986	352	15	5	7	25	2286	33	208
1987	294.8	20.1	4.1	6.7	36.7	2293.1	36.9	198.1
1988	251.8	24.2	3.6	6.5	42.9	2269.9	39.0	193.7
1989	216.3	27.6	3.2	6.3	46.9	2237.5	40.3	191.6
1990	187.6	30.5	2.9	6.2	48.9	2197.3	41.0	191.5
1991	147.5	33.9	2.3	6.0	58.3	2214.3	44.0	183.9
1992	147.9	34.9	2.8	6.0	47.9	2099.7	40.7	196.1
1993	135.3	36.4	2.8	5.9	45.5	2045.4	39.9	200.2
1994	126.8	37.6	3.0	5.9	42.2	1989.5	38.8	205.3
1995	121.5	38.5	3.2	5.9	38.3	1933.6	37.4	211.0
1996	128.6	38.4	3.6	5.9	28.3	1847.5	34.4	220.9
1997	125.1	39.4	3.9	5.9	24.5	1781.8	32.7	229.1
1998	121.7	39.8	4.1	5.9	23.1	1756.2	32.1	232.5
1999	118.4	40.0	4.2	5.9	22.3	1741.0	31.7	234.6
2000	115.2	40.2	4.2	5.9	21.7	1728.9	31.4	236.2
2001	112.1	40.4	4.3	5.9	21.1	1716.9	31.1	237.9
2002	109.1	40.6	4.4	5.9	20.4	1702.6	30.8	239.9
2003	106.1	40.9	4.5	5.8	19.5	1682.9	30.3	242.8
2004	103.3	41.5	4.7	5.8	18.1	1651.7	29.5	247.4

TABLE A3-53: COD Values Used in CH_4 Emission Estimates per Industry Type

Industry Group (Environment Canada, 1986, 1991, 1996)	IPCC Industry Type (IPCC, 2000)	IPCC Degradable Organic Component - COD (IPCC, 2000) *(g/L)*
Food	Vegetables, Fruits & Juices	5.0
Beverages	Soft Drinks	2.0
Rubber Products	Organic Chemicals	3.0
Plastic Products	Plastics and Resins	3.7
Primary Textiles & Textile Products	Textiles (Natural)	0.9
Wood Products	N/A	N/A
Paper + Allied Products	Pulp & Paper (Combined)	9.0
Primary Metals	N/A	N/A
Fabricated Metals	N/A	N/A
Transportation Equipment	N/A	N/A
Non-Metallic Mineral Products	N/A	N/A
Petroleum + Coal Products	Petroleum Refineries	1.0
Chemicals + Chemical Products	Organic Chemicals	3.0

Note:
N/A = not available

Equation A3-70:

$$N_2O_{(s1)} = Protein * Frac_{NPR} * NR_{PEOPLE} * EF_{N_2O}$$

where:

$N_2O_{(s1)}$ = N_2O emissions from human sewage, kg N_2O-N/year
Protein = annual per capita protein intake, kg/person per year
$Frac_{NPR}$ = fraction of nitrogen in protein: default = 0.16 kg N/kg protein
NR_{PEOPLE} = number of people in country
EF_{N_2O} = emission factor: default 0.01 (0.002–0.12) kg N_2O-N/kg sewage nitrogen produced

Equation A3-71:

$$N_2O_{(s)} = N_2O_{(s1)} * \frac{44 \text{ kg-mol}_{N_2O}}{28 \text{ kg-mol}_{N_2}}$$

where:

$N_2O_{(s)}$ = N_2O emissions from human sewage, kg N_2O/year
$N_2O_{(s1)}$ = N_2O emissions from human sewage, kg N_2O-N/year

A3.6.4 CO_2 EMISSIONS FROM WASTE INCINERATION

A3.6.4.1 Methodology

The IPCC Guidelines (IPCC/OECD/IEA, 1997) do not specify a method to calculate CO_2 emissions from incineration of fossil fuel–based waste (such as plastics and rubber). Therefore, the following three-step method was developed:

1. *Calculating the Amount of Waste Incinerated*: The amount of waste incinerated each year is based on two primary sources. The amount of MSW incinerated in the year 1992 has been estimated based on a study performed by the Hazardous Waste Branch of Environment Canada (Environment Canada, 1996). The amount of MSW incinerated for the years 1999, 2000, and 2001 has been estimated based on a study performed by A.J. Chandler & Associates Ltd. for Environment Canada (Environment Canada, 2003b). To estimate the amount of MSW incinerated in other years, a regression analysis was completed using the A.J. Chandler & Associates Ltd. and Environment Canada MSW incineration values. In the province of Ontario, there was a closure of

one of the incineration plants at the end of 2001. Therefore, the amount of waste incinerated in Ontario for the period 2002–2004 was estimated by trending the A.J. Chandler & Associates Ltd. incineration values for 1999–2001 with population (Statistics Canada, 2004b), assuming that the Ontario incineration plant was closed for this period.

MSW incineration estimates for the period 1990–2004 are shown in Table A3-54.

TABLE A3-54: Estimated MSW Incinerated (by Province) for 1990–2004

Year	MSW Incinerated					
	NL	PE	NS	QC	ON	BC
			(t)			
1990	0	32 000	76 500	619 522	258 700	239 752
1991	0	31 966	58 832	622 742	274 348	259 072
1992	35 500	29 800	56 700	541 100	277 000	257 500
1993	0	32 004	46 818	497 579	273 671	257 580
1994	0	32 023	42 213	447 152	273 332	256 834
1995	0	32 042	38 542	404 828	272 994	256 088
1996	0	32 062	35 807	370 607	272 655	255 342
1997	0	32 081	34 007	344 489	272 316	254 596
1998	0	32 100	33 141	326 475	271 977	253 850
1999	0	32 212	45 000	298 904	258 429	254 800
2000	0	33 000	42 000	303 887	270 811	256 400
2001	0	32 224	42 000	303 910	281 671	246 700
2002	0	32 176	39 028	335 447	167 511[1]	250 866
2003	0	32 196	42 836	357 948	183 970[1]	250 120
2004	0	32 215	47 580	388 552	200 314[1]	249 374

Note:

1 Ontario incineration plant closed as of 2001 year end.

2. *Developing Emission Factors*: Provincial CO_2 emission factors have been developed based on a study performed by the Hazardous Waste Branch of Environment Canada (Environment Canada, 1996). The CO_2 emission factors are based on the assumption that carbon contained in waste undergoes complete oxidation to CO_2. The provincial breakdown in the type of waste incinerated for 1992 has been estimated by the Hazardous Waste Branch of Environment Canada (Environment Canada, 1996). The amount of fossil fuel–based carbon available in the waste incinerated has been determined using typical percent weight carbon constants. Carbon constants and moisture contents were provided by Tchobanoglous *et al*. (1993). The amount of carbon per tonne of waste is estimated and converted to tonnes of CO_2 per tonne of waste by multiplying by the ratio of the molecular mass of CO_2 to that of carbon. The derivation of the CO_2 emission factor is shown in the following equations:

Equation A3-72:

$$C_{Avail\ (y)} = (WasteType) * (1 - \%Moisture) * \%C_{wastetype}$$

where:

$C_{Avail\ (y)}$ = available carbon per waste type for province y, t

WasteType = amount of waste type incinerated, t (1992 data provided by Environment Canada)

%Moisture = % moisture content per waste type (Tchobanoglous *et al*., 1993)

$\%C_{wastetype}$ = % of fossil fuel–based carbon per waste type incinerated

Equation A3-73:

$$EF_{CO_2-1992(y)} = \left(\frac{C_{Avail(y)}}{M_{Inc(y)}}\right) * \frac{MW_{CO_2}}{MW_C}$$

where:

$EF_{CO_2-1992(y)}$ = 1992 CO_2 emission factor for incineration for province y, t CO_2/t waste incinerated

$C_{Avail(y)}$ = available carbon per waste type for province y, t

$M_{Inc(y)}$ = total mass waste incinerated in 1992 for province y, t

MW_{CO_2} = molar weight of CO_2, 44 t/t-mol

MW_C = molar weight of carbon, 12 t/t-mol

3. *Calculating CO_2 Emissions*: Emissions were calculated on a provincial level by multiplying the amount of waste incinerated by the appropriate emission factors.

Equation A3-74:

$$CO_{2(x)} = EF_{CO_2-1992} * (M_{Inc(x)/province})$$

where:

$CO_{2(x)}$ = CO_2 emissions from waste incineration in year x, t/province per year

EF_{CO_2-1992} = 1992 provincial CO_2 emission factor for incineration, t CO_2/t incinerated

$M_{Inc(x)/province}$ = mass waste incinerated per province in year x, t/year

A3.6.5 N_2O EMISSIONS FROM WASTE INCINERATION

A3.6.5.1 Methodology

Emissions of N_2O from MSW incineration were estimated using the IPCC default method (IPCC/OECD/IEA, 1997). An average factor was calculated, assuming that the IPCC five stokers facility factors were most representative. The average N_2O emission factor for MSW five stokers facilities is 0.148 kg/t waste incinerated (IPCC/OECD/IEA, 1997). To estimate emissions, the calculated factor was multiplied by the amount of waste incinerated by each province. The national emission values were then determined as the summation of these emissions for all provinces.

Equation A3-75:

$$N_2O_{(s)} = M_{Inc} * EF_{N_2O}$$

where:

$N_2O_{(s)}$ = N_2O emissions from waste incineration, t/year

M_{Inc} = mass of waste incinerated, t/year

EF_{N_2O} = N_2O emission factor (0.148 kg N_2O/t incinerated / 1000 kg/t)

Emissions of N_2O from sewage sludge incineration were estimated using the IPCC default emission factor for fluidized beds, 0.8 kg/t of dry sewage sludge incinerated (IPCC, 2000). To estimate emissions, the calculated factor was multiplied by the amount of waste incinerated by each province. The national emission values were then determined as the summation of these emissions for all provinces.

A3.6.6 CH_4 EMISSIONS FROM WASTE INCINERATION

A3.6.6.1 Methodology

CH_4 emissions from the incineration of MSW are assumed to be negligible. However, waste incineration of the biosolids resulting from municipal wastewater treatment does produce CH_4 emissions. CH_4 emissions from sewage sludge incineration are dependent on the amount of dried solids incinerated. To calculate the CH_4 emissions, the amount of dried solids incinerated is multiplied by an appropriate emission factor. Estimates of the amount of dried solids in the sewage sludge incinerated in the years 1990–1992 are based on a study completed in 1994 (Fettes, 1994). Data for the years 1993–1996 were acquired through telephone surveys of facilities that incinerate sewage sludge (Environment Canada, 1997). Data for the years 1997 and 1998 were based on a study prepared by Compass Environmental Inc. for Environment Canada (Environment Canada, 1999). Activity data for the years 1999, 2000, and 2001 were taken from a study prepared by A.J. Chandler & Associates Ltd. for Environment Canada (Environment Canada, 2003b). To estimate the amount of sewage sludge incinerated in the years 2002–2004, a linear regression analysis was completed using the A.J. Chandler & Associates Ltd. and Compass Environmental Inc. MSW incineration values.

In view of the relatively small number of facilities that incinerate sewage sludge in Canada, we believe that all relevant facilities were contacted, and we expect that the activity data collected from all three sources of information are complete. As such, our approach in estimating the amount of sewage sludge incinerated over the time-series years is consistent.

A large step change is observed in the quantities of sewage sludge incinerated in Ontario for the period 1996–1997. This is as a result of two pilot projects that were approved in the mid-1990s for the non-incineration waste disposal of sewage sludge. The first project involved the spreading of treated sewage sludge on farmers' fields outside of Toronto, and the second project involved the transportation of sewage sludge to be spread on mine tailings. Both projects proved to have difficulties, however, due to odour problems and the large quantities of waste that were to be spread on farmers' fields. From 1996 to 2000, Toronto sludge was stored during periods when excess quantities of waste were unable to be used as land applications. In 2001, a new contract commenced that involved the spread of biosolids on Ontario farmers' fields, with excess biosolids being shipped to U.S. landfill sites.

Sewage sludge incineration estimates for the period 1990–2004 are shown in Table A3-55.

TABLE A3-55: Estimated Sewage Sludge Incinerated for 1990–2004

Year	Sewage Sludge Incinerated				
	QC	ON	SK	AB	Total
			(t)		
1990	49 200	222 795	1 840	0	273 835
1991	59 400	222 795	1 840	0	284 035
1992	79 800	222 795	1 840	0	304 435
1993	64 833	129 125	71	0	194 029
1994	100 181	93 072	59	0	193 311
1995	101 356	113 985	152	0	215 493
1996	93 276	112 697	70	0	206 043
1997	15 424	0	0	4 885	20 310
1998	18 341	0	0	4 951	23 292
1999	22 032	0	0	0	22 032
2000	24 651	0	0	0	24 651
2001	27 960	0	0	0	27 960
2002	31 096	0	0	0	31 096
2003	34 234	0	0	0	34 234
2004	37 373	0	0	0	37 373

Emissions of CH_4 are estimated based on emission factors obtained from the U.S. EPA publication, *Compilation of Air Pollutant Emission Factors* (EPA, 1995). The emission factors are 1.6 t/kt of total dried solids for fluidized bed sewage incinerators and 3.2 t/kt of dried solids for multiple hearth incinerators, both equipped with venture scrubbers.

Only CH_4 has been considered in calculating emissions from sewage sludge incineration. It was assumed that all incinerators were of the fluidized bed type. CH_4 emissions are calculated as follows:

Equation A3-76:

$$CH_{4(s)} = S_{Inc} * EF_{CH_4\text{-}FB}$$

where:

$CH_{4(s)}$ = CH_4 emissions from waste incineration, t/year

S_{Inc} = sewage sludge incinerated, t/year

$EF_{CH_4\text{-}FB}$ = CH_4 emission factor for fluidized bed incinerators: 1.6 t CH_4/kt sewage sludge incinerated / 1000 t/kt

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ANNEX 4: COMPARISON OF SECTORAL AND REFERENCE APPROACHES

This annex provides a description of the relevant information on the national energy balance for the comparison between Canada's sectoral approach and the reference approach.

A4.1 DESCRIPTION OF COMPARISON

Results from the reference approach were compared with the sectoral approach as a check of combustion-related emissions. The check was performed for all years from 1990 to 2004 and is an integral part of reporting to the UNFCCC.

A direct comparison of the energy and emission outputs from the reference approach and the sectoral approach as presented in the CRF shows a reference approach total that is consistently larger than the sectoral approach total. The reference approach, in theory, includes all CO_2 emissions from all fossil fuel uses (such as combustion, process, and flaring activities) in a country and should be compared with a set of emissions from the sectoral approach, which includes all CO_2 emissions from energy and non-energy (including feedstock) use of fossil fuels.

In the CRF reporting software, the reference approach is directly compared with the sectoral fuel combustion total. This comparison produces a significant discrepancy, since the sectoral approach total for combustion does not include fossil fuel–derived CO_2 from flaring activities, industrial processes, and non-energy uses of fuels. This can be seen in Table A4-1. When the reference approach and sectoral approach are directly compared, there is a 1.6–10.7% variation in kt CO_2 eq emissions and 9.0–14.5% variation in PJ of fuel use, with the reference approach values being consistently higher than the sectoral approach values.

To ensure that energy information is comparable, the apparent energy consumption output excluding non-energy use and feedstock (as presented in CRF Table 1.A.(c) Comparison of CO_2 Emissions from Fuel Combustion) should be compared with the energy consumption from the sectoral approach.

In Canada, a significant amount of fossil fuel is used for feedstock in industrial processes, such as aluminium production, ammonia production, ethylene production, and iron and steel production. The emissions resulting from these processes are reported under industrial processes, while CO_2 emissions resulting from non-energy use of fossil fuels in the oil and gas industries (e.g., natural gas used for flaring or hydrogen production) are reported in the Fugitive Emissions from Oil, Natural Gas and Other Sources table of the CRF. Due to these discrepancies, the predefined comparison of emissions used in the CRF reporting Table 1.A.(c) is not appropriate for Canada, since emissions comparison between the reference approach and the sectoral approach are not comparing similar emission sources. However, this can be rectified by incorporating the non-combustion emissions into the comparison.

The Canadian reporting procedure does follow the IPCC Guidelines (IPCC/OECD/IEA, 1997). When the reference approach energy amount is corrected to exclude non-energy feedstock use of fuels, the difference between the sectoral and adjusted reference approaches varies between −0.05% and +4.1%. Correcting the reference approach in the same way for emissions by subtracting the industrial process and fugitive emissions calculated by the sectoral approach, the totals match within −0.16% to +4.01%. A reconciliation of the reference and sectoral approaches is shown in Table A4-1.

TABLE A4-1: Reconciliation of Reference Approach and Sectoral Approach for Canada

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Energy – PJ															
Reference Approach Value	7 378	7 124	7 336	7 327	7 575	7 711	7 984	8 136	8 192	8 453	8 726	8 769	8 823	9 175	9 334
Sectoral Approach Value	6 446	6 296	6 533	6 549	6 777	6 936	7 131	7 267	7 400	7 644	7 997	7 874	8 051	8 420	8 359
Difference	14.5%	13.2%	12.3%	11.9%	11.8%	11.2%	12.0%	12.0%	10.7%	10.6%	9.1%	11.4%	9.6%	9.0%	11.7%
Adjusted Reference Approach Value Excluding Non-Energy Use and Feedstocks	6 712	6 464	6 653	6 611	6 848	6 955	7 192	7 312	7 428	7 640	7 963	7 932	7 945	8 297	8 337
Adjusted Difference	4.12%	2.67%	1.83%	0.94%	1.04%	0.28%	0.85%	0.61%	0.39%	−0.05%	−0.42%	0.73%	−1.32%	−1.46%	−0.26%
Emissions – kt CO_2															
Non-Energy Use of Fossil Fuels and Feedstock															
Ammonia Production	3 942	3 896	4 152	4 510	4 472	5 262	5 430	5 299	5 326	5 429	5 361	4 822	4 775	5 083	5 660
Iron and Steel Production	7 058	8 316	8 500	8 182	7 537	7 878	7 745	7 549	7 685	7 890	7 893	7 279	7 113	7 041	8 161
Aluminium Production	2 715	3 147	3 273	3 908	3 771	3 643	3 863	3 929	3 977	3 949	3 899	4 202	4 419	4 581	4 224
Other & Undifferentiated Production	8 312	8 716	8 262	8 291	8 841	8 718	9 610	10 189	9 264	9 645	9 685	10 368	9 894	10 894	12 052
Hydrogen Production from Refineries	526	500	473	562	383	402	744	764	621	355	869	1 006	1 030	1 035	1 057
Fugitive Flare CO_2 Emissions	5 288	5 242	5 286	5 523	5 594	6 248	6 571	6 640	6 550	6 950	5 351	7 377	7 376	5 351	5 351
Total Non-Energy Use of Fossil Fuels and Feedstock	27 841	24 075	24 187	24 891	24 622	25 500	26 648	26 965	26 253	26 913	26 838	26 672	26 201	27 599	30 097
Reference Approach Value	463 848	445 540	455 987	448 561	464 354	468 512	481 688	490 001	494 455	506 431	524 503	526 994	525 278	548 324	553 073
Sectoral Approach	419 210	409 582	423 195	420 585	433 494	444 498	455 751	467 137	474 283	490 561	513 847	507 914	515 579	539 815	536 894
Difference	10.65%	8.78%	7.75%	6.65%	7.12%	5.40%	5.69%	4.89%	4.25%	3.24%	2.07%	3.76%	1.88%	1.58%	3.01%
Adjusted Reference Approach Value Excluding Emissions from Non-Energy Use of Fossil Fuel and Feedstocks	436 007	421 465	431 800	423 669	439 732	443 012	455 040	463 035	468 202	479 518	497 665	500 322	499 077	520 725	522 976
Adjusted Difference	4.01%	2.90%	2.03%	0.73%	1.44%	−0.33%	−0.16%	−0.88%	−1.28%	−2.25%	−3.15%	−1.49%	−3.20%	−3.54%	−2.59%

In Canada, like the United States, HHV is used to record the energy content of fuels, and this has been used for energy data reporting in the CRF for the reference and sectoral approaches. Canada developed country-specific higher heating energy conversion and carbon emission factors for the majority of the raw fuels except for crude oil, lubricants, solid biomass, and liquid biomass, where default IPCC carbon emission factors were used along with the OECD's conversion factor of 95% for solid and liquid fuels from LHV to HHV.

To elaborate on the method of developing HHV conversion factors, a table has been included (Table A4-2) to illustrate the method and data sources used for the reference approach. The energy conversion factors are taken directly from the RESD (Statistics Canada, #57-003), except for NGLs, LPG, gasoline, gas/diesel oil, natural gas, and other bituminous coal, where the factors are based upon the proportion of their components.

TABLE A4-2: Reference Approach Conversion Factors for Canada

Fuel Types			Energy Conversion Factor - HHV			Carbon Emission Factor - HHV (t C/TJ)		
			2004 Value	Unit	Reference	2004 Value	Derivation	Reference
Liquid Fossil	Primary Fuels	Crude Oil	39.28	TJ/ML	Ref. 4	19.00	20.00 × 95%	Ref. 1
		Orimulsion	N/A	–	–	N/A	–	–
		NGLs	21.38[1]	TJ/ML	Ref. 4	16.13[1]	–	Ref. 2
	Secondary Fuels	Gasoline	35.00[2]	TJ/1000 m^3	Ref. 4	18.54[2]	–	Ref. 3
		Jet Kerosene	37.40	TJ/1000 m^3	Ref. 4	19.32	–	Ref. 3
		Other Kerosene	37.68	TJ/1000 m^3	Ref. 4	18.45	–	Ref. 3
		Shale Oil	N/A	–	–	N/A	–	–
		Gas/Diesel Oil	38.38[3]	TJ/1000 m^3	Ref. 4	18.60[3]	–	Ref. 3
		Residual Fuel Oil	42.50	TJ/1000 m^3	Ref. 4	20.18	–	Ref. 3
		LPG	26.38[4]	TJ/1000 m^3	Ref. 4	16.48[4]	–	Ref. 2
		Ethane	17.22	TJ/1000 m^3	Ref. 4	15.61	–	Ref. 2
		Naphtha	35.17	TJ/1000 m^3	Ref. 4	19.33	–	Ref. 3
		Bitumen	44.46	TJ/1000 m^3	Ref. 4	20.90	22.00 × 95%	Ref. 1
		Lubricants	39.16	TJ/1000 m^3	Ref. 4	19.66	–	Ref. 3
		Petroleum Coke	40.57	TJ/1000 m^3	Ref. 4	26.00	–	Ref. 2
		Refinery Feedstocks	35.17	TJ/1000 m^3	Ref. 4	19.33	–	Ref. 3
		Other Oil	39.82	TJ/1000 m^3	Ref. 4	19.84	–	Ref. 3
Solid Fossil	Primary Fuels	Anthracite	27.70	TJ/kt	Ref. 4	23.53	–	Ref. 2
		Coking Coal	N/A	–	–	N/A	–	–
		Other Bituminous Coal	28.42[5]	TJ/kt	Ref. 4	21.97[5]	–	Ref. 2
		Sub-Bituminous Coal	19.15	TJ/kt	Ref. 4	24.68	–	Ref. 2
		Lignite	15.00	TJ/kt	Ref. 4	25.73	–	Ref. 2
		Oil Shale	N/A	–	–	N/A	–	–
		Peat	N/A	–	–	N/A	–	–
	Secondary Fuels	BKB & Patent Fuel	N/A	–	–	N/A	–	–
		Coke Oven/Gas Coke	28.83	TJ/kt	Ref. 4	23.46	–	Ref. 3
Gaseous Fossil		Natural Gas	38.21[6]	TJ/GL	Ref. 4	13.87[6]	–	Ref. 2
Biomass		Solid Biomass	15.80[7]	TJ/kt	Ref. 4	23.22[7]	29.90 × 95%	Ref. 1
		Liquid Biomass	24.12	TJ/kt	Ref. 5	17.06	–	Ref. 5
		Gas Biomass	N/A	–	–	N/A	–	–

References:

(1) IPCC/OECD/IEA (1997); (2) McCann (2000); (3) Jaques (1992); (4) Statistics Canada, #57-003 (2003 data); (5) Heat of Combustion of Fuels, retrieved April 12, 2006, from: www.webmo.net/curriculum/heat_of_combustion/heat_of_combustion_key.html.

Notes:

1 Composite value is based on proportions of propane, butane, and ethane in Canada for the specific inventory year.

2 Composite value is based on proportions of motor gasoline and aviation gasoline in Canada for the specific inventory year.

3 Composite value is based on proportions of diesel fuel oil and light fuel oil in Canada for the specific inventory year.

4 Composite value is based on proportions of refinery propane and butane in Canada for the specific inventory year.

5 Composite value is based on provincial (domestic and imported) proportions for the specific inventory year.

6 Composite value is based on proportions of marketable natural gas and producer-consumed gas.

7 Composite value is based upon IPCC default values for solid and liquid biomass.

N/A = not applicable; BKB = charcoal briquettes

A4.2 REFERENCE APPROACH METHODOLOGY

The reference approach for the most part follows the IPCC-designated methods with the use of HHVs. In Canada, like the United States, HHV is used to record the energy content of fuels. Fuel quantities are recorded from the RESD (Statistics Canada, #57-003) and entered in their physical units (typically megalitres, thousands of cubic metres, kilotonnes, and gigalitres). Apparent consumption is determined, and country-specific energy conversion factors and carbon emission factors are used to calculate the carbon content and emissions. These factors are taken from three sources: the RESD; *Canada's Greenhouse Gas Emissions: Estimates for 1990* (Jaques, 1992); and the *1998 Fossil Fuel and Derivative Factors* (McCann, 2000). Emission factors and oxidation percentages for liquid fuels are from Jaques (1992). Factors for coal and natural gas fuels are from McCann (2000), with the use of default IPCC oxidation fractions. Some of the carbon emission factors take oxidation fractions into consideration. In these cases, the oxidation rate in the CRF has been listed as 1 so as not to double-count the oxidation fractions.

When necessary, the carbon emission factors (t C/TJ) are derived using the IPCC default (IPCC/OECD/IEA, 1997) and LHVs that are converted to HHVs using the OECD conversion factor of 95% for solid and liquid fuels. The IPCC default was used in the case of crude oil, bitumen (asphalt), and solid and liquid biomass.

A4.2.1 CRUDE OIL

The crude oil used in the reference approach includes pentanes plus, condensate, crude bitumen, and synthetic crude, as well as conventional crude. The crude oil production value has been adjusted to include the enrichment of synthetic crude at the oil sands plants by the addition of hydrogen, which originates from natural gas (Statistics Canada, #57-003).

A4.2.2 NATURAL GAS LIQUIDS (NGLs)

NGLs are accommodated by representing them as a virtual composite mixture of ethane, propane, and butane. The energy conversion factor (TJ/unit) and the carbon emission factor (t C/TJ) are dependent on the annual proportions of each fuel and are generated for each year based on those data.

A4.2.3 GASOLINE

This category is a combination of motor gasoline and aviation gasoline, with the former dominating the total. The energy conversion factor and carbon emission factor are based on the proportions of each fuel for each year and have been weighted accordingly.

A4.2.4 GAS/DIESEL OIL

Gas/diesel oil includes diesel fuel oil and light fuel oil. A weighted average carbon emission factor and energy conversion factor have been calculated for each year to accommodate the differences in annual consumption levels of these two fuels and their different energy and carbon contents.

A4.2.5 OTHER KEROSENE

Other kerosene includes kerosene and stove oil.

A4.2.6 JET KEROSENE

Jet kerosene includes aviation turbo fuel. Fuel from international bunkers has been removed.

A4.2.7 COKE OVEN GAS AND COKE

Coke oven gas and coke are produced from coal.

A4.2.8 PETROLEUM COKE

Petroleum coke includes petroleum coke and catalytic coke. A weighted energy conversion factor and carbon emission factor were developed for petroleum coke, taking this into consideration. Petroleum coke represents 60% of the fuel use, and catalytic coke represents 40% of the fuel use.

A4.2.9 LIQUEFIED PETROLEUM GAS (LPG)

LPG is accommodated by representing it as a virtual composite mixture of propane and butane produced by the refineries. Dependent upon the annual proportions, an energy conversion factor (TJ/unit) and carbon emission factor (t C/TJ) for that year are generated.

A4.2.10 BITUMEN

All calculations are made using default IPCC values for the carbon emission factors.

A4.2.11 OTHER OILS

This category includes stored carbon due to other products from Table 1-A(d) of the CRF.

A4.2.12 OTHER BITUMINOUS AND SUB-BITUMINOUS COAL

Other bituminous represents both Canadian bituminous and imported bituminous. The carbon and energy contents of Canadian bituminous vary by province. Factors for imported bituminous also vary depending on where the bituminous coal has been mined. The energy conversion factor and carbon emission factor have been weighted according to the provincial bituminous coal consumption values and their associated carbon and energy content values.

Sub-bituminous coal is both imported and produced domestically. The energy conversion factor and carbon emission factor are the same for both imported and domestic sub-bituminous coal.

A4.2.13 NATURAL GAS

The value listed as "natural gas production" in the RESD has been reduced to compensate for the inter-product transfer (which accounts for the natural gas being used as a source of hydrogen in oil sand upgrading). This production includes marketable (for commercial sales) production plus field flared and waste, gathering uses, and plant uses. The last three items are shown as producer consumption. Marketable natural gas and producer-consumed natural gas have different energy and carbon contents. The energy conversion factor and carbon emission factor for natural gas have been generated to take this into consideration.

A4.2.14 BIOMASS

Solid biomass includes Canadian industrial and residential solid wood combustion and spent pulping liquor combustion. For solid biomass, all calculations are made using default IPCC values for the carbon emission factors.

Liquid biomass includes ethanol used in the transportation sector. Both the energy conversion factor and carbon emission factor are country specific.

REFERENCES

IPCC/OECD/IEA (1997), *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, Intergovernmental Panel on Climate Change, Organisation for Economic Co-operation and Development, and International Energy Agency. Available online at: www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm.

Jaques, A.P. (1992), *Canada's Greenhouse Gas Emissions: Estimates for 1990*, Environmental Protection, Conservation and Protection, Environment Canada, Report No. EPS 5/AP/4.

McCann, T.J. (2000), *1998 Fossil Fuel and Derivative Factors*, Report prepared for Environment Canada by T.J. McCann and Associates Ltd.

Statistics Canada, *Report on Energy Supply–Demand in Canada* (Annual), Catalogue No. 57-003-XIB.

ANNEX 5: ASSESSMENT OF COMPLETENESS

Although this inventory report serves as a comprehensive assessment of anthropogenic GHG emissions and removals in Canada, some categories have not been included or have been included with other categories due to reasons explained in the CRF and in this annex.

A5.1 ENERGY

Overall, the Energy Sector of the national inventory provides a full estimate of all significant sources. The following list delineates those that are not currently estimated and that may represent a source in their particular subsector, but which do not affect the completeness of the inventory due to their relatively small contributions.

A5.1.1 FUEL COMBUSTION

Emissions from the combustion of waste fuels (e.g., tires, solvents, etc.) for the production of energy at industrial facilities (e.g., cement kilns) are not included. An appropriate data collection mechanism has not yet been identified for this emission source. Further emission factor research is needed to ensure that there is no double-counting of GHG emissions from the non-energy use of fossil fuels (reported under the Industrial Processes Sector). Where IPCC default factors are currently applied to estimate GHGs from the non-energy use of fossil fuels, it is assumed that these account for the emissions from both the non-energy use itself and the subsequent disposal of waste products (e.g., tires used as waste fuels by the cement production industry).

A5.1.2 EMISSIONS FROM COMBUSTION OF LANDFILL GAS

Emissions from the combustion of captured landfill gas used as a fuel source to generate heat or electricity are currently not included in the Energy Sector. In future, these will be estimated and reported in the appropriate category indicated by the IPCC Guidelines (IPCC/OECD/IEA, 1997).

A5.1.3 FUEL COMBUSTION — TRANSPORTATION

Due to historically elusive data on the quantities of biofuels consumed for transport in Canada, these fuels have not previously been introduced to the Canadian inventory. This year, with the inclusion of the small amounts of fuel ethanol used (0.6% of total gasoline consumption in 2004), consumption of biodiesel will remain as the next significant transport biofuel to be accounted for. While the country experiments with implementation and consumption of this fuel, biodiesel remains widely unregulated and untracked — so far, no data source has been identified that describes its use in Canada.

A5.2 INDUSTRIAL PROCESSES

Overall, the Industrial Processes Sector of the national inventory provides a comprehensive estimate of all significant sources. As mentioned in the paragraphs below, this year's inventory accounts for emissions coming from several sources that were not previously included. Also discussed in the following subsections are sources that are not currently estimated and that may represent a source in their particular subsector. However, their magnitudes are assumed to be small and not affecting the overall completeness of the GHG inventory in a major way.

A5.2.1 MINERAL PRODUCTS

Emissions from asphalt roofing, road paving with asphalt, and glass production (other than those related to the use of limestone and soda ash in the process) are not estimated and are thought to be negligible. The Solvay process in which soda ash is produced results in some CO_2 emissions; however, as CO_2 is also a necessary component in the reactions, it is most commonly recovered for reuse. Hence, the quantity of recovered CO_2 is estimated in this year's inventory, but the net amount of non-recovered CO_2 coming from soda ash production is not estimated and is considered to be minimal.

CO_2 emissions from magnesite (carbonate)–based production of magnesium and from limestone use in the pulp and paper industry, which were not estimated previously, are now inventoried.

A5.2.2 CHEMICAL PRODUCTION

N_2O emissions associated with the production of chemicals other than nitric and adipic acids are not estimated. Production of chemicals other than nitric acid and adipic acid may be a source of N_2O; however, more research is required to determine its significance.

Similarly, there are insufficient data available to estimate CH_4 emissions from chemical manufacturing processes in Canada, although they are thought to be insignificant.

Process-related CO_2 emissions from adipic acid production are not inventoried and are considered negligible.

As opposed to the previous inventory, CO_2 trapped in exported products (e.g., urea) are now estimated and subtracted from CO_2 emissions from ammonia production.

A5.2.3 METAL PRODUCTION

CH_4 emissions associated with the production of metals are not estimated and are thought to be insignificant.

SF_6 has been used by only a small number of aluminium plants for degassing purposes. Emissions coming from consumption of SF_6 by the aluminium industry are now taken into account in the inventory.

A5.2.4 PRODUCTION AND CONSUMPTION OF HALOCARBONS AND SF_6

Since data on PFCs used in aerosols are currently unavailable, the associated emissions are not inventoried. HFC emissions from electronic industries are reported under the category 2.F.5 Solvents, not 2.F.9 Other (Contained and Emissive Emissions from Electronic Industries), in the CRF reporter, since it is not possible for this submission to separate HFC consumption as solvent in electronic industries from other types of solvent use. There are also some PFCs emitted from the electronic industry, and these emissions are reported under 2.F.9 Other (Contained and Emissive Emissions from Electronic Industries). HFC and PFC emissions coming from electrical equipment are reported as not estimated because it is thought that there is no known use of these halocarbons for electrical insulation, arc quenching, and current interruption in equipment used in the electricity industry.

SF_6 emitted during semiconductor manufacturing was not a category in the previous inventory, but these emissions are now inventoried. There is currently no information on the export or destruction of SF_6.

A5.3 SOLVENT AND OTHER PRODUCT USE

In this sector, only N_2O emissions associated with the use of anaesthetics and propellants are estimated. Emissions from other sources, such as paint application, degreasing, and dry cleaning, are not estimated, since their corresponding activity data are currently not available.

A5.4 AGRICULTURE

Overall, the Agriculture Sector of the national inventory provides a complete estimate of the significant sources. The following list includes sources that are not currently estimated. Most of these are considered to be minor sources.

A5.4.1 ENTERIC FERMENTATION AND MANURE MANAGEMENT

Some smaller animal categories, such as domestic deer, elk, and llamas, have not yet been included. Due to their relatively low populations, these are considered to be minor sources.

A5.4.2 RESIDUE BURNING

Residue burning is practised to a small extent in Canada and concerns mostly flax residues. This category is considered to be a minor source of emissions. AAFC and Statistics Canada conducted a Farm Environmental Management Survey (FEMS) in 2001, which found that, in that year, 2.2% of crop residues on an area basis were burned, the majority in Manitoba and Saskatchewan (Korol, 2004). Expert opinion suggests that, on a national basis, field burning of crop residues has declined since the early 1990s. However, due to the paucity of the data and the absence of data collection mechanisms, no time series is available.

A5.4.3 RICE PRODUCTION

CH_4 emissions from rice production are not currently inventoried, as rice production is very small in Canada. An appropriate data collection method for this source has not been established.

A5.5 LAND USE, LAND-USE CHANGE AND FORESTRY

The major methodological improvements described in Chapter 7 and Section A3.5 of Annex 3 have had significant effects on the completeness of the LULUCF inventory. The Forest Land, Cropland, and Wetlands categories have all expanded their coverage of carbon pools and activity data and improved their spatial resolution.

A5.5.1 FOREST LAND

Forest land estimates are provided for both forest land remaining forest land and land converted to forest land. These estimates include carbon stock changes and emissions from all pools (biomass, dead organic matter, and soil) in managed forests resulting from growth and mortality, fire and insect disturbances, and management activities. Emissions of CO_2, CH_4, CO, and N_2O are estimated. Emissions of NO_x are not estimated. CO emissions occur during biomass burning only; they are reported as CO_2 emissions in the CRF Biomass Burning tables.

A5.5.2 CROPLAND

Estimates of cropland remaining cropland now include soil and partial biomass estimates. The current estimate in the land converted to cropland category includes only CO_2 emissions from all pools due to forest and grassland conversion to cropland. Non-CO_2 emissions (CH_4, CO, N_2O) from biomass burning are also reported; NO_x estimates have not been estimated. GHG emissions and removals from the conversion of wetlands and settlements to cropland have not been estimated.

A5.5.3 GRASSLAND

In Canada's definitional framework of LULUCF land categories (see Chapter 7), the conversion of forest land and cropland to grassland is not occurring (NO). Emissions from the conversion of wetlands to grassland have not been estimated (NE).

A5.5.4 WETLANDS

GHG emissions in land converted to flooded land, land converted to (managed) peatland, and (managed) peatland remaining peatland have been prepared but cannot be reported separately in the CRF tables. CO_2 estimates were developed in all categories; non-CO_2 (CH_4, CO, and N_2O) estimates associated with biomass burning are reported in forest land converted to flooded land and (managed) peatlands. Emissions of NO_x have not been estimated. Cropland and grassland converted to wetlands were not estimated; however, in many instances, they would be included in the subcategory other land converted to wetlands.

A5.5.5 SETTLEMENTS

The current estimates in the land converted to settlements category include forest loss to settlements and the conversion of tundra (reported under grassland) to settlements in the Canadian north. Non-CO_2 emissions (CH_4, CO, and N_2O) are reported only when biomass burning has occurred in the course of conversion activities. Emissions of NO_x have not been estimated. Emissions and removals from the conversion of cropland, agricultural grassland, wetlands, and other land to settlements have not been estimated. More complete estimates are under preparation. CO_2 estimates in settlements remaining settlements include only net carbon sequestration in the aboveground biomass of urban trees.

A5.6 WASTE

This category is for the most part complete, with the exception of the following.

A5.6.1 DOMESTIC AND COMMERCIAL WASTEWATER

N_2O emissions from domestic and commercial wastewater without human sewage/wastewater is given the notation IE (included elsewhere) in the CRF tables and is reported in the human sewage subsector. CH_4 recovery from domestic and commercial wastewater without human sewage/wastewater is reported as NE, as, although recovery of gases from wastewater treatment is not expected, this has not been confirmed. CH_4 and N_2O emissions from the sludge subsector are reported as NE, as the data required to evaluate the emissions and quantities captured from specific sites are not available at this time. CH_4 recovery from covered anaerobic digesters is expected but has not yet been quantified.

A5.6.2 INDUSTRIAL WASTEWATER

Although, for the 2006 NIR submission, confirmation of industrial wastewater treatment methods was obtained through personal communications with industry associations and provincial government officers, an appropriate data collection mechanism has not been identified for this source of emissions. The environment ministries for Ontario, Quebec, and British Columbia, provinces where the majority of the relevant industries are centred, were contacted. It was confirmed that, with the exception of a slaughterhouse in Quebec, anaerobic industrial wastewater treatment was not employed for those industries that were identified as the largest water consumers based upon process water. These industries are pulp and paper, food and beverage, rubber products, chemical and chemical products, petroleum products, textiles, and plastic. Since the slaughterhouse mentioned above captures and combusts the CH_4 generated from the anaerobic digestion, it is assumed that the CH_4 emissions are negligible on a national scale, and, therefore, the notation NO was reported. Gas collection is occurring for this facility; however, quantitative data are currently not available, so the CH_4 recovery is reported as NE. A study is being considered for 2006–2007 that will provide for a more complete collection of activity data and assist in developing an improved methodology to estimate emissions from this subsector. A study, mentioned in the 2005 NIR submission, that was to examine the anaerobic CH_4 emissions from tailings ponds in the oil sands operations in Canada will not be conducted for the Waste Sector, as it was reevaluated as a process under the fossil fuel industry subsector as a possible CH_4 source for the Energy Sector.

A5.6.3 WASTE INCINERATION

CH_4 emissions from MSW incineration are considered as negligible and have not been estimated. Less than 5% of all MSW is incinerated in Canada. Therefore, CH_4 emissions from this source are not expected to contribute significantly to the national inventory but are reported as NE, as we expect, through an inventory improvement study, to be able to quantify the emissions or at least confirm that the quantities are in the trace range. N_2O emissions from sewage sludge are now included, where in previous inventories they were not estimated due to lack of underlying emission research. A study is being considered to update incineration-related GHG sources for 2006–2007.

REFERENCES

IPCC (2003), *Good Practice Guidance for Land Use, Land-Use Change and Forestry*, Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at: www.ipcc-nggip.iges.or.jp/lulucf/gpglulucf_unedit.html.

Korol, M. (2004), Farm Environmental Management Survey in Canada, *Fertilizer and Pesticide Management in Canada*, 1(3), Statistics Canada.

ANNEX 6: QUALITY ASSURANCE AND QUALITY CONTROL

The application of QA/QC procedures is an essential requirement in the GHG inventory development and submission processes in order to ensure and improve transparency, consistency, comparability, completeness, and confidence in the national emission and removal estimates for the purposes of meeting Canada's reporting commitments under the UNFCCC. Two basic conditions have to be met so that control procedures qualify as QA/QC: firstly, checks and reviews have to be performed by staff not directly involved in the preparation of the inventory estimates; and secondly, their nature, outcome, and the appropriate corrective actions have to be documented.

The following describes the overall framework for the QA/QC plan that the Greenhouse Gas Division is currently developing and implementing. A description is also provided of the various formal procedures already implemented in the development of the 1990–2004 GHG inventory (2006 submission) and of the planned improvements. Any category-specific QA/QC activities are described, where applicable, in Chapters 3–8 in the relevant QA/QC subsection.

A6.1 FRAMEWORK OF A QA/QC PLAN FOR THE NATIONAL INVENTORY

Informal QC has been performed regularly over the inventory, and a formal external review process has been in place for many years, as described in previous NIRs. The design of a formal QA/QC plan meeting the UNFCCC and IPCC Good Practice Guidance (IPCC, 2000) requirements was initiated with the development of a QA/QC framework (SNC Lavalin, 2004). This framework provides the basis for the QA/QC program, the first step of which is the implementation of Tier 1 QC (see below). The plan is seen as an integrated approach to managing inventory quality, working towards continuously improved emission and removal estimates. It will encompass a quality management cycle that spans several years, ensuring that the complete inventory is subject to the full suite of QA/QC procedures.

A QA/QC coordinator function is planned with overall responsibility for the design and implementation of the full plan, including definition of quality objectives, coordination of the processes governing expert reviews, audits, and verification, as well as upgrades and maintenance of the documentation and archiving system.

The plan also includes the use of several standard, numbered forms for the consistent and systematic documentation of all QA/QC activities conducted in the annual inventory preparation and submission. Forms completed during each annual inventory preparation are stored in QA/QC Activity Books and archived along with other procedural and methodological documentation by inventory category and by submission year.

Coordination of QA/QC work is also done with outside agencies and organizations providing activity data and/or developing actual GHG estimates for Environment Canada (e.g., Statistics Canada, LULUCF partners, industry, etc.) to assess whether the QC and potential QA procedures in their respective data collection systems are in place or are being developed and meet the minimum requirements.

A6.2 QUALITY CONTROL PROCEDURES

QC is designed to provide routine technical checks to measure and control the quality of the inventory, to ensure data consistency, integrity, correctness, and completeness, and to identify and address errors and omissions. Its scope covers a wide range of inventory processes, from data acquisition and handling and application of approved procedures and methods to calculation of estimates and documentation (IPCC, 2000).

For the 2006 inventory submission, 47 inventory categories have been subject to formal Tier 1 QC checks, in a manner consistent with IPCC Good Practice Guidance (IPCC, 2000). Of the 47 categories, 44 are key categories (as listed in Annex 1), and 3 are non-key categories.

Standard Tier 1 QC checks applicable to all categories and listed on Form QP03 (Environment Canada, 2005a) are performed internally by Greenhouse Gas Division staff not directly involved in the development of the GHG estimates for those categories. Groups in AAFC and the CFS who developed GHG estimates for the inventory also undertook and documented some internal QC on their estimation procedures, data systems, and results, which were complemented by checks by Environment Canada.

The formal Tier 1 QC procedures consist of a series of 31 checks grouped into seven steps integrated at various stages of the inventory preparation process, as follows:

1. raw data collection, acquisition, and handling (e.g., completeness, accuracy of data sources and units, consistency of activity data trend, etc.);
2. data input into model/spreadsheet (e.g., transcription errors, accuracy of units, etc.);
3. GHG emissions and removals estimations (e.g., proper use of units and equations, integrity of files and spreadsheets, sample calculation checks, etc.);
4. treatment of category in sector summary tables and sector trend analysis (e.g., identification of potential trend anomalies, accuracy of aggregation, consistency of estimates, etc.);
5. uncertainty estimates (e.g., completeness, transcription errors, etc.);
6. input of category estimates in the CRF (e.g., consistency and accuracy checks, correct use of notation keys, etc.); and
7. treatment of category in NIR (e.g., consistency between CRF and NIR, accuracy and completeness of references, etc.).

Checks on the documentation and archiving of all the information required to produce the national emissions estimates are in the process of being performed, starting with the key categories. These QC procedures are listed in Form QP10 (Environment Canada, 2005b). In addition, formal cross-cutting QC checks on CRF and NIR assembly and final products were performed prior to the submission and documented in Form QP13 (Environment Canada, 2005c), also archived in the QA/QC Activity Books.

These QC Tier 1 checks allowed some transcription and calculation errors to be detected and addressed. The QC forms include a record of any corrective action taken and refer to supporting documentation such as phone logs, electronic mails, notes, or additional calculation checks. Both electronic and hard copies of these completed forms and the supporting documentation are archived in the QA/QC Activity Book specific to each inventory category for the 2006 submission.

In addition to general Tier 1 QC checks, the QA/QC framework of the national inventory provides for the application of Tier 2 QC checks on a case-by-case basis starting with key categories (for which typically higher-tier methodologies are used) and categories where a significant change in method or data has been made. Tier 2 QC procedures are specific to the source or sink category and require a more in-depth technical expertise. Due to resource constraints, Tier 2 QC checks could not be performed on this submission. Addressing all source and sink categories will constitute a multiyear process.

A6.3 QUALITY ASSURANCE

QA generally consists of independent third-party review activities to ensure that the inventory represents the best possible estimates of emissions and removals and to support the effectiveness of the QC program (IPCC, 2000). A formal review of the draft GHG estimates usually takes place over the month of March each year by experts from the EPWG, a federal–provincial–territorial expert group.

The draft inventory is also reviewed at the same time by government experts and scientists of AAFC and the CFS of NRCan, among others, under the auspices of the national MARS for LULUCF. Similarly, Environment Canada's Greenhouse Gas Division performed QA and QC on data and estimates received from MARS partners (forest land, deforestation, croplands, and N_2O agricultural soils estimates), in particular through reviewing documentation and methods, building the LULUCF geodatabase to reconcile all LULUCF categories, and preparing the NIR and CRF.

In addition, selected underlying data and methods are independently assessed each year by various groups or individual experts in industry, academia, and governments, in particular in the Energy and Industrial

Processes sectors (e.g., aluminium, fugitives, etc.). Findings are tracked, documented, and fed into the development of improvement work plans.

The quality management cycle will integrate these activities into the QA/QC plan, which will comprise a formal schedule of annual peer reviews with a focus on category- or sector-specific reviews, as required. It is also planned that an independent audit will be conducted to objectively evaluate how effectively the national system and the general inventory process comply with the minimum QC specifications outlined in the IPCC Good Practice Guidance (IPCC, 2000) and the QA/QC plan.

REFERENCES

Environment Canada (2005a), *Form No. QP03, Tier 1 QC Procedures, Version 10.0*, Gatineau, Quebec, Canada, February.

Environment Canada (2005b), *Form No. QP10, Documentation and Archiving QC Procedures, Version 2.0*, Gatineau, Quebec, Canada, February.

Environment Canada (2005c), *Form No. QP13, Cross-Cutting Inventory Tier 1 QC Checks, Version 1.0*, Gatineau, Quebec, Canada, February.

IPCC (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/.

SNC Lavalin (2004), *Framework for a Quality Assurance and Quality Control Plan*, Prepared for the Greenhouse Gas Division, Environment Canada.

ANNEX 7: UNCERTAINTY

A7.1 INTRODUCTION

Identifying sources of uncertainty in the emission and removal estimates of the GHG inventory and quantifying the magnitudes of the uncertainty are of assistance in defining and prioritizing future improvements to the NIR. Quantitative estimates of the uncertainty can also be used to assess the relative importance of the input parameters (e.g., activity data and emission factors) according to their relative contribution to the uncertainty of the respective source category estimates. This information allows prioritized resource allocation to the reduction of uncertainty in inventory estimates.

The UNFCCC reporting guidelines on annual inventories state that Annex I Parties shall quantitatively estimate the uncertainties in the data used for all source and sink categories using at least the Tier 1 method, as provided in the IPCC Good Practice Guidance (IPCC, 2000). Alternatively, Annex I Parties may use the Tier 2 method in the IPCC Good Practice Guidance (IPCC, 2000) to address technical limitations in the Tier 1 method. Uncertainty in the data used for all source and sink categories should also be qualitatively discussed in a transparent manner in the NIR, in particular for those sources that were identified as key sources.

Canada performed an uncertainty assessment of its 1990 estimates in 1994 (McCann, 1994). In 2003–2004, Canada embarked on a comprehensive study to quantify uncertainty associated with its source categories included in the 2001 GHG inventory (the latest inventory estimates available at the time of the study). The study report for this original phase of the study was published in September 2004 (ICF, 2004). At the time of the study, the IPCC report on Good Practice Guidance for LULUCF (IPCC, 2003) was still under preparation; therefore, the LULUCF Sector was excluded from the assessment.

The overall trend uncertainty for the 2001 GHG inventory, which was not performed in the original phase due to computational limitations, was performed in the subsequent phase (ICF, 2005) and is now reported in Table A7-1. Also performed in the subsequent phase and reported here was the study of sensitivity of the overall inventory uncertainty to source category uncertainties that contribute the most.

Since the 2003 NIR submission (Environment Canada, 2003), which contained emission estimates for the year 2001, updates to the methods and the activity data were made for certain source categories. Where available or relevant, updated quantitative uncertainty estimates for these categories are reported in the sectoral chapters of this NIR and highlighted in Section A7.4 of this annex.

In this annex, a picture of the overall uncertainty as assessed for the Canadian national GHG inventory of 1990–2001 (as reported in the 2003 NIR) is provided, followed by sections describing the scope of the ICF (2004, 2005) uncertainty study. A summary of sector uncertainty results for 2001 is discussed in the final section, in tabular and narrative formats, together with highlights on updates to uncertainty assessments.

A7.2 OVERALL INVENTORY UNCERTAINTY FOR 2001 (REPORTED IN NIR 2003)

Table A7-1 shows the overall level uncertainty picture for Canada's 2001 GHG inventory year (reported in NIR 2003) for each gas and for the overall inventory in CO_2 eq, with and without the incorporation of the uncertainty associated with the GWP of the component gases. This assessment excluded the LULUCF Sector.

Canada's GHG inventory level uncertainty currently falls within a range of −3% to +6% for all GHGs combined without consideration of the uncertainty within the GWPs. With GWP uncertainty considered, the overall uncertainty falls within a range of −5% to +10%. This compares with other Annex I Parties' reported uncertainties and reflects the range of uncertainties that such countries would see in their inventories.

In regards to the particular gases, N_2O exhibits the highest uncertainty range in the national inventory, with a range of −8% to +80%, followed by HFCs, with a range of −22% to +60%. CO_2 exhibits an uncertainty of −4% to 0%. The overall Canadian inventory uncertainty estimate falls within the range of the uncertainties reported by other Annex I countries.

TABLE A7-1: Quantitative Tier 2 Uncertainty Assessment of Overall National Inventory GHG Emissions and Trends for 2001 (by Gas)

Gas	Base Year Emissions (1990)[1]	Year t Emissions (2001)[1]	Uncertainty in Year t Emissions (2001) as % of Emissions for the Gas		% Change in Emissions between 2001 and 1990	Range of Likely % Change between 2001 and 1990	
	Gg CO_2 eq	Gg CO_2 eq	*% Below (2.5th percentile)*	*% Above (97.5th percentile)*	%	*Lower % (2.5th percentile)*	*Upper % (97.5th percentile)*
CO_2	472 000	566 000	–4	0	20	18	24
CH_4	73 000	93 000	–5	35	27	0	75
N_2O	53 000	51 000	–8	80	–3	–35	55
HFCs	0	920	–22	60	N/A	N/A	N/A
PFCs	6 000	6 200	–70	–60	3	–70	–60
SF_6	2 870	2 020	–1	1	–30	–30	–29
Total GHG Emissions (without GWP uncertainty)	608 000	720 000	–3	6	19	12	27
Total GHG Emissions (with GWP uncertainty)	608 000	720 000	–5	10	19	12	28

Notes:

[1] As reported in NIR 2003.

Excludes LULUCF Sector.

N/A = not applicable.

Sources: ICF (2004, 2005).

The use of IPCC default uncertainty ranges in certain categories (e.g., uncertainty associated with national cement production, with a value of 35%) is believed to have generated a larger uncertainty range for the overall inventory. In the coming years, the overall uncertainty estimates should be improved further once national uncertainty ranges for certain variables are obtained.

Further results of the study, on a sectoral and category basis, are detailed in Tables A7-6 to A7-16 in Section A7.4.

A7.3 SCOPE OF 2004/2005 UNCERTAINTY STUDY

The source categories assessed include key categories and various other source categories selected in accordance with an agreed-upon uncertainty model. This ensured that the important sources were included while avoiding overrepresentation of smaller sources with similar activity or emission factor uncertainty data.

A Tier 2 approach was adopted (IPCC, 2000), since i) the probability distributions underlying the estimates are non-Gaussian distributions, ii) the inventory estimation methodology is complex and includes several input variables, iii) the uncertainty surrounding the input variables is large, and iv) the variables are correlated between and/or within source categories. Tier 1 uncertainty analysis was not conducted due to time and resource constraints, but it will be performed in the future.

Level uncertainty estimates were developed through Tier 2 for each inventory source category based on the 2001 estimates (excluding LULUCF) and for the GHG inventory overall. Also developed were trend uncertainty estimates between 1990 and 2001. The Monte Carlo stochastic simulation technique was used for individual source categories.

The uncertainty ranges were developed for the 2.5th and 97.5th percentiles (95% confidence interval) for source categories. It is assumed that uncertainty ranges for many source categories included in the ICF (2004, 2005) study can be used for the current GHG inventory estimates, provided that the methods for obtaining activity data and estimates have not changed. For trend uncertainty estimates, the assumption has been that the uncertainty ranges apply to the 2001 inventory estimates only. This is because estimates for the trend uncertainty are more sensitive to the inventory values for base and current years.

A7.3.1 GENERAL CONCEPTS

Emission estimate uncertainty is composed of i) model uncertainty and ii) parameter uncertainty. Model uncertainty refers to the uncertainty associated with the estimation methodology (i.e., the mathematical equations or inventory estimation models, such as Emissions = Activity Data × Emission Factor). Model uncertainty results in biased inventory estimates. It can be detected through QA and reduced by developing an appropriate, alternative inventory estimation model.

Parameter uncertainty refers to the uncertainty associated with variables such as activity data, emission factors, and constants used as inputs to the inventory estimation models. Parameter uncertainty can be further divided into i) random (or statistical) uncertainty and ii) systematic uncertainty (or bias). While random uncertainty can be estimated statistically, systematic uncertainty can be quantified only through research and analysis. Both random and systematic uncertainty can be quantified through expert elicitation. Although random uncertainty cannot be removed, efforts can be undertaken to minimize it.

Canada's 2001 GHG inventory has been shown to possess all three types of uncertainties mentioned above. While random parameter uncertainty is present in all cases, systematic parameter and model uncertainties have also been found in some categories (e.g., PFCs from aluminium production). See also Section A7.4 below.

A7.3.2 INPUT DATA FOR THE UNCERTAINTY MODEL

The Monte Carlo method of uncertainty estimation requires specifying the probability distributions underlying every input parameter used in the inventory estimation for each source category. Credibility of the uncertainty estimates developed using the Monte Carlo approach is essentially dependent on the accurate characterization of these probability distribution functions. Because the values of many of the input parameters used for GHG estimation were point estimates, uncertainty ranges associated with the inventory estimates of the input variables were obtained from various best available data sources, consistent with the guidelines provided in the IPCC Good Practice Guidance (IPCC, 2000). The two main sources of uncertainty data were:

1. published references, survey data, sample statistics, and other unpublished reports; and
2. expert elicitations.

The important published references that were used in developing uncertainty for the input variables included McCann (2000), SGA (2000), IPCC Good Practice Guidance (IPCC, 2000), the IPCC Guidelines (IPCC/OECD/IEA, 1997), and the 2003 NIR (Environment Canada, 2003):

- McCann (2000) developed CO_2 emission factors for fossil fuel combustion, by fossil fuel type, for 1998 and the associated uncertainty ranges for 95% confidence intervals. McCann (2000) recommended CO_2 emission factors for coal (with the exception of anthracite), natural gas, and NGLs. These emission factors were used in the development of the 2001 inventory estimates. Therefore, for purposes of this study, uncertainty estimates developed by McCann (2000) were adopted.
- For marketed refined petroleum products, the CO_2 emission factors used in the 2001 inventory estimation differed from the emission factors reported by McCann (2000). However, based on the recommendation of Dr. John Nyboer of CIEEDAC, the uncertainty associated with the inventory estimates was developed based on the emission factors and the associated uncertainty ranges recommended by McCann (2000).
- SGA (2000) developed the CH_4 and N_2O emission factors and uncertainty estimates for fossil fuel combustion. These CH_4 and N_2O emission factor estimates are used in the inventory estimation for stationary and mobile fuel combustion source categories. Consequently, for this uncertainty analysis, the uncertainty ranges developed by SGA (2000) for CH_4 and N_2O were adopted for generating uncertainty estimates for the stationary and mobile fuel combustion source categories.
- In the case of other input variables for which uncertainty data were not available through expert elicitations, uncertainty estimates were developed based on the IPCC-recommended emission factors and/or uncertainty range associated with the emission factors.

- When pertinent uncertainty data were not available from any of these sources, educated estimates of uncertainty in the input variables were developed based on a review of i) the inventory estimation methodology and the data source used for the 2003 NIR and ii) the recommended estimation methodology and the methodological details provided in the IPCC Guidelines (IPCC/OECD/IEA, 1997) and the input data selection discussions provided in the IPCC Good Practice Guidance (IPCC, 2000) for that source category, as appropriate.

For many other variables, uncertainty data to characterize the input variables were obtained through expert elicitations. Two sets of expert elicitations were conducted: i) detailed expert elicitation and ii) less detailed expert elicitation. Both sets of elicitations were administered using elicitation protocols and differed in terms of the time commitments provided by the experts. The detailed expert elicitation protocol was structured similarly to the well-known Stanford/SRI International protocol (Morgan and Henrion, 1990; IPCC, 2000). A pre-elicitation template was used, since it was not possible to obtain significant time commitments from the experts to complete the process.

For uncertainty assessment of 1990 emissions, the data obtained from expert elicitations were limited. This was due to the long time that had passed since 1990 and the unavailability of appropriate records to which the experts could refer. Therefore, the uncertainty for the majority of source categories considered in this study for 1990 has been assumed to be equal to their uncertainty in 2001. The applicability of the uncertainty characteristics of 2001 estimates to the 1990 estimates needs to be further evaluated. Hence, the trend uncertainty results provided here (which use the uncertainty of 1990 as well as the uncertainty of 2001 estimates) should be considered preliminary and with caution.

Table A7-2 provides the list of input parameters for which expert elicitations were sought during this study.

Tables A7-3 and A7-4 show examples of uncertainty assessments obtained through the expert elicitation process and through source document research. Table A7-4 provides more detailed information on the uncertainty, such as the inventory central value, the shape of the probability distribution function, the uncertainty range, and the confidence interval for which the range is quoted.

A7.3.3 LEVEL OF AGGREGATION ADOPTED FOR UNCERTAINTY ANALYSIS

Theoretically, the ideal level of disaggregation for an uncertainty analysis should be the level at which the inventory estimation was performed, if the uncertainty input data can be reliably obtained for the variables at that level of disaggregation. However, from a practical implementation perspective, the appropriate level of disaggregation is also determined by budget and time constraints.

For each category, the appropriate level of disaggregation was determined in consultation between the NIR team and the consultant. It was generally conducted at the level at which it was believed that the uncertainty data associated with the inventory input variables could be obtained reliably. Table A7-5 reports the level of disaggregation adopted for performing the uncertainty analysis under this project. For identification of key categories among the categories shown in this table, the readers should refer to Tables A7-6 to A7-16 at the end of the annex (key sources in these tables are indicated by the symbol KS).

A7.3.4 SENSITIVITY ANALYSIS

A Tier 2 approach to uncertainty estimation, also known as the Monte Carlo stochastic simulation technique, was adopted in performing sensitivity analysis of the level uncertainty.

Development of uncertainty importance of level uncertainty estimates was performed through ICF (2005), with probabilistic sensitivity analysis to identify the key input variables that significantly influence the uncertainty in the output variables.

There are several measures for estimating the uncertainty importance of input variables (i.e., the degree of sensitivity of output variables to the variation in the input variables) used in the inventory estimation. However, rank correlation coefficients were considered to be the appropriate measure of uncertainty importance:

TABLE A7-2: Input Variables Selected for Expert Elicitation — Uncertainty Quantification

Index	Input Variable	Number of Variables	Variable Type	Unit of Measure	Suggested Experts
1	Electricity Generation – Coal Consumption (Canadian Bituminous, Sub-Bituminous, Anthracite, Lignite, and Imported Bituminous) – Provinces of Alberta, Ontario, Saskatchewan, and New Brunswick	5–7	Activity Data and Fuel Consumption	Kilotonnes	Statistics Canada & Canadian Coal Association
1a	Fuel Combustion – Electricity and Heat Generation – Coal Emission Factor – Canadian Bituminous, Sub-Bituminous, Anthracite, Lignite, and Imported Bituminous by Province	5–8	Emission Factors	–	T. McCann
3	Fuel Combustion – Other Sector – Residential CO_2 – Natural Gas and Heavy Fuel Oil, CH_4 and N_2O for Biomass Fuel	5	Activity Data and Fuel Consumption	Cubic metres & kilotonnes	Statistics Canada & Environment Canada (CAC Division)
3a	Fuel Combustion – Other Sector – Residential CH_4 and N_2O for Biomass Emission Factors	2–5	Emission Factors	–	–
4	Fuel Combustion – Manufacturing and Construction – Other Manufacturing – CO_2 – Natural Gas, Heavy Fuel Oil, and Propane	3	Activity Data	Cubic metres	Statistics Canada
5	Fuel Combustion – Manufacturing and Construction – Pulp, Paper and Print – CO_2 Emissions from Natural Gas and Heavy Fuel Oil; CH_4 and N_2O Emissions from Biomass Fuel	5	Activity Data	Cubic metres	Statistics Canada
6	Fuel Combustion – Manufacturing and Construction – Chemical Industries – CO_2 Emissions from Natural Gas and Heavy Fuel Oil	2	Activity Data	Cubic metres	Statistics Canada
7	Fuel Combustion – Manufacturing and Construction – Iron and Steel Industries – CO_2 Emissions from Coke Oven Gas and Natural Gas	2	Activity Data	Cubic metres	Statistics Canada
8	Fuel Combustion – Manufacturing and Construction – Other – Cement, Mining and Construction – CO_2 Emissions from Refined Petroleum Fuel Consumption, Natural Gas, and Bituminous Coal (Canadian Bituminous, Sub-Bituminous, and Import)	5	Activity Data	Cubic metres	Statistics Canada
9	Fugitive Emissions – Oil and Natural Gas – CH_4 Emissions from Conventional Oil Production	1	Activity Data	Cubic metres	Statistics Canada & Clearstone Engineering
10	Fugitive Emissions – Oil and Natural Gas – CO_2 and CH_4 Emissions from Natural Gas Production and Processing, Transmission, and Distribution	5	Activity Data	Cubic metres & kilometres	Statistics Canada & Clearstone Engineering
11	Fugitive Emissions – Oil and Natural Gas – CH_4 Emissions from Flaring	1	Activity Data	Cubic metres	Statistics Canada & Clearstone Engineering
12	Fuel Combustion – Manufacture of Solid Fuels and Other Energy Industries – CO_2 Emissions – Producer Consumed Fuels – Coal and Natural Gas	3	Activity Data	Cubic metres	Statistics Canada
13	Fuel Combustion – Petroleum Refining – CO_2 Emissions from the Consumption of Refined Petroleum Products – Heavy Fuel Oil, Petroleum Coke, and Catalytic Coke	5	Activity Data	Cubic metres	Statistics Canada
13a	Fuel Combustion – Petroleum Refining – CO_2 Emissions from the Consumption of Refined Petroleum Products – Petroleum Coke and Catalytic Coke	2	Emission Factors	–	CIEEDAC – John Nyboer
14	Industrial Processes – CO_2 Emissions from Other and Undifferentiated Production – Non-Energy Fuel Consumption and Feedstock Use	5–8	Activity Data	Cubic metres	Statistics Canada
14a	Industrial Processes – CO_2 Emissions from Other and Undifferentiated Processes – Non-Energy Fuel Consumption and Feedstock Use	5–8	Emission Factors	–	IPCC Guidelines (IPCC/OECD/IEA, 1997)
15	Industrial Processes – N_2O from Adipic Acid Production	1	Emissions	–	DuPont Canada
16	Aluminium Production – CO_2 and PFC Emissions (Plant Production Capacity and Technology)	2–3	Activity Data and Emissions	–	AAC & NRCan
17	Industrial Processes – Ammonia Production	2	Activity Data and Technology Split Factors	–	–
18	Industrial Processes – SF_6 Emissions from Magnesium Production	3	Emissions	–	NPRI and magnesium production industries
19	Industrial Processes – Cement Production	1	Activity Data	–	*Canadian Minerals Yearbook* – NRCan
20	Industrial Processes – Iron and Steel Production	1–2	Activity Data	–	Statistics Canada
21	Fugitive Emissions – Coal Mining – Quantity of Surface Coal Mined (Sub-Bituminous, Canadian Bituminous, and Lignite) and Underground Coal Mined by Region	5–8	Activity Data	kt/year	Statistics Canada
22	Fugitive Emissions – Coal Mining – Emission Factor for Coal Mined (Sub-Bituminous, Canadian Bituminous, and Lignite) and Underground Coal Mined by Region	3–5	Emission Factors	kt CH_4/kt coal	Environment Canada reference material

TABLE A7-3: Sample Input Parameter Uncertainty Estimates Obtained from Expert Elicitation — Activity Data for Quantity of Fuel Consumed

Fuel Consumption Uncertainty Estimates (2001) - in % around the mean value Stationary and Mobile Fuel Combustion		Natural Gas	Still Gas	Motor Gasoline	Kerosene & Stove Oil	Diesel Fuel Oil	Light Fuel Oil	Heavy Fuel Oil	Petroleum Coke	Aviation Gasoline	Aviation Turbo Fuel	NGL - Propane	NGL - Butane	NGL - Ethane	Canadian Bituminous	Sub-Bituminous	Lignite	Anthracite	U.S. (Imported) Bituminous	Coke	Coke Oven Gas
1.A.1	Energy Industries																				
1.A.1.a	Electricity Generation	1	–	–	–	1	1	1	1	–	–	–	–	–	1	1	1	–	1	1	1
1.A.1.b	Petroleum Refining (Upstream & Downstream Oil and Gas Industries)	1	2	–	1	1	1	1	1	–	–	1	1	–	–	–	–	–	–	–	–
1.A.2	Manufacturing Industries and Construction																				
1.A.2.a	Iron and Steel	1	–	–	–	3	–	1	1	–	–	–	–	–	1	–	–	1	–	1	1
1.A.2.b	Non-Ferrous Metals	1	–	–	–	3	–	1	1	–	–	–	–	–	1	–	–	1	–	1	–
1.A.2.c	Chemicals	1	–	–	–	3	2	1	1	–	–	–	–	1	–	–	–	–	–	–	–
1.A.2.d	Pulp, Paper and Print	1	–	–	–	3	2	1	–	–	–	–	–	–	–	–	1	–	1	–	–
1.A.4	Other Sectors																				
1.A.4.a	Commerical/Institutional	3	–	2	1	3	2	2	–	1	1	3	–	–	1	–	–	–	–	–	–
1.A.4.b	Residential	1	–	–	1	–	1	1	–	–	–	1	–	–	1	1	1	–	–	–	–
1.A.4.c	Agriculture/Forestry/Fisheries	1	–	2	1	3	1	1	–	–	–	1	–	–	–	–	–	–	–	–	–
Fuel consumed by all other sectors.		Assumed ±3% for all fuels as default value																			

Source: ICF (2004).

- A value of 0% rank order correlation coefficient indicates that there is no relationship between the rank ordered input and the corresponding output variable; the variation in the output variable is independent of (or non-responsive to) the variation in the input variable.
- A value of 100% indicates that the variation in the output variable is fully responsive to the variation in the input variable.

The rank correlation values ("r") generated through this sensitivity analysis are reported in the following section. They represent the magnitude of influence (or importance) of uncertainty in each of the specified categories to the uncertainty in the overall inventory GHG emissions.

A7.4 SUMMARY OF SECTOR UNCERTAINTIES

Canada has adopted Table 6.2 of IPCC (2000) for presenting its 2001 GHG inventory uncertainty estimates, as shown in Tables A7-6 to A7-16.

The tables provide the source category, followed by the rounded inventory estimates for the 1990 baseline inventory year and for the 2001 inventory year as reported in the 2003 NIR submission, followed by the level uncertainty range in percentage of the inventory estimate for 2001. The level uncertainty sensitivity is then reported as a ranked correlation, as a percentage, to identify the key source categories that significantly influence the uncertainty in the total overall inventory emissions. Finally, for the trend uncertainty, the values shown in the tables provide a picture of trend uncertainty in 2001.

Note that the uncertainty range as presented in these tables does not include the uncertainty associated with the GWP for the corresponding emission values.

Also, some uncertainty estimates for the source categories appear to be the same for the base year 1990 and for 2001, due to the rounding effects; however, the percent trend values and the uncertainty ranges shown are valid.

TABLE A7-4: Sample Input Parameter Uncertainty Estimates Obtained from Expert Elicitation and Source Reference Research — Emission Factor Data for Stationary Fuel Combustion

Source/Sub-Source Category	CO_2 Emission Factors	Probability Distribution	Uncertainty Range, Relative to 2001 Inventory Estimate		Confidence Interval	Data Source
	2001 Inventory Estimate		Low (%)	High (%)	(%)	
Coal	*g/kg*					
Lignite[1]	1420.22	Normal	–6	4	95	J. Gienow and O. Bussler, SaskPower
Anthracite[2]	2390.00	Normal	–5	5	95	Assumed
U.S. Bituminous[3]	2387.08	Normal	–3	3	95	McCann (2000)
Canadian Bituminous[3]	1973.13	Normal	–3	3	95	McCann (2000)
Sub-Bituminous[3]	1747.44	Normal	–3	3	95	McCann (2000)
Coke[2]	2480.00	Normal	–5	5	90	Assumed
Coke Oven Gas[2]	1600.00	Normal	–10	10	90	Assumed
Natural Gas	*g/m³*					
Non-Energy	1266.97	Normal	–5	5	95	Assumed
Interprovincial[4]	1891.00	Normal	–3	3	95	McCann (2000)
Petroleum Refineries for Hydrogen[4]	1892.00	Normal	–3	3	95	McCann (2000)
Liquid	*g/L*					
Petroleum Coke	4200.00	Normal	–37	–25	95	McCann (2000)
Propane (Non-Energy Use)	303.00	Normal	–5	5	95	Assumed
Butane (Non-Energy Use)	349.00	Normal	–5	5	95	Assumed
Ethane (Non-Energy Use)	197.00	Normal	–5	5	95	Assumed
Petrochemical Feedstocks[5]	2500.00	Normal	–15	15	90	Assumed
Naphthas	2500.00	Normal	–10	10	95	Assumed
Lubricants[5]	2820.00	Normal	–10	10	90	Assumed
Other Products[5]	1835.00	Normal	–20	20	90	Assumed

Notes:

1 Emission factor range for Saskatchewan for energy use applied.

2 Same as for energy use.

3 These uncertainty ranges may be different from those used for energy use, as energy use emission factors were provincial.

4 Same as for energy use — natural gas in industry.

5 The uncertainty around the emission factor is assumed to be larger, as petrochemical feedstock is not a unique product, but compares general products. Hence, a 90% confidence interval is assumed.

Source: ICF (2004).

TABLE A7-5: Level of Aggregation Adopted for the Uncertainty Analysis, by Key Source Category (2001 inventory submitted in 2003 NIR)[1]

Source Category	IPCC Source Category	Direct GHG	Criteria for Identification[2]	Level of Aggregation
1-A-1-a	Fuel Combustion – Public Electricity and Heat Production	CO_2	Level, Trend, Quality	Provincial level for coal and national level for others
1-A-1-b	Fuel Combustion – Petroleum Refining	CO_2	Level, Trend, Quality	Provincial level for coal (coal is not used as refinery fuel) and national level for others
1-A-1-c	Fuel Combustion – Manufacture of Solid Fuels and Other Energy Industries	CO_2	Level, Trend, Quality	Provincial level for coal and national level for others
1-A-2	Fuel Combustion – Manufacturing Industries and Construction	CO_2	Level, Trend	Provincial level for coal and national level for others
1-A-3-a	Fuel Combustion – Civil Aviation	CO_2	Level	National, by fuel type
1-A-3-b	Fuel Combustion – Road Transportation	CO_2	Level, Trend, Quality	National, by vehicle category and fuel type
1-A-3-b	Fuel Combustion – Road Transportation	N_2O	Level, Trend, Quality	National, by vehicle category and fuel type
1-A-3-c	Fuel Combustion – Railways	CO_2	Level, Trend	National, by fuel type
1-A-3-e	Fuel Combustion – Other Transport	CO_2	Level	National, by fuel type
1-A-3-f	Fuel Combustion – Pipeline Transport	CO_2	Level, Trend, Quality	National, by fuel type
1-A-4	Fuel Combustion – Other Sectors	CO_2	Level, Trend	Provincial level for coal and national level for others
1-B-1-a	Fugitive Emissions – Coal Mining	CH_4	Level	National, by mine type
1-B-2-(a+b)	Fugitive Emissions – Oil and Natural Gas	CH_4	Level, Trend, Quality	National, by economic activity
1-B-2-c	Fugitive Emissions – Oil and Natural Gas – Venting and Flaring	CO_2	Level, Trend, Quality	National
1-B-2-c	Fugitive Emissions – Oil and Natural Gas – Venting and Flaring	CH_4	Quality	National
2-A-1	Industrial Processes – Cement Production	CO_2	Level, Quality	National
2-B-1	Industrial Processes – Ammonia Production	CO_2	Level	National
2-B-3	Industrial Processes – Adipic Acid Production	N_2O	Level, Trend, Quality	National
2-C-1	Industrial Processes – Iron and Steel Production	CO_2	Level	National
2-C-3	Industrial Processes – Aluminium Production	PFCs	Level, Quality	National, by technology type
2-C-4	Industrial Processes – Aluminium and Magnesium Production	SF_6	Level, Quality	National
2-F	Industrial Processes – Other (Undifferentiated Production)	CO_2	Level	National, by feedstock fuel type
4-A	Agriculture – Enteric Fermentation	CH_4	Level	National, by cattle type
4-B	Agriculture – Manure Management	CH_4	Level	National, by cattle type
4-D	Agriculture – Agricultural Soils	N_2O	Level	National with subsector details
6-A	Waste – Solid Waste Disposal on Land	CH_4	Level, Quality	National, by waste category

Notes:

1 This table was adapted based on Table A1-1 of the 2003 NIR.

2 Level, trend, and quality refer to the source category being a key source category based on level, trend, and quality.

The sensitivity analysis of the overall uncertainty in the total inventory emissions indicates that:

- The uncertainty associated with the N_2O emissions source category from the mobile sources in the transport subsector has the most influence on the overall uncertainty in the inventory (with a correlation value or "r" of 47%), although CO_2 emissions from stationary source fossil fuel combustion accounted for over three-quarters of Canada's total GHG emissions in 2001. The other significant input variables include the uncertainty associated with CH_4 emissions from stationary source fossil fuel combustion (r = 37%), N_2O from agricultural soils (r = 36%), CH_4 from the Waste Sector (r = 31%), and CO_2 from stationary source fuel combustion (r = 30%).

Further analysis reveals that the respective uncertainties associated with the overall inventory emissions, by gas, were found to be most influenced by source category uncertainties associated with the following sectors:

- In the case of uncertainty associated with the overall CO_2 emissions, the key uncertainty-important source categories include stationary fuel combustion, followed by mobile sources, industrial processes, and fugitive emissions.
- In the case of uncertainty associated with the overall CH_4 emissions, the key uncertainty-important source categories include stationary fuel combustion, followed by the Waste Sector and fugitive emissions.
- In the case of uncertainty associated with the overall N_2O emissions, the principal uncertainty-important source categories include mobile sources, followed by agricultural soils and stationary fuel combustion.
- In the case of PFC emissions, the CF_4 from industrial sources is the primary uncertainty-important source category, followed by C_2F_6 from industrial processes.
- In the case of HFC emissions, the halocarbons use source category is, not surprisingly, the key uncertainty-important source category, as it was the only source of HFC emissions in Canada in 2001.
- Similarly, SF_6 from industrial processes is the only uncertainty-important source category that contributed to SF_6 emissions in Canada in 2001.

As mentioned before, the trend uncertainty estimates were developed by assigning the same or similar uncertainty characteristics associated with the 2001 input variables for both 1990 and 2001, which means that these estimates should be viewed with caution.

Highlights of the results obtained from analysis of uncertainty for various source sectors are presented at the end of this section, along with a summary of changes to the activity data and/or emission factors and uncertainty estimates that have occurred to some categories since the study of the 2001 inventory uncertainty. For details of findings, reference should be made to the uncertainty sections within Chapters 3–8.

A7.4.1 ENERGY

Emissions evaluated for this sector include CO_2, CH_4, and N_2O from stationary combustion and from transport and CO_2 and CH_4 from fugitive emissions. Uncertainty values were obtained from the ICF (2004, 2005) study based upon data and models that were developed for the 2003 NIR submission year for the year 2001 inventory.

A7.4.1.1 Energy — Stationary Combustion

The overall uncertainty for CO_2 is found to have a range of −4% to +1%. The highest uncertainty range for CO_2 from major fuel types used in this subsector relates to liquid fuels (−15% to +2%). Estimates for uncertainty ranges for CH_4 and N_2O emissions in this subsector are −24% to +700% and −11% to +650%, respectively. Additional analysis of uncertainty is provided in Chapter 3.

A7.4.1.2 Energy — Transport

The uncertainty range for CO_2 estimates from transport, including road, aviation, and marine mobile sources, follows closely the values quoted for stationary combustion (−4% to 0% in this case). This is understandable, since the uncertainty for CO_2 estimates directly follows the uncertainty existing in the fuel quantities consumed. Uncertainties for CH_4 and N_2O are in the ranges of −24% to +700% and −28% to +410%, respectively.

The picture of uncertainty for the categories in this subsector has generally remained the same, except for CO_2 emissions from domestic civil aviation, for which a new estimation method has been adopted. The uncertainties provided by the ICF (2004) study for this subsector are no longer applicable and need to be reassessed.

Historic fuel ethanol consumption has been added to the Transport subsector this year. The specific uncertainty associated with the emissions attributed to the use of this fuel has not yet been determined. Nevertheless, only minor quantities are combusted, and emissions from ethanol are very small, in relative terms. Thus, any uncertainty associated with their estimation will have very little impact on transportation category uncertainties.

A7.4.1.3 Energy — Fugitive Emissions

This subsector includes CH_4 and CO_2 fugitive emissions occurring in the coal mining and oil and gas industry. It includes emissions associated with leaks, venting, and flaring in the oil and gas operations, as well as in coal mining. The uncertainty ranges for emissions from venting and flaring activities in the oil and gas industry are –35% to –13% for CO_2 and –7% to +16% for CH_4. The uncertainties discussion presented in the Energy section for the upstream oil and gas industry are based on results from a Tier 1 analysis conducted by Clearstone Engineering for CAPP (2005). These base estimates were used by ICF (2004; 2005) in their Tier 2 uncertainty analyses.

For the refining industry, the uncertainty analysis was conducted by Levelton Consulting for the CPPI (2004). The overall uncertainty estimate, based on a Tier 1 analysis, was found to be ±8.3%. A Tier 2 analysis was also conducted; in this case, overall uncertainties were estimated to be ±14%. Note that the uncertainty estimates presented in Table A7-12 and Table A7-13 for the overall fugitive category (1.B), the overall oil category (1.B.2.a), Oil Production (1.B.2.a.i), and Venting and Flaring (1.B.2.c) do not incorporate this new information from the CPPI study on the oil refining industry.

A7.4.2 INDUSTRIAL PROCESSES

A study (ICF, 2004) was conducted to determine the uncertainties around the emission estimates under the Industrial Processes Sector that were presented in the 2003 NIR for the reporting period 1990–2001. According to this analysis, the uncertainty for the 2001 GHG emissions from Industrial Processes, excluding halocarbons, ranged from –7% to +5%. There has been addition of new sources, improvements in calculation methods, and acquisition of new activity data for a number of categories since the completion of the ICF study. It is therefore expected that the uncertainty associated with the Industrial Processes Sector will be slightly different from the value provided by ICF. Major factors that have affected the results of the ICF uncertainty assessment are described in the following sections. Further details on the level of uncertainty for each category are provided in Chapter 4.

A7.4.2.1 Industrial Processes — Mineral Products

The uncertainty levels associated with the subsectors of cement and lime production would be lower than those shown in the ICF report because of the improvements made to the calculation methods. Inclusion of additional emissions coming from uses of limestone, which were not reported in the 1990–2001 inventory, also affects the uncertainty estimates provided by ICF. Acquisition of new data on soda ash use changes the uncertainty range for this subsector. CO_2 emissions from magnesite use are a new category for this year's submission. The uncertainty range of 4.9% to 6.1% associated with these emissions is provided in the AMEC (2006) report.

A7.4.2.2 Industrial Processes — Chemical Industry

For the subsector of ammonia production, the exclusion of CO_2 trapped in exported urea would have lowered the uncertainty in the emission estimates. Since there has not been any change in method or data source for nitric acid and adipic acid production, the uncertainty values presented in the ICF report are still applicable to the emission estimates in this submission.

A7.4.2.3 Industrial Processes — Metal Production

The shift from a Tier 1 to a Tier 2 approach for estimating CO_2 emissions from iron and steel production would have decreased the uncertainty for this category. The uncertainties in CO_2 and PFC emission estimates for aluminium production, provided in the ICF report, are not applicable to the present submission due to an improvement in the calculation method. SF_6 from aluminium production is a new category for which uncertainty has not been assessed. Since there has not been any change in data source for magnesium production, the uncertainty value presented in the ICF report is still applicable to the emission estimate in this submission. SF_6 from magnesium casting was not a category considered in the ICF study. However, according to the Cheminfo Services (2005) study, it has an uncertainty of ±4%.

A7.4.2.4 Industrial Processes — Consumption of Halocarbons and SF_6

Owing to acquisition of more recent consumption data on both HFCs and PFCs and method improvements, the uncertainty ranges for HFC and PFC emissions of –21% to +55% and –28% to 70%, respectively, would be considered as highly conservative. Both the category of SF_6 from electrical equipment and the category of SF_6 from semiconductor manufacturing were not assessed by ICF in terms of uncertainty. Nonetheless, the Cheminfo Services (2005) study provides an uncertainty range of –50% to +19% for the former category.

A7.4.2.5 Industrial Processes — Other and Undifferentiated Production

The uncertainty range reported in the ICF study is still applicable to the emission estimate in this submission, since there has not been any change in method or data source for this subsector.

A7.4.3 SOLVENT AND OTHER PRODUCT USE

Results obtained from the uncertainty assessment are still valid for the emission estimates for this sector, because there has not been any change in method or data source since the completion of the ICF study. Further details can be found in Chapter 5.

A7.4.4 AGRICULTURE

Since the ICF study was performed, significant changes in methodologies and updates to parameters were made in the Agriculture Sector, through, in particular, the adoption of Tier 2 methods for CH_4 sources and N_2O from agricultural soils. A new analysis of uncertainty for these categories was undertaken by experts at AAFC, and results are presented in the respective sections in Chapter 6.

A7.4.5 LAND USE, LAND-USE CHANGE AND FORESTRY

So far, the LULUCF Sector has not been included in top-down uncertainty analyses such as the ICF study, since the most important uncertainty sources stemmed from model bias (omissions of carbon pools, lack of a unified land framework) and were not quantifiable. Quantitative uncertainty analyses have become possible due to the methodological improvements implemented in this submission; work is under way to develop formal uncertainty estimates in each of the LULUCF categories. Section A3.5 in Annex 3 presents preliminary assessments and expert-based, partial uncertainty estimates in, notably, wetlands and forest conversion.

All LULUCF categories do not equally contribute to the overall sectoral uncertainty. By virtue of the size of fluxes, uncertainties about forest land estimates and, to a lesser extent, cropland dominate the sector and are prioritized. Cross-cutting estimates, such as forest conversion to other land categories, introduce a covariance factor between estimates in different land categories, which adds to the complexity of developing an aggregate uncertainty value.

A7.4.6 WASTE

Emissions evaluated for this sector include CH_4 emissions from solid waste disposal on land, CH_4 and N_2O emissions from wastewater handling, and CO_2, CH_4, and N_2O emissions from waste incineration.

Uncertainty values were obtained from the ICF (2004, 2005) study based upon data and models that were developed for the 2003 NIR submission year for the year 2001 inventory.

A7.4.6.1 Waste — Solid Waste Disposal on Land

The only GHG being considered for this subsector is CH_4, since CO_2 emissions originate from the biodegradation of biomass and therefore are not included in the total emissions and since N_2O emissions are assumed to be negligible. The uncertainty associated with CH_4 emissions from the combined municipal and wood waste landfills was estimated to be in the range of –35% to +40%.

The uncertainty is mainly due to a difference of opinion, presented during the expert elicitation process, on the values of the CH_4 generation potential and the CH_4 rate constant used in the Scholl Canyon model for the MSW landfill CH_4 generation estimates. As a result of the ICF Consultants report, a study was conducted by the University of Manitoba, with the direct support of Environment Canada, which focused on the development of more accurate estimates for these two key parameters to the model (Thompson *et al*., 2005). In lieu of a quantitative statement based upon a follow-up Tier 2 uncertainty study, it is expected that the uncertainty of the CH_4 emissions from this source would be reduced by the introduction of these new values.

A7.4.6.2 Waste — Wastewater Handling

N_2O emissions were responsible for approximately 80% of the total emissions from this subsector. The overall level uncertainty associated with the Wastewater Handling subsector was estimated to be in the range of –40% to +55%.

Uncertainties for CH_4 and N_2O emissions were –40% to +45% and –60% to +65%, respectively. It is expected that the overall uncertainty range associated with the emissions from this subsector and uncertainties around the emission values related to the categories would be reduced due to the introduction of new activity data.

A7.4.6.3 Waste — Waste Incineration

The overall uncertainty associated with the Waste Incineration source category was estimated to be in the range of –12% to +65%. CO_2 contributed roughly 79% of the total emissions from this subsector. The uncertainties associated with CO_2, CH_4, and N_2O emissions were –3% to +85%, –60% to +60%, and –80% to +85%, respectively.

Since new activity data were obtained subsequent to the publication of the ICF Consulting report, it is expected that the uncertainties associated with these category emissions, for the present submission, would be less than those presented in the ICF Consulting study.

TABLE A7-6: Tier 2 Uncertainty Reporting — CO_2 Energy (Stationary Combustion)

IPCC Source Category	Gas	Base Year Emissions (1990)	Year t Emissions (2001)	Uncertainty in Year t Emissions as % of Emissions in the Category		Uncertainty Introduced on National Total in Year t (2001)	% Change in Emissions between 2001 and 1990	Range of Likely % Change between 2001 and 1990		Comments
		Gg CO_2 eq	*Gg CO_2 eq*	*% Below (2.5th percentile)*	*% Above (97.5th percentile)*	%	%	*Lower % (2.5th percentile)*	*Upper % (97.5th percentile)*	
1.A. Stationary Combustion	CO_2	276 000	335 000	–4	1	30	21	20	23	–
Liquid Fuels	CO_2	64 900	70 500	–15	2	–	–	–	–	–
Solid Fuels	CO_2	94 600	124 000	–3	3	–	–	–	–	–
Gaseous Fuels	CO_2	117 000	161 000	–2	2	–	–	–	–	–
1.A.1. Energy Industries	CO_2	144 000	206 000	–6	2	–	40	35	45	–
Liquid Fuels	CO_2	35 500	35 900	–24	5	–	–	–	–	–
Solid Fuels	CO_2	78 700	115 000	–3	4	–	–	–	–	–
Gaseous Fuels	CO_2	30 200	54 900	–5	5	–	–	–	–	–
1.A.1.a. Public Electricity and Heat Production (KS)	CO_2	94 700	136 000	–3	3	–	45	40	50	–
1.A.1.a.i Electricity Generation – Utilities	CO_2	91 850	127 000	–3	3	–	–	–	–	–
1.A.1.a.ii Electricity Generation – Industry	CO_2	2 210	4 570	–8	3	–	–	–	–	–
1.A.1.a.iii Heat/Steam Generation	CO_2	690	5 530	–2	2	–	–	–	–	–
1.A.1.b. Petroleum Refining (KS)	CO_2	26 000	29 000	–35	7	–	11	7	10	–
1.A.1.c. Manufacture of Solid Fuels and Other Energy Industries (KS)	CO_2	23 600	34 800	–8	8	–	50	45	60	–
1.A.2. Manufacturing Industries and Construction (KS)	CO_2	55 900	49 500	–3	2	–	–10	–5	–2	–
Liquid Fuels	CO_2	15 500	11 100	–9	1	–	–	–	–	–
Solid Fuels	CO_2	8 780	9 030	–4	5	–	–	–	–	–
Gaseous Fuels	CO_2	39 500	45 300	–3	3	–	–	–	–	–
1.A.2.a. Iron and Steel	CO_2	6 420	5 830	–5	5	–	–9	–15	–4	–
1.A.2.b. Non-Ferrous Metals	CO_2	3 210	3 480	–6	–1	–	8	18	22	–
1.A.2.c. Chemicals	CO_2	7 060	6 440	–3	2	–	–9	–10	–8	–
1.A.2.d. Pulp, Paper and Print	CO_2	13 400	9 500	–4	4	–	–29	–29	–27	–
1.A.2.e. Food Processing, Beverages and Tobacco	CO_2	IE	IE	–	–	–	–	–	–	Emissions from Food Processing, Beverages and Tobacco is included in Other Manufacturing (1.A.2.f.iv)
1.A.2.f. Other	CO_2	32 000	41 400	–3	2	–	8	4	9	–
1.A.2.f.i Cement	CO_2	3 370	3 270	9	16	–	–3	8	16	–
1.A.2.f.ii Mining	CO_2	6 150	10 200	–3	3	–	65	60	70	–
1.A.2.f.iii Construction	CO_2	1 860	1 000	–3	2	–	–45	–50	–45	–
1.A.2.f.iv Other Manufacturing	CO_2	20 600	20 000	–6	1	–	–3	–11	–4	–
1.A.4. Other Sectors (KS)	CO_2	69 400	83 800	–3	2	–	7	6	9	–
Liquid Fuels	CO_2	22 200	23 400	–5	1	–	–	–	–	–
Solid Fuels	CO_2	192	91	–5	1	–	–	–	–	–
Gaseous Fuels	CO_2	47 000	60 300	–3	3	–	–	–	–	–
1.A.4.a. Commercial/Institutional	CO_2	25 700	32 700	–3	3	–	27	23	30	–
1.A.4.b. Residential	CO_2	41 300	39 400	–3	2	–	–5	–6	–3	–
1.A.4.c. Agriculture/Forestry/Fisheries	CO_2	2 403	2 190	–3	1	–	–9	–9	–7	–

Note:
(KS) = key source; IE = included elsewhere

TABLE A7-7: Tier 2 Uncertainty Reporting — CH_4 Energy (Stationary Combustion)

IPCC Source Category	Gas	Base Year Emissions (1990)	Year t Emissions (2001)	Uncertainty in Year t Emissions as % of Emissions in the Category		Uncertainty Introduced on National Total in Year t (2001)	% Change in Emissions between 2001 and 1990	Range of Likely % Change between 2001 and 1990		Comments
		Gg CO_2 eq	*Gg CO_2 eq*	*% Below (2.5th percentile)*	*% Above (97.5th percentile)*	%	%	*Lower % (2.5th percentile)*	*Upper % (97.5th percentile)*	
1.A. Stationary Combustion	CH_4	4000	5000	–24	700	37	25	–2	45	See Note 1
Liquid Fuels	CH_4	20	20	1	490	–	–	–	–	–
Solid Fuels	CH_4	30	40	–24	210	–	–	–	–	–
Gaseous Fuels	CH_4	2000	3000	0	230	–	–	–	–	–
Biomass	CH_4	2000	2000	–95	1500	–	–	–	–	–
1.A.1. Energy Industries	CH_4	2000	2000	1	230		50	45	55	See Note 1
Liquid Fuels	CH_4	7	8	14	850	–	–	–	–	–
Solid Fuels	CH_4	20	30	–18	19	–	–	–	–	–
Gaseous Fuels	CH_4	2000	2000	0	230	–	–	–	–	Need to reassess the uncertainty assumption for non-marketable natural gas emission factor – Refer to Chapter 3 of the NIR for additional details
Biomass	CH_4	–	–	–	–	–	–	–	–	–
1.A.1.a. Public Electricity and Heat Production (KS)	CH_4	42	110	–20	40		162	100	200	–
1.A.1.a.i Electricity Generation – Utilities	CH_4	40	100	–23	35	–	–	–	–	–
1.A.1.a.ii Electricity Generation – Industry	CH_4	1	2	–28	220	–	–	–	–	–
1.A.1.a.iii Heat/Steam Generation	CH_4	1	2	24	1900	–	–	–	–	–
1.A.1.b. Petroleum Refining (KS)	CH_4	8	9	–50	900	–	13	–26	50	–
1.A.1.c. Manufacture of Solid Fuels and Other Energy Industries (KS)	CH_4	2000	2000	0	240	–	50	40	55	–
1.A.2. Manufacturing Industries and Construction (KS)	CH_4	40	40	–35	380	–	1	–35	45	See Note 1
Liquid Fuels	CH_4	10	7	–18	230	–	–	–	–	–
Solid Fuels	CH_4	5	6	–70	350	–	–	–	–	–
Gaseous Fuels	CH_4	16	19	–40	40	–	–	–	–	–
Biomass	CH_4	28	37	–95	1400	–	–	–	–	–
1.A.2.a. Iron and Steel	CH_4	5	5	–70	320	–	–6	–90	535	–
1.A.2.b. Non-Ferrous Metals	CH_4	1	2	–19	95	–	19	10	27	–
1.A.2.c. Chemicals	CH_4	3	3	–35	40	–	–7	–9	–1	–
1.A.2.d. Pulp, Paper and Print	CH_4	20	20	–60	900	–	–28	–28	35	–
1.A.2.e. Food Processing, Beverages and Tobacco	CH_4	IE	IE	–	–	–	–	–	–	Emissions from Food Processing, Beverages and Tobacco are included in Other Manufacturing (1.A.2.f.iv)
1.A.2.f. Other	CH_4	10	20	–28	120	–	3	0	21	–
1.A.2.f.i Cement	CH_4	1	2	–35	500	–	6	–7	27	–
1.A.2.f.ii Mining	CH_4	3	7	–28	160	–	60	18	155	–
1.A.2.f.iii Construction	CH_4	1	1	–35	190	–	–45	–60	–40	–
1.A.2.f.iv Other Manufacturing	CH_4	10	9	–30	70	–	–11	–14	5	–
1.A.4. Other Sectors (KS)	CH_4	2000	2000	–90	1500	–	–6	–13	6	See Note 1
Liquid Fuels	CH_4	5	6	–40	280	–	–	–	–	–
Solid Fuels	CH_4	8	5	–75	1100	–	–	–	–	–
Gaseous Fuels	CH_4	20	30	–40	40	–	–	–	–	–
Biomass	CH_4	2000	2000	–95	1500	–	–	–	–	–
1.A.4.a. Commercial/Institutional	CH_4	10	21	–28	160	–	30	30	185	–
1.A.4.b. Residential	CH_4	2000	2000	–90	1500	–	–6	–15	3	–
1.A.4.c. Agriculture/Forestry/Fisheries	CH_4	1	1	–28	230	–	0	–4	21	–

Notes:

1 Refer to Chapter 3 of the NIR for a discussion of the uncertainty associated with CH_4 emission factors.

(KS) = key source; IE = included elsewhere

TABLE A7-8: Tier 2 Uncertainty Reporting — N_2O Energy (Stationary Combustion)

IPCC Source Category	Gas	Base Year Emissions (1990)	Year t Emissions (2001)	Uncertainty in Year t Emissions as % of Emissions in the Category		Uncertainty Introduced on National Total in Year t (2001)	% Change in Emissions between 2001 and 1990	Range of Likely % Change between 2001 and 1990		Comments
		Gg CO_2 eq	*Gg CO_2 eq*	*% Below (2.5th percentile)*	*% Above (97.5th percentile)*	%	%	*Lower % (2.5th percentile)*	*Upper % (97.5th percentile)*	
1.A. Stationary Combustion	N_2O	2 000	2 000	–11	650	–	20	–45	190	See Note 1
Liquid Fuels	N_2O	400	300	–12	800	–	–	–	–	–
Solid Fuels	N_2O	500	600	–60	1 000	–	–	–	–	–
Gaseous Fuels	N_2O	700	900	–65	950	–	–	–	–	–
Biomass	N_2O	500	300	–85	1 200	–	–	–	–	–
1.A.1. Energy Industries	N_2O	1 000	1 000	–23	800	–	40	–65	490	See Note 1
Liquid Fuels	N_2O	200	300	0	1 100	–	–	–	–	–
Solid Fuels	N_2O	500	600	–70	1 100	–	–	–	–	–
Gaseous Fuels	N_2O	300	600	–80	1 200	–	–	–	–	–
Biomass	N_2O	–	–	–	–	–	–	–	–	–
1.A.1.a. Public Electricity and Heat Production (KS)	N_2O	600	600	–35	900	–	40	–75	950	–
1.A.1.a.i Electricity Generation – Utilities	N_2O	600	600	–50	900	–	–	–	–	–
1.A.1.a.ii Electricity Generation – Industry	N_2O	20	30	–70	1 000	–	–	–	–	–
1.A.1.a.iii Heat/Steam Generation	N_2O	4	100	170	12 000	–	–	–	–	–
1.A.1.b. Petroleum Refining (KS)	N_2O	100	100	–28	1 000	–	5	–40	40	–
1.A.1.c. Manufacture of Solid Fuels and Other Energy Industries (KS)	N_2O	300	300	–90	1 500	–	50	35	80	–
1.A.2. Manufacturing Industries and Construction (KS)	N_2O	300	300	–55	850	–	3	–35	65	See Note 1
Liquid Fuels	N_2O	110	100	–45	650	–	–	–	–	–
Solid Fuels	N_2O	60	60	–75	550	–	–	–	–	–
Gaseous Fuels	N_2O	200	200	–95	1 500	–	–	–	–	–
Biomass	N_2O	200	200	–95	1 500	–	–	–	–	–
1.A.2.a. Iron and Steel	N_2O	60	60	–85	650	–	–6	–90	640	–
1.A.2.b. Non-Ferrous Metals	N_2O	20	20	–55	850	–	21	–60	235	–
1.A.2.c. Chemicals	N_2O	40	30	–85	1 300	–	–9	–11	9	–
1.A.2.d. Pulp, Paper and Print	N_2O	200	300	–60	900	–	–6	–29	30	–
1.A.2.e. Food Processing, Beverages and Tobacco	N_2O	IE	IE	–	–	–	–	–	–	Emissions from Food Processing, Beverages and Tobacco are included in Other Manufacturing (1.A.2.f.iv)
1.A.2.f. Other	N_2O	200	200	–65	1 000	–	11	–25	65	–
1.A.2.f.i Cement	N_2O	10	10	–55	850	–	2	–80	540	–
1.A.2.f.ii Mining	N_2O	40	100	–70	1 000	–	110	3	280	–
1.A.2.f.iii Construction	N_2O	20	10	–75	1 100	–	–55	–65	–35	–
1.A.2.f.iv Other Manufacturing	N_2O	100	100	–75	1 200	–	–9	–30	17	–
1.A.4. Other Sectors (KS)	N_2O	1 000	1 000	–65	1 000	–	6	–13	40	See Note 1
Liquid Fuels	N_2O	90	100	–35	850	–	–	–	–	–
Solid Fuels	N_2O	1	1	–75	1 100	–	–	–	–	–
Gaseous Fuels	N_2O	300	300	–95	1 400	–	–	–	–	–
Biomass	N_2O	300	300	–95	1 400	–	–	–	–	–
1.A.4.a. Commercial/Institutional	N_2O	200	300	–70	1 000	–	40	22	110	–
1.A.4.b. Residential	N_2O	600	600	–75	1 100	–	–3	–24	10	–
1.A.4.c. Agriculture/Forestry/Fisheries	N_2O	30	30	–70	1 000	–	5	–12	19	–

Notes:

1 Refer to Chapter 3 of the NIR for a discussion of the uncertainty associated with N_2O emission factors.

(KS) = key source; IE = included elsewhere

TABLE A7-9: Tier 2 Uncertainty Reporting — CO_2 Energy (Transport)

IPCC Source Category	Gas	Base Year Emissions (1990)	Year t Emissions (2001)	Uncertainty in Year t Emissions as % of Emissions in the Category		Uncertainty Introduced on National Total in Year t (2001)	% Change in Emissions between 2001 and 1990	Range of Likely % Change between 2001 and 1990		Comments
		Gg CO_2 eq	*Gg CO_2 eq*	*% Below (2.5th percentile)*	*% Above (97.5th percentile)*	%	%	*Lower % (2.5th percentile)*	*Upper % (97.5th percentile)*	
1.A.3. Transport	CO_2	146 000	178 000	–	–	–	–	–	–	–
Total Mobile Sources (Total Transport excluding Pipelines)	CO_2	135 000	170 000	–4	0	–	20	18	23	–
Total Non-Rail Surface Transport Vehicles (On-Road & Off-Road)	CO_2	118 000	152 000	–4	0	–	23	20	26	–
1.A.3.a. Civil Aviation (KS)	CO_2	10 410	11 800	–1	1	–	13	12	15	Aviation methodology has been greatly enhanced. Fuel sold to Canadian airlines has now been allocated to either international or domestic use based upon supplemental t-km activity data.
1.A.3.b. Road Transportation (KS)	CO_2	103 000	127 000	–8	–3	–	24	20	28	A new M-GEM model was used this year, which has rebuilt the method in a database. The relationships are now uniform through the time series, and the structure allows for both more data resolution and future relationship enhancement for activity data.
On-Road Gasoline Vehicles (Cars + Trucks + Heavy-Duty + Motorcycles)	CO_2	75 000	87 000	–7	–3	–	16	12	19	See Note 1
On-Road Diesel Vehicles (Cars + Trucks + Heavy-Duty)	CO_2	25 500	39 400	–13	–1	–	55	45	70	See Note 1
On-Road Natural Gas Vehicles	CO_2	84	118	–4	4	–	40	35	45	–
On-Road Propane Vehicles	CO_2	2 080	979	–2	2		–55	–55	–50	–
1.A.3.c. Railways (KS)	CO_2	6 320	5 820	–5	3	–	–8	–13	–5	–
1.A.3.d. Navigation (KS)	CO_2	4 730	5 180	–3	3	–	9	6	13	–
1.A.3.e. Other Transportation (KS)	CO_2			–	–	–	–	–	–	–
1.A.3.e.i Off-Road	CO_2	15 100	17 700	4	45	–	17	–5	50	In unison with the M-GEM model update, Off-Road values would be commensurately improved. Some data previously truncated are now carried at full resolution.
Off-Road – Gasoline	CO_2	5 000	4 000	–1	110	–	–	–	–	–
Off-Road – Diesel	CO_2	10 000	13 000	–5	35	–	–	–	–	–
1.A.3.e.ii Pipeline (Transport) (KS)	CO_2	6 700	9 970	–3	3	–	–	–	–	–
Liquid Fuels	CO_2	43	56	–6	3	–	–	–	–	–
Gaseous Fuels	CO_2	6 670	8 790	–3	3	–	–	–	–	–

Notes:

1 It is the practitioner responsible for the Transportation sector estimates who feels that the uncertainty attributed to activity data, whether fuel consumption or, more specifically, vehicle populations, is flawed in its construction and solicitation. This, however, has minimal effects in a fuel-constrained model.

(KS) = key source

TABLE A7-10: Tier 2 Uncertainty Reporting — CH_4 Energy (Transport)

IPCC Source Category	Gas	Base Year Emissions (1990)	Year t Emissions (2001)	Uncertainty in Year t Emissions as % of Emissions in the Category		Uncertainty Introduced on National Total in Year t (2001)	% Change in Emissions between 2001 and 1990	Range of Likely % Change between 2001 and 1990		Comments
		Gg CO_2 eq	*Gg CO_2 eq*	*% Below (2.5th percentile)*	*% Above (97.5th percentile)*	%	%	*Lower % (2.5th percentile)*	*Upper % (97.5th percentile)*	
1.A.3. Transport	CH_4	700	700	–	–	–	–	–	–	–
Total Mobile Sources (Total Transport excluding Pipelines)	CH_4	500	400	–24	700	–	–12	–25	23	–
Total Non-Rail Surface Transport Vehicles (On-Road & Off-Road)	CH_4	500	400	–29	700	–	–13	–26	24	–
1.A.3.a. Civil Aviation (KS)	CH_4	20	20	–75	900	–	–12	–35	13	Aviation methodology has been greatly enhanced. Fuel sold to Canadian airlines has now been allocated to either international or domestic use based upon supplemental t-km activity data.
1.A.3.b. Road Transportation (KS)	CH_4	336	294	–19	18	–	–17	–24	–8	A new M-GEM model was used this year, which has rebuilt the method in a database. The relationships are now uniform through the time series, and the structure allows for both more data resolution and future relationship enhancement for activity data.
On-Road Gasoline Vehicles (Cars + Trucks + Heavy-Duty + Motorcycles)	CH_4	300	200	–22	16	–	–25	–30	–18	See Note 1
On-Road Diesel Vehicles (Cars + Trucks + Heavy-Duty)	CH_4	30	40	–65	55	–	55	45	70	See Note 1
On-Road Natural Gas Vehicles	CH_4	20	20	–50	120	–	40	35	45	–
On-Road Propane Vehicles	CH_4	20	20	–50	120		–55	–55	–50	–
1.A.3.c. Railways (KS)	CH_4	7	7	–60	60	–	–8	–12	–4	–
1.A.3.d. Navigation (KS)	CH_4	7	8	–40	190	–	11	6	15	–
1.A.3.e. Other Transportation (KS)	CH_4	300	300	–	–	–	–	–	–	–
1.A.3.e.i Off-Road	CH_4	100	100	–80	2300	–	–3	–35	60	In unison with the M-GEM model update, Off-Road values would be commensurately improved. Some data previously truncated are now carried at full resolution.
Off-Road – Gasoline	CH_4	100	100	–90	2600	–	–	–	–	–
Off-Road – Diesel	CH_4	10	10	–90	1700	–	–	–	–	–
1.A.3.e.ii Pipeline (Transport) (KS)	CH_4	147	210	–15	–15	–	–	–	–	–
Liquid Fuels	CH_4	0	0	–	–	–	–	–	–	–
Gaseous Fuels	CH_4	100	200	–	–	–	–	–	–	–

Notes:

1 It is the practitioner responsible for the Transportation sector estimates who feels that the uncertainty attributed to activity data, whether fuel consumption or, more specifically, vehicle populations, is flawed in its construction and solicitation. This, however, has minimal effects in a fuel-constrained model.

(KS) = key source

TABLE A7-11: Tier 2 Uncertainty Reporting — N_2O Energy (Transport)

IPCC Source Category	Gas	Base Year Emissions (1990)	Year t Emissions (2001)	Uncertainty in Year t Emissions as % of Emissions in the Category		Uncertainty Introduced on National Total in Year t (2001)	% Change in Emissions between 2001 and 1990	Range of Likely % Change between 2001 and 1990		Comments
		Gg CO_2 eq	*Gg CO_2 eq*	*% Below (2.5th percentile)*	*% Above (97.5th percentile)*	%	%	*Lower % (2.5th percentile)*	*Upper % (97.5th percentile)*	Method changes or any other factors that would alter the estimated uncertainty from 2001
1.A.3. Transport	N_2O	7000	9000	–	–	47	–	–	–	–
Total Mobile Sources (Total Transport excluding Pipelines)	N_2O	7000	9000	–28	410	–	–12	–25	23	–
Total Non-Rail Surface Transport Vehicles (On-Road & Off-Road)	N_2O	5000	7000	–35	390	–	–13	–26	24	–
1.A.3.a. Civil Aviation (KS)	N_2O	370	310	–90	1500	–	–12	–35	13	Aviation methodology has been greatly enhanced. Fuel sold to Canadian airlines has now been allocated to either international or domestic use based upon supplemental t-km activity data.
1.A.3.b. Road Transportation (KS)	N_2O	4000	6000	–35	35	–	–17	–24	–8	A new M-GEM model was used last year, which has rebuilt the method in a database. The relationships are now uniform through the time series, and the structure allows for both more data resolution and future relationship enhancement for activity data.
On-Road Gasoline Vehicles (Cars + Trucks + Heavy-Duty + Motorcycles)	N_2O	3000	5000	–35	30	–	–25	–30	–18	See Note 1
On-Road Diesel Vehicles (Cars + Trucks + Heavy-Duty)	N_2O	300	300	–70	260	–	55	45	70	See Note 1
On-Road Natural Gas Vehicles	N_2O	1	1	–95	1400	–	40	35	45	–
On-Road Propane Vehicles	N_2O	10	4	–95	1500	–	–55	–55	–50	–
1.A.3.c. Railways (KS)	N_2O	800	700	–95	1500	–	–8	–12	–4	–
1.A.3.d. Navigation (KS)	N_2O	300	300	–90	1300	–	11	6	15	–
1.A.3.e. Other Transportation (KS)	N_2O	1000	2000	–	–	–	–	–	–	–
1.A.3.e.i Off-Road	N_2O	1000	2000	–90	1800	–	–3	–35	60	In unison with the M-GEM model update, Off-Road values would be commensurately improved. Some data previously truncated are now carried at full resolution.
Off-Road – Gasoline	N_2O	30	30	–90	2600	–	–	–	–	–
Off-Road – Diesel	N_2O	1000	2000	–90	1700	–	–	–	–	–
1.A.3.e.ii Pipeline (Transport) (KS)	N_2O	90	60	–	–	–	–	–	–	–
Liquid Fuels	N_2O	2	3	–	–	–	–	–	–	–
Gaseous Fuels	N_2O	50	70	–	–	–	–	–	–	–

Notes:

1 It is the practitioner responsible for the Transportation sector estimates who feels that the uncertainty attributed to activity data, whether fuel consumption or, more specifically, vehicle populations, is flawed in its construction and solicitation. This, however, has minimal effects in a fuel-constrained model.

(KS) = key source

TABLE A7-12: Tier 2 Uncertainty Reporting — CO_2 Energy (Fugitives)

IPCC Source Category	Gas	Base Year Emissions (1990)	Year t Emissions (2001)	Uncertainty in Year t Emissions as % of Emissions in the Category		Uncertainty Introduced on National Total in Year t (2001)	% Change in Emissions between 2001 and 1990	Range of Likely % Change between 2001 and 1990		Comments
		Gg CO_2 eq	*Gg CO_2 eq*	*% Below (2.5th percentile)*	*% Above (97.5th percentile)*	%	%	*Lower % (2.5th percentile)*	*Upper % (97.5th percentile)*	
1.B. Fugitive Emissions from Coal Mining/ Handling and from Oil and Gas	CO_2	9 800	15 300	–35	–13	–	55	–3	45	ICF (2005)
1.B.1.a. Fugitive Emissions – Coal Mining	CO_2	–	–	–	–	–	–	–	–	–
1.B.2.(a+b) Fugitive Emissions – Oil and Natural Gas (KS)[1]	CO_2	10 000	15 000	–35	–13	–	55	–3	45	ICF (2005)
1.B.2.a. Oil	CO_2	27	78	–60	–40	–	190	–60	–40	–
1.B.2.a.ii Production	CO_2	30	80	–60	–40	–	–	–	–	–
1.B.2.a.iii Transport	CO_2	0	0	–35	35	–	–	–	–	–
1.B.2.b. Natural Gas	CO_2	19	29	25	55	–	55	35	85	–
1.B.2.b.ii Production/Processing	CO_2	20	30	26	60	–	–	–	–	–
1.B.2.b.iii Transmission	CO_2	2	2	–5	70	–	–	–	–	–
1.B.2.b.v Other Leakage	CO_2	1	2	–40	35	–	–	–	–	–
1.B.2.c. Fugitive Emissions – Oil and Natural Gas – Venting and Flaring (KS)	CO_2	9 800	15 300	–35	–13	–	55	–4	44	ICF (2005)
Venting	CO_2	4 500	7 800	–29	10	–	–	–	–	ICF (2005)
Flaring	CO_2	5 300	7 400	–50	–30	–	–	–	–	ICF (2005)

Notes:

1 Overall uncertainty for Total GHG (CO_2 eq) Fugitive Emissions (oil and gas excluding coal) is –10% and +9% as per the ICF (2005) study.

(KS) = key source

TABLE A7-13: Tier 2 Uncertainty Reporting — CH_4 Energy (Fugitives)

IPCC Source Category	Gas	Base Year Emissions (1990)	Year t Emissions (2001)	Uncertainty in Year t Emissions as % of Emissions in the Category		Uncertainty Introduced on National Total in Year t (2001)	% Change in Emissions between 2001 and 1990	Range of Likely % Change between 2001 and 1990		Comments
		Gg CO_2 eq	*Gg CO_2 eq*	*% Below (2.5th percentile)*	*% Above (97.5th percentile)*	%	%	*Lower % (2.5th percentile)*	*Upper % (97.5th percentile)*	Method changes or any other factors that would alter the estimated uncertainty from 2001
1.B. Fugitive Emissions from Coal Mining/ Handling and from Oil and Gas	CH_4	27 000	40 000	–7	16	–	40	23	65	ICF (2005)
1.B.1.a. Fugitive Emissions – Coal Mining (KS)	CH_4	1 900	1 000	–30	130	–	–50	–70	22	ICF (2005)
1.B.1.a.i Underground Mines	CH_4	1 000	300	–50	50	–	–	–	–	–
1.B.1.a.ii Surface Mines	CH_4	700	700	–40	180	–	–	–	–	–
1.B.2.(a+b) Fugitive Emissions – Oil and Natural Gas (KS)	CH_4	25 000	38 000	–7	15	–	45	28	75	ICF (2005)
1.B.2.a. Oil	CH_4	8 600	13 900	–29	13	–	65	29	150	–
1.B.2.a.ii Production	CH_4	9 000	13 000	–29	13	–	–	–	–	
1.B.2.a.iii Transport	CH_4	30	40	–35	35	–	–	–	–	–
1.B.2.b. Natural Gas	CH_4	17 200	23 100	1	28	–	40	19	70	ICF (2005)
1.B.2.b.ii Production/Processing	CH_4	9 000	13 000	–9	21	–	–	–	–	–
1.B.2.b.iii Transmission	CH_4	4 000	6 000	–7	65	–	–	–	–	–
1.B.2.b.iv Distribution	CH_4	3 000	3 000	–6	70	–	–	–	–	–
1.B.2.b.v Other Leakage	CH_4	1 500	1 800	–40	35	–	–	–	–	–
1.B.2.c. Fugitive Emissions – Oil and Natural Gas – Venting and Flaring (KS)	CH_4	500	700	–95	–90	–	35	–90	–85	ICF (2005)
Venting	CH_4	0	0	–	–	–	–	–	–	ICF (2005)
Flaring	CH_4	500	650	–95	–90	–	–	–	–	ICF (2005)

Note:

(KS) = key source

TABLE A7-14: Tier 2 Uncertainty Reporting — Industrial Processes, Solvent and Other Product Use

IPCC Source Category	Gas	Base Year Emissions (1990)	Year t Emissions (2001)	Uncertainty in Year t Emissions as % of Emissions in the Category		Uncertainty Introduced on National Total in Year t (2001)	% Change in Emissions between 2001 and 1990	Range of Likely % Change between 2001 and 1990		Comments
		Gg CO_2 eq	*Gg CO_2 eq*	*% Below (2.5th percentile)*	*% Above (97.5th percentile)*	%	%	*Lower % (2.5th percentile)*	*Upper % (97.5th percentile)*	
2.A. Mineral Products	–	–	–	–	–	–	6	–28	55	–
2.A.1. Cement Production (KS)	CO_2	5 800	6 500	–35	35	–	11	–35	85	See Note 1
2.A.2. Lime Production (KS)	CO_2	1 900	1 800	–2	110	–	–5	–45	65	See Note 1
2.A.3. Limestone and Dolomite Use (KS)	CO_2	397	339	–16	16	–	–9	–15	–2	–
2.A.4. Soda Ash Use (KS)	CO_2	68	64	–26	29	–	–6	–35	30	See Note 1
2.B. Chemical Industry	–	–	–	–	–	–	18	–16	65	–
2.B.1. Ammonia Production (KS)	CO_2	5 000	5 900	–23	55	–	18	–16	65	–
2.B.2. Nitric Acid Production (KS)	N_2O	930	930	–15	–16	–	2	–18	28	–
2.B.3. Adipic Acid Production (KS)	N_2O	10 850	930	–2	2	–	–95	–95	–90	–
2.C. Metal Production	–	–	–	–	–	–	18	14	22	–
2.C.1. Iron and Steel Production (KS)	CO_2	7 590	7 920	–5	5	–	4	3	6	See Note 1
2.C.3. Aluminium Production (Total GHGs)	–	9 000	10 000	–45	–30	–	20	–35	–19	–
(Breakdown of the GHG Emissions)	CO_2 (KS)	2 640	4 160	–15	15	–	60	45	70	See Note 2
	C_2F_6 CO_2 eq	6 000	6 000	–70	–60	–	4	–70	–60	See Note 2
	C_2F_6 CO_2 eq	600	300	–70	–60	–	–8	–70	–60	See Note 2
	PFC (KS)	6 000	6 000	–70	–60	–	3	–70	–60	–
2.C.4. SF_6 Used in Magnesium Foundries (KS)	SF_6	2 870	2 020	–1	1	–	–30	–30	–29	–
2.G. Other	–	–	–	–	–	–	–	–	–	
Other and Undifferentiated Production (KS)	CO_2	9 200	11 700	–40	1	–	27	–30	50	See Note 3
Total GHG Emissions from Industrial Processes	CO_2 eq	44 000	49 000	–7	5	–	–9	–27	–12	See Note 4
Total CO_2 Emissions – Industrial Processes	CO_2	32 600	38 300	2	19	–	18	–3	27	See Note 4
Total N_2O Emissions – Industrial Processes	N_2O	11 470	1 550	–8	8	–	–	–	–	–
Total HFC Emissions from ODS Substitutes (KS)	HFC	0	3 000	–21	55	–	–	–	–	See Note 5
Total PFC Emissions – Industrial Processes	PFC	6 000	6 000	–70	–60	–	–	–	–	–
Total SF_6 Emissions – Industrial Processes	SF_6	3 000	2 000	–1	1	–	–	–	–	Differences are due to addition of new SF_6 sources: SF_6 from casters and electrical utilities
3. Solvent and Other Product Use	–	–	–	–	–	–	–	–	–	
Total Emissions from Solvent Use (KS)	N_2O	420	470	–23	22	–	12	12	12	Differences are due to the update in population statistics

Notes:

1 There has been a methodological improvement in this category since 2004 (i.e., 2002 inventory). The uncertainty estimates in the ICF report were associated with the emission estimates shown in the 2001 inventory. The current emission numbers developed using an improved methodology have not been assessed for their uncertainties. However, the uncertainty values provided in the ICF study can be considered as acceptable, since they are actually uncertainties for worst-case emission estimates. In other words, they are conservative estimates of uncertainty for improved and more accurate emission figures.

2 Audited data were obtained directly from the AAC. The uncertainty estimates in the ICF report were associated with the emission estimates developed using emission factors (as shown in the 2001 inventory). Therefore, they are not applicable to the current emission estimates, which are significantly more accurate than before. One of the planned improvements for this category is to obtain, from industry experts, uncertainty estimates that correspond to the current emission figures.

3 The 1990–2004 emission estimates for this category shown in the 2004 inventory are different from the ones in previous inventories. Differences are due to the change in CO_2 emission estimates (for 1990–2002) for aluminium production, which are subtracted from the total non-energy emissions to avoid double-counting. The current emission numbers have not been assessed for their uncertainties. There has also been a reallocation of CO_2 from natural gas used for hydrogen making from this category to the Energy Sector categories.

4 The 1990–2004 emission estimates shown in the 2004 inventory are different from the ones in previous inventories. Differences come from the reasons mentioned above. The current emission numbers have not been assessed for their uncertainties. However, the uncertainty values provided in the ICF study can be considered as acceptable, since they are actually uncertainties for worst-case emission estimates. In other words, they are conservative estimates of uncertainty for improved and more accurate emission figures.

5 There has been a methodological improvement in calculating emissions from HFC consumption for the 2004 inventory. The uncertainty estimates in the ICF report were associated with the emission estimates shown in the 2001 inventory. The current emission numbers developed using an improved methodology have not been assessed for their uncertainties. However, the uncertainty values provided in the ICF study can be considered as acceptable, since they are actually uncertainties for worst-case emission estimates. In other words, they are conservative estimates of uncertainty for improved and more accurate emission figures.

(KS) = key source

ODS = ozone-depleting substance

TABLE A7-15: Tier 2 Uncertainty Reporting — Agriculture

IPCC Source Category	Gas	Base Year Emissions (1990)	Year t Emissions (2001)	Uncertainty in Year t Emissions as % of Emissions in the Category		Uncertainty Introduced on National Total in Year t (2001)	% Change in Emissions between 2001 and 1990	Range of Likely % Change between 2001 and 1990		Comments
		Gg CO_2 eq	*Gg CO_2 eq*	*% Below (2.5th percentile)*	*% Above (97.5th percentile)*	%	%	*Lower % (2.5th percentile)*	*Upper % (97.5th percentile)*	See Note 1
4.A. Enteric Fermentation (KS)	CH_4	16 000	18 900	–9	9	–	18	15	20	See Note 1
4.B. Manure Management	CH_4 (KS)	4 620	5 460	–15	15	–	19	15	23	See Note 1
	N_2O (KS)	3 700	4 700	–30	35	–	25	–10	60	See Note 1
	CO_2 eq	8 300	10 000	–16	18	–	22	6	40	–
4.D. Agricultural Soils	–	–	–	–	–	36	–	–	–	–
Direct Soil Emissions (KS)	N_2O	21 700	24 500	–25	35	–	11	7	16	See Note 1
Indirect Soil Emissions (KS)	N_2O	6 200	7 100	–60	120	–	28	24	35	See Note 1
Total (Direct and Indirect Soil Emissions)	N_2O	28 000	31 000	–25	40	–	15	11	20	See Note 1

Notes:

1 These uncertainties estimated by ICF (2004) are no longer relevant because of significant upgrades in methodologies. Revised estimates by sources are reported in Chapter 6.

(KS) = key source

TABLE A7-16: Tier 2 Uncertainty Reporting — Waste

IPCC Source Category	Gas	Base Year Emissions (1990)	Year t Emissions (2001)	Uncertainty in Year t Emissions as % of Emissions in the Category		Uncertainty Introduced on National Total in Year t (2001)	% Change in Emissions between 2001 and 1990	Range of Likely % Change between 2001 and 1990		Comments
		Gg CO_2 eq	*Gg CO_2 eq*	*% Below (2.5th percentile)*	*% Above (97.5th percentile)*	*%*	*%*	*Lower % (2.5th percentile)*	*Upper % (97.5th percentile)*	Method changes or any other factors that would alter the estimated uncertainty from 2001
Waste		–	–	–	–	31	–	–	–	–
6.A. Solid Waste Disposal on Land (KS)	CH_4	18 500	23 100	−35	40	–	25	29	55	–
Emissions from MSW Landfills	CH_4	17 000	22 000	−40	35	–	25	27	55	See Note 1
Emissions from Wood Waste	CH_4	2 000	2 000	−60	190	–	35	35	40	See Note 2
6.B. Wastewater Handling/Treatment (KS)	CO_2 eq	1 220	1 370	−40	55	–	12	12	13	–
Emissions from Wastewater Treatment	CH_4	360	400	−40	45	–	13	12	13	See Note 2
	N_2O	930	930	−60	65	–	12	12	12	The wastewater input uncertainties were assumed values.
6.C. Waste Incineration (KS)	CO_2 eq	320	350	−12	65	–	10	10	11	–
Emissions from MSW Incineration	CO_2	300	300	−3	85	–	12	11	12	Uncertainties for all inputs were assumed.
	N_2O	60	60	−80	85	–	11	11	12	Uncertainties for all inputs were assumed, except for the N_2O emissions, which were based on IPCC estimates.
Emissions from Sewage Sludge Incineration	CH_4	10	10	−60	60	–	−25	−30	−19	The uncertainty range for the CH_4 emission factor for fluidized beds in the 2001 inventory year was assumed. For simplicity, the multihearth incinerators were not included. Uncertainty about the quantity of sewage sludge incinerated was assumed based upon IPCC values.

Notes:

1 The accuracy of these values is subject to the following limitations: (1) the uncertainty values from the ICF (2004) study were calculated from the Monte Carlo method employing a much simplified CH_4 generation model compared with that utilized in the NIR; (2) only one expert's opinion was used to provide the uncertainty lower and upper limits for each activity data input (CH_4 volume capture, MSW landfilling rate per capita, Scholl Canyon constants [CH_4 generation potential, L_0, and the CH_4 rate constant, k]), and population statistics. A revision of the landfill gas collection inventory in 2004 has since found the 2001 inventory value of the quantity of CH_4 captured to be 10% overestimated. The uncertainty about the quantity of CH_4 captured was overestimated due to a transcription error.

2 The input values for this category were IPCC default values or assumed values.

(KS) = key source

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ANNEX 8: CANADA'S GREENHOUSE GAS EMISSION TABLES, 1990–2004

Annex 8 contains summary tables illustrating national GHG emissions by year, by gas, and by sector.

TABLE A8-1: Greenhouse Gas Category Description

GHG Source/Sink Categories	
ENERGY	
a. Stationary Combustion Sources	
Electricity and Heat Generation	Emissions from fuels consumed by:
Electricity Generation	Utility and industry electricity generation
Heat Generation	Steam generation (for sale)
Fossil Fuel Industries	Emissions from fuels consumed by:
Petroleum Refining and Upgrading	Petroleum refining industry and the heavy oil and bitumen upgrading industry
Fossil Fuel Production	Natural gas production and some conventional and unconventional oil production industries (some refining is included)
Mining	Emissions from commercial fuel sold to:
	Metal and non-metal mines, stone quarries, and gravel pits
	Oil and gas extraction industries
	Mineral exploration and contract drilling operation
Manufacturing Industries	Emissions from fuels consumed by the following industries:
	Iron and steel (steel foundries, casting and rolling mills)
	Non-ferrous metals (aluminium, magnesium, and other production)
	Chemical (fertilizer manufacturing, organic and inorganic chemical manufacturing)
	Pulp and paper (primarily pulp, paper, and paper product manufacturers)
	Cement production
	Other manufacturing industries not listed (such as automobile manufacturing, textiles, food and beverage industries)
Construction	Emissions from fuels consumed by the construction industry – buildings, highways, etc.
Commercial & Institutional	Emissions from fuels consumed by:
	Service industries related to mining, communication, wholesale and retail trade, finance and insurance, real estate, education, etc.
	Federal, provincial, and municipal establishments
	National Defence and Canadian Coast Guard
	Train stations, airports, and warehouses
Residential	Emissions from fuels consumed for personal residences (homes, apartment hotels, condominiums, and farm houses)
Agriculture & Forestry	Emissions from fuels consumed by:
	Forestry and logging service industry
	Agriculture, hunting and trapping industry (excluding food processing, farm machinery manufacturing and repair)
b. Transportation	Emissions resulting from the combustion and/or fugitive releases due to moving passengers, freight, and commodities throughout Canada
Domestic Aviation	Emissions resulting from the consumption of fossil fuels by Canadian-registered airlines flying domestically
Road Transportation	Emissions resulting from the consumption of fossil fuels by vehicles licensed to operate on roads
Railways	Emissions resulting from the consumption of fossil fuels by Canadian railways
Domestic Marine	Emissions resulting from the consumption of fossil fuels by Canadian-registered marine vessels fuelled domestically
Others – Off-Road	Emissions resulting from the consumption of fossil fuels by combustion devices not licensed to operate on roads
Others – Pipelines	Emissions resulting from the transportation and distribution of crude oil, natural gas, and other products
c. Fugitive Sources	Intentional and unintentional releases of GHGs from the following activities:
Coal Mining	Underground and surface mining
Oil and Natural Gas	Conventional and unconventional oil and gas exploration, production, processing, transportation, and distribution
INDUSTRIAL PROCESSES	Emissions resulting from the following process activities:
a. Mineral Products	Production of cement and lime; use of soda ash, limestone & dolomite, and magnesite
b. Chemical Industry	Production of ammonia, nitric acid, and adipic acid
c. Metal Production	Production of aluminium, iron and steel; magnesium production and casting
d. Consumption of Halocarbons and SF_6	Use of HFCs and/or PFCs in air conditioning units, refrigeration units, fire extinguishers, aerosol cans, solvents, foam blowing, semiconductor manufacturing and electronics industry; use of SF_6 in electrical equipment and semiconductors
e. Other & Undifferentiated Production	Non-energy use of fossil fuels
SOLVENT & OTHER PRODUCT USE	Emissions resulting from the use of N_2O as anaesthetic and propellant
AGRICULTURE	Emissions resulting from:
a. Enteric Fermentation	Livestock enteric fermentation
b. Manure Management	Livestock waste management
c. Agricultural Soils	
Direct Sources	Direct N_2O emissions from synthetic fertilizer, manure on cropland, crop residue, tillage, summerfallow, and cultivation of organic soils
Manure on Pasture, Range, and Paddock	Direct N_2O emissions from manure deposited on pasture, range, and paddock
Indirect Sources	Indirect N_2O emissions from volatilization and leaching of animal manure nitrogen, synthetic fertilizer nitrogen, and crop residue nitrogen
WASTE	Emissions resulting from:
a. Solid Waste Disposal on Land	Municipal waste management sites (landfills) and wood waste landfills
b. Wastewater Handling	Domestic and industrial wastewater treatment
c. Waste Incineration	Municipal solid waste and sewage sludge incineration
LAND USE, LAND-USE CHANGE AND FORESTRY	Emissions and removals resulting from:
a. Forest Land	Managed forests and lands converted to forests; includes growth, natural and anthropogenic disturbances
b. Cropland	Mineral and organic cropland soils management, liming, woody biomass (CO_2), lands converted to cropland
c. Grassland	Managed grasslands, lands converted to grasslands (CO_2)
d. Wetlands	Lands converted to wetlands (peatlands, flooded lands) and wetlands remaining wetlands (peatlands only)
e. Settlements	Urban trees and forest and grassland conversion to built-up lands (settlements, transport infrastructure, oil & gas infrastructure)

TABLE A8-2: Canada's 1990–2004 Greenhouse Gas Emissions by Sector

GHG Source/Sink Categories	GHG Emissions														
	kt CO_2 eq														
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
TOTAL[1]	**599 000**	**592 000**	**609 000**	**611 000**	**631 000**	**649 000**	**667 000**	**680 000**	**686 000**	**698 000**	**725 000**	**719 000**	**726 000**	**754 000**	**758 000**
ENERGY	**475 000**	**467 000**	**485 000**	**485 000**	**502 000**	**517 000**	**532 000**	**545 000**	**555 000**	**569 000**	**596 000**	**590 000**	**597 000**	**622 000**	**620 000**
a. Stationary Combustion Sources	**283 000**	**278 000**	**288 000**	**283 000**	**289 000**	**296 000**	**304 000**	**309 000**	**313 000**	**325 000**	**347 000**	**343 000**	**348 000**	**368 000**	**360 000**
Electricity and Heat Generation	95 300	96 700	103 000	93 900	96 400	101 000	99 700	111 000	124 000	121 000	132 000	134 000	129 000	139 000	130 000
Fossil Fuel Industries	53 000	51 000	53 000	54 000	55 000	56 000	57 000	53 000	57 000	68 000	70 000	71 000	76 000	77 000	79 000
Petroleum Refining and Upgrading	23 000	23 000	24 000	25 000	24 000	25 000	25 000	23 000	21 000	23 000	24 000	26 000	30 000	30 000	29 000
Fossil Fuel Production	30 000	28 000	30 000	29 000	31 000	32 000	32 000	30 000	35 000	44 000	45 000	45 000	46 000	47 000	49 000
Mining	6 200	5 080	4 900	7 420	7 490	7 860	8 740	8 970	8 020	7 450	10 400	10 300	11 800	15 700	15 400
Manufacturing Industries	54 900	52 400	51 800	49 300	52 400	53 100	54 800	54 800	52 600	52 900	53 200	49 000	49 100	49 500	50 900
Iron and Steel	6 490	6 450	6 720	6 660	7 470	7 040	7 330	7 300	7 000	7 280	7 190	5 890	6 490	6 370	6 550
Non-Ferrous Metals	3 230	2 610	2 830	2 730	3 310	3 110	3 500	3 180	3 410	3 260	3 190	3 470	3 220	3 200	3 230
Chemical	7 100	7 480	7 450	7 310	8 530	8 460	8 800	8 890	8 570	8 460	7 860	6 760	6 130	5 820	6 290
Pulp and Paper	13 600	13 000	12 200	12 100	12 000	11 700	12 200	12 000	11 100	11 100	11 000	9 790	9 210	9 010	9 310
Cement	3 590	3 000	2 870	2 860	3 280	3 420	3 270	3 250	3 290	3 990	3 970	3 930	4 180	4 180	4 330
Other Manufacturing	20 900	19 900	19 600	17 600	17 800	19 400	19 700	20 100	19 200	18 800	20 000	19 100	19 900	20 900	21 200
Construction	1 880	1 630	1 750	1 390	1 400	1 180	1 270	1 260	1 120	1 170	1 080	1 010	1 240	1 300	1 350
Commercial & Institutional	25 800	26 500	27 000	28 100	27 400	29 000	29 600	30 000	27 200	28 900	33 200	33 200	35 400	37 900	37 900
Residential	44 000	42 000	43 000	46 000	46 000	45 000	50 000	46 000	41 000	43 000	45 000	42 000	44 000	45 000	43 000
Agriculture & Forestry	2 420	2 760	3 270	3 060	2 560	2 790	2 950	2 940	2 610	2 690	2 570	2 210	2 110	2 210	2 100
b. Transportation[2]	**150 000**	**140 000**	**150 000**	**150 000**	**160 000**	**160 000**	**170 000**	**170 000**	**180 000**	**180 000**	**180 000**	**180 000**	**180 000**	**190 000**	**190 000**
Domestic Aviation	6 400	5 700	5 500	5 300	5 500	5 900	6 200	6 400	6 500	6 600	6 600	6 200	6 800	7 300	7 800
Road Transportation	107 000	104 000	108 000	110 000	116 000	119 000	120 000	126 000	127 000	131 000	131 000	133 000	137 000	140 000	145 000
Light-Duty Gasoline Vehicles	53 800	51 300	51 600	51 800	52 400	51 400	49 900	50 100	49 700	49 800	48 300	49 100	49 700	49 400	49 800
Light-Duty Gasoline Trucks	21 700	22 200	24 000	25 500	27 400	28 400	29 900	31 900	32 800	36 700	37 600	38 800	40 700	41 900	43 600
Heavy-Duty Gasoline Vehicles	3 140	3 340	3 740	4 080	4 490	4 760	4 990	5 050	5 500	4 210	4 370	4 040	4 140	4 140	4 210
Motorcycles	230	221	218	220	222	214	210	220	232	233	238	239	227	226	219
Light-Duty Diesel Vehicles	672	635	633	626	618	594	603	600	597	605	604	642	683	722	768
Light-Duty Diesel Trucks	591	507	456	429	432	417	402	505	454	500	645	681	755	796	893
Heavy-Duty Diesel Vehicles	24 500	23 800	24 300	25 700	28 500	30 800	32 500	35 500	35 500	37 300	38 700	38 500	39 600	42 300	44 900
Propane & Natural Gas Vehicles	2 200	2 300	2 700	2 000	1 900	2 100	2 000	1 800	1 800	1 500	1 100	1 100	850	820	870
Railways	7 000	7 000	7 000	7 000	7 000	6 000	6 000	6 000	6 000	7 000	7 000	7 000	6 000	6 000	6 000
Domestic Marine	5 000	5 200	5 100	4 500	4 700	4 400	4 500	4 500	5 100	5 000	5 100	5 500	5 500	6 100	6 600
Others	20 000	20 000	20 000	30 000	30 000	30 000	30 000	30 000	30 000	30 000	30 000	30 000	30 000	30 000	30 000
Off-Road Gasoline	5 000	5 000	4 000	4 000	4 000	4 000	5 000	4 000	6 000	5 000	6 000	5 000	4 000	4 000	4 000
Off-Road Diesel	10 000	10 000	9 000	10 000	10 000	10 000	10 000	10 000	10 000	20 000	20 000	10 000	10 000	10 000	20 000
Pipelines	6 900	7 650	9 890	10 400	10 800	12 000	12 500	12 600	12 500	12 600	11 300	10 300	10 900	9 110	8 520
c. Fugitive Sources	**43 300**	**44 800**	**48 000**	**50 400**	**53 500**	**57 000**	**61 000**	**62 400**	**64 800**	**62 000**	**64 900**	**66 300**	**65 800**	**66 200**	**66 500**
Coal Mining	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	1 000	1 000	900	1 000	1 000	1 000	1 000
Oil and Natural Gas	41 400	42 700	46 100	48 600	51 700	55 300	59 200	60 700	63 400	60 900	64 000	65 300	64 800	65 200	65 500
Oil	6 700	6 900	7 200	7 400	8 000	8 400	9 000	9 300	9 100	8 900	9 400	9 900	9 800	10 000	9 900
Natural Gas	18 000	18 000	20 000	21 000	22 000	23 000	25 000	25 000	27 000	26 000	27 000	28 000	28 000	28 000	28 000
Venting	13 000	13 000	15 000	16 000	17 000	18 000	19 000	21 000	21 000	20 000	22 000	22 000	22 000	22 000	22 000
Flaring	4 400	4 200	4 300	4 600	4 800	5 400	5 700	5 600	7 200	5 400	5 500	5 400	5 500	5 700	5 400
INDUSTRIAL PROCESSES	**53 300**	**54 700**	**53 100**	**52 700**	**54 600**	**55 500**	**56 500**	**56 500**	**52 500**	**49 800**	**49 800**	**48 700**	**48 300**	**50 100**	**54 300**
a. Mineral Production	**8 300**	**7 300**	**7 400**	**7 200**	**8 100**	**8 800**	**8 400**	**9 000**	**9 100**	**9 500**	**9 600**	**9 000**	**9 000**	**9 100**	**9 500**
Cement Production	5 400	4 400	4 500	4 600	5 400	6 100	5 800	6 200	6 400	6 600	6 700	6 500	6 700	6 800	7 100
Lime Production	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000
Mineral Product Use[3]	1 100	1 100	1 100	860	840	880	880	930	930	910	1 000	840	640	610	630
b. Chemical Industry	**15 000**	**15 000**	**15 000**	**14 000**	**16 000**	**17 000**	**18 000**	**16 000**	**11 000**	**8 000**	**7 100**	**6 400**	**6 800**	**7 000**	**9 600**
Ammonia Production	3 900	3 900	4 200	4 500	4 500	5 300	5 400	5 300	5 300	5 400	5 400	4 800	4 800	5 100	5 700
Nitric Acid Production	780	770	780	780	770	780	790	790	770	790	800	800	810	810	830
Adipic Acid Production	10 700	10 000	9 950	9 080	11 000	10 700	11 500	9 890	5 070	1 750	900	804	1 250	1 090	3 090
c. Metal Production	**19 500**	**22 100**	**20 800**	**20 800**	**19 600**	**19 200**	**18 800**	**18 600**	**19 500**	**18 700**	**18 900**	**17 400**	**17 500**	**17 200**	**17 600**
Iron and Steel Production	7 060	8 320	8 500	8 180	7 540	7 880	7 740	7 550	7 690	7 890	7 890	7 280	7 110	7 040	8 160
Aluminium Production	9 310	10 200	9 890	10 400	9 800	9 160	9 440	9 430	9 610	8 620	8 220	7 710	7 460	7 660	7 280
SF_6 Used in Magnesium Smelters and Casters	3 110	3 580	2 400	2 210	2 280	2 110	1 620	1 660	2 170	2 230	2 770	2 360	2 940	2 490	2 190
d. Consumption of Halocarbons and SF_6	**1 800**	**1 900**	**1 800**	**2 000**	**1 800**	**2 100**	**2 000**	**2 800**	**3 400**	**4 000**	**4 500**	**5 600**	**5 000**	**6 000**	**5 500**
e. Other & Undifferentiated Production	**8 300**	**8 700**	**8 300**	**8 300**	**8 800**	**8 700**	**9 600**	**10 000**	**9 300**	**9 600**	**9 700**	**10 000**	**9 900**	**11 000**	**12 000**
SOLVENT & OTHER PRODUCT USE	**420**	**420**	**430**	**430**	**440**	**440**	**450**	**450**	**450**	**460**	**460**	**470**	**470**	**480**	**480**
AGRICULTURE	**45 000**	**44 000**	**45 000**	**46 000**	**47 000**	**49 000**	**51 000**	**51 000**	**51 000**	**51 000**	**51 000**	**51 000**	**51 000**	**53 000**	**55 000**
a. Enteric Fermentation	**18 400**	**18 600**	**19 200**	**19 400**	**20 000**	**21 100**	**21 700**	**21 700**	**21 600**	**21 500**	**21 700**	**22 400**	**22 500**	**22 600**	**24 000**
b. Manure Management	**6 700**	**6 700**	**6 900**	**6 900**	**7 000**	**7 400**	**7 500**	**7 600**	**7 600**	**7 600**	**7 800**	**8 000**	**8 100**	**8 100**	**8 400**
c. Agricultural Soils	**20 000**	**19 000**	**19 000**	**20 000**	**20 000**	**21 000**	**22 000**	**21 000**	**22 000**	**22 000**	**22 000**	**21 000**	**20 000**	**22 000**	**22 000**
Direct Sources	11 000	10 000	10 000	11 000	11 000	11 000	11 000	11 000	12 000	12 000	11 000	11 000	10 000	11 000	12 000
Pasture, Range, and Paddock Manure	3 200	3 200	3 400	3 400	3 500	3 700	3 800	3 800	3 800	3 800	3 900	4 000	4 000	4 000	4 300
Indirect Sources	6 000	5 000	5 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	7 000
WASTE	**25 000**	**25 000**	**26 000**	**26 000**	**26 000**	**26 000**	**26 000**	**27 000**	**28 000**	**28 000**	**28 000**	**28 000**	**28 000**	**29 000**	**29 000**
a. Solid Waste Disposal on Land	**23 000**	**24 000**	**24 000**	**25 000**	**25 000**	**25 000**	**25 000**	**26 000**	**26 000**	**26 000**	**27 000**	**27 000**	**27 000**	**27 000**	**27 000**
b. Wastewater Handling	**1 100**	**1 100**	**1 100**	**1 100**	**1 100**	**1 100**	**1 200**	**1 200**	**1 200**	**1 200**	**1 200**	**1 200**	**1 200**	**1 200**	**1 200**
c. Waste Incineration	**400**	**410**	**400**	**350**	**330**	**330**	**310**	**250**	**250**	**240**	**250**	**250**	**230**	**240**	**250**
LAND USE, LAND-USE CHANGE AND FORESTRY	**–82 000**	**–97 000**	**–160 000**	**–75 000**	**15 000**	**190 000**	**–78 000**	**–130 000**	**89 000**	**–45 000**	**–130 000**	**–120 000**	**6 100**	**–11 000**	**81 000**
a. Forest Land	**–110 000**	**–120 000**	**–190 000**	**–96 000**	**–3 100**	**180 000**	**–94 000**	**–140 000**	**75 000**	**–59 000**	**–140 000**	**–130 000**	**–3 700**	**–20 000**	**73 000**
b. Cropland	**14 000**	**13 000**	**11 000**	**9 700**	**8 400**	**7 000**	**6 100**	**5 700**	**5 100**	**4 200**	**3 100**	**2 000**	**1 600**	**830**	**58**
c. Grassland	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
d. Wetlands	**6 000**	**5 000**	**3 000**	**3 000**	**2 000**	**3 000**	**2 000**	**2 000**	**2 000**	**2 000**	**2 000**	**2 000**	**1 000**	**1 000**	**1 000**
e. Settlements	**8 000**	**8 000**	**8 000**	**8 000**	**7 000**	**7 000**	**8 000**	**8 000**	**7 000**	**7 000**	**7 000**	**7 000**	**7 000**	**7 000**	**7 000**

Notes:

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

2 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

3 The category mineral product use includes CO_2 emissions from the use of limestone & dolomite, soda ash, and magnesite.

Totals may not add due to rounding.

TABLE A8-3: 2004 Greenhouse Gas Emissions Summary for Canada

GHG Source/Sink Categories	Greenhouse Gases								
	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	TOTAL
Global Warming Potential			21		310				
Unit	*kt*	*kt*	*kt CO_2 eq*	*kt*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*
TOTAL[1]	**593 000**	**5 200**	**110 000**	**140**	**44 000**	**4 700**	**3 060**	**3 000**	**758 000**
ENERGY	**553 000**	**3 000**	**60 000**	**30**	**10 000**	**–**	**–**	**–**	**620 000**
a. Stationary Combustion Sources	**352 000**	**200**	**5 000**	**9**	**3 000**	**–**	**–**	**–**	**360 000**
Electricity and Heat Generation	129 000	4.7	99	2	700	–	–	–	130 000
Fossil Fuel Industries	75 000	100	3 000	2	500	–	–	–	79 000
Petroleum Refining and Upgrading	29 000	0.6	10	0.5	200	–	–	–	29 000
Fossil Fuel Production	46 200	100	3 000	1	400	–	–	–	49 000
Mining	15 300	0.3	6	0.3	100	–	–	–	15 400
Manufacturing Industries	50 300	3	60	2	500	–	–	–	50 900
Iron and Steel	6 480	0.3	5	0.2	60	–	–	–	6 550
Non-Ferrous Metals	3 220	0.07	2	0.05	20	–	–	–	3 230
Chemical	6 250	0.13	2.7	0.1	30	–	–	–	6 290
Pulp and Paper	8 990	2	40	0.9	300	–	–	–	9 310
Cement	4 310	0.09	2	0.05	20	–	–	–	4 330
Other Manufacturing	21 100	0.4	9	0.4	100	–	–	–	21 200
Construction	1 340	0.02	0.5	0.03	9	–	–	–	1 350
Commercial & Institutional	37 700	0.7	10	0.8	200	–	–	–	37 900
Residential	40 700	90	2 000	2	500	–	–	–	43 000
Agriculture & Forestry	2 080	0.04	0.7	0.06	20	–	–	–	2 100
b. Transportation[2]	**185 000**	**30**	**600**	**30**	**8 000**	**–**	**–**	**–**	**190 000**
Domestic Aviation	7 590	0.4	9	0.7	200	–	–	–	7 800
Road Transportation	140 000	12	260	16	5 100	–	–	–	145 000
Light-Duty Gasoline Vehicles	47 800	3.5	74	6.0	1 900	–	–	–	49 800
Light-Duty Gasoline Trucks	41 000	4.5	95	8.3	2 600	–	–	–	43 600
Heavy-Duty Gasoline Vehicles	4 010	0.57	12	0.60	190	–	–	–	4 210
Motorcycles	214	0.17	3.6	0.00	1.3	–	–	–	219
Light-Duty Diesel Vehicles	750	0.02	0.4	0.05	20	–	–	–	768
Light-Duty Diesel Trucks	873	0.02	0.5	0.06	20	–	–	–	893
Heavy-Duty Diesel Vehicles	44 400	2	50	1	400	–	–	–	44 900
Propane & Natural Gas Vehicles	837	1	30	0.02	5	–	–	–	870
Railways	5 350	0.3	6	2	700	–	–	–	6 000
Domestic Marine	6 260	0.5	10	1	400	–	–	–	6 600
Others	26 000	10	300	6	2 000	–	–	–	30 000
Off-Road Gasoline	4 000	4	90	0.08	20	–	–	–	4 000
Off-Road Diesel	14 000	0.7	10	5	2 000	–	–	–	20 000
Pipelines	8 280	8.3	170	0.2	70	–	–	–	8 520
c. Fugitive Sources	**16 000**	**2 400**	**50 000**	**0.1**	**40**	**–**	**–**	**–**	**66 500**
Coal Mining	–	50	1 000	–	–	–	–	–	1 000
Oil and Natural Gas	16 000	2 300	49 000	0	40	–	–	–	65 500
Oil	3 650	300	6 300	–	–	–	–	–	9 900
Natural Gas	7 200	1 000	21 000	–	–	–	–	–	28 000
Venting	160	1 000	22 000	0.1	40	–	–	–	22 000
Flaring	5 350	3.91	82.2	0.00	0.06	–	–	–	5 400
INDUSTRIAL PROCESSES	**39 600**	**–**	**–**	**12.7**	**3 920**	**4 700**	**3 060**	**3 020**	**54 300**
a. Mineral Production	**9 500**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**9 500**
Cement Production	7 100	–	–	–	–	–	–	–	7 100
Lime Production	2 000	–	–	–	–	–	–	–	2 000
Mineral Product Use[3]	630	–	–	–	–	–	–	–	630
b. Chemical Industry	**5 700**	**–**	**–**	**12.7**	**3 920**	**–**	**–**	**–**	**9 600**
Ammonia Production	5 700	–	–	–	–	–	–	–	5 700
Nitric Acid Production	–	–	–	2.7	830	–	–	–	830
Adipic Acid Production	–	–	–	9.98	3 090	–	–	–	3 090
c. Metal Production	**12 000**	**–**	**–**	**–**	**–**	**–**	**3 030**	**2 220**	**17 600**
Iron and Steel Production	8 160	–	–	–	–	–	–	–	8 160
Aluminium Production	4 200	–	–	–	–	–	3 030	–	7 280
SF_6 Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	2 190	2 190
d. Consumption of Halocarbons and SF_6	**–**	**–**	**–**	**–**	**–**	**4 700**	**30**	**800**	**5 500**
e. Other & Undifferentiated Production	**12 000**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**12 000**
SOLVENT & OTHER PRODUCT USE	**–**	**–**	**–**	**1.6**	**480**	**–**	**–**	**–**	**480**
AGRICULTURE	**–**	**1 290**	**27 200**	**89**	**28 000**	**–**	**–**	**–**	**55 000**
a. Enteric Fermentation	**–**	**1 140**	**24 000**	**–**	**–**	**–**	**–**	**–**	**24 000**
b. Manure Management	**–**	**150**	**3 200**	**17**	**5 300**	**–**	**–**	**–**	**8 400**
c. Agricultural Soils	**–**	**–**	**–**	**72**	**22 000**	**–**	**–**	**–**	**22 000**
Direct Sources	–	–	–	37	12 000	–	–	–	12 000
Pasture, Range, and Paddock Manure	–	–	–	14	4 300	–	–	–	4 300
Indirect Sources	–	–	–	20	7 000	–	–	–	7 000
WASTE	**200**	**1 300**	**28 000**	**3**	**1 000**	**–**	**–**	**–**	**29 000**
a. Solid Waste Disposal on Land	**–**	**1 300**	**27 000**	**–**	**–**	**–**	**–**	**–**	**27 000**
b. Wastewater Handling	**–**	**12**	**250**	**3**	**1 000**	**–**	**–**	**–**	**1 200**
c. Waste Incineration	**200**	**0.06**	**1**	**0.2**	**50**	**–**	**–**	**–**	**250**
LAND USE, LAND-USE CHANGE AND FORESTRY	**59 000**	**640**	**14 000**	**27**	**8 400**	**–**	**–**	**–**	**81 000**
a. Forest Land	**51 000**	**640**	**13 000**	**27**	**8 300**	**–**	**–**	**–**	**73 000**
b. Cropland	**–140**	**5**	**100**	**0.3**	**100**	**–**	**–**	**–**	**58**
c. Grassland	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
d. Wetlands	**1 000**	**0.1**	**3**	**0.01**	**2**	**–**	**–**	**–**	**1 000**
e. Settlements	**7 000**	**3**	**60**	**0**	**30**	**–**	**–**	**–**	**7 000**

Notes:

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

2 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

3 The category mineral product use includes CO_2 emissions from the use of limestone & dolomite, soda ash, and magnesite.

Totals may not add due to rounding.

TABLE A8-4: 2003 Greenhouse Gas Emissions Summary for Canada

GHG Source/Sink Categories	Greenhouse Gases								
	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	TOTAL
Global Warming Potential			21		310				
Unit	*kt*	*kt*	*kt CO_2 eq*	*kt*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*
TOTAL[1]	**593 000**	**5 200**	**110 000**	**130**	**41 000**	**4 400**	**3 030**	**4 200**	**754 000**
ENERGY	**556 000**	**3 000**	**60 000**	**30**	**10 000**	**–**	**–**	**–**	**622 000**
a. Stationary Combustion Sources	**361 000**	**200**	**5 000**	**9**	**3 000**	**–**	**–**	**–**	**368 000**
Electricity and Heat Generation	139 000	5.1	110	2	800	–	–	–	139 000
Fossil Fuel Industries	74 000	100	3 000	2	500	–	–	–	77 000
Petroleum Refining and Upgrading	30 000	0.5	10	0.5	100	–	–	–	30 000
Fossil Fuel Production	43 900	100	3 000	1	300	–	–	–	47 000
Mining	15 600	0.3	7	0.3	100	–	–	–	15 700
Manufacturing Industries	48 900	3	60	2	500	–	–	–	49 500
Iron and Steel	6 310	0.2	5	0.2	60	–	–	–	6 370
Non-Ferrous Metals	3 190	0.07	1	0.05	20	–	–	–	3 200
Chemical	5 780	0.12	2.5	0.1	30	–	–	–	5 820
Pulp and Paper	8 690	2	40	0.9	300	–	–	–	9 010
Cement	4 160	0.08	2	0.05	10	–	–	–	4 180
Other Manufacturing	20 800	0.4	9	0.4	100	–	–	–	20 900
Construction	1 290	0.02	0.5	0.03	9	–	–	–	1 300
Commercial & Institutional	37 700	0.7	10	0.8	200	–	–	–	37 900
Residential	42 900	90	2 000	2	500	–	–	–	45 000
Agriculture & Forestry	2 190	0.04	0.8	0.06	20	–	–	–	2 210
b. Transportation[2]	**179 000**	**30**	**600**	**30**	**8 000**	**–**	**–**	**–**	**190 000**
Domestic Aviation	7 040	0.4	9	0.7	200	–	–	–	7 300
Road Transportation	135 000	12	260	17	5 200	–	–	–	140 000
Light-Duty Gasoline Vehicles	47 300	3.7	78	6.3	2 000	–	–	–	49 400
Light-Duty Gasoline Trucks	39 200	4.5	94	8.4	2 600	–	–	–	41 900
Heavy-Duty Gasoline Vehicles	3 950	0.56	12	0.59	180	–	–	–	4 140
Motorcycles	221	0.18	3.7	0.00	1.3	–	–	–	226
Light-Duty Diesel Vehicles	706	0.02	0.4	0.05	20	–	–	–	722
Light-Duty Diesel Trucks	778	0.02	0.4	0.06	20	–	–	–	796
Heavy-Duty Diesel Vehicles	41 800	2	40	1	400	–	–	–	42 300
Propane & Natural Gas Vehicles	791	1	30	0.02	5	–	–	–	820
Railways	5 260	0.3	6	2	700	–	–	–	6 000
Domestic Marine	5 840	0.5	10	0.90	300	–	–	–	6 100
Others	26 000	10	300	6	2 000	–	–	–	30 000
Off-Road Gasoline	4 000	5	100	0.09	30	–	–	–	4 000
Off-Road Diesel	13 000	0.7	10	5	2 000	–	–	–	10 000
Pipelines	8 850	8.8	190	0.2	70	–	–	–	9 110
c. Fugitive Sources	**16 000**	**2 400**	**50 000**	**0.1**	**40**	**–**	**–**	**–**	**66 200**
Coal Mining	–	50	1 000	–	–	–	–	–	1 000
Oil and Natural Gas	16 000	2 300	49 000	0.1	40	–	–	–	65 200
Oil	3 630	300	6 400	–	–	–	–	–	10 000
Natural Gas	7 000	990	21 000	–	–	–	–	–	28 000
Venting	160	1 000	22 000	0.1	40	–	–	–	22 000
Flaring	5 580	4.06	85.3	0.00	0.1	–	–	–	5 700
INDUSTRIAL PROCESSES	**36 700**	**–**	**–**	**6.10**	**1 890**	**4 400**	**3 030**	**4 180**	**50 100**
a. Mineral Production	**9 100**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**9 100**
Cement Production	6 800	–	–	–	–	–	–	–	6 800
Lime Production	2 000	–	–	–	–	–	–	–	2 000
Mineral Product Use[3]	610	–	–	–	–	–	–	–	610
b. Chemical Industry	**5 100**	**–**	**–**	**6.10**	**1 890**	**–**	**–**	**–**	**7 000**
Ammonia Production	5 100	–	–	–	–	–	–	–	5 100
Nitric Acid Production	–	–	–	2.6	810	–	–	–	810
Adipic Acid Production	–	–	–	3.50	1 090	–	–	–	1 090
c. Metal Production	**12 000**	**–**	**–**	**–**	**–**	**–**	**3 000**	**2 560**	**17 200**
Iron and Steel Production	7 040	–	–	–	–	–	–	–	7 040
Aluminium Production	4 600	–	–	–	–	–	3 000	–	7 660
SF_6 Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	2 490	2 490
d. Consumption of Halocarbons and SF_6	**–**	**–**	**–**	**–**	**–**	**4 400**	**30**	**1 600**	**6 000**
e. Other & Undifferentiated Production	**11 000**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**11 000**
SOLVENT & OTHER PRODUCT USE	**–**	**–**	**–**	**1.5**	**480**	**–**	**–**	**–**	**480**
AGRICULTURE	**–**	**1 230**	**25 700**	**86**	**27 000**	**–**	**–**	**–**	**53 000**
a. Enteric Fermentation	**–**	**1 080**	**22 600**	**–**	**–**	**–**	**–**	**–**	**22 600**
b. Manure Management	**–**	**150**	**3 100**	**16**	**5 000**	**–**	**–**	**–**	**8 100**
c. Agricultural Soils	**–**	**–**	**–**	**70**	**22 000**	**–**	**–**	**–**	**22 000**
Direct Sources	–	–	–	37	11 000	–	–	–	11 000
Pasture, Range, and Paddock Manure	–	–	–	13	4 000	–	–	–	4 000
Indirect Sources	–	–	–	20	6 000	–	–	–	6 000
WASTE	**190**	**1 300**	**27 000**	**3**	**1 000**	**–**	**–**	**–**	**29 000**
a. Solid Waste Disposal on Land	**–**	**1 300**	**27 000**	**–**	**–**	**–**	**–**	**–**	**27 000**
b. Wastewater Handling	**–**	**12**	**240**	**3**	**1 000**	**–**	**–**	**–**	**1 200**
c. Waste Incineration	**190**	**0.05**	**1**	**0.2**	**50**	**–**	**–**	**–**	**240**
LAND USE, LAND-USE CHANGE AND FORESTRY	**–24 000**	**390**	**8 100**	**16**	**5 100**	**–**	**–**	**–**	**–11 000**
a. Forest Land	**–33 000**	**380**	**7 900**	**16**	**4 900**	**–**	**–**	**–**	**–20 000**
b. Cropland	**620**	**5**	**100**	**0.3**	**100**	**–**	**–**	**–**	**830**
c. Grassland	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
d. Wetlands	**1 000**	**0.1**	**3**	**0.01**	**2**	**–**	**–**	**–**	**1 000**
e. Settlements	**7 000**	**3**	**60**	**0.1**	**30**	**–**	**–**	**–**	**7 000**

Notes:

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

2 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

3 The category mineral product use includes CO_2 emissions from the use of limestone & dolomite, soda ash, and magnesite.

Totals may not add due to rounding.

TABLE A8-5: 2002 Greenhouse Gas Emissions Summary for Canada

GHG Source/Sink Categories	Greenhouse Gases								
	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	TOTAL
Global Warming Potential			21		310				
Unit	*kt*	*kt*	*kt CO_2 eq*	*kt*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*
TOTAL[1]	**567 000**	**5 100**	**110 000**	**130**	**40 000**	**3 900**	**2 990**	**4 100**	**726 000**
ENERGY	**532 000**	**3 000**	**50 000**	**30**	**10 000**	**–**	**–**	**–**	**597 000**
a. Stationary Combustion Sources	**341 000**	**200**	**5 000**	**8**	**3 000**	**–**	**–**	**–**	**348 000**
Electricity and Heat Generation	128 000	4.7	99	2	700	–	–	–	129 000
Fossil Fuel Industries	73 000	100	2 000	2	500	–	–	–	76 000
Petroleum Refining and Upgrading	30 000	0.5	10	0.5	100	–	–	–	30 000
Fossil Fuel Production	43 100	100	2 000	1	300	–	–	–	46 000
Mining	11 700	0.2	5	0.3	90	–	–	–	11 800
Manufacturing Industries	48 600	3	60	2	500	–	–	–	49 100
Iron and Steel	6 420	0.2	5	0.2	60	–	–	–	6 490
Non-Ferrous Metals	3 210	0.07	1	0.05	20	–	–	–	3 220
Chemical	6 090	0.12	2.6	0.1	30	–	–	–	6 130
Pulp and Paper	8 900	2	40	0.9	300	–	–	–	9 210
Cement	4 170	0.08	2	0.05	20	–	–	–	4 180
Other Manufacturing	19 800	0.4	8	0.4	100	–	–	–	19 900
Construction	1 230	0.02	0.5	0.03	9	–	–	–	1 240
Commercial & Institutional	35 200	0.6	10	0.7	200	–	–	–	35 400
Residential	41 000	90	2 000	2	500	–	–	–	44 000
Agriculture & Forestry	2 090	0.03	0.7	0.06	20	–	–	–	2 110
b. Transportation[2]	**174 000**	**30**	**600**	**30**	**8 000**	**–**	**–**	**–**	**180 000**
Domestic Aviation	6 580	0.4	9	0.6	200	–	–	–	6 800
Road Transportation	131 000	13	260	17	5 300	–	–	–	137 000
Light-Duty Gasoline Vehicles	47 600	4.0	84	6.7	2 100	–	–	–	49 700
Light-Duty Gasoline Trucks	37 900	4.5	95	8.7	2 700	–	–	–	40 700
Heavy-Duty Gasoline Vehicles	3 950	0.56	12	0.59	180	–	–	–	4 140
Motorcycles	222	0.18	3.8	0.00	1.3	–	–	–	227
Light-Duty Diesel Vehicles	667	0.02	0.4	0.05	20	–	–	–	683
Light-Duty Diesel Trucks	738	0.02	0.4	0.05	20	–	–	–	755
Heavy-Duty Diesel Vehicles	39 200	2	40	1	400	–	–	–	39 600
Propane & Natural Gas Vehicles	819	1	30	0.02	5	–	–	–	850
Railways	5 280	0.3	6	2	700	–	–	–	6 000
Domestic Marine	5 150	0.4	8	1	300	–	–	–	5 500
Others	26 000	20	300	5	2 000	–	–	–	30 000
Off-Road Gasoline	4 000	4	90	0.08	20	–	–	–	4 000
Off-Road Diesel	12 000	0.6	10	5	2 000	–	–	–	10 000
Pipelines	10 600	11	220	0.3	90	–	–	–	10 900
c. Fugitive Sources	**16 000**	**2 300**	**49 000**	**0.1**	**30**	**–**	**–**	**–**	**65 800**
Coal Mining	–	50	1 000	–	–	–	–	–	1 000
Oil and Natural Gas	16 000	2 300	48 000	0.1	30	–	–	–	64 800
Oil	3 600	300	6 200	–	–	–	–	–	9 800
Natural Gas	7 300	980	20 000	–	–	–	–	–	28 000
Venting	170	1 000	21 000	0.1	30	–	–	–	22 000
Flaring	5 430	3.97	83.5	0.00	0.1	–	–	–	5 500
INDUSTRIAL PROCESSES	**35 200**	**–**	**–**	**6.66**	**2 060**	**3 900**	**2 990**	**4 060**	**48 300**
a. Mineral Production	**9 000**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**9 000**
Cement Production	6 700	–	–	–	–	–	–	–	6 700
Lime Production	2 000	–	–	–	–	–	–	–	2 000
Mineral Product Use[3]	640	–	–	–	–	–	–	–	640
b. Chemical Industry	**4 800**	**–**	**–**	**6.66**	**2 060**	**–**	**–**	**–**	**6 800**
Ammonia Production	4 800	–	–	–	–	–	–	–	4 800
Nitric Acid Production	–	–	–	2.6	810	–	–	–	810
Adipic Acid Production	–	–	–	4.04	1 250	–	–	–	1 250
c. Metal Production	**12 000**	**–**	**–**	**–**	**–**	**–**	**2 960**	**3 020**	**17 500**
Iron and Steel Production	7 110	–	–	–	–	–	–	–	7 110
Aluminium Production	4 400	–	–	–	–	–	2 960	–	7 460
SF_6 Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	2 940	2 940
d. Consumption of Halocarbons and SF_6	**–**	**–**	**–**	**–**	**–**	**3 900**	**30**	**1 000**	**5 000**
e. Other & Undifferentiated Production	**9 900**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**9 900**
SOLVENT & OTHER PRODUCT USE	**–**	**–**	**–**	**1.5**	**470**	**–**	**–**	**–**	**470**
AGRICULTURE	**–**	**1 220**	**25 700**	**82**	**25 000**	**–**	**–**	**–**	**51 000**
a. Enteric Fermentation	**–**	**1 070**	**22 500**	**–**	**–**	**–**	**–**	**–**	**22 500**
b. Manure Management	**–**	**150**	**3 100**	**16**	**5 000**	**–**	**–**	**–**	**8 100**
c. Agricultural Soils	**–**	**–**	**–**	**66**	**20 000**	**–**	**–**	**–**	**20 000**
Direct Sources	–	–	–	34	10 000	–	–	–	10 000
Pasture, Range, and Paddock Manure	–	–	–	13	4 000	–	–	–	4 000
Indirect Sources	–	–	–	20	6 000	–	–	–	6 000
WASTE	**180**	**1 300**	**27 000**	**3**	**1 000**	**–**	**–**	**–**	**28 000**
a. Solid Waste Disposal on Land	**–**	**1 300**	**27 000**	**–**	**–**	**–**	**–**	**–**	**27 000**
b. Wastewater Handling	**–**	**11**	**240**	**3**	**1 000**	**–**	**–**	**–**	**1 200**
c. Waste Incineration	**180**	**0.05**	**1**	**0.1**	**50**	**–**	**–**	**–**	**230**
LAND USE, LAND-USE CHANGE AND FORESTRY	**–9 800**	**470**	**9 800**	**20**	**6 100**	**–**	**–**	**–**	**6 100**
a. Forest Land	**–19 000**	**460**	**9 600**	**19**	**6 000**	**–**	**–**	**–**	**–3 700**
b. Cropland	**1 400**	**5**	**100**	**0.3**	**100**	**–**	**–**	**–**	**1 600**
c. Grassland	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
d. Wetlands	**1 000**	**0.1**	**2**	**0.00**	**1**	**–**	**–**	**–**	**1 000**
e. Settlements	**7 000**	**3**	**60**	**0.1**	**30**	**–**	**–**	**–**	**7 000**

Notes:

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

2 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

3 The category mineral product use includes CO_2 emissions from the use of limestone & dolomite, soda ash, and magnesite.

Totals may not add due to rounding.

TABLE A8-6: 2001 Greenhouse Gas Emissions Summary for Canada

GHG Source/Sink Categories	Greenhouse Gases								
	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	TOTAL
Global Warming Potential			21		310				
Unit	*kt*	*kt*	*kt CO_2 eq*	*kt*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*
TOTAL[1]	**560 000**	**5 100**	**110 000**	**130**	**40 000**	**3 500**	**3 490**	**4 400**	**719 000**
ENERGY	**524 000**	**3 000**	**60 000**	**40**	**10 000**	**–**	**–**	**–**	**590 000**
a. Stationary Combustion Sources	**336 000**	**200**	**5 000**	**8**	**3 000**	**–**	**–**	**–**	**343 000**
Electricity and Heat Generation	133 000	5.0	110	3	800	–	–	–	134 000
Fossil Fuel Industries	68 000	100	2 000	1	500	–	–	–	71 000
Petroleum Refining and Upgrading	26 000	0.5	10	0.4	100	–	–	–	26 000
Fossil Fuel Production	42 300	100	2 000	1	300	–	–	–	45 000
Mining	10 200	0.2	4	0.3	80	–	–	–	10 300
Manufacturing Industries	48 400	3	60	2	500	–	–	–	49 000
Iron and Steel	5 830	0.2	5	0.2	50	–	–	–	5 890
Non-Ferrous Metals	3 450	0.08	2	0.05	20	–	–	–	3 470
Chemical	6 720	0.14	2.9	0.1	40	–	–	–	6 760
Pulp and Paper	9 490	2	40	0.8	300	–	–	–	9 790
Cement	3 920	0.07	2	0.05	10	–	–	–	3 930
Other Manufacturing	19 000	0.4	8	0.4	100	–	–	–	19 100
Construction	1 000	0.02	0.4	0.02	8	–	–	–	1 010
Commercial & Institutional	33 000	0.6	10	0.7	200	–	–	–	33 200
Residential	39 400	90	2 000	2	500	–	–	–	42 000
Agriculture & Forestry	2 190	0.04	0.8	0.06	20	–	–	–	2 210
b. Transportation[2]	**172 000**	**30**	**600**	**30**	**8 000**	**–**	**–**	**–**	**180 000**
Domestic Aviation	6 000	0.4	9	0.6	200	–	–	–	6 200
Road Transportation	127 000	13	270	18	5 400	–	–	–	133 000
Light-Duty Gasoline Vehicles	46 800	4.3	90	7.0	2 200	–	–	–	49 100
Light-Duty Gasoline Trucks	36 000	4.5	95	8.8	2 700	–	–	–	38 800
Heavy-Duty Gasoline Vehicles	3 850	0.54	11	0.57	180	–	–	–	4 040
Motorcycles	234	0.19	3.9	0.00	1.4	–	–	–	239
Light-Duty Diesel Vehicles	628	0.02	0.4	0.05	10	–	–	–	642
Light-Duty Diesel Trucks	665	0.02	0.4	0.05	20	–	–	–	681
Heavy-Duty Diesel Vehicles	38 100	2	40	1	300	–	–	–	38 500
Propane & Natural Gas Vehicles	1 110	1	30	0.02	7	–	–	–	1 100
Railways	5 820	0.3	7	2	700	–	–	–	7 000
Domestic Marine	5 180	0.4	8	1	300	–	–	–	5 500
Others	28 000	20	300	6	2 000	–	–	–	30 000
Off-Road Gasoline	5 000	5	100	0.1	30	–	–	–	5 000
Off-Road Diesel	13 000	0.7	10	5	2 000	–	–	–	10 000
Pipelines	9 970	10	210	0.3	80	–	–	–	10 300
c. Fugitive Sources	**16 000**	**2 400**	**50 000**	**0.1**	**30**	**–**	**–**	**–**	**66 300**
Coal Mining	–	50	1 000	–	–	–	–	–	1 000
Oil and Natural Gas	16 000	2 300	49 000	0.1	30	–	–	–	65 300
Oil	3 530	310	6 400	–	–	–	–	–	9 900
Natural Gas	7 100	970	20 000	–	–	–	–	–	28 000
Venting	180	1 100	22 000	0.1	30	–	–	–	22 000
Flaring	5 280	3.68	77.2	0.00	0.1	–	–	–	5 400
INDUSTRIAL PROCESSES	**35 700**	**–**	**–**	**5.16**	**1 600**	**3 500**	**3 490**	**4 390**	**48 700**
a. Mineral Production	**9 000**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**9 000**
Cement Production	6 500	–	–	–	–	–	–	–	6 500
Lime Production	2 000	–	–	–	–	–	–	–	2 000
Mineral Product Use[3]	840	–	–	–	–	–	–	–	840
b. Chemical Industry	**4 800**	**–**	**–**	**5.16**	**1 600**	**–**	**–**	**–**	**6 400**
Ammonia Production	4 800	–	–	–	–	–	–	–	4 800
Nitric Acid Production	–	–	–	2.6	800	–	–	–	800
Adipic Acid Production	–	–	–	2.59	804	–	–	–	804
c. Metal Production	**11 000**	**–**	**–**	**–**	**–**	**–**	**3 460**	**2 410**	**17 400**
Iron and Steel Production	7 280	–	–	–	–	–	–	–	7 280
Aluminium Production	4 200	–	–	–	–	–	3 460	–	7 710
SF_6 Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	2 360	2 360
d. Consumption of Halocarbons and SF_6	**–**	**–**	**–**	**–**	**–**	**3 500**	**30**	**2 000**	**5 600**
e. Other & Undifferentiated Production	**10 000**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**10 000**
SOLVENT & OTHER PRODUCT USE	**–**	**–**	**–**	**1.5**	**470**	**–**	**–**	**–**	**470**
AGRICULTURE	**–**	**1 210**	**25 400**	**83**	**26 000**	**–**	**–**	**–**	**51 000**
a. Enteric Fermentation	**–**	**1 060**	**22 400**	**–**	**–**	**–**	**–**	**–**	**22 400**
b. Manure Management	**–**	**150**	**3 000**	**16**	**4 900**	**–**	**–**	**–**	**8 000**
c. Agricultural Soils	**–**	**–**	**–**	**67**	**21 000**	**–**	**–**	**–**	**21 000**
Direct Sources	–	–	–	35	11 000	–	–	–	11 000
Pasture, Range, and Paddock Manure	–	–	–	13	4 000	–	–	–	4 000
Indirect Sources	–	–	–	20	6 000	–	–	–	6 000
WASTE	**200**	**1 300**	**27 000**	**3**	**1 000**	**–**	**–**	**–**	**28 000**
a. Solid Waste Disposal on Land	**–**	**1 300**	**27 000**	**–**	**–**	**–**	**–**	**–**	**27 000**
b. Wastewater Handling	**–**	**11**	**240**	**3**	**1 000**	**–**	**–**	**–**	**1 200**
c. Waste Incineration	**200**	**0.04**	**0.9**	**0.2**	**50**	**–**	**–**	**–**	**250**
LAND USE, LAND-USE CHANGE AND FORESTRY	**–130 000**	**110**	**2 400**	**4.9**	**1 500**	**–**	**–**	**–**	**–120 000**
a. Forest Land	**–140 000**	**110**	**2 200**	**4.5**	**1 400**	**–**	**–**	**–**	**–130 000**
b. Cropland	**1 800**	**5**	**100**	**0.3**	**100**	**–**	**–**	**–**	**2 000**
c. Grassland	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
d. Wetlands	**2 000**	**0.1**	**3**	**0.01**	**2**	**–**	**–**	**–**	**2 000**
e. Settlements	**7 000**	**3**	**60**	**0.1**	**30**	**–**	**–**	**–**	**7 000**

Notes:

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

2 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

3 The category mineral product use includes CO_2 emissions from the use of limestone & dolomite, soda ash, and magnesite.

Totals may not add due to rounding.

TABLE A8-7: 2000 Greenhouse Gas Emissions Summary for Canada

GHG Source/Sink Categories	Greenhouse Gases								
	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	TOTAL
Global Warming Potential			21		310				
Unit	*kt*	*kt*	*kt CO_2 eq*	*kt*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*
TOTAL[1]	**566 000**	**5 000**	**110 000**	**130**	**41 000**	**3 000**	**4 310**	**4 300**	**725 000**
ENERGY	**530 000**	**3 000**	**50 000**	**40**	**10 000**	**–**	**–**	**–**	**596 000**
a. Stationary Combustion Sources	**340 000**	**200**	**5 000**	**8**	**3 000**	**–**	**–**	**–**	**347 000**
Electricity and Heat Generation	131 000	4.8	100	2	800	–	–	–	132 000
Fossil Fuel Industries	67 000	100	2 000	1	500	–	–	–	70 000
Petroleum Refining and Upgrading	24 000	0.5	10	0.4	100	–	–	–	24 000
Fossil Fuel Production	42 700	100	2 000	1	300	–	–	–	45 000
Mining	10 300	0.2	4	0.2	80	–	–	–	10 400
Manufacturing Industries	52 600	3	60	2	500	–	–	–	53 200
Iron and Steel	7 120	0.3	5	0.2	60	–	–	–	7 190
Non-Ferrous Metals	3 180	0.07	1	0.05	10	–	–	–	3 190
Chemical	7 820	0.16	3.3	0.1	40	–	–	–	7 860
Pulp and Paper	10 700	2	40	0.9	300	–	–	–	11 000
Cement	3 950	0.07	1	0.05	10	–	–	–	3 970
Other Manufacturing	19 800	0.4	8	0.4	100	–	–	–	20 000
Construction	1 070	0.02	0.4	0.03	8	–	–	–	1 080
Commercial & Institutional	33 000	0.6	10	0.7	200	–	–	–	33 200
Residential	42 500	90	2 000	2	500	–	–	–	45 000
Agriculture & Forestry	2 550	0.04	0.9	0.06	20	–	–	–	2 570
b. Transportation[2]	**174 000**	**30**	**700**	**30**	**9 000**	**–**	**–**	**–**	**180 000**
Domestic Aviation	6 390	0.4	9	0.6	200	–	–	–	6 600
Road Transportation	126 000	14	280	18	5 600	–	–	–	131 000
Light-Duty Gasoline Vehicles	45 900	4.5	95	7.2	2 200	–	–	–	48 300
Light-Duty Gasoline Trucks	34 700	4.6	96	9.0	2 800	–	–	–	37 600
Heavy-Duty Gasoline Vehicles	4 170	0.59	12	0.62	190	–	–	–	4 370
Motorcycles	233	0.19	3.9	0.00	1.4	–	–	–	238
Light-Duty Diesel Vehicles	591	0.02	0.3	0.04	10	–	–	–	604
Light-Duty Diesel Trucks	630	0.02	0.4	0.05	10	–	–	–	645
Heavy-Duty Diesel Vehicles	38 300	2	40	1	300	–	–	–	38 700
Propane & Natural Gas Vehicles	1 060	2	40	0.02	7	–	–	–	1 100
Railways	5 920	0.3	7	2	700	–	–	–	7 000
Domestic Marine	4 780	0.3	7	1	300	–	–	–	5 100
Others	31 000	20	400	6	2 000	–	–	–	30 000
Off-Road Gasoline	5 000	6	100	0.1	40	–	–	–	6 000
Off-Road Diesel	15 000	0.8	20	6	2 000	–	–	–	20 000
Pipelines	11 000	11	230	0.3	90	–	–	–	11 300
c. Fugitive Sources	**16 000**	**2 300**	**49 000**	**0.1**	**30**	**–**	**–**	**–**	**64 900**
Coal Mining	–	50	900	–	–	–	–	–	900
Oil and Natural Gas	16 000	2 300	48 000	0.1	30	–	–	–	64 000
Oil	3 290	290	6 100	–	–	–	–	–	9 400
Natural Gas	6 900	960	20 000	–	–	–	–	–	27 000
Venting	180	1 000	22 000	0.1	30	–	–	–	22 000
Flaring	5 420	3.81	80.0	0.00	0.1	–	–	–	5 500
INDUSTRIAL PROCESSES	**36 500**	**–**	**–**	**5.48**	**1 700**	**3 000**	**4 310**	**4 350**	**49 800**
a. Mineral Production	**9 600**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**9 600**
Cement Production	6 700	–	–	–	–	–	–	–	6 700
Lime Production	2 000	–	–	–	–	–	–	–	2 000
Mineral Product Use[3]	1 000	–	–	–	–	–	–	–	1 000
b. Chemical Industry	**5 400**	**–**	**–**	**5.48**	**1 700**	**–**	**–**	**–**	**7 100**
Ammonia Production	5 400	–	–	–	–	–	–	–	5 400
Nitric Acid Production	–	–	–	2.6	800	–	–	–	800
Adipic Acid Production	–	–	–	2.90	900	–	–	–	900
c. Metal Production	**12 000**	**–**	**–**	**–**	**–**	**–**	**4 280**	**2 820**	**18 900**
Iron and Steel Production	7 890	–	–	–	–	–	–	–	7 890
Aluminium Production	3 900	–	–	–	–	–	4 280	–	8 220
SF_6 Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	2 770	2 770
d. Consumption of Halocarbons and SF_6	**–**	**–**	**–**	**–**	**–**	**3 000**	**30**	**1 500**	**4 500**
e. Other & Undifferentiated Production	**9 700**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**9 700**
SOLVENT & OTHER PRODUCT USE	**–**	**–**	**–**	**1.5**	**460**	**–**	**–**	**–**	**460**
AGRICULTURE	**–**	**1 180**	**24 700**	**86**	**27 000**	**–**	**–**	**–**	**51 000**
a. Enteric Fermentation	**–**	**1 040**	**21 700**	**–**	**–**	**–**	**–**	**–**	**21 700**
b. Manure Management	**–**	**140**	**2 900**	**16**	**4 800**	**–**	**–**	**–**	**7 800**
c. Agricultural Soils	**–**	**–**	**–**	**70**	**22 000**	**–**	**–**	**–**	**22 000**
Direct Sources	–	–	–	37	11 000	–	–	–	11 000
Pasture, Range, and Paddock Manure	–	–	–	13	3 900	–	–	–	3 900
Indirect Sources	–	–	–	20	6 000	–	–	–	6 000
WASTE	**200**	**1 300**	**27 000**	**3**	**1 000**	**–**	**–**	**–**	**28 000**
a. Solid Waste Disposal on Land	**–**	**1 300**	**27 000**	**–**	**–**	**–**	**–**	**–**	**27 000**
b. Wastewater Handling	**–**	**11**	**240**	**3**	**1 000**	**–**	**–**	**–**	**1 200**
c. Waste Incineration	**200**	**0.04**	**0.8**	**0.2**	**50**	**–**	**–**	**–**	**250**
LAND USE, LAND-USE CHANGE AND FORESTRY	**–130 000**	**67**	**1 400**	**2.9**	**900**	**–**	**–**	**–**	**–130 000**
a. Forest Land	**–150 000**	**59**	**1 200**	**2.5**	**770**	**–**	**–**	**–**	**–140 000**
b. Cropland	**2 900**	**5**	**100**	**0.3**	**100**	**–**	**–**	**–**	**3 100**
c. Grassland	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
d. Wetlands	**2 000**	**0.1**	**3**	**0.01**	**2**	**–**	**–**	**–**	**2 000**
e. Settlements	**7 000**	**2**	**50**	**0.1**	**30**	**–**	**–**	**–**	**7 000**

Notes:

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

2 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

3 The category mineral product use includes CO_2 emissions from the use of limestone & dolomite, soda ash, and magnesite.

Totals may not add due to rounding.

TABLE A8-8: 1999 Greenhouse Gas Emissions Summary for Canada

GHG Source/Sink Categories	Greenhouse Gases								
	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	TOTAL
Global Warming Potential			21		310				
Unit	*kt*	*kt*	*kt CO_2 eq*	*kt*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*
TOTAL[1]	**542 000**	**4 900**	**100 000**	**140**	**42 000**	**2 500**	**4 640**	**3 800**	**698 000**
ENERGY	**506 000**	**2 000**	**50 000**	**40**	**10 000**	**–**	**–**	**–**	**569 000**
a. Stationary Combustion Sources	**318 000**	**200**	**5 000**	**8**	**2 000**	**–**	**–**	**–**	**325 000**
Electricity and Heat Generation	121 000	3.9	81	2	700	–	–	–	121 000
Fossil Fuel Industries	65 000	100	2 000	1	400	–	–	–	68 000
Petroleum Refining and Upgrading	23 000	0.4	9	0.4	100	–	–	–	23 000
Fossil Fuel Production	41 600	100	2 000	1	300	–	–	–	44 000
Mining	7 390	0.1	3	0.2	50	–	–	–	7 450
Manufacturing Industries	52 400	3	60	2	500	–	–	–	52 900
Iron and Steel	7 210	0.3	6	0.2	60	–	–	–	7 280
Non-Ferrous Metals	3 240	0.06	1	0.05	10	–	–	–	3 260
Chemical	8 410	0.18	3.7	0.1	50	–	–	–	8 460
Pulp and Paper	10 800	2	40	0.9	300	–	–	–	11 100
Cement	3 970	0.07	2	0.05	10	–	–	–	3 990
Other Manufacturing	18 700	0.4	8	0.3	100	–	–	–	18 800
Construction	1 160	0.02	0.4	0.03	10	–	–	–	1 170
Commercial & Institutional	28 700	0.5	10	0.6	200	–	–	–	28 900
Residential	40 500	90	2 000	2	500	–	–	–	43 000
Agriculture & Forestry	2 670	0.04	0.8	0.06	20	–	–	–	2 690
b. Transportation[2]	**172 000**	**30**	**700**	**30**	**9 000**	**–**	**–**	**–**	**180 000**
Domestic Aviation	6 400	0.4	9	0.6	200	–	–	–	6 600
Road Transportation	125 000	14	300	19	5 900	–	–	–	131 000
Light-Duty Gasoline Vehicles	47 200	5.1	110	7.8	2 400	–	–	–	49 800
Light-Duty Gasoline Trucks	33 700	4.7	99	9.3	2 900	–	–	–	36 700
Heavy-Duty Gasoline Vehicles	4 010	0.56	12	0.60	190	–	–	–	4 210
Motorcycles	228	0.18	3.9	0.00	1.4	–	–	–	233
Light-Duty Diesel Vehicles	591	0.02	0.3	0.04	10	–	–	–	605
Light-Duty Diesel Trucks	489	0.01	0.3	0.04	10	–	–	–	500
Heavy-Duty Diesel Vehicles	36 900	2	40	1	300	–	–	–	37 300
Propane & Natural Gas Vehicles	1 450	2	40	0.03	9	–	–	–	1 500
Railways	5 780	0.3	7	2	700	–	–	–	7 000
Domestic Marine	4 650	0.3	7	1	300	–	–	–	5 000
Others	31 000	20	400	6	2 000	–	–	–	30 000
Off-Road Gasoline	5 000	6	100	0.1	30	–	–	–	5 000
Off-Road Diesel	13 000	0.7	10	5	2 000	–	–	–	20 000
Pipelines	12 200	12	260	0.3	100	–	–	–	12 600
c. Fugitive Sources	**15 000**	**2 200**	**47 000**	**0.1**	**30**	**–**	**–**	**–**	**62 000**
Coal Mining	–	50	1 000	–	–	–	–	–	1 000
Oil and Natural Gas	15 000	2 200	46 000	0.1	30	–	–	–	60 900
Oil	2 860	290	6 000	–	–	–	–	–	8 900
Natural Gas	6 800	930	19 000	–	–	–	–	–	26 000
Venting	180	960	20 000	0.1	30	–	–	–	20 000
Flaring	5 310	3.53	74.2	0.00	0.1	–	–	–	5 400
INDUSTRIAL PROCESSES	**36 400**	**–**	**–**	**8.18**	**2 530**	**2 500**	**4 640**	**3 750**	**49 800**
a. Mineral Production	**9 500**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**9 500**
Cement Production	6 600	–	–	–	–	–	–	–	6 600
Lime Production	2 000	–	–	–	–	–	–	–	2 000
Mineral Product Use[3]	910	–	–	–	–	–	–	–	910
b. Chemical Industry	**5 400**	**–**	**–**	**8.18**	**2 530**	**–**	**–**	**–**	**8 000**
Ammonia Production	5 400	–	–	–	–	–	–	–	5 400
Nitric Acid Production	–	–	–	2.5	790	–	–	–	790
Adipic Acid Production	–	–	–	5.64	1 750	–	–	–	1 750
c. Metal Production	**12 000**	**–**	**–**	**–**	**–**	**–**	**4 620**	**2 280**	**18 700**
Iron and Steel Production	7 890	–	–	–	–	–	–	–	7 890
Aluminium Production	3 900	–	–	–	–	–	4 620	–	8 620
SF_6 Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	2 230	2 230
d. Consumption of Halocarbons and SF_6	**–**	**–**	**–**	**–**	**–**	**2 500**	**22**	**1 500**	**4 000**
e. Other & Undifferentiated Production	**9 600**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**9 600**
SOLVENT & OTHER PRODUCT USE	**–**	**–**	**–**	**1.5**	**460**	**–**	**–**	**–**	**460**
AGRICULTURE	**–**	**1 160**	**24 400**	**86**	**27 000**	**–**	**–**	**–**	**51 000**
a. Enteric Fermentation	**–**	**1 020**	**21 500**	**–**	**–**	**–**	**–**	**–**	**21 500**
b. Manure Management	**–**	**140**	**2 900**	**15**	**4 800**	**–**	**–**	**–**	**7 600**
c. Agricultural Soils	**–**	**–**	**–**	**71**	**22 000**	**–**	**–**	**–**	**22 000**
Direct Sources	–	–	–	38	12 000	–	–	–	12 000
Pasture, Range, and Paddock Manure	–	–	–	12	3 800	–	–	–	3 800
Indirect Sources	–	–	–	20	6 000	–	–	–	6 000
WASTE	**200**	**1 300**	**27 000**	**3**	**1 000**	**–**	**–**	**–**	**28 000**
a. Solid Waste Disposal on Land	**–**	**1 300**	**26 000**	**–**	**–**	**–**	**–**	**–**	**26 000**
b. Wastewater Handling	**–**	**13**	**270**	**3**	**1 000**	**–**	**–**	**–**	**1 200**
c. Waste Incineration	**200**	**0.04**	**0.7**	**0.1**	**50**	**–**	**–**	**–**	**240**
LAND USE, LAND-USE CHANGE AND FORESTRY	**–55 000**	**300**	**6 300**	**13**	**3 900**	**–**	**–**	**–**	**–45 000**
a. Forest Land	**–68 000**	**290**	**6 100**	**12**	**3 800**	**–**	**–**	**–**	**–59 000**
b. Cropland	**4 000**	**6**	**100**	**0.3**	**100**	**–**	**–**	**–**	**4 200**
c. Grassland	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
d. Wetlands	**2 000**	**0.2**	**3**	**0.01**	**2**	**–**	**–**	**–**	**2 000**
e. Settlements	**7 000**	**2**	**50**	**0.1**	**30**	**–**	**–**	**–**	**7 000**

Notes:

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

2 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

3 The category mineral product use includes CO_2 emissions from the use of limestone & dolomite, soda ash, and magnesite.

Totals may not add due to rounding.

TABLE A8-9: 1998 Greenhouse Gas Emissions Summary for Canada

GHG Source/Sink Categories	Greenhouse Gases								
	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	TOTAL
Global Warming Potential			21		310				
Unit	*kt*	*kt*	*kt CO_2 eq*	*kt*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*
TOTAL[1]	**527 000**	**4 900**	**100 000**	**140**	**45 000**	**1 900**	**5 600**	**3 700**	**686 000**
ENERGY	**491 000**	**3 000**	**50 000**	**40**	**10 000**	**–**	**–**	**–**	**555 000**
a. Stationary Combustion Sources	**306 000**	**200**	**4 000**	**8**	**2 000**	**–**	**–**	**–**	**313 000**
Electricity and Heat Generation	123 000	3.9	82	2	700	–	–	–	124 000
Fossil Fuel Industries	54 000	90	2 000	1	400	–	–	–	57 000
Petroleum Refining and Upgrading	21 000	0.4	9	0.4	100	–	–	–	21 000
Fossil Fuel Production	33 100	90	2 000	0.8	300	–	–	–	35 000
Mining	7 960	0.2	3	0.2	60	–	–	–	8 020
Manufacturing Industries	52 000	3	60	2	500	–	–	–	52 600
Iron and Steel	6 940	0.3	5	0.2	60	–	–	–	7 000
Non-Ferrous Metals	3 390	0.07	1	0.05	20	–	–	–	3 410
Chemical	8 520	0.18	3.7	0.2	50	–	–	–	8 570
Pulp and Paper	10 900	2	40	0.8	300	–	–	–	11 100
Cement	3 270	0.07	1	0.04	10	–	–	–	3 290
Other Manufacturing	19 100	0.4	8	0.3	100	–	–	–	19 200
Construction	1 110	0.02	0.4	0.03	10	–	–	–	1 120
Commercial & Institutional	27 000	0.5	10	0.6	200	–	–	–	27 200
Residential	38 400	90	2 000	2	500	–	–	–	41 000
Agriculture & Forestry	2 590	0.04	0.8	0.06	20	–	–	–	2 610
b. Transportation[2]	**168 000**	**40**	**700**	**30**	**9 000**	**–**	**–**	**–**	**180 000**
Domestic Aviation	6 300	0.4	9	0.6	200	–	–	–	6 500
Road Transportation	120 000	15	310	19	5 800	–	–	–	127 000
Light-Duty Gasoline Vehicles	47 100	5.5	120	8.1	2 500	–	–	–	49 700
Light-Duty Gasoline Trucks	29 900	4.5	94	8.8	2 700	–	–	–	32 800
Heavy-Duty Gasoline Vehicles	5 240	0.74	15	0.78	240	–	–	–	5 500
Motorcycles	227	0.18	3.8	0.00	1.4	–	–	–	232
Light-Duty Diesel Vehicles	583	0.02	0.3	0.04	10	–	–	–	597
Light-Duty Diesel Trucks	444	0.01	0.3	0.03	10	–	–	–	454
Heavy-Duty Diesel Vehicles	35 200	2	40	1	300	–	–	–	35 500
Propane & Natural Gas Vehicles	1 730	2	40	0.03	10	–	–	–	1 800
Railways	5 460	0.3	6	2	700	–	–	–	6 000
Domestic Marine	4 830	0.4	8	1	300	–	–	–	5 100
Others	31 000	20	400	6	2 000	–	–	–	30 000
Off-Road Gasoline	6 000	7	100	0.1	40	–	–	–	6 000
Off-Road Diesel	13 000	0.7	10	5	2 000	–	–	–	10 000
Pipelines	12 100	12	260	0.3	100	–	–	–	12 500
c. Fugitive Sources	**17 000**	**2 300**	**48 000**	**0.1**	**30**	**–**	**–**	**–**	**64 800**
Coal Mining	–	60	1 000	–	–	–	–	–	1 000
Oil and Natural Gas	17 000	2 200	46 000	0.1	30	–	–	–	63 400
Oil	3 060	290	6 000	–	–	–	–	–	9 100
Natural Gas	6 700	940	20 000	–	–	–	–	–	27 000
Venting	180	970	20 000	0.1	30	–	–	–	21 000
Flaring	7 080	4.57	96.1	0.00	0.1	–	–	–	7 200
INDUSTRIAL PROCESSES	**35 400**	**–**	**–**	**18.8**	**5 840**	**1 900**	**5 600**	**3 710**	**52 500**
a. Mineral Production	**9 100**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**9 100**
Cement Production	6 400	–	–	–	–	–	–	–	6 400
Lime Production	2 000	–	–	–	–	–	–	–	2 000
Mineral Product Use[3]	930	–	–	–	–	–	–	–	930
b. Chemical Industry	**5 300**	**–**	**–**	**18.8**	**5 840**	**–**	**–**	**–**	**11 000**
Ammonia Production	5 300	–	–	–	–	–	–	–	5 300
Nitric Acid Production	–	–	–	2.5	770	–	–	–	770
Adipic Acid Production	–	–	–	16.3	5 070	–	–	–	5 070
c. Metal Production	**12 000**	**–**	**–**	**–**	**–**	**–**	**5 580**	**2 220**	**19 500**
Iron and Steel Production	7 690	–	–	–	–	–	–	–	7 690
Aluminium Production	4 000	–	–	–	–	–	5 580	–	9 610
SF_6 Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	2 170	2 170
d. Consumption of Halocarbons and SF_6	**–**	**–**	**–**	**–**	**–**	**1 900**	**18**	**1 500**	**3 400**
e. Other & Undifferentiated Production	**9 300**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**9 300**
SOLVENT & OTHER PRODUCT USE	**–**	**–**	**–**	**1.5**	**450**	**–**	**–**	**–**	**450**
AGRICULTURE	**–**	**1 160**	**24 400**	**85**	**26 000**	**–**	**–**	**–**	**51 000**
a. Enteric Fermentation	**–**	**1 030**	**21 600**	**–**	**–**	**–**	**–**	**–**	**21 600**
b. Manure Management	**–**	**140**	**2 900**	**15**	**4 700**	**–**	**–**	**–**	**7 600**
c. Agricultural Soils	**–**	**–**	**–**	**70**	**22 000**	**–**	**–**	**–**	**22 000**
Direct Sources	–	–	–	37	12 000	–	–	–	12 000
Pasture, Range, and Paddock Manure	–	–	–	12	3 800	–	–	–	3 800
Indirect Sources	–	–	–	20	6 000	–	–	–	6 000
WASTE	**200**	**1 300**	**26 000**	**3**	**1 000**	**–**	**–**	**–**	**28 000**
a. Solid Waste Disposal on Land	**–**	**1 200**	**26 000**	**–**	**–**	**–**	**–**	**–**	**26 000**
b. Wastewater Handling	**–**	**11**	**220**	**3**	**900**	**–**	**–**	**–**	**1 200**
c. Waste Incineration	**200**	**0.03**	**0.6**	**0.2**	**50**	**–**	**–**	**–**	**250**
LAND USE, LAND-USE CHANGE AND FORESTRY	**64 000**	**740**	**16 000**	**31**	**9 700**	**–**	**–**	**–**	**89 000**
a. Forest Land	**50 000**	**730**	**15 000**	**31**	**9 600**	**–**	**–**	**–**	**75 000**
b. Cropland	**4 800**	**5**	**100**	**0.3**	**100**	**–**	**–**	**–**	**5 100**
c. Grassland	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
d. Wetlands	**2 000**	**0.1**	**3**	**0.01**	**1**	**–**	**–**	**–**	**2 000**
e. Settlements	**7 000**	**3**	**60**	**0.1**	**30**	**–**	**–**	**–**	**7 000**

Notes:

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

2 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

3 The category mineral product use includes CO_2 emissions from the use of limestone & dolomite, soda ash, and magnesite.

Totals may not add due to rounding.

TABLE A8-10: 1997 Greenhouse Gas Emissions Summary for Canada

GHG Source/Sink Categories	Greenhouse Gases								
	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	TOTAL
Global Warming Potential			21		310				
Unit	*kt*	*kt*	*kt CO_2 eq*	*kt*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*
TOTAL[1]	**519 000**	**4 900**	**100 000**	**160**	**49 000**	**1 400**	**5 460**	**3 000**	**680 000**
ENERGY	**482 000**	**2 000**	**50 000**	**40**	**10 000**	**–**	**–**	**–**	**545 000**
a. Stationary Combustion Sources	**303 000**	**200**	**4 000**	**7**	**2 000**	**–**	**–**	**–**	**309 000**
Electricity and Heat Generation	111 000	3.2	67	2	600	–	–	–	111 000
Fossil Fuel Industries	51 000	80	2 000	1	300	–	–	–	53 000
Petroleum Refining and Upgrading	23 000	0.4	9	0.3	100	–	–	–	23 000
Fossil Fuel Production	28 000	80	2 000	0.7	200	–	–	–	30 000
Mining	8 900	0.2	4	0.2	60	–	–	–	8 970
Manufacturing Industries	54 200	3	60	2	500	–	–	–	54 800
Iron and Steel	7 230	0.3	5	0.2	60	–	–	–	7 300
Non-Ferrous Metals	3 170	0.06	1	0.05	10	–	–	–	3 180
Chemical	8 830	0.18	3.9	0.2	50	–	–	–	8 890
Pulp and Paper	11 700	2	40	0.9	300	–	–	–	12 000
Cement	3 230	0.06	1	0.04	10	–	–	–	3 250
Other Manufacturing	20 000	0.4	8	0.4	100	–	–	–	20 100
Construction	1 250	0.02	0.4	0.03	10	–	–	–	1 260
Commercial & Institutional	29 800	0.5	10	0.6	200	–	–	–	30 000
Residential	43 800	90	2 000	2	500	–	–	–	46 000
Agriculture & Forestry	2 920	0.04	0.9	0.07	20	–	–	–	2 940
b. Transportation[2]	**164 000**	**30**	**700**	**30**	**9 000**	**–**	**–**	**–**	**170 000**
Domestic Aviation	6 160	0.4	9	0.6	200	–	–	–	6 400
Road Transportation	120 000	15	320	19	5 900	–	–	–	126 000
Light-Duty Gasoline Vehicles	47 400	6.0	130	8.4	2 600	–	–	–	50 100
Light-Duty Gasoline Trucks	29 100	4.6	97	8.9	2 800	–	–	–	31 900
Heavy-Duty Gasoline Vehicles	4 820	0.68	14	0.72	220	–	–	–	5 050
Motorcycles	216	0.17	3.6	0.00	1.3	–	–	–	220
Light-Duty Diesel Vehicles	586	0.02	0.3	0.04	10	–	–	–	600
Light-Duty Diesel Trucks	494	0.01	0.3	0.04	10	–	–	–	505
Heavy-Duty Diesel Vehicles	35 200	2	40	1	300	–	–	–	35 500
Propane & Natural Gas Vehicles	1 790	2	40	0.04	10	–	–	–	1 800
Railways	5 660	0.3	7	2	700	–	–	–	6 000
Domestic Marine	4 220	0.3	6	1	300	–	–	–	4 500
Others	29 000	20	400	5	2 000	–	–	–	30 000
Off-Road Gasoline	4 000	5	100	0.09	30	–	–	–	4 000
Off-Road Diesel	13 000	0.6	10	5	2 000	–	–	–	10 000
Pipelines	12 200	12	260	0.3	100	–	–	–	12 600
c. Fugitive Sources	**15 000**	**2 200**	**47 000**	**0.1**	**30**	**–**	**–**	**–**	**62 400**
Coal Mining	–	80	2 000	–	–	–	–	–	2 000
Oil and Natural Gas	15 000	2 200	45 000	0.1	30	–	–	–	60 700
Oil	3 150	290	6 100	–	–	–	–	–	9 300
Natural Gas	6 400	870	18 000	–	–	–	–	–	25 000
Venting	190	990	21 000	0.1	30	–	–	–	21 000
Flaring	5 500	3.57	74.9	0.00	0.0	–	–	–	5 600
INDUSTRIAL PROCESSES	**35 900**	**–**	**–**	**34.4**	**10 700**	**1 400**	**5 460**	**3 040**	**56 500**
a. Mineral Production	**9 000**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**9 000**
Cement Production	6 200	–	–	–	–	–	–	–	6 200
Lime Production	2 000	–	–	–	–	–	–	–	2 000
Mineral Product Use[3]	930	–	–	–	–	–	–	–	930
b. Chemical Industry	**5 300**	**–**	**–**	**34.4**	**10 700**	**–**	**–**	**–**	**16 000**
Ammonia Production	5 300	–	–	–	–	–	–	–	5 300
Nitric Acid Production	–	–	–	2.5	790	–	–	–	790
Adipic Acid Production	–	–	–	31.9	9 890	–	–	–	9 890
c. Metal Production	**11 000**	**–**	**–**	**–**	**–**	**–**	**5 440**	**1 710**	**18 600**
Iron and Steel Production	7 550	–	–	–	–	–	–	–	7 550
Aluminium Production	3 900	–	–	–	–	–	5 440	–	9 430
SF_6 Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	1 660	1 660
d. Consumption of Halocarbons and SF_6	**–**	**–**	**–**	**–**	**–**	**1 400**	**18**	**1 300**	**2 800**
e. Other & Undifferentiated Production	**10 000**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**10 000**
SOLVENT & OTHER PRODUCT USE	**–**	**–**	**–**	**1.5**	**450**	**–**	**–**	**–**	**450**
AGRICULTURE	**–**	**1 170**	**24 500**	**84**	**26 000**	**–**	**–**	**–**	**51 000**
a. Enteric Fermentation	**–**	**1 030**	**21 700**	**–**	**–**	**–**	**–**	**–**	**21 700**
b. Manure Management	**–**	**130**	**2 800**	**15**	**4 700**	**–**	**–**	**–**	**7 600**
c. Agricultural Soils	**–**	**–**	**–**	**69**	**21 000**	**–**	**–**	**–**	**21 000**
Direct Sources	–	–	–	37	11 000	–	–	–	11 000
Pasture, Range, and Paddock Manure	–	–	–	12	3 800	–	–	–	3 800
Indirect Sources	–	–	–	20	6 000	–	–	–	6 000
WASTE	**210**	**1 200**	**26 000**	**3**	**1 000**	**–**	**–**	**–**	**27 000**
a. Solid Waste Disposal on Land	**–**	**1 200**	**26 000**	**–**	**–**	**–**	**–**	**–**	**26 000**
b. Wastewater Handling	**–**	**11**	**220**	**3**	**900**	**–**	**–**	**–**	**1 200**
c. Waste Incineration	**210**	**0.02**	**0.5**	**0.2**	**50**	**–**	**–**	**–**	**250**
LAND USE, LAND-USE CHANGE AND FORESTRY	**–130 000**	**71**	**1 500**	**3.1**	**950**	**–**	**–**	**–**	**–130 000**
a. Forest Land	**–140 000**	**63**	**1 300**	**2.6**	**820**	**–**	**–**	**–**	**–140 000**
b. Cropland	**5 500**	**5**	**100**	**0.3**	**100**	**–**	**–**	**–**	**5 700**
c. Grassland	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
d. Wetlands	**2 000**	**0.1**	**3**	**0.00**	**1**	**–**	**–**	**–**	**2 000**
e. Settlements	**8 000**	**3**	**60**	**0.1**	**30**	**–**	**–**	**–**	**8 000**

Notes:

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

2 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

3 The category mineral product use includes CO_2 emissions from the use of limestone & dolomite, soda ash, and magnesite.

Totals may not add due to rounding.

TABLE A8-11: 1996 Greenhouse Gas Emissions Summary for Canada

GHG Source/Sink Categories	Greenhouse Gases								
	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	TOTAL
Global Warming Potential			21		310				
Unit	*kt*	*kt*	*kt CO_2 eq*	*kt*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*
TOTAL[1]	**506 000**	**4 800**	**100 000**	**160**	**51 000**	**870**	**5 540**	**2 800**	**667 000**
ENERGY	**471 000**	**2 000**	**50 000**	**40**	**10 000**	**–**	**–**	**–**	**532 000**
a. Stationary Combustion Sources	**297 000**	**200**	**4 000**	**7**	**2 000**	**–**	**–**	**–**	**304 000**
Electricity and Heat Generation	99 000	2.6	55	2	600	–	–	–	99 700
Fossil Fuel Industries	55 000	80	2 000	1	400	–	–	–	57 000
Petroleum Refining and Upgrading	24 000	0.5	10	0.5	100	–	–	–	25 000
Fossil Fuel Production	30 200	80	2 000	0.8	200	–	–	–	32 000
Mining	8 680	0.2	4	0.2	60	–	–	–	8 740
Manufacturing Industries	54 300	3	60	2	500	–	–	–	54 800
Iron and Steel	7 260	0.3	5	0.2	60	–	–	–	7 330
Non-Ferrous Metals	3 490	0.07	1	0.05	20	–	–	–	3 500
Chemical	8 740	0.18	3.8	0.2	50	–	–	–	8 800
Pulp and Paper	11 900	2	40	0.8	300	–	–	–	12 200
Cement	3 250	0.07	1	0.04	10	–	–	–	3 270
Other Manufacturing	19 600	0.4	8	0.3	100	–	–	–	19 700
Construction	1 260	0.02	0.4	0.03	10	–	–	–	1 270
Commercial & Institutional	29 400	0.5	10	0.6	200	–	–	–	29 600
Residential	47 100	90	2 000	2	500	–	–	–	50 000
Agriculture & Forestry	2 930	0.04	0.9	0.07	20	–	–	–	2 950
b. Transportation[2]	**158 000**	**30**	**700**	**30**	**9 000**	**–**	**–**	**–**	**170 000**
Domestic Aviation	5 960	0.4	9	0.6	200	–	–	–	6 200
Road Transportation	114 000	15	320	19	5 800	–	–	–	120 000
Light-Duty Gasoline Vehicles	47 200	6.5	140	8.5	2 600	–	–	–	49 900
Light-Duty Gasoline Trucks	27 100	4.6	96	8.6	2 700	–	–	–	29 900
Heavy-Duty Gasoline Vehicles	4 760	0.67	14	0.71	220	–	–	–	4 990
Motorcycles	205	0.16	3.5	0.00	1.2	–	–	–	210
Light-Duty Diesel Vehicles	589	0.02	0.3	0.04	10	–	–	–	603
Light-Duty Diesel Trucks	393	0.01	0.2	0.03	9	–	–	–	402
Heavy-Duty Diesel Vehicles	32 100	2	30	1	300	–	–	–	32 500
Propane & Natural Gas Vehicles	1 930	2	40	0.04	10	–	–	–	2 000
Railways	5 580	0.3	6	2	700	–	–	–	6 000
Domestic Marine	4 160	0.3	6	1	300	–	–	–	4 500
Others	28 000	20	400	5	2 000	–	–	–	30 000
Off-Road Gasoline	5 000	5	100	0.1	30	–	–	–	5 000
Off-Road Diesel	12 000	0.6	10	5	1 000	–	–	–	10 000
Pipelines	12 200	12	250	0.3	100	–	–	–	12 500
c. Fugitive Sources	**15 000**	**2 200**	**46 000**	**0.1**	**30**	**–**	**–**	**–**	**61 000**
Coal Mining	–	80	2 000	–	–	–	–	–	2 000
Oil and Natural Gas	15 000	2 100	44 000	0.1	30	–	–	–	59 200
Oil	3 110	280	5 800	–	–	–	–	–	9 000
Natural Gas	6 400	890	19 000	–	–	–	–	–	25 000
Venting	180	910	19 000	0.1	30	–	–	–	19 000
Flaring	5 670	3.51	73.6	0.00	0.0	–	–	–	5 700
INDUSTRIAL PROCESSES	**35 100**	**–**	**–**	**39.6**	**12 300**	**870**	**5 540**	**2 790**	**56 500**
a. Mineral Production	**8 400**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**8 400**
Cement Production	5 800	–	–	–	–	–	–	–	5 800
Lime Production	2 000	–	–	–	–	–	–	–	2 000
Mineral Product Use[3]	880	–	–	–	–	–	–	–	880
b. Chemical Industry	**5 400**	**–**	**–**	**39.6**	**12 300**	**–**	**–**	**–**	**18 000**
Ammonia Production	5 400	–	–	–	–	–	–	–	5 400
Nitric Acid Production	–	–	–	2.6	790	–	–	–	790
Adipic Acid Production	–	–	–	37.0	11 500	–	–	–	11 500
c. Metal Production	**12 000**	**–**	**–**	**–**	**–**	**–**	**5 520**	**1 680**	**18 800**
Iron and Steel Production	7 740	–	–	–	–	–	–	–	7 740
Aluminium Production	3 900	–	–	–	–	–	5 520	–	9 440
SF_6 Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	1 620	1 620
d. Consumption of Halocarbons and SF_6	**–**	**–**	**–**	**–**	**–**	**870**	**21**	**1 100**	**2 000**
e. Other & Undifferentiated Production	**9 600**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**9 600**
SOLVENT & OTHER PRODUCT USE	**–**	**–**	**–**	**1.4**	**450**	**–**	**–**	**–**	**450**
AGRICULTURE	**–**	**1 170**	**24 500**	**85**	**26 000**	**–**	**–**	**–**	**51 000**
a. Enteric Fermentation	**–**	**1 030**	**21 700**	**–**	**–**	**–**	**–**	**–**	**21 700**
b. Manure Management	**–**	**130**	**2 800**	**15**	**4 700**	**–**	**–**	**–**	**7 500**
c. Agricultural Soils	**–**	**–**	**–**	**69**	**22 000**	**–**	**–**	**–**	**22 000**
Direct Sources	–	–	–	37	11 000	–	–	–	11 000
Pasture, Range, and Paddock Manure	–	–	–	12	3 800	–	–	–	3 800
Indirect Sources	–	–	–	20	6 000	–	–	–	6 000
WASTE	**210**	**1 200**	**25 000**	**3**	**1 000**	**–**	**–**	**–**	**26 000**
a. Solid Waste Disposal on Land	**–**	**1 200**	**25 000**	**–**	**–**	**–**	**–**	**–**	**25 000**
b. Wastewater Handling	**–**	**12**	**240**	**3**	**900**	**–**	**–**	**–**	**1 200**
c. Waste Incineration	**210**	**0.3**	**7**	**0.3**	**100**	**–**	**–**	**–**	**310**
LAND USE, LAND-USE CHANGE AND FORESTRY	**–85 000**	**220**	**4 600**	**9.3**	**2 900**	**–**	**–**	**–**	**–78 000**
a. Forest Land	**–100 000**	**210**	**4 400**	**8.8**	**2 700**	**–**	**–**	**–**	**–94 000**
b. Cropland	**5 900**	**5**	**100**	**0.3**	**100**	**–**	**–**	**–**	**6 100**
c. Grassland	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
d. Wetlands	**2 000**	**0.1**	**2**	**0.00**	**1**	**–**	**–**	**–**	**2 000**
e. Settlements	**7 000**	**3**	**70**	**0.1**	**40**	**–**	**–**	**–**	**8 000**

Notes:

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

2 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

3 The category mineral product use includes CO_2 emissions from the use of limestone & dolomite, soda ash, and magnesite.

Totals may not add due to rounding.

TABLE A8-12: 1995 Greenhouse Gas Emissions Summary for Canada

GHG Source/Sink Categories	Greenhouse Gases								
	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	TOTAL
Global Warming Potential			21		310				
Unit	*kt*	*kt*	*kt CO_2 eq*	*kt*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*
TOTAL[1]	**493 000**	**4 600**	**96 000**	**160**	**49 000**	**480**	**5 490**	**3 700**	**649 000**
ENERGY	**459 000**	**2 000**	**50 000**	**40**	**10 000**	**–**	**–**	**–**	**517 000**
a. Stationary Combustion Sources	**290 000**	**200**	**4 000**	**7**	**2 000**	**–**	**–**	**–**	**296 000**
Electricity and Heat Generation	100 000	3.0	63	2	600	–	–	–	101 000
Fossil Fuel Industries	54 000	80	2 000	1	400	–	–	–	56 000
Petroleum Refining and Upgrading	24 000	0.5	10	0.5	100	–	–	–	25 000
Fossil Fuel Production	29 600	80	2 000	0.8	200	–	–	–	32 000
Mining	7 800	0.2	3	0.2	60	–	–	–	7 860
Manufacturing Industries	52 500	3	60	2	500	–	–	–	53 100
Iron and Steel	6 980	0.3	5	0.2	60	–	–	–	7 040
Non-Ferrous Metals	3 090	0.06	1	0.04	10	–	–	–	3 110
Chemical	8 410	0.17	3.6	0.1	50	–	–	–	8 460
Pulp and Paper	11 400	2	40	0.8	300	–	–	–	11 700
Cement	3 400	0.07	1	0.05	10	–	–	–	3 420
Other Manufacturing	19 300	0.4	8	0.3	100	–	–	–	19 400
Construction	1 170	0.02	0.4	0.03	10	–	–	–	1 180
Commercial & Institutional	28 800	0.5	10	0.6	200	–	–	–	29 000
Residential	42 400	100	2 000	2	500	–	–	–	45 000
Agriculture & Forestry	2 770	0.04	0.9	0.07	20	–	–	–	2 790
b. Transportation[2]	**155 000**	**30**	**700**	**30**	**9 000**	**–**	**–**	**–**	**160 000**
Domestic Aviation	5 750	0.4	9	0.6	200	–	–	–	5 900
Road Transportation	112 000	16	340	19	5 900	–	–	–	119 000
Light-Duty Gasoline Vehicles	48 400	7.1	150	9.0	2 800	–	–	–	51 400
Light-Duty Gasoline Trucks	25 700	4.5	95	8.4	2 600	–	–	–	28 400
Heavy-Duty Gasoline Vehicles	4 540	0.64	13	0.67	210	–	–	–	4 760
Motorcycles	210	0.17	3.5	0.00	1.3	–	–	–	214
Light-Duty Diesel Vehicles	581	0.02	0.3	0.04	10	–	–	–	594
Light-Duty Diesel Trucks	407	0.01	0.2	0.03	9	–	–	–	417
Heavy-Duty Diesel Vehicles	30 500	1	30	1	300	–	–	–	30 800
Propane & Natural Gas Vehicles	2 050	2	40	0.04	10	–	–	–	2 100
Railways	5 710	0.3	7	2	700	–	–	–	6 000
Domestic Marine	4 060	0.3	6	1	300	–	–	–	4 400
Others	27 000	20	300	5	2 000	–	–	–	30 000
Off-Road Gasoline	4 000	4	90	0.08	30	–	–	–	4 000
Off-Road Diesel	11 000	0.6	10	5	1 000	–	–	–	10 000
Pipelines	11 700	12	240	0.3	100	–	–	–	12 000
c. Fugitive Sources	**14 000**	**2 000**	**43 000**	**0.1**	**30**	**–**	**–**	**–**	**57 000**
Coal Mining	–	80	2 000	–	–	–	–	–	2 000
Oil and Natural Gas	14 000	1 900	41 000	0.1	30	–	–	–	55 300
Oil	2 730	270	5 700	–	–	–	–	–	8 400
Natural Gas	6 200	820	17 000	–	–	–	–	–	23 000
Venting	170	860	18 000	0.1	30	–	–	–	18 000
Flaring	5 330	3.29	69.1	0.00	0.0	–	–	–	5 400
INDUSTRIAL PROCESSES	**34 300**	**–**	**–**	**37.1**	**11 500**	**480**	**5 490**	**3 730**	**55 500**
a. Mineral Production	**8 800**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**8 800**
Cement Production	6 100	–	–	–	–	–	–	–	6 100
Lime Production	2 000	–	–	–	–	–	–	–	2 000
Mineral Product Use[3]	880	–	–	–	–	–	–	–	880
b. Chemical Industry	**5 300**	**–**	**–**	**37.1**	**11 500**	**–**	**–**	**–**	**17 000**
Ammonia Production	5 300	–	–	–	–	–	–	–	5 300
Nitric Acid Production	–	–	–	2.5	780	–	–	–	780
Adipic Acid Production	–	–	–	34.6	10 700	–	–	–	10 700
c. Metal Production	**12 000**	**–**	**–**	**–**	**–**	**–**	**5 460**	**2 170**	**19 200**
Iron and Steel Production	7 880	–	–	–	–	–	–	–	7 880
Aluminium Production	3 600	–	–	–	–	–	5 460	–	9 160
SF_6 Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	2 110	2 110
d. Consumption of Halocarbons and SF_6	**–**	**–**	**–**	**–**	**–**	**480**	**28**	**1 600**	**2 100**
e. Other & Undifferentiated Production	**8 700**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**8 700**
SOLVENT & OTHER PRODUCT USE	**–**	**–**	**–**	**1.4**	**440**	**–**	**–**	**–**	**440**
AGRICULTURE	**–**	**1 140**	**23 900**	**82**	**25 000**	**–**	**–**	**–**	**49 000**
a. Enteric Fermentation	**–**	**1 000**	**21 100**	**–**	**–**	**–**	**–**	**–**	**21 100**
b. Manure Management	**–**	**130**	**2 800**	**15**	**4 600**	**–**	**–**	**–**	**7 400**
c. Agricultural Soils	**–**	**–**	**–**	**67**	**21 000**	**–**	**–**	**–**	**21 000**
Direct Sources	–	–	–	36	11 000	–	–	–	11 000
Pasture, Range, and Paddock Manure	–	–	–	12	3 700	–	–	–	3 700
Indirect Sources	–	–	–	20	6 000	–	–	–	6 000
WASTE	**220**	**1 200**	**25 000**	**3**	**1 000**	**–**	**–**	**–**	**26 000**
a. Solid Waste Disposal on Land	**–**	**1 200**	**25 000**	**–**	**–**	**–**	**–**	**–**	**25 000**
b. Wastewater Handling	**–**	**10**	**210**	**3**	**900**	**–**	**–**	**–**	**1 100**
c. Waste Incineration	**220**	**0.3**	**7**	**0.3**	**100**	**–**	**–**	**–**	**330**
LAND USE, LAND-USE CHANGE AND FORESTRY	**160 000**	**1 100**	**24 000**	**47**	**15 000**	**–**	**–**	**–**	**190 000**
a. Forest Land	**140 000**	**1 100**	**23 000**	**47**	**15 000**	**–**	**–**	**–**	**180 000**
b. Cropland	**6 800**	**5**	**100**	**0.3**	**90**	**–**	**–**	**–**	**7 000**
c. Grassland	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
d. Wetlands	**3 000**	**0.1**	**3**	**0.01**	**1**	**–**	**–**	**–**	**3 000**
e. Settlements	**7 000**	**3**	**60**	**0.1**	**30**	**–**	**–**	**–**	**7 000**

Notes:

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

2 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

3 The category mineral product use includes CO_2 emissions from the use of limestone & dolomite, soda ash, and magnesite.

Totals may not add due to rounding.

TABLE A8-13: 1994 Greenhouse Gas Emissions Summary for Canada

GHG Source/Sink Categories	Greenhouse Gases								
	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	TOTAL
Global Warming Potential			21		310				
Unit	*kt*	*kt*	*kt CO_2 eq*	*kt*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*
TOTAL[1]	**480 000**	**4 400**	**93 000**	**160**	**49 000**	**–**	**5 970**	**4 200**	**631 000**
ENERGY	**447 000**	**2 000**	**40 000**	**30**	**10 000**	**–**	**–**	**–**	**502 000**
a. Stationary Combustion Sources	**283 000**	**200**	**4 000**	**7**	**2 000**	**–**	**–**	**–**	**289 000**
Electricity and Heat Generation	95 800	2.6	54	2	600	–	–	–	96 400
Fossil Fuel Industries	53 000	80	2 000	1	400	–	–	–	55 000
Petroleum Refining and Upgrading	24 000	0.4	9	0.4	100	–	–	–	24 000
Fossil Fuel Production	29 100	80	2 000	0.7	200	–	–	–	31 000
Mining	7 440	0.2	3	0.2	50	–	–	–	7 490
Manufacturing Industries	51 900	3	60	2	500	–	–	–	52 400
Iron and Steel	7 400	0.3	6	0.2	60	–	–	–	7 470
Non-Ferrous Metals	3 290	0.07	2	0.05	20	–	–	–	3 310
Chemical	8 480	0.18	3.7	0.1	50	–	–	–	8 530
Pulp and Paper	11 700	2	40	0.8	200	–	–	–	12 000
Cement	3 260	0.07	1	0.04	10	–	–	–	3 280
Other Manufacturing	17 700	0.4	7	0.3	100	–	–	–	17 800
Construction	1 390	0.02	0.5	0.03	10	–	–	–	1 400
Commercial & Institutional	27 300	0.5	10	0.6	200	–	–	–	27 400
Residential	43 700	100	2 000	2	500	–	–	–	46 000
Agriculture & Forestry	2 540	0.04	0.8	0.06	20	–	–	–	2 560
b. Transportation[2]	**151 000**	**30**	**700**	**30**	**8 000**	**–**	**–**	**–**	**160 000**
Domestic Aviation	5 290	0.4	8	0.5	200	–	–	–	5 500
Road Transportation	110 000	16	340	18	5 700	–	–	–	116 000
Light-Duty Gasoline Vehicles	49 400	7.6	160	8.9	2 800	–	–	–	52 400
Light-Duty Gasoline Trucks	24 800	4.5	95	7.9	2 400	–	–	–	27 400
Heavy-Duty Gasoline Vehicles	4 280	0.60	13	0.64	200	–	–	–	4 490
Motorcycles	217	0.17	3.7	0.00	1.3	–	–	–	222
Light-Duty Diesel Vehicles	604	0.02	0.4	0.04	10	–	–	–	618
Light-Duty Diesel Trucks	423	0.01	0.2	0.03	10	–	–	–	432
Heavy-Duty Diesel Vehicles	28 200	1	30	0.8	300	–	–	–	28 500
Propane & Natural Gas Vehicles	1 870	2	40	0.04	10	–	–	–	1 900
Railways	6 310	0.3	7	3	800	–	–	–	7 000
Domestic Marine	4 350	0.3	7	1	300	–	–	–	4 700
Others	25 000	20	300	5	1 000	–	–	–	30 000
Off-Road Gasoline	4 000	4	90	0.08	30	–	–	–	4 000
Off-Road Diesel	11 000	0.5	10	4	1 000	–	–	–	10 000
Pipelines	10 500	10	220	0.3	90	–	–	–	10 800
c. Fugitive Sources	**13 000**	**1 900**	**40 000**	**0.1**	**30**	**–**	**–**	**–**	**53 500**
Coal Mining	–	80	2 000	–	–	–	–	–	2 000
Oil and Natural Gas	13 000	1 800	38 000	0.1	30	–	–	–	51 700
Oil	2 560	260	5 400	–	–	–	–	–	8 000
Natural Gas	5 800	790	17 000	–	–	–	–	–	22 000
Venting	150	780	16 000	0.1	30	–	–	–	17 000
Flaring	4 780	3.15	66.1	0.00	0.0	–	–	–	4 800
INDUSTRIAL PROCESSES	**32 700**	**–**	**–**	**37.9**	**11 700**	**–**	**5 970**	**4 180**	**54 600**
a. Mineral Production	**8 100**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**8 100**
Cement Production	5 400	–	–	–	–	–	–	–	5 400
Lime Production	2 000	–	–	–	–	–	–	–	2 000
Mineral Product Use[3]	840	–	–	–	–	–	–	–	840
b. Chemical Industry	**4 500**	**–**	**–**	**37.9**	**11 700**	**–**	**–**	**–**	**16 000**
Ammonia Production	4 500	–	–	–	–	–	–	–	4 500
Nitric Acid Production	–	–	–	2.5	770	–	–	–	770
Adipic Acid Production	–	–	–	35.4	11 000	–	–	–	11 000
c. Metal Production	**11 000**	**–**	**–**	**–**	**–**	**–**	**5 970**	**2 340**	**19 600**
Iron and Steel Production	7 540	–	–	–	–	–	–	–	7 540
Aluminium Production	3 800	–	–	–	–	–	5 970	–	9 800
SF_6 Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	2 280	2 280
d. Consumption of Halocarbons and SF_6	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**1 800**	**1 800**
e. Other & Undifferentiated Production	**8 800**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**8 800**
SOLVENT & OTHER PRODUCT USE	**–**	**–**	**–**	**1.4**	**440**	**–**	**–**	**–**	**440**
AGRICULTURE	**–**	**1 080**	**22 700**	**80**	**25 000**	**–**	**–**	**–**	**47 000**
a. Enteric Fermentation	**–**	**953**	**20 000**	**–**	**–**	**–**	**–**	**–**	**20 000**
b. Manure Management	**–**	**130**	**2 600**	**14**	**4 400**	**–**	**–**	**–**	**7 000**
c. Agricultural Soils	**–**	**–**	**–**	**66**	**20 000**	**–**	**–**	**–**	**20 000**
Direct Sources	–	–	–	36	11 000	–	–	–	11 000
Pasture, Range, and Paddock Manure	–	–	–	11	3 500	–	–	–	3 500
Indirect Sources	–	–	–	20	6 000	–	–	–	6 000
WASTE	**230**	**1 200**	**25 000**	**3**	**1 000**	**–**	**–**	**–**	**26 000**
a. Solid Waste Disposal on Land	**–**	**1 200**	**25 000**	**–**	**–**	**–**	**–**	**–**	**25 000**
b. Wastewater Handling	**–**	**11**	**220**	**3**	**900**	**–**	**–**	**–**	**1 100**
c. Waste Incineration	**230**	**0.3**	**6**	**0.3**	**100**	**–**	**–**	**–**	**330**
LAND USE, LAND-USE CHANGE AND FORESTRY	**–5 800**	**610**	**13 000**	**26**	**7 900**	**–**	**–**	**–**	**15 000**
a. Forest Land	**–23 000**	**600**	**13 000**	**25**	**7 800**	**–**	**–**	**–**	**–3 100**
b. Cropland	**8 100**	**6**	**100**	**0**	**100**	**–**	**–**	**–**	**8 400**
c. Grassland	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
d. Wetlands	**2 000**	**0.1**	**3**	**0.01**	**1**	**–**	**–**	**–**	**2 000**
e. Settlements	**7 000**	**3**	**60**	**0.1**	**30**	**–**	**–**	**–**	**7 000**

Notes:

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

2 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

3 The category mineral product use includes CO_2 emissions from the use of limestone & dolomite, soda ash, and magnesite.

Totals may not add due to rounding.

TABLE A8-14: 1993 Greenhouse Gas Emissions Summary for Canada

GHG Source/Sink Categories	Greenhouse Gases								
	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	TOTAL
Global Warming Potential			21		310				
Unit	*kt*	*kt*	*kt CO_2 eq*	*kt*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*
TOTAL[1]	**465 000**	**4 300**	**90 000**	**150**	**45 000**	**–**	**6 450**	**4 300**	**611 000**
ENERGY	**433 000**	**2 000**	**40 000**	**30**	**10 000**	**–**	**–**	**–**	**485 000**
a. Stationary Combustion Sources	**277 000**	**200**	**4 000**	**7**	**2 000**	**–**	**–**	**–**	**283 000**
Electricity and Heat Generation	93 300	2.5	53	2	600	–	–	–	93 900
Fossil Fuel Industries	52 000	80	2 000	1	400	–	–	–	54 000
Petroleum Refining and Upgrading	25 000	0.5	10	0.4	100	–	–	–	25 000
Fossil Fuel Production	27 600	80	2 000	0.7	200	–	–	–	29 000
Mining	7 370	0.2	3	0.2	50	–	–	–	7 420
Manufacturing Industries	48 700	3	50	1	500	–	–	–	49 300
Iron and Steel	6 600	0.3	5	0.2	60	–	–	–	6 660
Non-Ferrous Metals	2 710	0.06	1	0.04	10	–	–	–	2 730
Chemical	7 270	0.15	3.2	0.1	40	–	–	–	7 310
Pulp and Paper	11 900	2	30	0.7	200	–	–	–	12 100
Cement	2 840	0.06	1	0.04	10	–	–	–	2 860
Other Manufacturing	17 500	0.4	8	0.3	100	–	–	–	17 600
Construction	1 370	0.02	0.5	0.03	10	–	–	–	1 390
Commercial & Institutional	27 900	0.5	10	0.6	200	–	–	–	28 100
Residential	42 900	100	2 000	2	500	–	–	–	46 000
Agriculture & Forestry	3 040	0.05	1	0.07	20	–	–	–	3 060
b. Transportation[2]	**144 000**	**30**	**700**	**20**	**8 000**	**–**	**–**	**–**	**150 000**
Domestic Aviation	5 110	0.4	8	0.5	200	–	–	–	5 300
Road Transportation	105 000	16	340	17	5 100	–	–	–	110 000
Light-Duty Gasoline Vehicles	49 100	7.8	160	8.2	2 500	–	–	–	51 800
Light-Duty Gasoline Trucks	23 300	4.3	91	6.9	2 100	–	–	–	25 500
Heavy-Duty Gasoline Vehicles	3 890	0.55	11	0.58	180	–	–	–	4 080
Motorcycles	215	0.17	3.6	0.00	1.3	–	–	–	220
Light-Duty Diesel Vehicles	612	0.02	0.4	0.04	10	–	–	–	626
Light-Duty Diesel Trucks	419	0.01	0.2	0.03	10	–	–	–	429
Heavy-Duty Diesel Vehicles	25 400	1	30	0.7	200	–	–	–	25 700
Propane & Natural Gas Vehicles	1 970	2	40	0.04	10	–	–	–	2 000
Railways	6 090	0.3	7	2	800	–	–	–	7 000
Domestic Marine	4 190	0.3	6	0.9	300	–	–	–	4 500
Others	23 000	10	300	4	1 000	–	–	–	30 000
Off-Road Gasoline	4 000	4	90	0.08	20	–	–	–	4 000
Off-Road Diesel	9 600	0.5	10	4	1 000	–	–	–	10 000
Pipelines	10 100	10	210	0.3	80	–	–	–	10 400
c. Fugitive Sources	**12 000**	**1 800**	**38 000**	**0.1**	**30**	**–**	**–**	**–**	**50 400**
Coal Mining	–	90	2 000	–	–	–	–	–	2 000
Oil and Natural Gas	12 000	1 700	36 000	0.1	30	–	–	–	48 600
Oil	2 150	250	5 300	–	–	–	–	–	7 400
Natural Gas	5 400	740	16 000	–	–	–	–	–	21 000
Venting	140	740	15 000	0.1	30	–	–	–	16 000
Flaring	4 520	3.04	63.9	0.00	0.1	–	–	–	4 600
INDUSTRIAL PROCESSES	**32 100**	**–**	**–**	**31.8**	**9 860**	**–**	**6 450**	**4 270**	**52 700**
a. Mineral Production	**7 200**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**7 200**
Cement Production	4 600	–	–	–	–	–	–	–	4 600
Lime Production	2 000	–	–	–	–	–	–	–	2 000
Mineral Product Use[3]	860	–	–	–	–	–	–	–	860
b. Chemical Industry	**4 500**	**–**	**–**	**31.8**	**9 860**	**–**	**–**	**–**	**14 000**
Ammonia Production	4 500	–	–	–	–	–	–	–	4 500
Nitric Acid Production	–	–	–	2.5	780	–	–	–	780
Adipic Acid Production	–	–	–	29.3	9 080	–	–	–	9 080
c. Metal Production	**12 000**	**–**	**–**	**–**	**–**	**–**	**6 450**	**2 270**	**20 800**
Iron and Steel Production	8 180	–	–	–	–	–	–	–	8 180
Aluminium Production	3 900	–	–	–	–	–	6 450	–	10 400
SF_6 Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	2 210	2 210
d. Consumption of Halocarbons and SF_6	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**2 000**	**2 000**
e. Other & Undifferentiated Production	**8 300**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**8 300**
SOLVENT & OTHER PRODUCT USE	**–**	**–**	**–**	**1.4**	**430**	**–**	**–**	**–**	**430**
AGRICULTURE	**–**	**1 050**	**22 000**	**77**	**24 000**	**–**	**–**	**–**	**46 000**
a. Enteric Fermentation	**–**	**923**	**19 400**	**–**	**–**	**–**	**–**	**–**	**19 400**
b. Manure Management	**–**	**120**	**2 600**	**14**	**4 200**	**–**	**–**	**–**	**6 900**
c. Agricultural Soils	**–**	**–**	**–**	**64**	**20 000**	**–**	**–**	**–**	**20 000**
Direct Sources	–	–	–	35	11 000	–	–	–	11 000
Pasture, Range, and Paddock Manure	–	–	–	11	3 400	–	–	–	3 400
Indirect Sources	–	–	–	20	6 000	–	–	–	6 000
WASTE	**240**	**1 200**	**25 000**	**3**	**1 000**	**–**	**–**	**–**	**26 000**
a. Solid Waste Disposal on Land	**–**	**1 200**	**25 000**	**–**	**–**	**–**	**–**	**–**	**25 000**
b. Wastewater Handling	**–**	**10**	**220**	**3**	**900**	**–**	**–**	**–**	**1 100**
c. Waste Incineration	**240**	**0.3**	**7**	**0.3**	**100**	**–**	**–**	**–**	**350**
LAND USE, LAND-USE CHANGE AND FORESTRY	**–86 000**	**320**	**6 800**	**14**	**4 300**	**–**	**–**	**–**	**–75 000**
a. Forest Land	**–110 000**	**320**	**6 600**	**13**	**4 100**	**–**	**–**	**–**	**–96 000**
b. Cropland	**9 400**	**6**	**100**	**0.4**	**100**	**–**	**–**	**–**	**9 700**
c. Grassland	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
d. Wetlands	**3 000**	**0.09**	**2**	**0.00**	**1**	**–**	**–**	**–**	**3 000**
e. Settlements	**8 000**	**3**	**60**	**0.1**	**40**	**–**	**–**	**–**	**8 000**

Notes:

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

2 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

3 The category mineral product use includes CO_2 emissions from the use of limestone & dolomite, soda ash, and magnesite.

Totals may not add due to rounding.

TABLE A8-15: 1992 Greenhouse Gas Emissions Summary for Canada

GHG Source/Sink Categories	Greenhouse Gases								
	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	TOTAL
Global Warming Potential			21		310				
Unit	*kt*	*kt*	*kt CO_2 eq*	*kt*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*
TOTAL[1]	**466 000**	**4 200**	**87 000**	**140**	**45 000**	**–**	**6 560**	**4 200**	**609 000**
ENERGY	**434 000**	**2 000**	**40 000**	**30**	**9 000**	**–**	**–**	**–**	**485 000**
a. Stationary Combustion Sources	**283 000**	**200**	**4 000**	**7**	**2 000**	**–**	**–**	**–**	**288 000**
Electricity and Heat Generation	102 000	2.3	49	2	600	–	–	–	103 000
Fossil Fuel Industries	51 000	80	2 000	1	400	–	–	–	53 000
Petroleum Refining and Upgrading	24 000	0.4	9	0.4	100	–	–	–	24 000
Fossil Fuel Production	27 700	80	2 000	0.7	200	–	–	–	30 000
Mining	4 860	0.1	2	0.1	30	–	–	–	4 900
Manufacturing Industries	51 200	3	60	2	500	–	–	–	51 800
Iron and Steel	6 650	0.3	5	0.2	60	–	–	–	6 720
Non-Ferrous Metals	2 820	0.06	1	0.04	10	–	–	–	2 830
Chemical	7 410	0.15	3.2	0.1	40	–	–	–	7 450
Pulp and Paper	12 000	2	40	0.8	200	–	–	–	12 200
Cement	2 860	0.06	1	0.04	10	–	–	–	2 870
Other Manufacturing	19 500	0.4	8	0.4	100	–	–	–	19 600
Construction	1 730	0.03	0.6	0.06	20	–	–	–	1 750
Commercial & Institutional	26 900	0.5	10	0.5	200	–	–	–	27 000
Residential	41 000	90	2 000	2	500	–	–	–	43 000
Agriculture & Forestry	3 250	0.05	1.0	0.08	20	–	–	–	3 270
b. Transportation[2]	**141 000**	**30**	**700**	**20**	**7 000**	**–**	**–**	**–**	**150 000**
Domestic Aviation	5 360	0.4	9	0.5	200	–	–	–	5 500
Road Transportation	103 000	16	340	15	4 600	–	–	–	108 000
Light-Duty Gasoline Vehicles	49 100	8.1	170	7.5	2 300	–	–	–	51 600
Light-Duty Gasoline Trucks	22 000	4.2	88	5.9	1 800	–	–	–	24 000
Heavy-Duty Gasoline Vehicles	3 560	0.50	11.0	0.53	160	–	–	–	3 740
Motorcycles	213	0.17	3.6	0.00	1.3	–	–	–	218
Light-Duty Diesel Vehicles	618	0.02	0.4	0.05	10	–	–	–	633
Light-Duty Diesel Trucks	445	0.01	0.3	0.03	10	–	–	–	456
Heavy-Duty Diesel Vehicles	24 100	1	20	0.7	200	–	–	–	24 300
Propane & Natural Gas Vehicles	2 610	2	50	0.05	20	–	–	–	2 700
Railways	6 120	0.3	7	2	800	–	–	–	7 000
Domestic Marine	4 790	0.4	8	1	300	–	–	–	5 100
Others	22 000	10	300	4	1 000	–	–	–	20 000
Off-Road Gasoline	4 000	4	90	0.08	20	–	–	–	4 000
Off-Road Diesel	8 400	0.4	9	3	1 000	–	–	–	9 000
Pipelines	9 610	9.6	200	0.3	80	–	–	–	9 890
c. Fugitive Sources	**11 000**	**1 700**	**37 000**	**0.1**	**30**	**–**	**–**	**–**	**48 000**
Coal Mining	–	90	2 000	–	–	–	–	–	2 000
Oil and Natural Gas	11 000	1 700	35 000	0.1	30	–	–	–	46 100
Oil	1 950	250	5 300	–	–	–	–	–	7 200
Natural Gas	4 900	710	15 000	–	–	–	–	–	20 000
Venting	140	700	15 000	0.1	30	–	–	–	15 000
Flaring	4 200	2.76	57.9	0.00	0.1	–	–	–	4 300
INDUSTRIAL PROCESSES	**31 500**	**–**	**–**	**34.6**	**10 700**	**–**	**6 560**	**4 230**	**53 100**
a. Mineral Production	**7 400**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**7 400**
Cement Production	4 500	–	–	–	–	–	–	–	4 500
Lime Production	2 000	–	–	–	–	–	–	–	2 000
Mineral Product Use[3]	1 100	–	–	–	–	–	–	–	1 100
b. Chemical Industry	**4 200**	**–**	**–**	**34.6**	**10 700**	**–**	**–**	**–**	**15 000**
Ammonia Production	4 200	–	–	–	–	–	–	–	4 200
Nitric Acid Production	–	–	–	2.5	780	–	–	–	780
Adipic Acid Production	–	–	–	32.1	9 950	–	–	–	9 950
c. Metal Production	**12 000**	**–**	**–**	**–**	**–**	**–**	**6 560**	**2 460**	**20 800**
Iron and Steel Production	8 500	–	–	–	–	–	–	–	8 500
Aluminium Production	3 300	–	–	–	–	–	6 560	–	9 890
SF_6 Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	2 400	2 400
d. Consumption of Halocarbons and SF_6	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**1 800**	**1 800**
e. Other & Undifferentiated Production	**8 300**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**8 300**
SOLVENT & OTHER PRODUCT USE	**–**	**–**	**–**	**1.4**	**430**	**–**	**–**	**–**	**430**
AGRICULTURE	**–**	**1 040**	**21 900**	**75**	**23 000**	**–**	**–**	**–**	**45 000**
a. Enteric Fermentation	**–**	**915**	**19 200**	**–**	**–**	**–**	**–**	**–**	**19 200**
b. Manure Management	**–**	**130**	**2 600**	**14**	**4 200**	**–**	**–**	**–**	**6 900**
c. Agricultural Soils	**–**	**–**	**–**	**62**	**19 000**	**–**	**–**	**–**	**19 000**
Direct Sources	–	–	–	33	10 000	–	–	–	10 000
Pasture, Range, and Paddock Manure	–	–	–	11	3 400	–	–	–	3 400
Indirect Sources	–	–	–	20	5 000	–	–	–	5 000
WASTE	**260**	**1 200**	**24 000**	**3**	**1 000**	**–**	**–**	**–**	**26 000**
a. Solid Waste Disposal on Land	**–**	**1 200**	**24 000**	**–**	**–**	**–**	**–**	**–**	**24 000**
b. Wastewater Handling	**–**	**10**	**220**	**3**	**900**	**–**	**–**	**–**	**1 100**
c. Waste Incineration	**260**	**0.5**	**10**	**0.4**	**100**	**–**	**–**	**–**	**400**
LAND USE, LAND-USE CHANGE AND FORESTRY	**–170 000**	**57**	**1 200**	**2.5**	**780**	**–**	**–**	**–**	**–160 000**
a. Forest Land	**–190 000**	**47**	**990**	**2.0**	**620**	**–**	**–**	**–**	**–190 000**
b. Cropland	**11 000**	**7**	**200**	**0.4**	**100**	**–**	**–**	**–**	**11 000**
c. Grassland	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
d. Wetlands	**3 000**	**0.08**	**2**	**0.00**	**1**	**–**	**–**	**–**	**3 000**
e. Settlements	**8 000**	**3**	**60**	**0.1**	**30**	**–**	**–**	**–**	**8 000**

Notes:

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

2 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

3 The category mineral product use includes CO_2 emissions from the use of limestone & dolomite, soda ash, and magnesite.

Totals may not add due to rounding.

TABLE A8-16: 1991 Greenhouse Gas Emissions Summary for Canada

GHG Source/Sink Categories	Greenhouse Gases								
	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	TOTAL
Global Warming Potential			21		310				
Unit	*kt*	*kt*	*kt CO_2 eq*	*kt*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*
TOTAL[1]	**452 000**	**4 000**	**84 000**	**140**	**44 000**	**–**	**6 950**	**5 500**	**592 000**
ENERGY	**420 000**	**2 000**	**40 000**	**30**	**9 000**	**–**	**–**	**–**	**467 000**
a. Stationary Combustion Sources	**272 000**	**200**	**4 000**	**7**	**2 000**	**–**	**–**	**–**	**278 000**
Electricity and Heat Generation	96 100	1.7	36	2	500	–	–	–	96 700
Fossil Fuel Industries	49 000	70	2 000	1	300	–	–	–	51 000
Petroleum Refining and Upgrading	23 000	0.4	9	0.4	100	–	–	–	23 000
Fossil Fuel Production	26 400	70	2 000	0.7	200	–	–	–	28 000
Mining	5 040	0.1	2	0.1	30	–	–	–	5 080
Manufacturing Industries	51 900	3	60	2	500	–	–	–	52 400
Iron and Steel	6 390	0.3	5	0.2	60	–	–	–	6 450
Non-Ferrous Metals	2 600	0.06	1	0.04	10	–	–	–	2 610
Chemical	7 440	0.15	3.2	0.1	40	–	–	–	7 480
Pulp and Paper	12 700	2	40	0.8	200	–	–	–	13 000
Cement	2 980	0.06	1	0.04	10	–	–	–	3 000
Other Manufacturing	19 800	0.4	8	0.4	100	–	–	–	19 900
Construction	1 610	0.03	0.6	0.05	20	–	–	–	1 630
Commercial & Institutional	26 300	0.5	10	0.5	200	–	–	–	26 500
Residential	39 800	90	2 000	2	500	–	–	–	42 000
Agriculture & Forestry	2 740	0.04	0.8	0.06	20	–	–	–	2 760
b. Transportation[2]	**137 000**	**30**	**600**	**20**	**6 000**	**–**	**–**	**–**	**140 000**
Domestic Aviation	5 510	0.4	9	0.5	200	–	–	–	5 700
Road Transportation	100 000	16	340	13	4 000	–	–	–	104 000
Light-Duty Gasoline Vehicles	49 000	8.3	170	6.8	2 100	–	–	–	51 300
Light-Duty Gasoline Trucks	20 600	4.0	83	4.9	1 500	–	–	–	22 200
Heavy-Duty Gasoline Vehicles	3 180	0.45	9.4	0.47	150	–	–	–	3 340
Motorcycles	216	0.17	3.6	0.00	1.3	–	–	–	221
Light-Duty Diesel Vehicles	620	0.02	0.4	0.05	10	–	–	–	635
Light-Duty Diesel Trucks	495	0.01	0.3	0.04	10	–	–	–	507
Heavy-Duty Diesel Vehicles	23 600	1	20	0.7	200	–	–	–	23 800
Propane & Natural Gas Vehicles	2 260	2	40	0.04	10	–	–	–	2 300
Railways	5 850	0.3	7	2	700	–	–	–	7 000
Domestic Marine	4 940	0.4	8	1	300	–	–	–	5 200
Others	21 000	10	300	4	1 000	–	–	–	20 000
Off-Road Gasoline	4 000	5	100	0.09	30	–	–	–	5 000
Off-Road Diesel	9 000	0.5	10	4	1 000	–	–	–	10 000
Pipelines	7 430	7.4	160	0.2	60	–	–	–	7 650
c. Fugitive Sources	**11 000**	**1 600**	**34 000**	**0.1**	**30**	**–**	**–**	**–**	**44 800**
Coal Mining	–	100	2 000	–	–	–	–	–	2 000
Oil and Natural Gas	11 000	1 500	32 000	0.1	30	–	–	–	42 700
Oil	1 940	230	4 900	–	–	–	–	–	6 900
Natural Gas	4 500	660	14 000	–	–	–	–	–	18 000
Venting	120	630	13 000	0.1	30	–	–	–	13 000
Flaring	4 110	2.55	53.5	0.00	0.1	–	–	–	4 200
INDUSTRIAL PROCESSES	**31 400**	**–**	**–**	**34.7**	**10 800**	**–**	**6 950**	**5 550**	**54 700**
a. Mineral Production	**7 300**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**7 300**
Cement Production	4 400	–	–	–	–	–	–	–	4 400
Lime Production	2 000	–	–	–	–	–	–	–	2 000
Mineral Product Use[3]	1 100	–	–	–	–	–	–	–	1 100
b. Chemical Industry	**3 900**	**–**	**–**	**34.7**	**10 800**	**–**	**–**	**–**	**15 000**
Ammonia Production	3 900	–	–	–	–	–	–	–	3 900
Nitric Acid Production	–	–	–	2.5	770	–	–	–	770
Adipic Acid Production	–	–	–	32.3	10 000	–	–	–	10 000
c. Metal Production	**11 000**	**–**	**–**	**–**	**–**	**–**	**6 950**	**3 640**	**22 100**
Iron and Steel Production	8 320	–	–	–	–	–	–	–	8 320
Aluminium Production	3 100	–	–	–	–	–	6 950	–	10 200
SF_6 Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	3 580	3 580
d. Consumption of Halocarbons and SF_6	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**1 900**	**1 900**
e. Other & Undifferentiated Production	**8 700**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**8 700**
SOLVENT & OTHER PRODUCT USE	**–**	**–**	**–**	**1.4**	**420**	**–**	**–**	**–**	**420**
AGRICULTURE	**–**	**1 010**	**21 200**	**75**	**23 000**	**–**	**–**	**–**	**44 000**
a. Enteric Fermentation	**–**	**888**	**18 600**	**–**	**–**	**–**	**–**	**–**	**18 600**
b. Manure Management	**–**	**120**	**2 600**	**13**	**4 100**	**–**	**–**	**–**	**6 700**
c. Agricultural Soils	**–**	**–**	**–**	**61**	**19 000**	**–**	**–**	**–**	**19 000**
Direct Sources	–	–	–	33	10 000	–	–	–	10 000
Pasture, Range, and Paddock Manure	–	–	–	10	3 200	–	–	–	3 200
Indirect Sources	–	–	–	20	5 000	–	–	–	5 000
WASTE	**270**	**1 100**	**24 000**	**3**	**1 000**	**–**	**–**	**–**	**25 000**
a. Solid Waste Disposal on Land	**–**	**1 100**	**24 000**	**–**	**–**	**–**	**–**	**–**	**24 000**
b. Wastewater Handling	**–**	**9.8**	**210**	**3**	**900**	**–**	**–**	**–**	**1 100**
c. Waste Incineration	**270**	**0.5**	**10**	**0.4**	**100**	**–**	**–**	**–**	**410**
LAND USE, LAND-USE CHANGE AND FORESTRY	**–110 000**	**240**	**5 100**	**10**	**3 200**	**–**	**–**	**–**	**–97 000**
a. Forest Land	**–130 000**	**230**	**4 900**	**9.8**	**3 000**	**–**	**–**	**–**	**–120 000**
b. Cropland	**12 000**	**8**	**200**	**0.4**	**100**	**–**	**–**	**–**	**13 000**
c. Grassland	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
d. Wetlands	**5 000**	**0.09**	**2**	**0.00**	**1**	**–**	**–**	**–**	**5 000**
e. Settlements	**8 000**	**3**	**60**	**0.1**	**40**	**–**	**–**	**–**	**8 000**

Notes:

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

2 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

3 The category mineral product use includes CO_2 emissions from the use of limestone & dolomite, soda ash, and magnesite.

Totals may not add due to rounding.

TABLE A8-17: 1990 Greenhouse Gas Emissions Summary for Canada

GHG Source/Sink Categories	Greenhouse Gases								
	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	TOTAL
Global Warming Potential			21		310				
Unit	*kt*	*kt*	*kt CO_2 eq*	*kt*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*
TOTAL[1]	**460 000**	**3 900**	**82 000**	**150**	**45 000**	**–**	**6 540**	**5 000**	**599 000**
ENERGY	**430 000**	**2 000**	**40 000**	**30**	**8 000**	**–**	**–**	**–**	**475 000**
a. Stationary Combustion Sources	**277 000**	**200**	**4 000**	**7**	**2 000**	**–**	**–**	**–**	**283 000**
Electricity and Heat Generation	94 700	1.8	38	2	500	–	–	–	95 300
Fossil Fuel Industries	51 000	80	2 000	1	400	–	–	–	53 000
Petroleum Refining and Upgrading	23 000	0.4	9	0.4	100	–	–	–	23 000
Fossil Fuel Production	28 100	80	2 000	0.7	200	–	–	–	30 000
Mining	6 160	0.1	3	0.1	40	–	–	–	6 200
Manufacturing Industries	54 400	3	60	2	500	–	–	–	54 900
Iron and Steel	6 420	0.2	5	0.2	60	–	–	–	6 490
Non-Ferrous Metals	3 210	0.07	1	0.05	10	–	–	–	3 230
Chemical	7 060	0.15	3.0	0.1	40	–	–	–	7 100
Pulp and Paper	13 400	2	40	0.8	200	–	–	–	13 600
Cement	3 570	0.07	1	0.05	10	–	–	–	3 590
Other Manufacturing	20 700	0.4	9	0.4	100	–	–	–	20 900
Construction	1 860	0.03	0.7	0.05	20	–	–	–	1 880
Commercial & Institutional	25 700	0.5	10	0.5	200	–	–	–	25 800
Residential	41 300	100	2 000	2	500	–	–	–	44 000
Agriculture & Forestry	2 400	0.04	0.8	0.05	20	–	–	–	2 420
b. Transportation[2]	**142 000**	**30**	**600**	**20**	**6 000**	**–**	**–**	**–**	**150 000**
Domestic Aviation	6 220	0.5	10	0.6	200	–	–	–	6 400
Road Transportation	103 000	16	350	12	3 600	–	–	–	107 000
Light-Duty Gasoline Vehicles	51 600	9.0	190	6.3	2 000	–	–	–	53 800
Light-Duty Gasoline Trucks	20 300	4.0	83	4.2	1 300	–	–	–	21 700
Heavy-Duty Gasoline Vehicles	2 990	0.42	8.8	0.44	140	–	–	–	3 140
Motorcycles	225	0.18	3.8	0.00	1.4	–	–	–	230
Light-Duty Diesel Vehicles	657	0.02	0.4	0.05	10	–	–	–	672
Light-Duty Diesel Trucks	578	0.02	0.3	0.04	10	–	–	–	591
Heavy-Duty Diesel Vehicles	24 300	1	30	0.7	200	–	–	–	24 500
Propane & Natural Gas Vehicles	2 160	2	40	0.04	10	–	–	–	2 200
Railways	6 320	0.3	7	3	800	–	–	–	7 000
Domestic Marine	4 730	0.4	7	1	300	–	–	–	5 000
Others	22 000	10	300	4	1 000	–	–	–	20 000
Off-Road Gasoline	5 000	6	100	0.1	30	–	–	–	5 000
Off-Road Diesel	10 000	0.5	10	4	1 000	–	–	–	10 000
Pipelines	6 700	6.7	140	0.2	60	–	–	–	6 900
c. Fugitive Sources	**11 000**	**1 600**	**33 000**	**0.1**	**30**	**–**	**–**	**–**	**43 300**
Coal Mining	–	90	2 000	–	–	–	–	–	2 000
Oil and Natural Gas	11 000	1 500	31 000	0.1	30	–	–	–	41 400
Oil	1 910	230	4 800	–	–	–	–	–	6 700
Natural Gas	4 200	640	13 000	–	–	–	–	–	18 000
Venting	110	600	13 000	0.1	30	–	–	–	13 000
Flaring	4 340	2.61	54.8	0.00	0.1	–	–	–	4 400
INDUSTRIAL PROCESSES	**30 300**	**–**	**–**	**37.1**	**11 500**	**–**	**6 540**	**5 000**	**53 300**
a. Mineral Production	**8 300**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**8 300**
Cement Production	5 400	–	–	–	–	–	–	–	5 400
Lime Production	2 000	–	–	–	–	–	–	–	2 000
Mineral Product Use[3]	1 100	–	–	–	–	–	–	–	1 100
b. Chemical Industry	**3 900**	**–**	**–**	**37.1**	**11 500**	**–**	**–**	**–**	**15 000**
Ammonia Production	3 900	–	–	–	–	–	–	–	3 900
Nitric Acid Production	–	–	–	2.5	780	–	–	–	780
Adipic Acid Production	–	–	–	34.6	10 700	–	–	–	10 700
c. Metal Production	**9 800**	**–**	**–**	**–**	**–**	**–**	**6 540**	**3 170**	**19 500**
Iron and Steel Production	7 060	–	–	–	–	–	–	–	7 060
Aluminium Production	2 700	–	–	–	–	–	6 540	–	9 310
SF_6 Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	3 110	3 110
d. Consumption of Halocarbons and SF_6	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**1 800**	**1 800**
e. Other & Undifferentiated Production	**8 300**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**8 300**
SOLVENT & OTHER PRODUCT USE	**–**	**–**	**–**	**1.3**	**420**	**–**	**–**	**–**	**420**
AGRICULTURE	**–**	**1 000**	**21 000**	**77**	**24 000**	**–**	**–**	**–**	**45 000**
a. Enteric Fermentation	**–**	**877**	**18 400**	**–**	**–**	**–**	**–**	**–**	**18 400**
b. Manure Management	**–**	**120**	**2 600**	**13**	**4 100**	**–**	**–**	**–**	**6 700**
c. Agricultural Soils	**–**	**–**	**–**	**63**	**20 000**	**–**	**–**	**–**	**20 000**
Direct Sources	–	–	–	35	11 000	–	–	–	11 000
Pasture, Range, and Paddock Manure	–	–	–	10	3 200	–	–	–	3 200
Indirect Sources	–	–	–	20	6 000	–	–	–	6 000
WASTE	**270**	**1 100**	**24 000**	**3**	**1 000**	**–**	**–**	**–**	**25 000**
a. Solid Waste Disposal on Land	**–**	**1 100**	**23 000**	**–**	**–**	**–**	**–**	**–**	**23 000**
b. Wastewater Handling	**–**	**11**	**220**	**3**	**900**	**–**	**–**	**–**	**1 100**
c. Waste Incineration	**270**	**0.4**	**9**	**0.4**	**100**	**–**	**–**	**–**	**400**
LAND USE, LAND-USE CHANGE AND FORESTRY	**–87 000**	**160**	**3 500**	**7.0**	**2 200**	**–**	**–**	**–**	**–82 000**
a. Forest Land	**–110 000**	**150**	**3 200**	**6.4**	**2 000**	**–**	**–**	**–**	**–110 000**
b. Cropland	**13 000**	**9**	**200**	**0.5**	**200**	**–**	**–**	**–**	**14 000**
c. Grassland	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
d. Wetlands	**6 000**	**0.08**	**2**	**0.00**	**0.9**	**–**	**–**	**–**	**6 000**
e. Settlements	**8 000**	**3**	**60**	**0.1**	**30**	**–**	**–**	**–**	**8 000**

Notes:

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

2 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

3 The category mineral product use includes CO_2 emissions from the use of limestone & dolomite, soda ash, and magnesite.

Totals may not add due to rounding.

ANNEX 9: ELECTRICITY INTENSITY TABLES

Detailed GHG information for the electricity sector is presented for the complete time series within the following tables by region and by generation source. The purpose of these tables is to provide additional trends information on utility- and industry-generated intensity value, electricity generation, and emission data. The information presented in this annex excludes the emissions associated with heat generation. Information on the contribution of emissions from the electricity and heat generation sector is presented in Canada's Greenhouse Gas Emission Tables, 1990–2004 (Annex 8) and Provincial/Territorial Greenhouse Gas Emission Tables, 1990–2004 (Annex 12).

National-level trends analysis for the electricity sector is covered in the Emission Trends (Section 2.3.1.1, Emissions from Fuel Combustion) and the Energy (Section 3.2.1, Energy Industries) chapters of this report.

The electricity intensity values were derived for each fuel type using GHG emission estimates and electricity generation data. The methodology used to develop the GHG emissions is discussed in the Energy Industries section (Section 3.2.1) and in Annex 2 (Methodology and Data for Estimating Emissions from Fuel Combustion) of this report. Electricity generation data are from Statistics Canada's RESD (Statistics Canada, #53-003).

TABLE A9-1: Electricity Generation and Greenhouse Gas Emission Details for Canada[1]

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Greenhouse Gas Emissions *kt CO_2 eq*															
Coal	78 800	82 500	85 400	78 200	81 700	83 100	84 800	91 400	97 500	96 700	104 800	103 400	101 900	105 400	96 000
Refined Petroleum Products[2]	11 400	9 590	10 500	7 780	6 040	6 990	5 620	8 110	11 900	9 600	8 800	10 600	8 500	10 300	12 300
Natural Gas	4 050	3 530	5 850	6 860	7 020	9 150	7 770	9 670	11 800	12 400	16 100	17 100	15 600	17 000	15 500
Nuclear	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Hydro[3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Biomass[4]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Others[5]	404	428	512	462	652	522	346	1 100	1 080	1 230	1 260	1 380	1 470	5 090	4 340
Total	**94 600**	**96 000**	**102 000**	**93 300**	**95 400**	**99 700**	**98 600**	**110 000**	**122 000**	**120 000**	**131 000**	**132 000**	**128 000**	**138 000**	**128 000**
Electricity Generation[a] *GWh*															
Coal	76 794	82 592	84 024	76 863	80 837	81 563	83 981	92 903	99 914	100 528	109 895	110 026	109 391	104 698	95 198
Refined Petroleum Products[2]	14 388	12 195	13 454	9 995	7 765	9 390	7 855	11 169	16 105	13 239	12 339	14 547	12 372	19 547	19 411
Natural Gas	9 018	8 054	12 258	14 291	15 406	19 784	17 150	20 031	24 692	25 961	31 678	34 054	32 042	32 174	29 686
Nuclear	68 761	80 123	76 019	88 639	101 711	92 306	87 510	77 857	67 466	69 331	68 674	72 320	71 252	70 652	85 240
Hydro[3]	293 985	305 323	313 325	320 445	326 699	332 705	352 183	347 274	328 706	342 167	354 812	329 881	346 917	334 104	337 606
Biomass[4]	3 546	3 562	3 992	4 303	5 142	5 049	5 233	5 651	5 810	6 388	6 372	6 795	7 138	6 905	7 221
Others[5]	1 118	1 195	1 318	1 439	1 899	1 946	1 909	1 199	1 172	2 323	2 045	1 799	1 987	1 409	2 061
Total	**467 609**	**493 043**	**504 391**	**515 974**	**539 458**	**542 744**	**555 822**	**556 084**	**543 865**	**559 937**	**585 816**	**569 422**	**581 097**	**569 489**	**576 422**
Greenhouse Gas Intensity[7] *g CO_2 eq/kWh*															
Coal	1 030	1 000	1 020	1 020	1 010	1 020	1 010	980	980	960	950	940	930	1 010	1 010
Refined Petroleum Products[2]	792	786	780	779	778	745	715	726	737	720	710	730	690	520	640
Natural Gas	449	439	478	480	455	463	453	483	476	478	508	501	487	528	523
Nuclear	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Hydro[3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Biomass[4]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Others[5,6]	362	358	388	321	343	268	181	920	921	531	615	766	740	3 609	2 105
Average Intensity	**202**	**195**	**203**	**181**	**177**	**184**	**177**	**198**	**225**	**214**	**223**	**233**	**219**	**242**	**222**

Source:

a Report on Energy Supply – Demand in Canada, Catalogue No. 57-003, Statistics Canada.

Notes:

1 Data presented include both utility and industrial emissions, generation, and intensity.

2 Includes emissions from the use of light fuel oil, heavy fuel oil, and diesel fuel oil.

3 Emissions from the flooding of land for hydro dams are not included.

4 Emissions related to the use of biomass for electric power generation are not included.

5 Others – includes electricity generation by wind, tidal, and other refined petroleum product fuels.

6 Greenhouse Gas Intensity for Others – emission intensity values are not shown due to the miscellaneous nature of other categories.

7 Accuracy of GHG intensity diminished in cases where industrial cogeneration is significant.

TABLE A9-2: Electricity Generation and Greenhouse Gas Emission Details for Newfoundland and Labrador[1]

							Greenhouse Gas Emissions *kt CO_2 eq*								
Sources	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Coal	0	0	0	0	0	0	0	0	0	0	0	X	X	X	X
Refined Petroleum Products[2]	1 610	1 280	1 480	1 340	720	1 250	1 160	1 210	1 020	810	800	X	X	X	X
Natural Gas	0	0	0	0	0	0	0	0	0	124	115	X	X	X	X
Nuclear	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Hydro[3]	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Biomass[4]	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Others[5]	0	0	0	0	0	0	0	0	0	0	0	X	X	X	X
Total	**1 610**	**1 280**	**1 480**	**1 340**	**720**	**1 250**	**1 160**	**1 210**	**1 020**	**940**	**920**	**X**	**X**	**X**	**X**
							Electricity Generation[a] *GWh*								
Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Refined Petroleum Products[2]	1 978	1 534	1 784	1 659	879	1 626	1 484	1 573	1 317	971	1 025	2 155	2 436	2 008	1 706
Natural Gas	0	0	0	0	0	0	0	0	164	283	261	273	273	284	264
Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydro[3]	34 687	35 410	34 875	39 194	37 606	36 287	35 292	40 177	43 640	41 382	42 313	38 824	41 416	39 801	39 589
Biomass[4]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Others[5]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**36 665**	**36 944**	**36 659**	**40 853**	**38 485**	**37 913**	**36 776**	**41 750**	**45 121**	**42 636**	**43 599**	**41 252**	**44 125**	**42 093**	**41 559**
							Greenhouse Gas Intensity[7] *g CO_2 eq/kWh*								
Coal	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Refined Petroleum Products[2]	816	835	829	809	815	770	782	770	772	836	785	X	X	X	X
Natural Gas	–	–	–	–	–	–	–	–	0	440	440	X	X	X	X
Nuclear	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Hydro[3]	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Biomass[4]	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Others[5,6]	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Average Intensity	**44**	**35**	**40**	**33**	**19**	**33**	**32**	**29**	**23**	**22**	**21**	**X**	**X**	**X**	**X**

Source:

a Report on Energy Supply – Demand in Canada, Catalogue No. 57-003, Statistics Canada.

Notes:

1 Data presented include both utility and industrial emissions, generation, and intensity.

2 Includes emissions from the use of light fuel oil, heavy fuel oil, and diesel fuel oil.

3 Emissions from the flooding of land for hydro dams are not included.

4 Emissions related to the use of biomass for electric power generation are not included.

5 Others – includes electricity generation by wind, tidal, and other refined petroleum product fuels.

6 Greenhouse Gas Intensity for Others – emission intensity values are not shown due to the miscellaneous nature of other categories.

7 Accuracy of GHG intensity diminished in cases where industrial cogeneration is significant.

X Denotes confidential values.

TABLE A9-3: Electricity Generation and Greenhouse Gas Emission Details for Prince Edward Island[1]

Greenhouse Gas Emissions
kt CO_2 eq

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Coal	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Refined Petroleum Products[2]	101	91	50	73	57	38	24	31	10	19	55	X	X	X	X
Natural Gas	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Nuclear	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Hydro[3]	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Biomass[4]	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Others[5]	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Total	**101**	**91**	**50**	**73**	**57**	**38**	**24**	**31**	**10**	**19**	**55**	**X**	**X**	**X**	**X**

Electricity Generation[a]
GWh

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Refined Petroleum Products[2]	81	72	34	59	41	23	11	22	4	10	49	43	20	43	13
Natural Gas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydro[3]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass[4]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Others[5]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**81**	**72**	**34**	**59**	**41**	**23**	**11**	**22**	**4**	**10**	**49**	**43**	**20**	**43**	**13**

Greenhouse Gas Intensity[7]
g CO_2 eq/kWh

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Coal	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Refined Petroleum Products[2]	1250	1270	1480	1250	1410	1660	2320	1390	2910	1890	1120	X	X	X	X
Natural Gas	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Nuclear	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Hydro[3]	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Biomass[4]	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Others[5, 6]	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Average Intensity	**1250**	**1270**	**1480**	**1250**	**1410**	**1660**	**2320**	**1390**	**2910**	**1890**	**1120**	**X**	**X**	**X**	**X**

Source:

a Report on Energy Supply – Demand in Canada, Catalogue No. 57-003, Statistics Canada.

Notes:

1 Data presented include both utility and industrial emissions, generation, and intensity.
2 Includes emissions from the use of light fuel oil, heavy fuel oil, and diesel fuel oil.
3 Emissions from the flooding of land for hydro dams are not included.
4 Emissions related to the use of biomass for electric power generation are not included.
5 Others – includes electricity generation by wind, tidal, and other refined petroleum product fuels.
6 Greenhouse Gas Intensity for Others – emission intensity values are not shown due to the miscellaneous nature of other categories.
7 Accuracy of GHG intensity diminished in cases where industrial cogeneration is significant.
X Denotes confidential values.

TABLE A9-4: Electricity Generation and Greenhouse Gas Emission Details for Nova Scotia[1]

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Greenhouse Gas Emissions *kt CO_2 eq*															
Coal	5 050	5 280	5 390	5 530	6 100	5 840	6 510	6 860	5 890	6 530	7 590	X	X	X	X
Refined Petroleum Products[2]	1 790	1 720	1 990	1 770	1 020	1 050	600	680	1 920	1 520	1 230	X	X	X	X
Natural Gas	0	0	0	0	0	0	0	0	0	0	0	X	X	X	X
Nuclear	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Hydro[3]	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Biomass[4]	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Others[5]	0	0	0	0	0	0	0	0	0	0	0	X	X	X	X
Total	**6 830**	**7 000**	**7 380**	**7 310**	**7 120**	**6 900**	**7 100**	**7 530**	**7 800**	**8 060**	**8 820**	**X**	**X**	**X**	**X**
Electricity Generation[a] *GWh*															
Coal	5 760	5 933	6 079	6 337	7 136	6 987	7 944	8 367	7 119	7 916	8 959	9 801	8 576	7 335	7 567
Refined Petroleum Products[2]	2 233	2 113	2 447	2 201	1 290	1 407	791	887	2 475	1 978	1 547	1 106	424	3 618	3 813
Natural Gas	0	0	0	0	0	0	0	0	0	0	0	0	1 930	127	101
Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydro[3]	1 181	1 071	905	916	1 054	937	1 156	978	932	1 018	924	748	1 082	1 142	961
Biomass[4]	259	277	290	260	287	240	302	281	235	158	191	189	127	161	155
Others[5]	0	0	0	0	0	0	0	0	19	6	4	5	8	8	0
Total	**9 432**	**9 394**	**9 720**	**9 714**	**9 767**	**9 571**	**10 193**	**10 513**	**10 780**	**11 076**	**11 624**	**11 849**	**12 146**	**12 391**	**12 597**
Greenhouse Gas Intensity[7] *g CO_2 eq/kWh*															
Coal	880	890	890	870	860	840	820	820	830	830	850	X	X	X	X
Refined Petroleum Products[2]	800	813	813	805	788	749	753	761	775	770	790	X	X	X	X
Natural Gas	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Nuclear	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Hydro[3]	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Biomass[4]	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Others[5, 6]	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Average Intensity	**724**	**745**	**759**	**752**	**729**	**721**	**697**	**717**	**724**	**727**	**759**	**X**	**X**	**X**	**X**

Source:

a Report on Energy Supply – Demand in Canada, Catalogue No. 57-003, Statistics Canada.

Notes:

1 Data presented include both utility and industrial emissions, generation, and intensity.
2 Includes emissions from the use of light fuel oil, heavy fuel oil, and diesel fuel oil.
3 Emissions from the flooding of land for hydro dams are not included.
4 Emissions related to the use of biomass for electric power generation are not included.
5 Others – includes electricity generation by wind, tidal, and other refined petroleum product fuels.
6 Greenhouse Gas Intensity for Others – emission intensity values are not shown due to the miscellaneous nature of other categories.
7 Accuracy of GHG intensity diminished in cases where industrial cogeneration is significant.
X Denotes confidential values.

TABLE A9-5: Electricity Generation and Greenhouse Gas Emission Details for New Brunswick[1]

Greenhouse Gas Emissions
kt CO_2 eq

Sources	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Coal	1 140	940	1 030	1 190	2 680	3 040	3 150	3 030	3 240	3 130	2 820	X	X	X	X
Refined Petroleum Products[2]	4 700	4 320	4 950	3 830	3 280	3 560	2 670	5 090	5 970	4 820	5 550	X	X	X	X
Natural Gas	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Nuclear	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Hydro[3]	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Biomass[4]	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Others[5]	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Total	**5 840**	**5 270**	**5 980**	**5 010**	**5 960**	**6 600**	**5 820**	**8 120**	**9 210**	**7 950**	**8 360**	**X**	**X**	**X**	**X**

Electricity Generation[a]
GWh

Sources	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Coal	1 285	1 120	1 226	1 377	3 118	3 445	3 551	3 625	3 901	3 885	3 607	3 849	3 462	4 296	2 999
Refined Petroleum Products[2]	6 092	5 718	6 477	4 931	4 249	4 538	3 308	6 564	7 687	6 415	7 586	8 455	7 184	6 443	8 384
Natural Gas	0	0	0	0	0	0	0	0	0	0	0	0	245	1 331	1 137
Nuclear	5 338	5 440	4 833	5 323	5 239	1 579	4 591	3 444	3 773	4 083	3 959	4 487	3 757	4 742	4 299
Hydro[3]	3 533	3 003	3 011	3 057	2 773	2 706	3 532	2 373	2 862	3 380	3 293	2 059	2 251	3 233	3 013
Biomass[4]	505	527	462	471	516	520	507	779	815	910	847	871	974	914	931
Others[5]	0	0	0	0	0	0	0	0	0	2	3	8	10	9	9
Total	**16 752**	**15 808**	**16 009**	**15 158**	**15 895**	**12 788**	**15 488**	**16 784**	**19 038**	**18 676**	**19 295**	**19 728**	**17 883**	**20 968**	**20 772**

Greenhouse Gas Intensity[7]
g CO_2 eq/kWh

Sources	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Coal	880	840	840	860	860	880	890	840	830	810	780	X	X	X	X
Refined Petroleum Products[2]	772	756	764	776	772	784	806	775	777	750	730	X	X	X	X
Natural Gas	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Nuclear	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Hydro[3]	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Biomass[4]	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Others[5, 6]	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Average Intensity	**348**	**333**	**374**	**331**	**375**	**516**	**376**	**484**	**484**	**426**	**433**	**X**	**X**	**X**	**X**

Source:

a Report on Energy Supply – Demand in Canada, Catalogue No. 57-003, Statistics Canada.

Notes:

1 Data presented include both utility and industrial emissions, generation, and intensity.
2 Includes emissions from the use of light fuel oil, heavy fuel oil, and diesel fuel oil.
3 Emissions from the flooding of land for hydro dams are not included.
4 Emissions related to the use of biomass for electric power generation are not included.
5 Others – includes electricity generation by wind, tidal, and other refined petroleum product fuels.
6 Greenhouse Gas Intensity for Others – emission intensity values are not shown due to the miscellaneous nature of other categories.
7 Accuracy of GHG intensity diminished in cases where industrial cogeneration is significant.
X Denotes confidential values.

TABLE A9-6: Electricity Generation and Greenhouse Gas Emission Details for Quebec[1]

	Greenhouse Gas Emissions *kt CO_2 eq*														
Sources	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Coal	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Refined Petroleum Products[2]	1 360	374	794	144	310	188	184	215	1 330	910	310	340	240	1 500	1 280
Natural Gas	75	75	75	75	82	80	81	81	76	63	72	68	72	73	74
Nuclear	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Hydro[3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Biomass[4]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Others[5]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Total	**1 430**	**448**	**869**	**219**	**392**	**268**	**265**	**296**	**1 400**	**980**	**380**	**410**	**310**	**1 580**	**1 350**
	Electricity Generation[a] *GWh*														
Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Refined Petroleum Products[2]	1 707	415	1 015	166	247	370	556	695	2 329	1 753	869	1 047	894	2 972	2 472
Natural Gas	156	123	145	140	105	268	385	392	252	244	332	358	428	214	209
Nuclear	4 070	3 910	4 600	4 807	5 406	4 511	5 243	4 204	3 814	3 775	4 886	4 705	4 530	3 548	4 878
Hydro[3]	129 939	138 550	141 983	150 048	157 851	167 946	165 016	160 686	148 148	162 890	173 179	164 529	170 713	170 498	166 759
Biomass[4]	0	0	0	0	0	0	185	273	403	506	478	485	584	617	634
Others[5]	11	0	0	0	0	4	1	5	4	8	13	7	0	0	0
Total	**135 883**	**142 998**	**147 743**	**155 160**	**163 609**	**173 099**	**171 386**	**166 255**	**154 950**	**169 176**	**179 757**	**171 131**	**177 150**	**177 849**	**174 951**
	Greenhouse Gas Intensity[7] *g CO_2 eq/kWh*														
Coal	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Refined Petroleum Products[2]	795	900	782	869	1 257	508	331	309	569	520	360	330	270	510	520
Natural Gas	482	607	519	538	776	300	210	206	302	259	217	189	168	344	353
Nuclear	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Hydro[3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Biomass[4]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Others[5, 6]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Average Intensity	**11**	**3**	**6**	**1**	**2**	**2**	**2**	**2**	**9**	**6**	**2**	**2**	**2**	**9**	**8**

Source:

a Report on Energy Supply – Demand in Canada, Catalogue No. 57-003, Statistics Canada.

Notes:

1 Data presented include both utility and industrial emissions, generation, and intensity.
2 Includes emissions from the use of light fuel oil, heavy fuel oil, and diesel fuel oil.
3 Emissions from the flooding of land for hydro dams are not included.
4 Emissions related to the use of biomass for electric power generation are not included.
5 Others – includes electricity generation by wind, tidal, and other refined petroleum product fuels.
6 Greenhouse Gas Intensity for Others – emission intensity values are not shown due to the miscellaneous nature of other categories.
7 Accuracy of GHG intensity diminished in cases where industrial cogeneration is significant.

TABLE A9-7: Electricity Generation and Greenhouse Gas Emission Details for Ontario[1]

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Greenhouse Gas Emissions *kt CO_2 eq*															
Coal	24 800	26 200	25 400	16 500	13 500	14 300	16 400	20 600	27 200	28 200	36 200	33 300	33 100	37 300	27 700
Refined Petroleum Products[2]	1 130	934	710	139	278	348	308	356	1 210	1 060	400	690	500	1 110	720
Natural Gas	528	554	1 270	1 550	1 900	3 750	3 650	4 290	4 500	5 620	5 460	6 040	6 160	6 600	5 860
Nuclear	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Hydro[3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Biomass[4]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Others[5]	26	56	61	70	78	79	86	329	235	264	223	186	283	252	273
Total	26 400	27 700	27 400	18 300	15 800	18 500	20 500	25 600	33 100	35 200	42 300	40 200	40 100	45 300	34 600
Electricity Generation[a] *GWh*															
Coal	26 121	30 298	28 221	19 452	16 377	16 677	19 515	26 310	34 096	34 809	42 442	38 236	37 951	37 511	27 593
Refined Petroleum Products[2]	1 377	1 238	894	169	378	508	519	547	1 657	1 525	583	982	762	1 289	826
Natural Gas	1 597	1 683	2 996	3 545	4 302	7 750	7 892	8 874	9 838	12 143	11 283	12 216	12 959	12 073	10 644
Nuclear	59 353	70 773	66 586	78 509	91 066	86 216	77 676	70 209	59 879	61 473	59 829	63 128	62 965	62 003	76 063
Hydro[3]	40 561	37 647	40 151	40 753	39 311	38 809	41 662	39 963	35 416	37 294	37 908	37 136	38 438	36 062	39 500
Biomass[4]	657	611	761	687	792	860	790	918	947	922	972	964	1 020	881	954
Others[5]	108	194	180	195	203	199	219	221	262	228	204	194	240	232	266
Total	129 773	142 444	139 788	143 310	152 430	151 018	148 271	147 041	142 094	148 392	153 221	152 856	154 336	150 051	155 847
Greenhouse Gas Intensity[7] *g CO_2 eq/kWh*															
Coal	948	865	899	848	826	859	841	782	797	811	852	871	872	995	1 004
Refined Petroleum Products[2]	824	754	794	822	735	686	594	652	728	690	690	700	660	860	870
Natural Gas	330	329	424	438	442	484	463	483	458	463	484	495	475	547	550
Nuclear	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Hydro[3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Biomass[4]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Others[5, 6]	238	287	342	359	384	399	393	1 490	899	1 160	1 090	957	1 180	1 090	1 030
Average Intensity	204	195	196	127	104	123	138	174	233	237	276	263	259	302	222

Source:

a Report on Energy Supply – Demand in Canada, Catalogue No. 57-003, Statistics Canada.

Notes:

1 Data presented include both utility and industrial emissions, generation, and intensity.

2 Includes emissions from the use of light fuel oil, heavy fuel oil, and diesel fuel oil.

3 Emissions from the flooding of land for hydro dams are not included.

4 Emissions related to the use of biomass for electric power generation are not included.

5 Others – includes electricity generation by wind, tidal, and other refined petroleum product fuels.

6 Greenhouse Gas Intensity for Others – emission intensity values are not shown due to the miscellaneous nature of other categories.

7 Accuracy of GHG intensity diminished in cases where industrial cogeneration is significant.

TABLE A9-8: Electricity Generation and Greenhouse Gas Emission Details for Manitoba[1]

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Greenhouse Gas Emissions *kt CO_2 eq*															
Coal	455	352	351	252	276	180	282	224	944	522	971	X	X	X	X
Refined Petroleum Products[2]	66	64	61	30	45	35	56	20	18	24	22	X	X	X	X
Natural Gas	3	2	5	2	2	4	2	0	0	0	0	X	X	X	X
Nuclear	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Hydro[3]	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Biomass[4]	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Others[5]	0	0	0	0	0	0	0	0	0	0	0	X	X	X	X
Total	**525**	**418**	**417**	**284**	**323**	**219**	**340**	**244**	**962**	**546**	**993**	**X**	**X**	**X**	**X**
Electricity Generation[a] *GWh*															
Coal	322	233	237	188	195	128	200	178	844	461	869	443	365	611	296
Refined Petroleum Products[2]	61	65	57	31	54	57	61	27	25	36	36	45	46	33	32
Natural Gas	13	9	14	9	8	14	11	1	0	0	0	0	134	184	63
Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydro[3]	19 827	22 554	26 434	26 891	28 146	29 013	30 866	33 391	30 781	28 138	31 536	32 899	28 821	20 246	27 219
Biomass[4]	31	30	43	40	42	26	45	64	74	56	60	61	72	67	75
Others[5]	0	0	0	0	0	0	0	0	0	0	0	0	0	12	18
Total	**20 254**	**22 891**	**26 785**	**27 159**	**28 445**	**29 238**	**31 184**	**33 661**	**31 724**	**28 691**	**32 501**	**33 448**	**29 438**	**21 152**	**27 703**
Greenhouse Gas Intensity[7] *g CO_2 eq/kWh*															
Coal	1 410	1 510	1 480	1 340	1 420	1 410	1 410	1 260	1 120	1 130	1 120	X	X	X	X
Refined Petroleum Products[2]	1 080	999	1 080	970	828	616	911	741	733	650	600	X	X	X	X
Natural Gas	236	248	371	257	238	258	225	272	–	–	–	X	X	X	X
Nuclear	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Hydro[3]	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Biomass[4]	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Others[5, 6]	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Average Intensity	**26**	**18**	**16**	**11**	**11**	**7**	**11**	**7**	**30**	**19**	**31**	**X**	**X**	**X**	**X**

Source:

a Report on Energy Supply – Demand in Canada, Catalogue No. 57-003, Statistics Canada.

Notes:

1 Data presented include both utility and industrial emissions, generation, and intensity.

2 Includes emissions from the use of light fuel oil, heavy fuel oil, and diesel fuel oil.

3 Emissions from the flooding of land for hydro dams are not included.

4 Emissions related to the use of biomass for electric power generation are not included.

5 Others – includes electricity generation by wind, tidal, and other refined petroleum product fuels.

6 Greenhouse Gas Intensity for Others – emission intensity values are not shown due to the miscellaneous nature of other categories.

7 Accuracy of GHG intensity diminished in cases where industrial cogeneration is significant.

X Denotes confidential values.

TABLE A9-9: Electricity Generation and Greenhouse Gas Emission Details for Saskatchewan[1]

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Greenhouse Gas Emissions *kt CO_2 eq*															
Coal	10 100	10 300	11 600	12 100	13 100	13 400	13 500	14 000	14 100	14 000	13 200	X	X	X	X
Refined Petroleum Products[2]	22	21	21	19	28	57	63	82	50	50	40	X	X	X	X
Natural Gas	260	306	571	268	129	412	419	759	989	880	1 440	X	X	X	X
Nuclear	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Hydro[3]	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Biomass[4]	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Others[5]	0	0	0	0	0	0	0	0	0	0	0	X	X	X	X
Total	**10 400**	**10 600**	**12 100**	**12 400**	**13 300**	**13 900**	**14 000**	**14 900**	**15 100**	**14 900**	**14 700**	**X**	**X**	**X**	**X**
Electricity Generation[a] *GWh*															
Coal	8 634	8 617	9 889	10 443	11 544	11 258	11 175	11 290	11 622	11 644	11 819	11 756	11 848	11 576	12 157
Refined Petroleum Products[2]	47	43	46	41	64	95	95	98	58	59	50	40	37	34	30
Natural Gas	545	622	1 048	579	374	816	813	1 337	1 725	1 483	2 448	2 678	2 839	4 440	4 152
Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydro[3]	4 215	4 214	3 059	4 051	3 393	4 118	4 376	3 987	3 442	3 689	3 046	2 393	2 879	3 475	2 820
Biomass[4]	100	102	94	98	103	107	96	126	114	115	125	349	367	265	277
Others[5]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**13 541**	**13 598**	**14 137**	**15 212**	**15 479**	**16 394**	**16 554**	**16 837**	**16 961**	**16 988**	**17 488**	**17 215**	**17 970**	**19 790**	**19 437**
Greenhouse Gas Intensity[7] *g CO_2 eq/kWh*															
Coal	1 170	1 190	1 170	1 160	1 140	1 190	1 210	1 240	1 210	1 200	1 120	X	X	X	X
Refined Petroleum Products[2]	478	480	459	473	433	594	666	841	853	850	810	X	X	X	X
Natural Gas	476	492	545	464	345	506	516	568	573	594	590	X	X	X	X
Nuclear	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Hydro[3]	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Biomass[4]	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Others[5, 6]	–	–	–	–	–	–	–	–	–	–	–	X	X	X	X
Average Intensity	**765**	**780**	**859**	**815**	**857**	**846**	**847**	**882**	**891**	**878**	**840**	**X**	**X**	**X**	**X**

Source:

a Report on Energy Supply – Demand in Canada, Catalogue No. 57-003, Statistics Canada.

Notes:

1 Data presented include both utility and industrial emissions, generation, and intensity.

2 Includes emissions from the use of light fuel oil, heavy fuel oil, and diesel fuel oil.

3 Emissions from the flooding of land for hydro dams are not included.

4 Emissions related to the use of biomass for electric power generation are not included.

5 Others – includes electricity generation by wind, tidal, and other refined petroleum product fuels.

6 Greenhouse Gas Intensity for Others – emission intensity values are not shown due to the miscellaneous nature of other categories.

7 Accuracy of GHG intensity diminished in cases where industrial cogeneration is significant.

X Denotes confidential values.

TABLE A9-10: Electricity Generation and Greenhouse Gas Emission Details for Alberta[1]

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Greenhouse Gas Emissions *kt CO_2 eq*															
Coal	37 300	39 400	41 700	42 600	46 000	46 300	44 900	46 700	46 200	44 300	44 000	45 200	46 000	45 600	45 200
Refined Petroleum Products[2]	12	14	15	18	18	16	43	8	31	30	40	30	30	40	40
Natural Gas	2 290	2 040	2 850	2 810	2 790	2 220	2 900	3 350	4 360	4 480	6 550	6 210	5 060	5 260	4 640
Nuclear	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Hydro[3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Biomass[4]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Others[5]	334	345	425	392	543	443	260	770	840	970	1 040	1 190	1 190	3 200	2 220
Total	**40 000**	**41 800**	**45 000**	**45 800**	**49 300**	**49 000**	**48 100**	**50 800**	**51 400**	**49 800**	**51 700**	**52 600**	**52 300**	**54 100**	**52 100**
Electricity Generation[a] *GWh*															
Coal	34 672	36 391	38 373	39 066	42 467	43 069	41 596	43 134	42 332	41 814	42 199	45 943	47 189	43 368	44 586
Refined Petroleum Products[2]	14	16	18	21	21	20	52	10	39	33	41	39	37	2 508	1 507
Natural Gas	4 971	4 484	5 960	5 911	6 000	5 111	6 273	6 817	8 816	8 516	12 141	11 969	9 998	9 971	8 944
Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydro[3]	2 060	2 030	1 563	1 808	1 806	2 190	1 990	1 837	2 098	2 239	1 845	1 568	1 884	2 162	2 497
Biomass[4]	446	557	565	717	771	756	725	828	821	829	778	1 216	1 220	1 236	1 246
Others[5]	999	1 001	1 139	1 141	1 295	1 308	1 316	535	315	1 716	1 530	1 303	1 313	1 069	1 663
Total	**43 162**	**44 480**	**47 617**	**48 663**	**52 361**	**52 453**	**51 951**	**53 161**	**54 421**	**55 147**	**58 534**	**62 038**	**61 641**	**60 314**	**60 443**
Greenhouse Gas Intensity[7] *g CO_2 eq/kWh*															
Coal	1 080	1 080	1 090	1 090	1 080	1 070	1 080	1 080	1 090	1 060	1 040	980	980	1 050	1 010
Refined Petroleum Products[2]	857	841	851	847	845	835	832	792	793	830	850	790	690	20	30
Natural Gas	461	455	478	475	465	435	463	492	495	526	539	519	506	528	519
Nuclear	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Hydro[3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Biomass[4]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Others[5, 6]	334	345	373	343	419	339	198	1 450	2 680	564	677	915	904	2 991	1 332
Average Intensity	**926**	**940**	**946**	**941**	**942**	**934**	**927**	**956**	**944**	**902**	**882**	**848**	**849**	**898**	**861**

Source:

a Report on Energy Supply – Demand in Canada, Catalogue No. 57-003, Statistics Canada.

Notes:

1 Data presented include both utility and industrial emissions, generation, and intensity.

2 Includes emissions from the use of light fuel oil, heavy fuel oil, and diesel fuel oil.

3 Emissions from the flooding of land for hydro dams are not included.

4 Emissions related to the use of biomass for electric power generation are not included.

5 Others – includes electricity generation by wind, tidal, and other refined petroleum product fuels.

6 Greenhouse Gas Intensity for Others – emission intensity values are not shown due to the miscellaneous nature of other categories.

7 Accuracy of GHG intensity diminished in cases where industrial cogeneration is significant

TABLE A9-11: Electricity Generation and Greenhouse Gas Emission Details for British Columbia[1]

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Greenhouse Gas Emissions *kt CO_2 eq*															
Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Refined Petroleum Products[2]	333	532	236	243	118	91	135	77	76	70	88	108	60	82	85
Natural Gas	841	507	1 030	2 100	2 060	2 610	632	1 110	1 770	1 200	2 360	2 920	1 120	1 250	1 380
Nuclear	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Hydro[3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Biomass[4]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Others[5]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**1 170**	**1 040**	**1 270**	**2 340**	**2 180**	**2 700**	**770**	**1 190**	**1 840**	**1 270**	**2 450**	**3 030**	**1 180**	**1 330**	**1 460**
Electricity Generation[a] *GWh*															
Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Refined Petroleum Products[2]	510	688	391	433	213	169	373	223	141	154	157	204	140	165	180
Natural Gas	1 647	1 040	1 999	4 012	4 523	5 728	1 675	2 508	3 795	3 190	5 106	6 454	3 126	3 440	4 065
Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydro[3]	57 308	60 197	60 663	53 174	54 305	50 181	67 668	63 332	60 860	61 582	60 208	49 162	58 878	56 929	54 653
Biomass[4]	1 549	1 458	1 778	2 030	2 630	2 540	2 583	2 383	2 402	2 893	2 921	2 660	2 775	2 766	2 948
Others[5]	0	0	0	103	401	436	374	438	573	362	293	283	416	82	105
Total	**61 015**	**63 383**	**64 831**	**59 753**	**62 071**	**59 054**	**72 673**	**68 884**	**67 771**	**68 182**	**68 684**	**58 763**	**65 335**	**63 382**	**61 951**
Greenhouse Gas Intensity[7] *g CO_2 eq/kWh*															
Coal	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Refined Petroleum Products[2]	653	773	605	562	555	536	363	346	538	450	560	530	430	500	470
Natural Gas	510	488	516	523	456	456	378	442	466	376	463	453	359	363	339
Nuclear	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Hydro[3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Biomass[4]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Others[5, 6]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Average Intensity	**19**	**16**	**20**	**39**	**35**	**46**	**11**	**17**	**27**	**19**	**36**	**52**	**18**	**21**	**24**

Source:

a Report on Energy Supply – Demand in Canada, Catalogue No. 57-003, Statistics Canada.

Notes:

1 Data presented include both utility and industrial emissions, generation, and intensity.

2 Includes emissions from the use of light fuel oil, heavy fuel oil, and diesel fuel oil.

3 Emissions from the flooding of land for hydro dams are not included.

4 Emissions related to the use of biomass for electric power generation are not included.

5 Others – includes electricity generation by wind, tidal, and other refined petroleum product fuels.

6 Greenhouse Gas Intensity for Others – emission intensity values are not shown due to the miscellaneous nature of other categories.

7 Accuracy of GHG intensity diminished in cases where industrial cogeneration is significant.

TABLE A9-12: Electricity Generation and Greenhouse Gas Emission Details for Yukon, Northwest Territories, and Nunavut[1]

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Greenhouse Gas Emissions *kt CO_2 eq*															
Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Refined Petroleum Products[2]	262	224	188	176	176	355	378	360	304	273	239	247	198	200	218
Natural Gas	49	51	53	53	50	71	77	77	56	56	72	70	78	82	68
Nuclear	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Hydro[3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Biomass[4]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Others[5]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**311**	**274**	**240**	**228**	**226**	**426**	**455**	**437**	**360**	**329**	**310**	**317**	**275**	**282**	**286**
Electricity Generation[a] *GWh*															
Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Refined Petroleum Products[2]	289	293	291	285	330	578	608	524	373	306	396	430	392	433	448
Natural Gas	89	92	96	96	94	99	103	103	102	103	107	105	108	110	106
Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydro[3]	674	647	681	553	454	518	625	550	527	555	560	563	555	556	595
Biomass[4]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Others[5]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**1052**	**1033**	**1068**	**934**	**877**	**1194**	**1335**	**1177**	**1002**	**963**	**1063**	**1099**	**1055**	**1099**	**1149**
Greenhouse Gas Intensity[7] *g CO_2 eq/kWh*															
Coal	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Refined Petroleum Products[2]	905	762	646	615	534	614	622	686	816	890	600	570	500	460	490
Natural Gas	550	550	547	547	539	721	748	747	542	546	668	666	719	747	640
Nuclear	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Hydro[3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Biomass[4]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Others[5, 6]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Average Intensity	**295**	**266**	**225**	**244**	**258**	**357**	**341**	**371**	**359**	**341**	**292**	**288**	**261**	**257**	**249**

Source:

a Report on Energy Supply – Demand in Canada, Catalogue No. 57-003, Statistics Canada.

Notes:

1 Data presented include both utility and industrial emissions, generation, and intensity.

2 Includes emissions from the use of light fuel oil, heavy fuel oil, and diesel fuel oil.

3 Emissions from the flooding of land for hydro dams are not included.

4 Emissions related to the use of biomass for electric power generation are not included.

5 Others – includes electricity generation by wind, tidal, and other refined petroleum product fuels.

6 Greenhouse Gas Intensity for Others – emission intensity values are not shown due to the miscellaneous nature of other categories.

7 Accuracy of GHG intensity diminished in cases where industrial cogeneration is significant.

REFERENCES

Statistics Canada, *Report on Energy Supply–Demand in Canada* (Annual), Catalogue No. 57-003-XIB.

ANNEX 10: ANALYSIS OF EMISSION TRENDS FOR CANADIAN INDUSTRIAL SECTORS

A10.1 INTRODUCTION

This annex discusses, identifies, and groups together the GHG emissions and GDP indicators for a series of Canadian industrial sectors. This analysis is different from any other discussion presented in this report, in that it provides information by industrial sector rather than using the standard IPCC format.

In other places within this report, information and discussions are separated into the six conventional IPCC sectors: Energy, Industrial Processes, Solvent and Other Product Use, Agriculture, LULUCF, and Waste. This examination of GHG emissions groups emission data that may otherwise appear in separate IPCC sectors into the Canadian industrial sectors in which they occur. That is, for a given industry, fuel combustion, process-related, and fugitive emissions are combined, and industry emission totals are provided for each sector. Overall emission details along with corresponding GDP indicators by industrial sector are presented in Table A10-1.

In addition, fuel combustion emissions include both stationary and transport-related sources. Emissions associated with off-road machinery and equipment are grouped into the various industrial sectors in which they occur, such as the fossil fuel industry, mining, and other industries (which include agriculture and the forestry industry). Fugitive sources include flaring and venting emissions from fossil fuel production and processing. Table A10-2 provides a detailed breakdown of fugitive emissions by activity.

In Table A10-1, Canadian industrial sectors are separated into categories based on the NAICS. Fuel combustion emissions are consistent with the NAICS code breakdown used by Statistics Canada's Industrial Consumption of Energy survey and the RESD (Statistics Canada, #57-003); as such, the RESD should be used as a reference to interpret the NAICS groupings.

TABLE A10-1: GHG Emissions by Industrial Sector for 1990, 1995, 2000, and 2004

		Greenhouse Gas Emissions[1]																GDP			
		Total GHG Emissions				Energy: Fuel Combustion				Industrial Processes				Fugitive[2]							
		1990	1995	2000	2004	1990	1995	2000	2004	1990	1995	2000	2004	1990	1995	2000	2004	1990	1995	2000	2004
Industrial Sector	**NAICS Code**	*Mt CO_2 eq*																$Million (constant 1997 dollars)			
Fossil Fuel Industry		**103**	**126**	**146**	**155**	**60.0**	**68.6**	**81.5**	**88.2**	–	–	–	–	**43**	**57**	**65**	**66**	**22 067**	**29 260**	**30 714**	**33 529**
Upstream Fossil Fuel Industry		83.9	107	125	133	43.5	52.5	62.8	68.6	–	–	–	–	40	53	61	62	18 123	24 823	25 753	28 304
Crude Oil Production Industry[4]	211	22.5	29.9	35.9	50.2	5.77	7.92	10.2	25.4	–	–	–	–	17	22	26	25	15 795[3]	22 355[3]	21 609[3]	23 580[3]
Natural Gas Industry		26.8	37.1	45.7	34.2	12.8	17.3	22.7	10.6	–	–	–	–	14	20	23	24				
Other – Oil Sands, Coal, and Coke Production[5]		23.5	22.9	26.8	34.3	18.7	16.4	20.5	26.6	–	–	–	–	4.8	6.5	6.2	7.7				
Natural Gas Transmission	486	11.2	17.1	16.8	14.2	6.90	12.0	11.3	8.52	–	–	–	–	4.3	5.1	5.6	5.7	2 328	3 793	4 144	4 724
Downstream Fossil Fuel Industry		19.5	18.6	21.3	21.7	15.9	15.0	16.9	17.0	–	–	–	–	3.5	3.6	4.4	4.7	3 944	4 437	4 961	5 225
Petroleum Refining Industry	324	16.7	15.6	18.0	18.3	15.9	15.0	16.9	17.0	–	–	–	–	0.8	0.6	1.1	1.3	1 516	1 538	1 629	1 972
Natural Gas Distribution	2212	2.8	3.0	3.3	3.4	–	–	–	–	–	–	–	–	2.8	3.0	3.3	3.4	2 428	2 899	3 332	3 253
Mining and Manufacturing Industries		**131**	**133**	**134**	**139**	**77.8**	**77.9**	**83.9**	**84.4**	**53**	**56**	**50**	**54**	–	–	–	–	**199 024**	**201 063**	**264 737**	**277 641**
Mining[6]	212	8.5	10.4	14.0	17.8	8.47	10.4	14.0	17.8	–	–	–	–	–	–	–	–	11 397	11 641	13 850	16 845
Smelting and Refining Industries	3313, 3314, & 33152	15.6	14.4	14.2	12.7	3.23	3.11	3.19	3.23	12	11	11	9.5	–	–	–	–	3 390	3 966	6 164	6 724
Pulp, Paper, and Saw Mills	322	13.6	11.7	11.0	9.31	13.6	11.7	11.0	9.31	–	–	–	–	–	–	–	–	9 794	10 550	12 043	11 713
Primary & Other Steel Industries	3311, 3312, & 33151	13.5	14.9	15.1	14.7	6.49	7.04	7.19	6.55	7.1	7.9	7.9	8.2	–	–	–	–	4 515	4 975	5 503	5 362
Cement	32731	9.02	9.51	10.7	11.4	3.59	3.42	3.97	4.33	5.4	6.1	6.7	7.1	–	–	–	–	706.6	547.5	679	749
Industrial Chemical Industries	3251 & 3253	27.7	30.5	19.8	21.8	7.10	8.46	7.86	6.29	21	22	12	15	–	–	–	–	4 257	4 331	5 303	5 433
Other Manufacturing[7] (all others not included elsewhere)	311 to 339 (not listed elsewhere)	28.7	27.6	32.2	35.3	20.9	19.4	20.0	21.2	7.8	8.2	12	14	–	–	–	–	101 694	110 850	156 180	154 933
Other Industries[8]	23, 111 to 114 and 1151 to 1153	14.5	14.4	16.7	15.6	14.5	14.4	16.7	15.6	–	–	–	–	–	–	–	–	63 270	54 203	65 015	75 882

Notes:

1 Totals may not add due to rounding.

2 Fugitive: Includes emissions from production and processing vents, flaring activities, equipment leaks, storage losses, transmission and distribution losses, accidents, and spills.

3 GDP values for Crude Oil Production Industry, Natural Gas Industry, and Other - Oil Sands, Coal, and Coke Production were calculated as a combined GDP total.

4 Crude Oil Production Industry includes emissions associated with conventional crude oil and thermal heavy synthetic oil production.

5 Other – Oil Sands, Coal, and Coke Production also includes emissions from combined oil and gas production and emissions associated with oil sands mining equipment.

6 Mining excludes off-road emissions from oil and gas production.

7 Other Manufacturing includes emissions associated with product use (such as HFCs, PFCs, and SF_6) and emissions from the food production industry, vehicle and vehicle parts production, textiles, plastics, pharmaceuticals and medicine, etc.

8 Other Industries includes the construction, agriculture, and forestry sector.

References:

GDP – Informetrica Limited, Industrial GDP at Basic Prices by NAICS in 1997 Dollars: 1981–2025, Informetrica Limited, Ottawa, Ontario, Canada.

Corresponding NAICS identification number: Statistics Canada, 2004 Report on Energy Supply – Demand in Canada, Catalogue No. 57-003-XIB.

A10.2 FOSSIL FUEL INDUSTRY

The fossil fuel industry as a whole contributed 155 Mt (20%) of Canada's total GHG emissions in 2004, of which 133 Mt (over 86%) were contributed by the upstream industry and 21.7 Mt (14%) by the downstream industry. Of the overall emissions, fuel combustion and fugitive emission sources accounted for 57% and 43%, respectively. Of the 66 Mt of emissions from fugitive sources in 2004, over 48% (32 Mt) are attributed to venting,[55] another 44% (or 29 Mt) to production and process vents, and the remaining 8.2% (or 5.4 Mt) to flaring-related activities. Emission details for the industry are presented in Table A10-1 and Table A10-2.

From an economic standpoint, the fossil fuel industry's GDP grew by 52% between 1990 and 2004, accounting for over $33.5 billion in 2004 (Informetrica Limited and Statistics Canada). The upstream fossil fuel industry saw an increase of approximately 56% (or $10.2 billion) in economic activity, while the downstream (refining and distribution) industry's economic growth was about 33% (or $1.28 billion).

GHG emissions also increased as a result of growing foreign sales. Since 1990, the fossil fuel industry has experienced a 192% rise in net energy exports,[56] with an increase of 48 Mt (123%) in GHG emissions associated with those exports alone.

In 2004, emissions from the upstream fossil fuel industry were dominated by those from crude oil production and natural gas production, with a combined total of 65% (84.4 Mt). This is followed by oil sands mining, extraction, and upgrading, which accounted for over 18% of the overall emissions.[57] The remaining contributions of about 6% and 11% are mainly from the coal and coke production industry and from natural gas transmission activities. Emissions from asphalt plants and from combined oil and gas activities that cannot be disaggregated are also included in the other – oil sands, coal, and coke production category.

TABLE A10-2: Fossil Fuel Industry's Emission Details for 2004

Industrial Sector	Total GHG Emissions[1]	Energy: Fuel Combustion	Fugitive[2]		
	Mt CO_2 eq				
			Production/Process Vent	Flaring	Venting
Fossil Fuel Industry	**155**	**88.2**	**29**	**5.4**	**32**
Upstream Fossil Fuel Industry	**133**	**68.6**	**28**	**5.2**	**29**
Crude Oil Production Industry[3]	50.2	25.4	6.5	2.9	15
Natural Gas Industry	34.2	10.6	19	0.5	3.9
Other – Oil Sands, Coal, and Coke Production[4]	34.3	26.6	2.4	1.7	3.6
Natural Gas Transmission	14.2	8.5	–	–	5.7
Downstream Fossil Fuel Industry	**21.7**	**17.0**	**1.1**	**0.2**	**3.4**
Petroleum Refining Industry	18.3	17.0	1.1	0.2	–
Natural Gas Distribution	3.4	–	–	–	3.4

Notes:
1 Totals may not add due to rounding.
2 Fugitive: Includes emissions from production and processing vents, flaring activities, equipment leaks, storage losses, transmission and distribution losses, accidents, and spills.
3 Crude Oil Production Industry includes emissions associated with conventional crude oil and thermal heavy synthetic oil production.
4 Other – Oil Sands, Coal, and Coke Production also includes emissions from combined oil and gas production and emissions associated with oil sands mining equipment.

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[55] Venting is considered to be an unintentional loss. Production and process vents (and flaring) are considered to be intentional.

[56] Net energy exports are the totals of exports minus imports of all oil and gas products.

[57] Note that the synthetic crude oil industry (including oil sands and thermal synthetic production) has been expanding quickly. It is expected to continue to grow rapidly in the future. As a consequence, GHG emissions from synthetic oil production are projected to overshadow those from conventional oil and natural gas production combined within 10–20 years (Nyboer and Tu, 2006).

Between 1990 and 2004, the upstream fossil fuel industry experienced more than 56% growth in GDP, with an increase of about 57% in GHG emissions. In 2004, fossil fuel production contributed 116 Mt of emissions to the upstream sector, while the transmission of natural gas contributed the remaining 14.2 Mt. The natural gas transmission sector experienced a 103% growth in GDP in the 1990–2004 period. The downstream petroleum refining and natural gas distribution industries experienced 30% and 34% growth in GDP, with only 1.6 and 0.6 Mt increases in emissions, respectively.

A10.3 MINING AND MANUFACTURING INDUSTRIES

Overall, the mining and manufacturing industries contributed 139 Mt (18%) of Canada's total GHG emissions in 2004, of which combustion-related emissions accounted for about 61%, followed by process-related sources, with over 39%. Between 1990 and 2004, GHG emissions and GDP grew by 5.7% (7.5 Mt) and 40% ($78.6 billion), respectively. Over 92.3 Mt (66%) of the mining and manufacturing emissions are from the other manufacturing, industrial chemical, mining, and other industries. While some industrial sectors experienced an increase in GHG emissions since 1990, the smelting and refining, pulp, paper, and saw mills, and industrial chemical industries saw their emissions fall by 2.9, 4.3, and 5.9 Mt, respectively. For more details on the mining and manufacturing industries, refer to Table A10-1 and Table A10-3. Table A10-3 is a further breakdown of the industrial process emissions included in Table A10-1.

In total, the mining and manufacturing industries contributed $278 billion to Canada's GDP in 2004. It should be noted that the overall economic GHG intensity of this broad sector was 0.51 Mt per billion dollars, 30% below the Canadian average of 0.725 Mt per billion dollars.[58] In the same year, the fossil fuel industry, which contributed about $33 billion to Canada's GDP, displayed an economic intensity of 4.6 Mt per billion dollars, more than six times the national average.

TABLE A10-3: Breakdown of Emissions from Process Sources for 1990, 2003, and 2004[1]

	Emissions *Mt CO_2 eq* 1990	 2003	 2004
Mining and Manufacturing Industries	**53**	**50**	**54**
Mining	–	–	–
Smelting and Refining Industries	12	10	9.5
Aluminium Production	9.3	7.7	7.3
Magnesium Production	2.9	2.2	2.0
Magnesium Casting	0.2	0.3	0.2
Pulp, Paper, and Saw Mills	–	–	–
Primary & Other Steel Industries	**7.1**	**7.0**	**8.2**
Cement	**5.4**	**6.8**	**7.1**
Industrial Chemical Industries	**21**	**12**	**15**
Ammonia Production	3.9	5.1	5.7
Adipic Acid Production	10.7	1.1	3.1
Nitric Acid Production	0.8	0.8	0.8
Non-Energy Use of Liquid and Gaseous Fuels[2]	5.2	5.5	5.9
Other Manufacturing[3]	**7.8**	**14**	**14**
Lime Production	1.7	1.6	1.8
Limestone and Dolomite Use	0.7	0.3	0.3
Soda Ash Use	0.2	0.1	0.1
Magnesite Use	0.1	0.2	0.2
Consumption of Halocarbons	0.0	4.4	4.7
Consumption of SF_6[4]	1.8	1.6	0.8
Non-Energy Use of Solid Fuels[5]	1.3	1.6	1.5
Other Refined Petroleum Products (lubricating oils and greases, waxes, etc.)	1.8	3.8	4.7

Notes:

1 Totals may not add due to rounding.

2 Includes process emissions associated with non-energy use of NGLs, petrochemical feedstocks, naphthas, and natural gas (minus those already accounted for in ammonia production).

3 Other Manufacturing also includes emissions associated with the use of halocarbons and SF_6.

4 Includes SF_6 emissions from its use in semiconductor manufacturing and electric utilities.

5 Includes process emissions associated with non-energy use of primary and secondary solid fuels, such as coal, lignite, metallurgical coke, and petroleum coke (minus those already accounted for in aluminium production).

A10.3.1 MINING

The mining industry contributed 17.8 Mt (2.3%) to Canada's GHG emissions in 2004. Between 1990 and 2004, the industry observed a 48% increase in sector GDP (Informetrica Limited and Statistics Canada), while GHG emissions rose by 9.3 Mt. Emissions from combustion activities increased by about 110%. This was impacted by increasing demand for natural gas, which grew by over 243% since 1990.

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[58] See Table S-1, Executive Summary.

Low GHG-intensive fossil fuels, such as natural gas, accounted for 85% of the overall fuel mix in 2004, relative to 68% in 1990. Also, in 2004, refined petroleum products, including propane, butane, and ethane, contributed 13% to the overall fuel mix, relative to a 24% contribution in 1990 (Statistics Canada, #57-003).

A10.3.2 SMELTING AND REFINING INDUSTRIES

GHG emissions from non-ferrous smelting and refining activities were estimated at 12.7 Mt, or 1.7% of Canada's GHG emissions total, in 2004. Between 1990 and 2004, the non-ferrous smelting and refining industry experienced growth in sector GDP of 98%, while GHG emissions decreased by 19% (Informetrica Limited and Statistics Canada). There has been little change in the emissions from stationary combustion, which were 3.23 Mt in 2004. Process emissions from primary aluminium production decreased by 22% between 1990 and 2004, while primary aluminium production increased by 66%. This reduction in emissions in the aluminium industry can be attributed to better control of anode events in smelters, through the use of electronic monitoring and automated emission controls. In the same time frame, the production of primary magnesium increased by more than 212% (NRCan), but the emissions from this industry showed a reduction of 30%. This resulted from the progressive replacement of SF_6 with alternative cover gases. SF_6 emissions from magnesium casting facilities stayed relatively constant at the 1990 level.

Production of primary aluminium in Canada declined 7.2% in 2004, compared with 2003. The decrease was due to lower production at Aluminerie Bécancour and the closure of Søderberg capacity at Alcan's Jonquière smelter (NRCan). This contributed to the sector's 5% drop in process emissions.

A10.3.3 PULP, PAPER, AND SAW MILLS

Stationary fuel combustion from the pulp, paper, and saw mill industry contributed 9.31 Mt (or 1.2%) to Canada's total GHG emissions in 2004. Between 1990 and 2004, the industry saw a 4.34 Mt reduction in GHG emissions, with a 20% growth in sector GDP (Informetrica Limited and Statistics Canada). A 46% increase in the use of spent pulping liquors[59] combined with increased use of waste wood and a 35% reduction in the use of refined petroleum products contributed to an overall emission reduction of 32%.

In 2004, biomass fuel contributed about 79% to the fuel mix, as compared with 12% from natural gas, 9% from refined petroleum products, and 0.7% from coal (Statistics Canada, #57-003).

A10.3.4 PRIMARY AND OTHER STEEL INDUSTRIES

The primary and other steel industries contributed 14.7 Mt (or 1.9%) to Canada's total GHG emissions in 2004 (refer to Table A10-1). Stationary fuel combustion and process-related sources accounted for 45% (or 6.55 Mt) and over 55% (or 8.2 Mt) of the GHG emissions for the industry, respectively.

Between 1990 and 2004, the industry experienced a 19% growth in sector GDP (Informetrica Limited and Statistics Canada) and an increase of 8.6% in GHG emissions. Total pig iron and total steel production between 1990 and 2004 increased by 20% and 33%, respectively (Statistics Canada, #41-001). Process emissions from pig iron and raw steel production showed an increase of 16% (or 1.1 Mt), while emissions from combustion sources for all ferrous metal production increased by only about 1.0% (or 60 kt CO_2 eq) during this time frame.

A10.3.5 CEMENT

In 2004, GHG emissions from cement production contributed an estimated 11.4 Mt (or 1.5%) to Canada's GHG emission total. CO_2 emissions occurring as a result of the clinker production process account for 62% of the total emissions from the cement industry, while the balance is attributable to fuel combustion.

Over the 1990–2004 period, the cement industry experienced a 27% increase in GHG emissions and a 6% increase in sector GDP (Informetrica Limited and Statistics Canada). Process CO_2 emissions from the production of clinker increased by 31%, while stationary combustion emissions increased by 21%.

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[59] CO_2 resulting from the use of biomass is not included in inventory totals (IPCC/OECD/IEA, 1997).

A10.3.6 INDUSTRIAL CHEMICAL INDUSTRIES

GHG emissions from industrial chemical industries were estimated at 21.8 Mt, or 2.9% of Canada's GHG emission total, in 2004. Over 71% of the GHG emissions from this industry are process emissions, which have decreased about 25% since 1990.

When combustion emissions are included, the Canadian chemical industries exhibited a 21% decrease in GHG emissions between 1990 and 2004. From an economic standpoint, since 1990, the Canadian chemical industry has continued to expand, with sector GDP growing by 28% (Informetrica Limited and Statistics Canada).

Production of adipic acid has increased since 1990 at Canada's only adipic acid production plant. The installation of an emission abatement system in 1997 has resulted in a 7.6 Mt (or 71%) reduction in process-related N_2O emissions over the 1990–2004 period. The abatement system went off-line for a short period in 2004 for maintenance, causing an emission augmentation of 185% for this category between 2003 and 2004. Process emissions associated with the production of ammonia and nitric acid increased by 44% and 7%, respectively, since 1990.

A10.3.7 OTHER MANUFACTURING

In 2004, other manufacturing industries contributed 35.3 Mt of Canada's total GHG emissions; 60% of the emissions were from fuel combustion, and 40% were from process-related activities. These industries saw a 23% increase in emissions and a 52% growth in GDP.

Emission sources included in other manufacturing industries are lime production, the use of various minerals, consumption of halocarbons and SF_6, and non-energy use of coal, coke, and refined petroleum products (as shown in Table A10-3). The other manufacturing industries also include all other industries that are not specifically listed in Table A10-1 and Table A10-3, such as the textile, vehicle manufacturing, semiconductor manufacturing, and food and beverage production industries.

Between 1990 and 2004, process and product use emissions grew by 81%, mainly because of the replacement of CFCs with HFCs and increasing use of refined petroleum products as feedstocks. Process emissions for other manufacturing industries stayed relatively constant between 2003 and 2004.

A10.3.8 OTHER INDUSTRIES

The category of other industries accounts for GHG emissions from the combustion of fossil fuels for the following three industries:

1. *Construction*: construction of buildings, highways, and construction industry services, such as plumbing, carpentry, painting, etc.;
2. *Agriculture*: agriculture, hunting and trapping industry (excluding food processing); and
3. *Forestry*: includes the forestry and logging service industry.

Overall, other industries emitted 15.6 Mt of GHGs in 2004. This is an increase of about 8% since 1990. There has been a 20% increase in GDP over this period. Between 2003 and 2004, emissions decreased by 6.5%, while GDP increased by about 17%.

Of the three "other" industries, agriculture showed the largest emissions. In 2004, the agriculture sector contributed 12.5 Mt, or 71% of the emissions from this category, while the forestry and construction industries contributed about 10% (or 1.8 Mt) and 7.8% (or 1.3 Mt), respectively. Between 1990 and 2004, emissions from the construction industry decreased by over 28%. In the forestry sector, emissions from off-road machinery and equipment contributed 93% (or 1.68 Mt), as compared with 7% from stationary combustion sources in 2004.

Low GHG-intensive fossil fuels, such as natural gas, accounted for 67% of the overall fuel mix in 2004, relative to 58% in 1990. Also in 2004, refined petroleum products, including propane, butane, and ethane, contributed 33% to the overall fuel mix, compared with a 43% contribution in 1990 (Statistics Canada, #57-003).

A discussion of the emission trends for stationary fuel combustion-related emissions in the agriculture and forestry industries is available in Section 2.3.1.1 of this report.

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ANNEX 11: PROVINCIAL/TERRITORIAL ANALYSIS

The following discussion describes GHG emission trends for each of the provinces and territories in Canada for both the long term (1990–2004) and the short term (2003–2004). Owing to data limitations — specifically confidentiality — there are a number of caveats associated with the data and analysis. While the national inventory of GHG emissions is developed utilizing national, provincial, and territorial information and data, the information used to develop the national estimates relies on survey and sampling data that, while statistically valid and nationally representative, may not represent every discrete and small source within a province or territory. Therefore, the analysis that follows, while reflecting an accurate national picture, may differ slightly from a more bottom-up, precise regional inventory. Nevertheless, the trends in emissions from each region are considered representative of the actual emission trends in each region.

All emission references are from the 1990–2004 national GHG inventory and are given in units of CO_2 equivalent unless otherwise stated. All energy quantities, GDP, and HDD values originate from Statistics Canada (2005), although GDP information is further enhanced by Informetrica (2006). All values provided within these graphs are presented in kilotonnes CO_2 equivalent.

HDDs are an indicator of the necessity for space heating in a region. The number of HDDs is calculated for each day by subtracting the day's mean temperature from a base temperature (usually 18°C). The daily totals are accumulated for each month, and the monthly totals are accumulated for the "heating year" from July through June. The amount of energy consumed for heating is closely correlated to these HDDs. Only one value is given per province/territory per year, and, although real, this value is a weighted average of many weather stations in a province/territory and therefore may not be completely indicative of local conditions; it does, nonetheless, give a relative indication of year-to-year regional heating requirements. Furthermore, as this is a function of weather and climate, a trend may not be indicative of the region's performance with respect to emission mitigation actions.

A11.1 NEWFOUNDLAND AND LABRADOR

TABLE A11-1: Trends in GHG Emissions and GHG Intensity, Newfoundland and Labrador

	1990	1995	2000	2003	2004
Total GHG (Mt)	**10.06**	**8.78**	**9.16**	**11.35**	**10.49**
Growth Since 1990	N/A	−12.7%	−8.9%	12.9%	4.4%
Annual Change	N/A	11.5%	−2.8%	−5.5%	−7.5%
GDP Expense – Annual Change	N/A	1.3%	6.3%	2.5%	1.7%
GHG Intensity (Mt/$B GDP)	**1.05**	**0.92**	**0.81**	**0.87**	**0.79**
Annual Change	N/A	10.1%	−8.6%	−7.8%	−9.1%

Note:
N/A = not applicable

In 2004, Newfoundland and Labrador represented 1.6% of Canada's population and generated 1.4% of the GHG emissions and 1.3% of Canada's total GDP. Combined, these parameters registered GHG emissions of 20.3 t per person and 795 kt per billion dollars GDP (Table A11-1). Since 1990, socioeconomic indicators show a 37.7% increase in total GDP, while population and HDDs show decreases of 10.6% and 5.6%, respectively.

Emissions from the Energy and Waste sectors account for 90.2% and 9.0%, respectively, of their total regional contribution. Within the Energy Sector, stationary sources comprise 52% of emissions, while transportation is responsible for 40%.

A11.1.1 LONG-TERM TRENDS (1990–2004)

Over the long term (1990–2004), Newfoundland and Labrador's GHG emissions increased 4.4%, from 10.1 to 10.5 Mt. Energy Sector sources were responsible for both the greatest growth and the greatest decline. Increases due to fugitive emissions resulting from oil and natural gas production (0.8 Mt), fossil fuel industries (0.5 Mt), off-road fuel use (0.2 Mt), HDDVs (0.2 Mt), and LDGTs (0.2 Mt) were offset by reductions in mining industries (confidential), residential heating (0.3 Mt), electricity and heat generation (confidential), manufacturing industries (0.2 Mt), and gasoline automobiles (0.2 Mt).

The 605% increase in energy production (primary) since 1990 has been a major driver of the emissions increase, evidenced by a 132% growth at the start of the offshore operation during the 1997–1998 period and a further 72% spike between 2001 and 2002 following the ramping up of production from the Hibernia oil field.

Agricultural emissions from enteric fermentation, manure management, and soils remained relatively unchanged between 1990 and 2004.

Long-term emission trends in Newfoundland and Labrador are illustrated in Figure A11-1.

A11.1.2 SHORT-TERM TRENDS (2003–2004)

Over the short term, GHG emissions decreased by 7.5%, primarily as a result of a decline in emissions from the electricity and heat generation industries (confidential), off-road fuel use (0.2 Mt), and fugitive emissions from oil and natural gas production (0.2 Mt).

Short-term emission trends in Newfoundland and Labrador are illustrated in Figure A11-2.

FIGURE A11-1: Newfoundland and Labrador Long-Term Emission Trends, 1990–2004

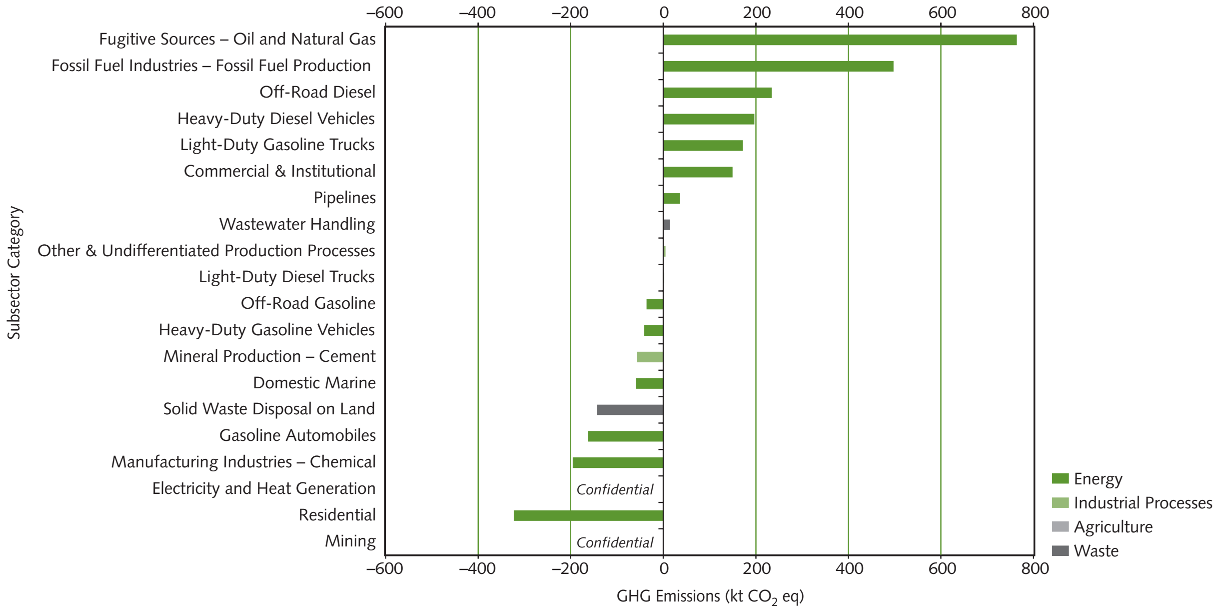
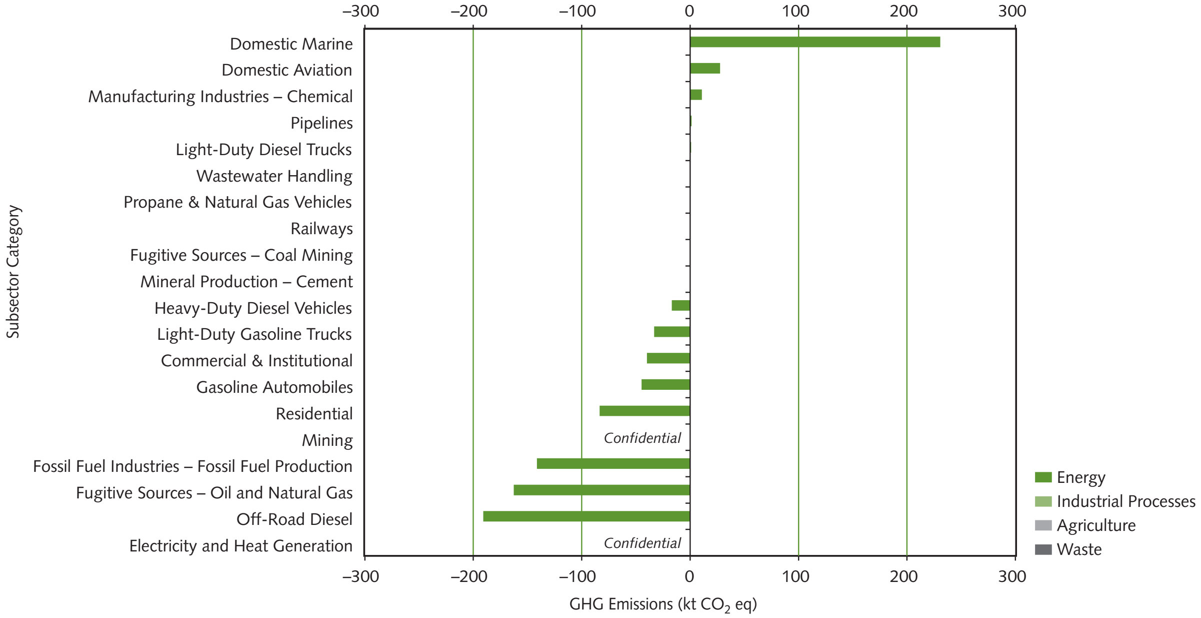


FIGURE A11-2: **Newfoundland and Labrador Short-Term Emission Trends, 2003–2004**



A11.2 PRINCE EDWARD ISLAND

TABLE A11-2: **Trends in GHG Emissions and GHG Intensity, Prince Edward Island**

	1990	1995	2000	2003	2004
Total GHG (Mt)	**2.10**	**2.02**	**2.29**	**2.30**	**2.31**
Growth Since 1990	N/A	–3.7%	9.1%	9.6%	10.1%
Annual Change	N/A	–1.3%	6.8%	4.5%	0.5%
GDP Expense – Annual Change	N/A	6.6%	3.5%	3.9%	2.3%
GHG Intensity (Mt/$B GDP)	**0.95**	**0.82**	**0.80**	**0.73**	**0.72**
Annual Change	N/A	–7.4%	3.1%	0.6%	–1.8%

Note:
N/A = not applicable

In 2004, Prince Edward Island, with 0.4% of Canada's population (137 900), contributed 2.3 Mt (0.3%) and $3.2 billion (0.3%) towards Canada's GHG and GDP totals, respectively. These values are up 5.6%, 10.1%, and 45.6%, respectively, since 1990, while GHG emissions increased 0.5% and GDP increased 2.3% since 2003 (Table A11-2).

The Energy, Agriculture, and Waste sectors are responsible for over 99% of the province's total emissions, with a relatively larger portion coming from agricultural sources and a relatively smaller portion from the Energy Sector compared with the other Atlantic provinces (22% and 70%, respectively).

A11.2.1 LONG-TERM TRENDS (1990–2004)

The Energy Sector showed an overall long-term increase of 11% (0.2 Mt), resulting from a 36% increase in road transport–related emissions, specifically 97% and 94% increases in the emissions from LDGTs and HDDVs, respectively. However, these increases were offset by decreases from the residential sector (27%), electricity and heat generation industries (confidential), and gasoline vehicle emissions (8%).

N_2O emissions from agricultural soils fluctuated but generally increased between 1990 and 2004, while CH_4 emissions from enteric fermentation and manure management declined over this period. Higher synthetic fertilizer consumption increased emissions, while reductions in both dairy and non-dairy cattle populations lowered emissions, even though swine populations increased during the same period.

Long-term emission trends in Prince Edward Island are illustrated in Figure A11-3.

A11.2.2 SHORT-TERM TRENDS (2003–2004)

Overall, emissions of GHGs increased by 0.5% between 2003 and 2004. This slight increase was primarily due to increases in emissions from the domestic marine subsector, HDDVs, and LDGTs that were offset by decreases in emissions from electricity and heat generation, off-road transportation, and the residential subsectors. The short-term trend between 2003 and 2004 showed no change in N_2O and CH_4 emissions from enteric fermentation, manure management, and agricultural soils.

Short-term emission trends in Prince Edward Island are illustrated in Figure A11-4.

FIGURE A11-3: Prince Edward Island Long-Term Emission Trends, 1990–2004

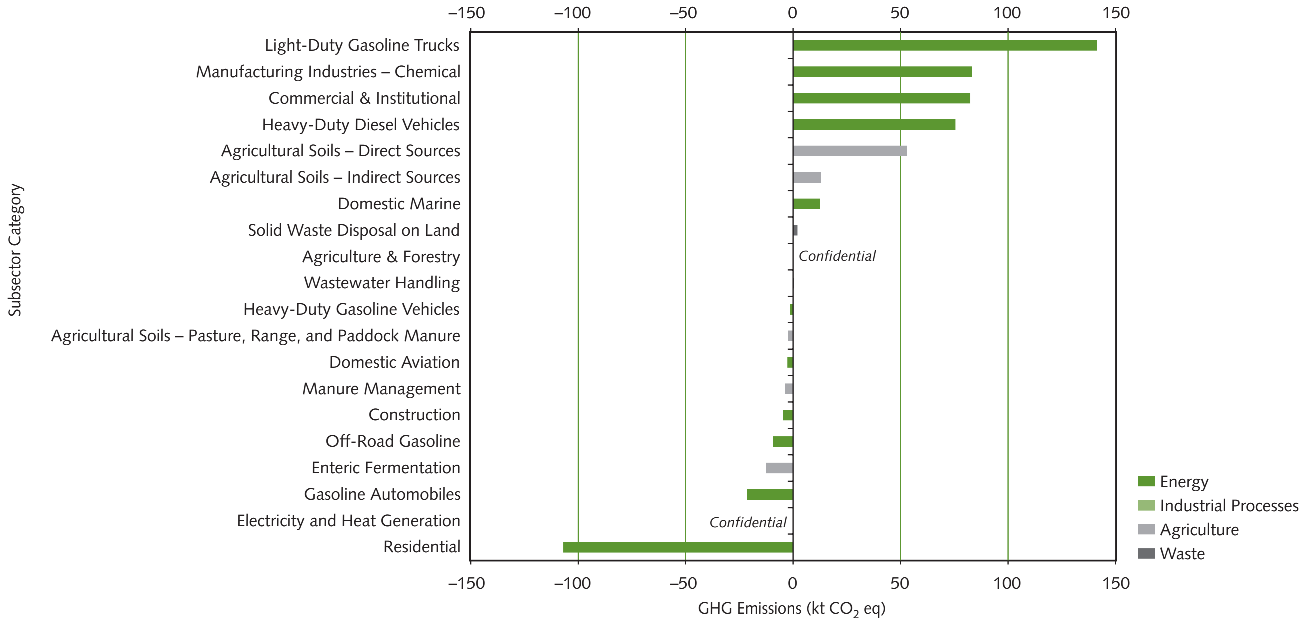
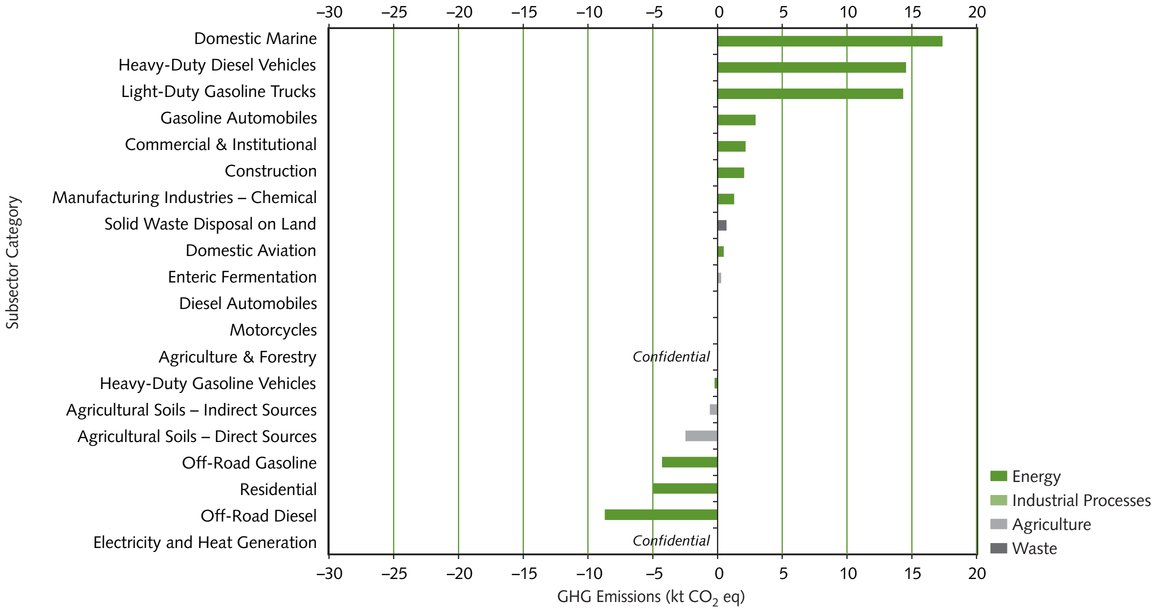


FIGURE A11-4: Prince Edward Island Short-Term Emission Trends, 2003–2004



A11.3 NOVA SCOTIA

TABLE A11-3: Trends in GHG Emissions and GHG Intensity, Nova Scotia

	1990	1995	2000	2003	2004
Total GHG (Mt)	**19.72**	**19.30**	**21.51**	**22.63**	**22.98**
Growth Since 1990	N/A	–2.2%	9.1%	14.7%	16.5%
Annual Change	N/A	–0.6%	5.3%	12.5%	1.5%
GDP Expense – Annual Change	N/A	2.0%	3.4%	0.9%	3.0%
GHG Intensity (Mt/$B GDP)	**1.14**	**1.08**	**1.03**	**1.00**	**0.98**
Annual Change	N/A	–2.5%	1.8%	11.4%	–1.4%

Note:
N/A = not applicable

In 2004, Nova Scotia generated 23.0 Mt or 3.1% of Canada's total GHG emissions (Table A11-3). Nova Scotians represent 2.9% of the population and contribute 2.3% to the total GDP. Since 1990, GHG emissions, population, and GDP output increased 16.5%, 3.0%, and 35.1%, respectively, while HDDs increased by 7.4% from 1990 and 5.3% from 2003.

The Energy Sector accounted for 92% of provincial GHG emissions in 2004, with the Waste and Agriculture sectors contributing 4% and 2%, respectively.

A11.3.1 LONG-TERM TRENDS (1990–2004)

Energy-related emissions increased 20% between 1990 and 2004, while emissions from the Waste Sector decreased by 22%. In Nova Scotia, the dominant Energy subsectors are electricity and heat generation, commercial and institutional industries, road transport, and fossil fuel production. All subsectors have experienced growth since 1990. LDGTs and HDDVs dominate the transport subsector. The annual contributions from gasoline automobiles and HDGVs have decreased by 11% and 50%, respectively, since 1990, while those from LDGTs and HDDVs have shown constant growth over the same period.

Fugitive emissions from coal mining have declined by 77% since 1990 but are slowly being replaced with those from the oil and gas industry, as the primary energy production source in this province shifts from coal to petroleum.

CH_4 emissions from enteric fermentation and manure management decreased by 12%, while N_2O emissions from manure management and agricultural soils remained unchanged in the long term. A small decrease in N_2O emissions from manure management was offset by a similar increase from agricultural soils. Higher N_2O emissions were due mainly to higher synthetic fertilizer nitrogen consumption, while reductions in dairy and non-dairy cattle as well as swine populations reduced emissions from enteric fermentation and manure management.

Long-term emission trends in Nova Scotia are illustrated in Figure A11-5.

A11.3.2 SHORT-TERM TRENDS (2003–2004)

Between 2003 and 2004, total GHG emissions in Nova Scotia increased by 1.5%, primarily as a result of increased commercial and institutional energy (55%) and electricity and heat production (confidential). During the same period, residential and fossil fuel production emissions declined by 32% and 29%, respectively. The short-term trend between 2003 and 2004 showed no change in N_2O emissions from the Agriculture Sector.

Short-term emission trends in Nova Scotia are illustrated in Figure A11-6.

FIGURE A11-5: Nova Scotia Long-Term Emission Trends, 1990–2004

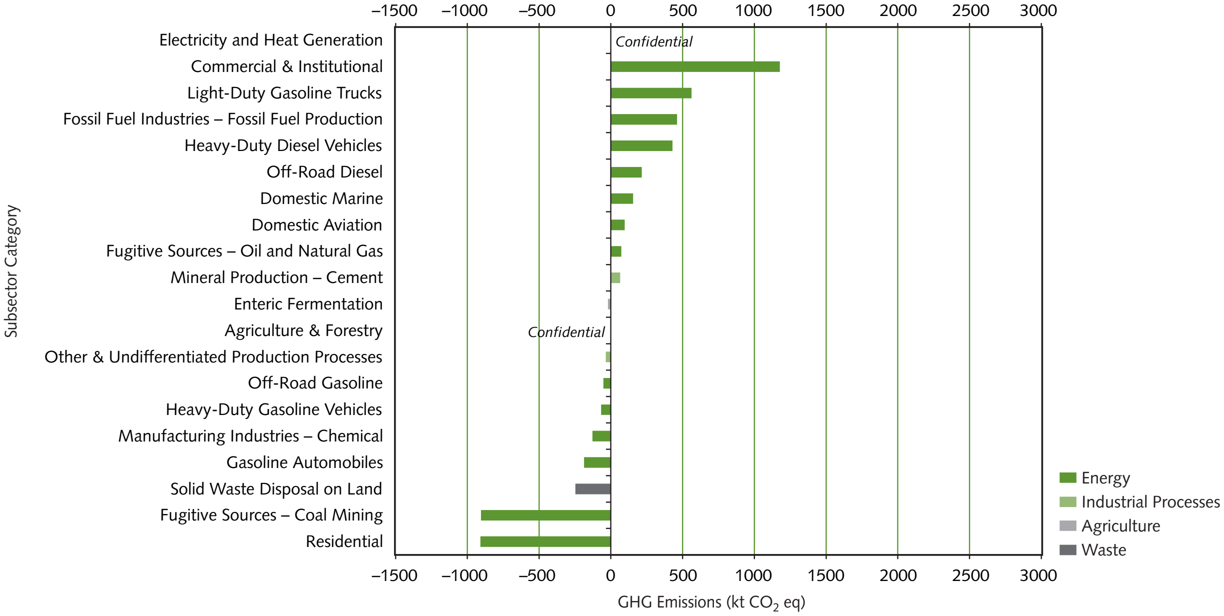
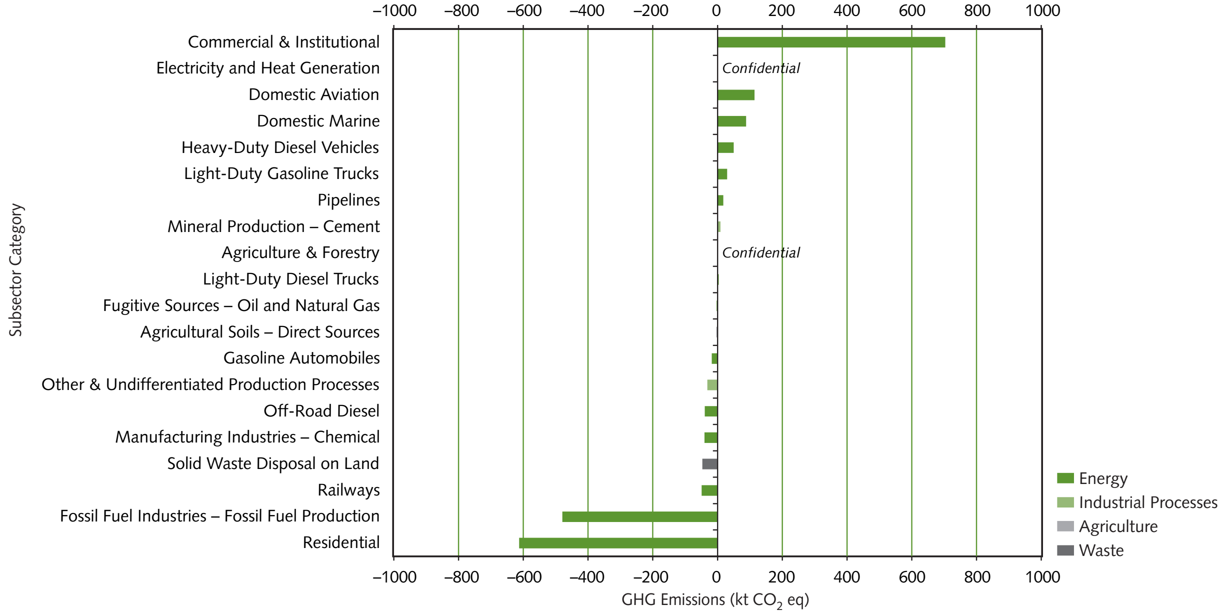


FIGURE A11-6: Nova Scotia Short-Term Emission Trends, 2003–2004



A11.4 NEW BRUNSWICK

TABLE A11-4: Trends in GHG Emissions and GHG Intensity, New Brunswick

	1990	1995	2000	2003	2004
Total GHG (Mt)	**16.42**	**17.43**	**20.73**	**21.47**	**24.12**
Growth Since 1990	N/A	6.2%	26.3%	30.8%	46.9%
Annual Change	N/A	2.8%	6.2%	–1.8%	12.4%
GDP Expense – Annual Change	N/A	3.2%	4.3%	–0.2%	3.4%
GHG Intensity (Mt/$B GDP)	**1.17**	**1.17**	**1.18**	**1.17**	**1.27**
Annual Change	N/A	–0.5%	1.8%	–1.7%	8.7%

Note:
N/A = not applicable

In 2004, New Brunswick contributed 24.1 Mt or 3.2% of Canada's total GHG emissions (Table A11-4), which represents an increase of 47% since 1990. With 2.4% of Canada's population, New Brunswick's GDP contribution increased 36% between 1990 and 2004, representing 1.8% of the national total in 2004. Total HDDs were up 13% compared with 1990. In 2004, GHG emissions were 32.1 t per person, up 45% from 1990.

The Energy Sector represents 92% of total provincial GHG emissions, with the Waste, Agriculture, and Industrial Processes sectors contributing 4.4%, 2.0%, and 1.2%, respectively.

A11.4.1 LONG-TERM TRENDS (1990–2004)

Emissions growth over the long term (7.7 Mt) was driven by Energy Sector contributions, and emissions have shown almost steady growth from electricity and heat generation (confidential), fossil fuel industries (136%), and transportation (37%). The latter is a result of increases from HDDVs (62%), LDGTs (61%), and off-road use (109%).

Agricultural N_2O emissions from manure management and agricultural soils generally increased between 1990 and 2004, while emissions from enteric fermentation declined over this period. Higher swine and poultry populations resulted in higher CH_4 emissions from manure management. Reductions in both dairy and non-dairy cattle populations reduced emissions from enteric fermentation.

Long-term emission trends in New Brunswick are illustrated in Figure A11-7.

A11.4.2 SHORT-TERM TRENDS (2003–2004)

The short-term 12% increase in emissions is primarily attributed to contributions by electricity and heat generation and commercial and institutional subsectors. The short-term trend also showed a small decline in emissions from fossil fuel production.

Short-term emission trends in New Brunswick are illustrated in Figure A11-8.

FIGURE A11-7: New Brunswick Long-Term Emission Trends, 1990–2004

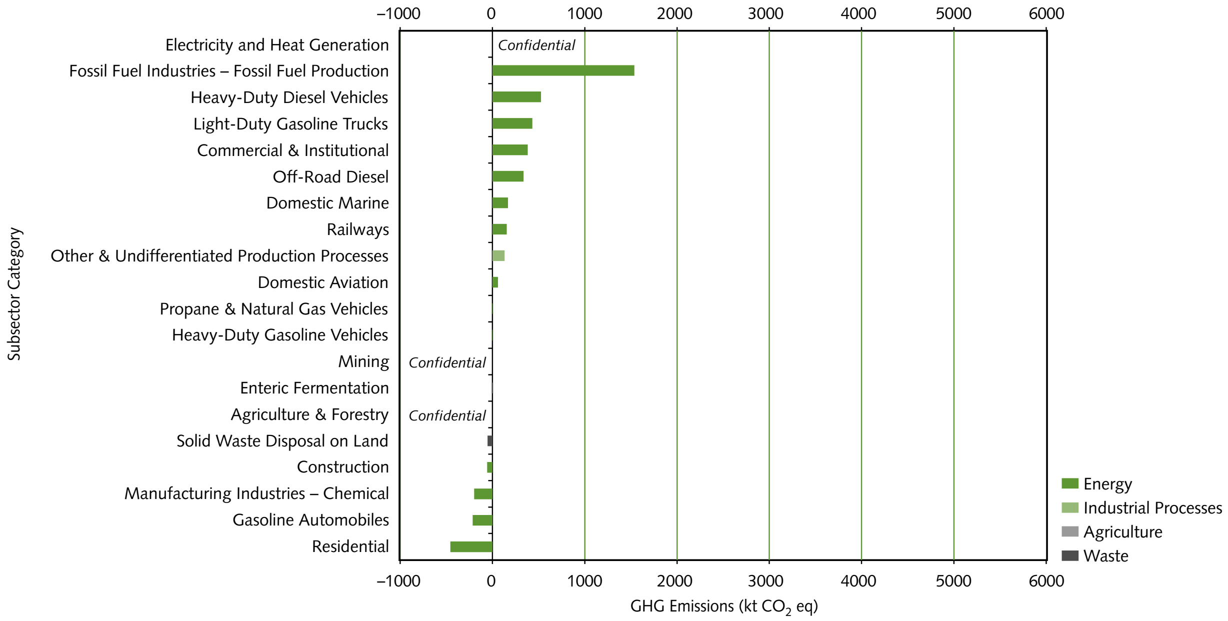
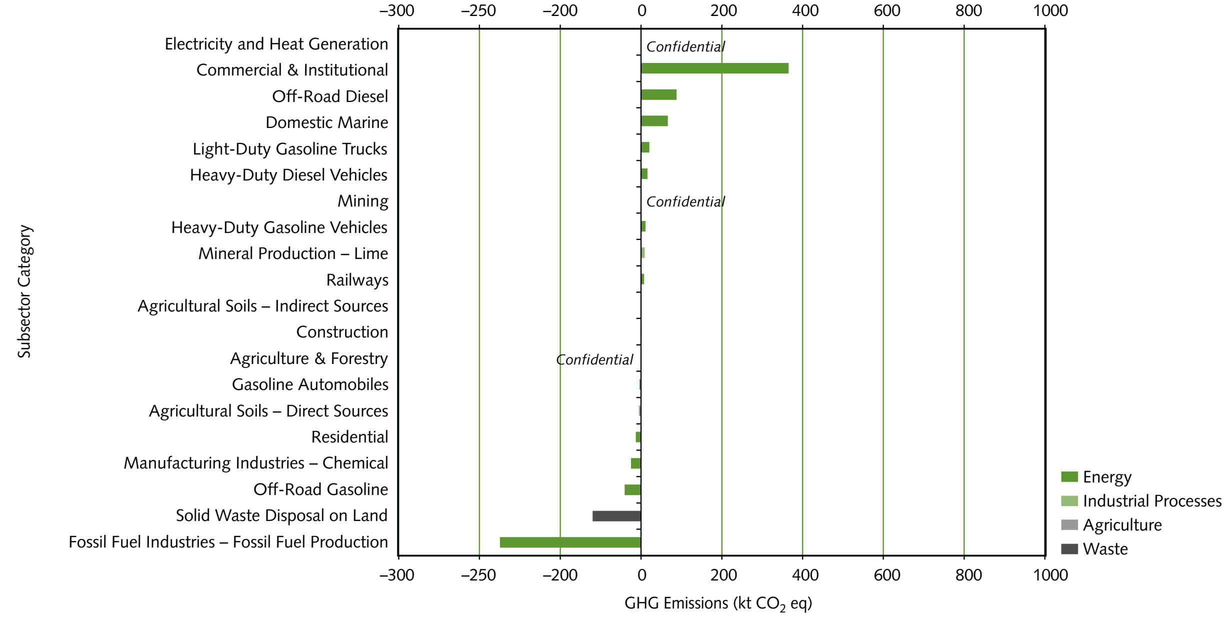


FIGURE A11-8: New Brunswick Short-Term Emission Trends, 2003–2004



A11.5 QUEBEC

TABLE A11-5: Trends in GHG Emissions and GHG Intensity, Quebec

	1990	1995	2000	2003	2004
Total GHG (Mt)	**86.57**	**83.69**	**87.54**	**93.00**	**91.84**
Growth Since 1990	N/A	–3.3%	1.1%	7.4%	6.1%
Annual Change	N/A	–1.1%	1.2%	5.4%	–1.3%
GDP Expense – Annual Change	N/A	1.0%	5.2%	0.8%	3.5%
GHG Intensity (Mt/$B GDP)	**0.53**	**0.49**	**0.43**	**0.43**	**0.41**
Annual Change	N/A	–2.0%	–3.8%	4.5%	–4.6%

Note:
N/A = not applicable

The province of Quebec represented 23.6% (7.5 million) of the country's population and accounted for 21.6% ($224.4 billion) and 12.3% (91.8 Mt) of Canada's GDP and GHG totals, respectively, in 2004 (Table A11-5). GHG emissions per capita, at 12.2 t GHGs per person, and economic GHG intensity, at 0.41 Mt per billion dollars GDP, were both lower than the Canadian average. Since 1990, Quebec's GHG emissions have increased 6.1%, while the population increased by 7.7% and the province's economic output jumped 37.8%. The year 2004 registered a 9.4% increase in HDDs compared with 1990.

Because of Quebec's abundant hydro-generated electricity and small petroleum industry, the contribution to total emissions from the Energy Sector is favourable. The Energy, Industrial Processes, Agriculture, and Waste sectors comprise 72%, 11%, 8%, and 9%, respectively, of the regional total. Transportation sources and manufacturing industry emissions contributed 54% and 16%, respectively, to the Energy Sector, while 70% of industrial process emissions are released during aluminium production and magnesium production and casting. CH_4 emissions from solid waste disposal on land accounted for 95% of the regional waste total in 2004.

A11.5.1 LONG-TERM TRENDS (1990–2004)

According to data obtained from the AAC and the *Canadian Minerals Yearbook*, published by NRCan, the province of Quebec is by far Canada's primary producer of aluminium and magnesium, with lower-level activities in Ontario and British Columbia. In 2004, Quebec accounted for 81% of Canada's process emissions associated with primary aluminium production. Between 1990 and 2004, the subsector of aluminium production experienced an emission decrease of 24%, which can be attributed to better control of anode events in smelters through the use of electronic monitoring and automated emission controls. Although the GDP of the aluminium industry has grown significantly since 1990, its fuel combustion–related GHG emissions stayed about the same, which indicates efficiency achievements for the industry in regards to its combustion activities.

Emissions from the Energy Sector increased 13% between 1990 and 2004. Transportation emissions increased 25% during the same period, with LDGTs and HDDVs contributing to 53% and 43% of the increase, respectively. Commercial and institutional energy emissions also increased by 62% from 1990 levels. CH_4 emissions from the Waste Sector increased by 10% between 1990 and 2004.

Long-term emission trends in Quebec are illustrated in Figure A11-9.

A11.5.2 SHORT-TERM TRENDS (2003–2004)

In the short term, a 1.3% decrease in 2004 is largely attributable to decreases in emissions from commercial and institutional energy (13%), solid waste disposal (7%), off-road gasoline vehicles (73%), aluminium production (8%), and mining (52%). Quebec's magnesium industry emissions declined by 21% between 2003 and 2004, the result of substituting other cover gases for SF_6 in the smelting and casting processes. Increases in emissions came mainly from the manufacturing industries and transportation subsectors.

The short-term trend between 2003 and 2004 in agricultural emissions showed an overall increase of 3.2%, with increases in CH_4 emissions from enteric fermentation and manure management and increases in N_2O emissions from agricultural soils.

Short-term emission trends in Quebec are illustrated in Figure A11-10.

FIGURE A11-9: Quebec Long-Term Emission Trends, 1990–2004

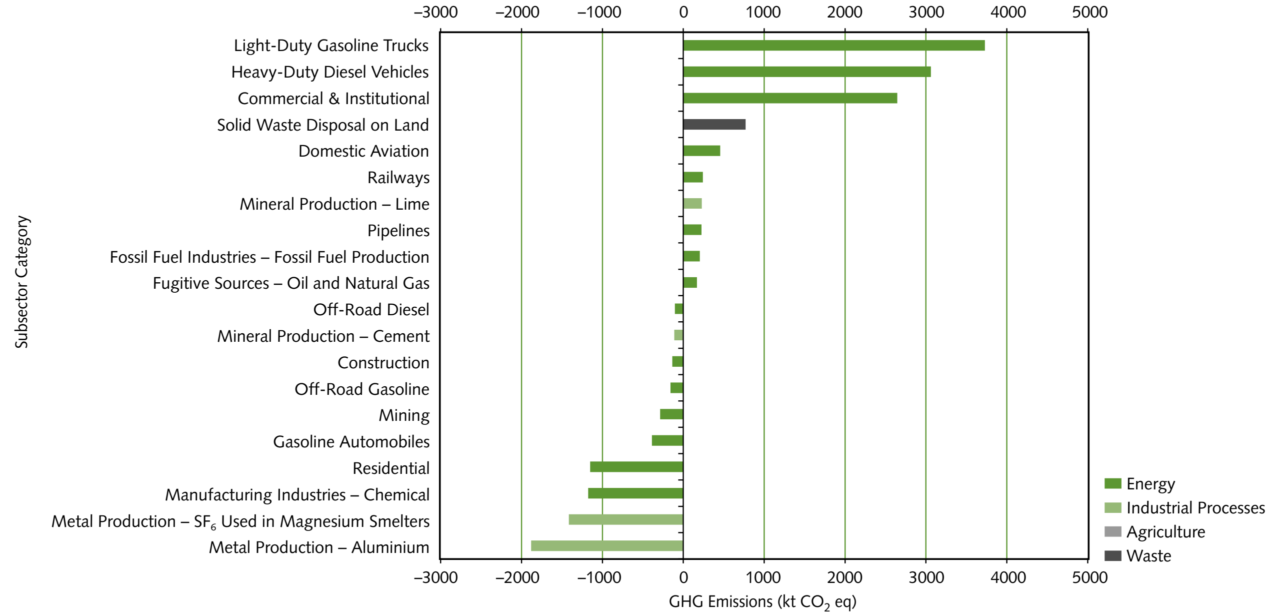
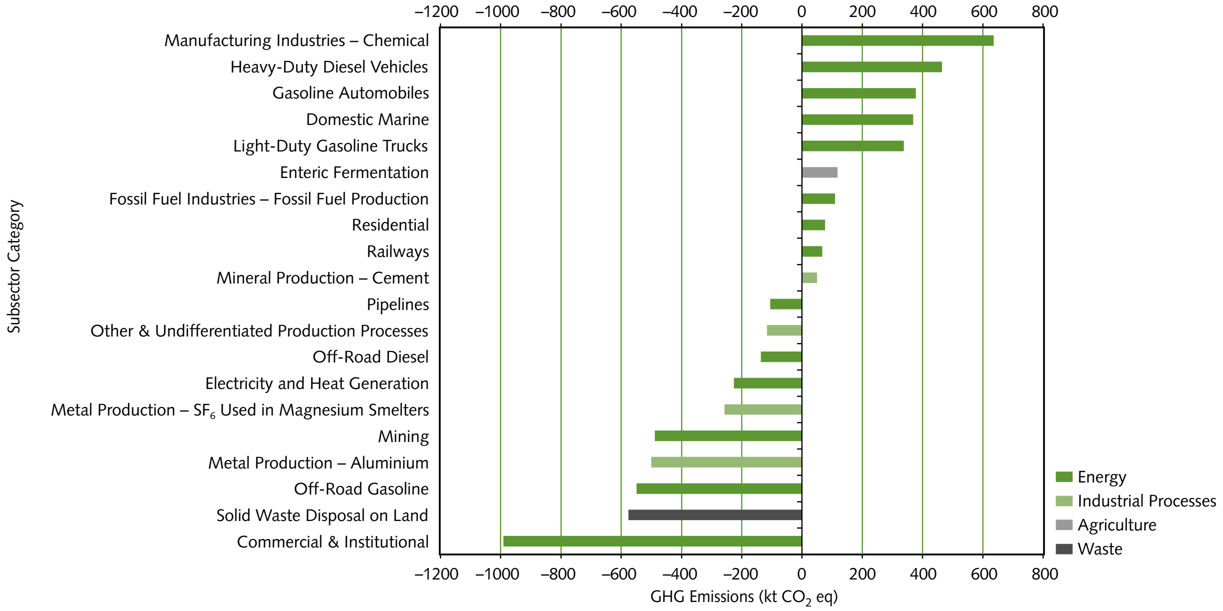


FIGURE A11-10: Quebec Short-Term Emission Trends, 2003–2004



A11.6 ONTARIO

TABLE A11-6: Trends in GHG Emissions and GHG Intensity, Ontario

	1990	1995	2000	2003	2004
Total GHG (Mt)	**176.59**	**176.50**	**202.77**	**209.46**	**203.11**
Growth Since 1990	N/A	–0.1%	14.8%	18.6%	15.0%
Annual Change	N/A	2.3%	5.0%	4.3%	–3.0%
GDP Expense – Annual Change	N/A	4.0%	6.2%	2.9%	3.3%
GHG Intensity (Mt/$B GDP)	**0.60**	**0.56**	**0.51**	**0.49**	**0.46**
Annual Change	N/A	–1.7%	–1.1%	1.3%	–6.2%

Note:
N/A = not applicable

In 2004, Canada's most populated province — at 12.4 million, or 38.8% of the total — generated 27.2% (203.1 Mt) of total GHG emissions (Table A11-6) and 42.1% of the country's GDP ($438.3 billion). Between 1990 and 2004, Ontario's emissions increased 26.5 Mt (15.0%), while GDP and population increased 49.9% and 20.3%, respectively. In the short term (2003–2004), total emission output decreased by 3.0% or 6.3 Mt, with a 4.6% decrease in HDDs.

Over 90% of Ontario's GHG emissions are attributable to the Energy (81%) and Industrial Processes (11%) sectors, with the Agriculture (5.0%) and Waste (3.7%) sectors making up the majority of the remainder.

A11.6.1 LONG-TERM TRENDS (1990–2004)

Between 1990 and 2004, increases in GHG emissions from LDGTs (9.5 Mt), electricity and heat generation (8.4 Mt), HDDVs (7.4 Mt), and commercial and institutional sources (5.0 Mt) were offset by a 71% reduction (7.6 Mt) in the process emissions of the adipic acid industry that resulted from the installation of pollution abatement equipment in 1997. Total electricity generated in Ontario has increased 20% since the early 1990s, with coal- and natural gas–fired thermal sources increasing by 5.6% and 560%, respectively, to offset the reduced contribution from refined petroleum products (down 40%) in 2004 and the reduced availability of nuclear sources beginning in the mid-1990s. In Ontario, hydro-generated electricity is still second to nuclear, although coal is now a close third.

In the Agriculture Sector, CH_4 emissions from enteric fermentation remained relatively unchanged between 1990 and 2004. There was a 3% decrease in N_2O emissions from soils over this period, mainly because of lower synthetic fertilizer nitrogen consumption and lower crop production.

Long-term emission trends in Ontario are illustrated in Figure A11-11.

A11.6.2 SHORT-TERM TRENDS (2003–2004)

The majority of the short-term reductions are realized in the Energy Sector, the bulk of which are a result of decreases in the electricity and heat generation subsector (10.7 Mt). Short-term emissions growth is led by the adipic acid production industry (2.0 Mt), process emissions from iron and steel production (1.1 Mt), HDDVs (0.8 Mt), and LDGTs (0.6 Mt).

The short-term trend in Agriculture showed a 2% increase in CH_4 emissions, due mainly to a higher beef cattle population.

Short-term emission trends in Ontario are illustrated in Figure A11-12.

FIGURE A11-11: Ontario Long-Term Emission Trends, 1990–2004

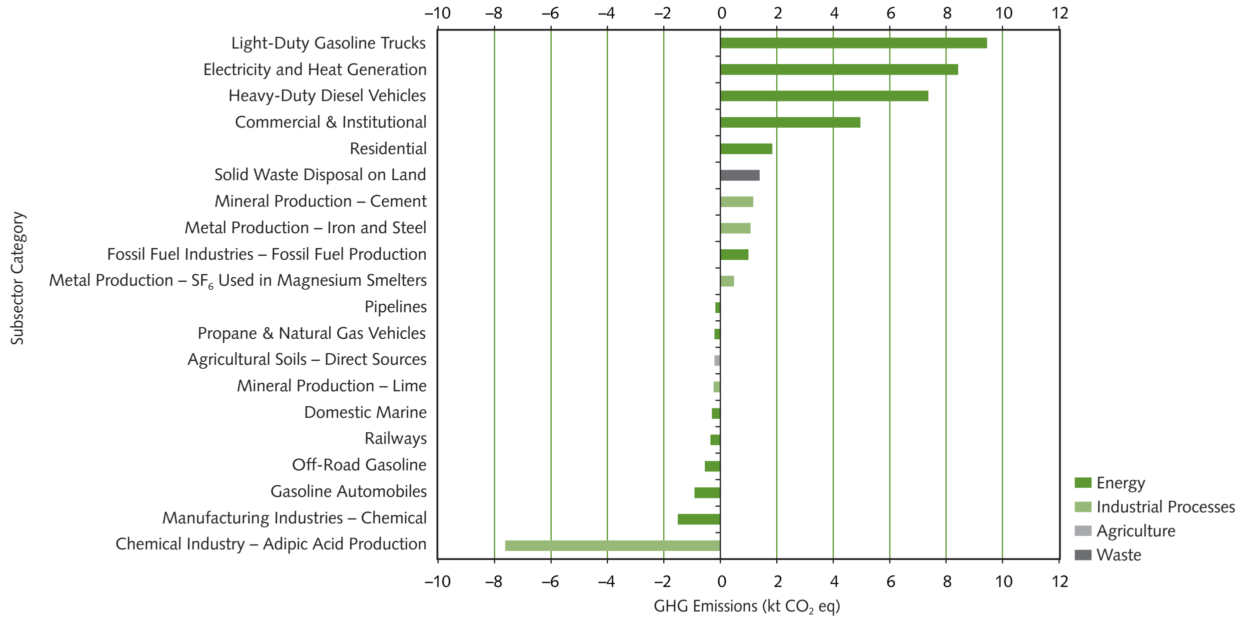
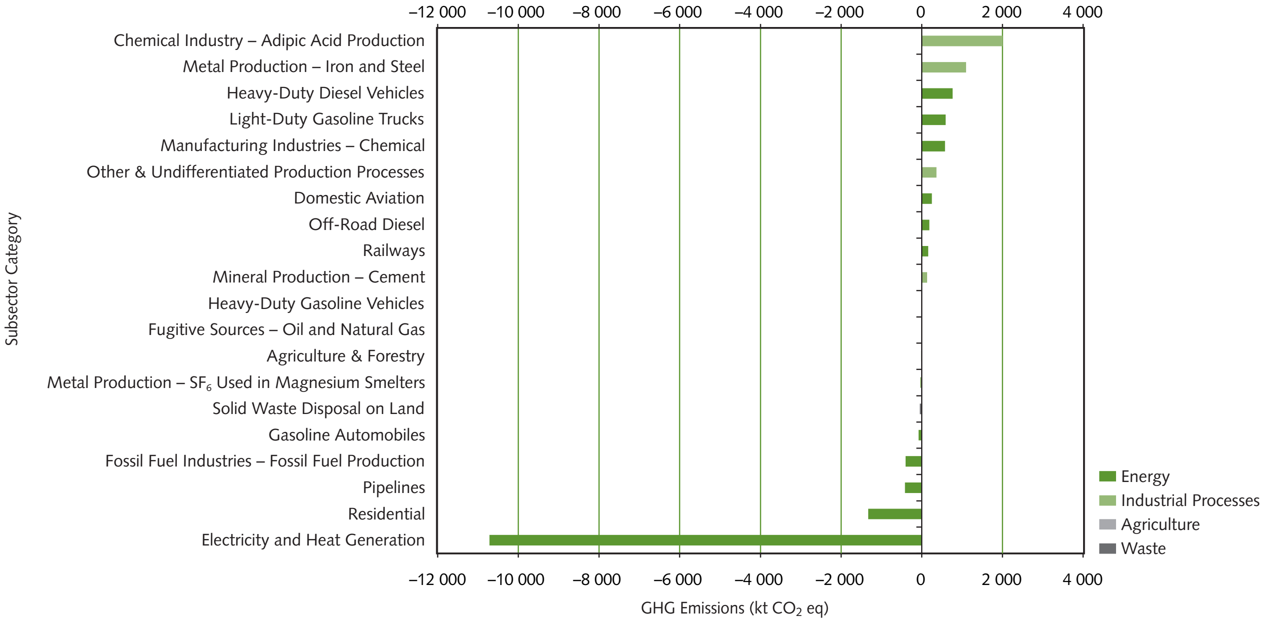


FIGURE A11-12: Ontario Short-Term Emission Trends, 2003–2004



A11.7 MANITOBA

TABLE A11-7: Trends in GHG Emissions and GHG Intensity, Manitoba

	1990	1995	2000	2003	2004
Total GHG (Mt)	**17.96**	**18.98**	**20.18**	**19.43**	**20.01**
Growth Since 1990	N/A	5.7%	12.4%	8.2%	11.4%
Annual Change	N/A	4.6%	3.3%	–0.1%	2.9%
GDP Expense – Annual Change	N/A	1.1%	4.3%	0.5%	2.8%
GHG Intensity (Mt/$B GDP)	**0.70**	**0.74**	**0.66**	**0.61**	**0.61**
Annual Change	N/A	3.5%	–1.0%	–0.6%	0.1%

Note:
N/A = not applicable

In 2004, Manitoba's GHG emissions were up 11% (2.0 Mt) with respect to 1990's total of 18.0 Mt and up 3.0% (0.6 Mt) since 2003 (Table A11-7). Over the long term, the province's annual GDP and population increased 28.6% and 5.8%, respectively, contributing 17.1 t of GHGs per person and 609 kt GHGs per billion dollars GDP in 2004.

A11.7.1 LONG-TERM TRENDS (1990–2004)

Manitoba's economic structure gives its GHG inventory the lowest percentage of emissions from the Energy Sector (61%) and the highest percentage from the Agriculture Sector (32%). The overall contributions from the Energy Sector have been fairly stable over the long term, with increases from LDGTs (0.7 Mt) and HDDVs (0.6 Mt) being offset by reductions from LDGVs (0.5 Mt), electricity and heat generation (confidential), pipelines (0.4 Mt), and residential (0.4 Mt) subsectors.

Agricultural emissions from all sources increased significantly between 1990 and 2004. CH_4 emissions from enteric fermentation and manure management increased by 63%, due mainly to increases in beef cattle and swine populations. N_2O emissions from manure management and agricultural soils increased by 33%, due mainly to increases in nitrogen fertilizer consumption, animal manure on pasture, and animal manure applied as fertilizers on cropland.

Long-term emission trends in Manitoba are illustrated in Figure A11-13.

A11.7.2 SHORT-TERM TRENDS (2003–2004)

From 2003 to 2004, emissions increased primarily within the enteric fermentation and transportation subsectors. A 12% increase in emissions was also observed in the manufacturing industries subsector. Short-term decreases in emissions were related to electricity and heat generation and direct emissions from agricultural soils.

Short-term emission trends in Manitoba are illustrated in Figure A11-14.

FIGURE A11-13: Manitoba Long-Term Emission Trends, 1990–2004

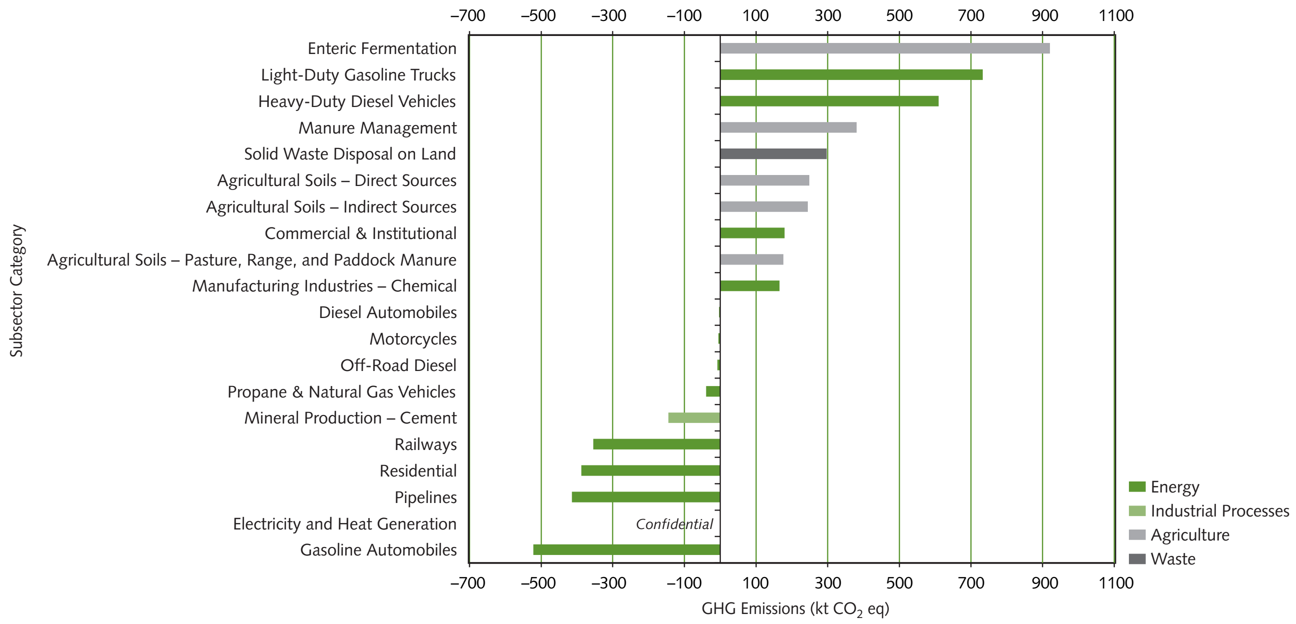
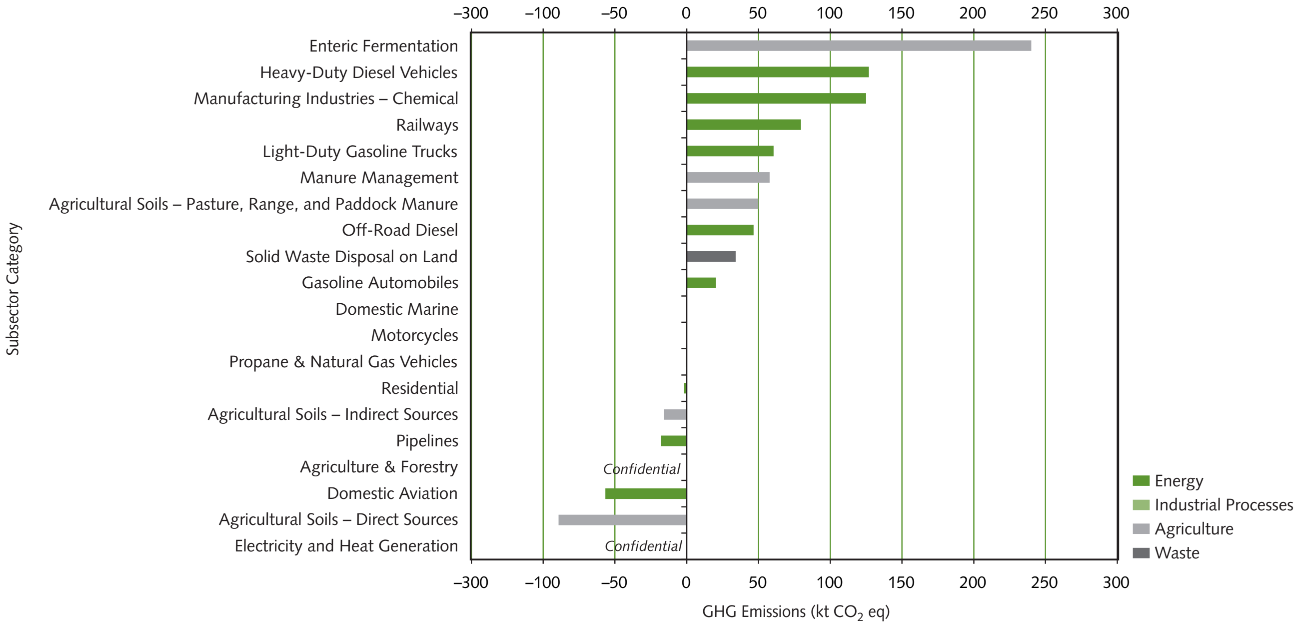


FIGURE A11-14: Manitoba Short-Term Emission Trends, 2003–2004



A11.8 SASKATCHEWAN

TABLE A11-8: Trends in GHG Emissions and GHG Intensity, Saskatchewan

	1990	1995	2000	2003	2004
Total GHG (Mt)	**42.73**	**56.99**	**63.67**	**66.45**	**69.08**
Growth Since 1990	N/A	33.4%	49.0%	55.5%	61.7%
Annual Change	N/A	4.6%	2.7%	2.7%	4.0%
GDP Expense – Annual Change	N/A	0.3%	2.4%	3.4%	3.1%
GHG Intensity (Mt/$B GDP)	**1.85**	**2.32**	**2.19**	**2.28**	**2.30**
Annual Change	N/A	4.3%	0.3%	–0.7%	0.8%

Note:
N/A = not applicable

Saskatchewan generated 69.1 Mt GHGs in 2004 (9.2% of Canada's total), a 62% increase over the 1990 base year and a 4.0% increase compared with 2003 (Table A11-8). GDP output increased 29.6% between 1990 and 2004, while population declined by 1.2%. In 2004, these measures translated to over 69 t GHGs per person and 2.3 Mt GHGs per billion dollars GDP.

Saskatchewan's emission contribution per sector represents the natural westerly transition across Canada's central provinces — that is, an increasing portion of energy-related emissions, accounting for 82% of the province's emission sources.

A11.8.1 LONG-TERM TRENDS (1990–2004)

Long-term growth trends show Energy subsectors as strong contributors, specifically fugitive emissions from oil and natural gas, emissions from electricity and heat generation, fossil fuel production, and HDDVs. Combustion-related emissions from electricity production showed 63% growth since 1990. Coal-generated capacity has remained the predominant source of electricity, at about 41%, while the demand for electricity from low-GHG-intensive natural gas sources continues to increase, by over 660% between 1990 and 2004.

Combustion and fugitive emissions from fossil fuel production sources increased by 71% (2.7 Mt) and by 167% (10.1 Mt), respectively, between 1990 and 2004. The annual HDDs observed in 2004 were 4.9% greater than in 1990 and 0.6% greater than in 2003, with residential emissions decreasing by 0.39 Mt between 1990 and 2004.

Agricultural emissions from enteric fermentation, manure management, and agricultural soils grew by almost 51% between 1990 and 2004. Emissions from enteric fermentation and manure management increased 62% and 58%, respectively, due mainly to increases in beef cattle and swine populations.

Long-term emission trends in Saskatchewan are illustrated in Figure A11-15.

A11.8.2 SHORT-TERM TRENDS (2003–2004)

The short-term trends in energy and agricultural emissions between 2003 and 2004 followed the same general pattern as described for the long term, with the exception of an increase of 21% in emissions from solid waste disposal on land.

Short-term emission trends in Saskatchewan are illustrated in Figure A11-16.

FIGURE A11-15: Saskatchewan Long-Term Emission Trends, 1990–2004

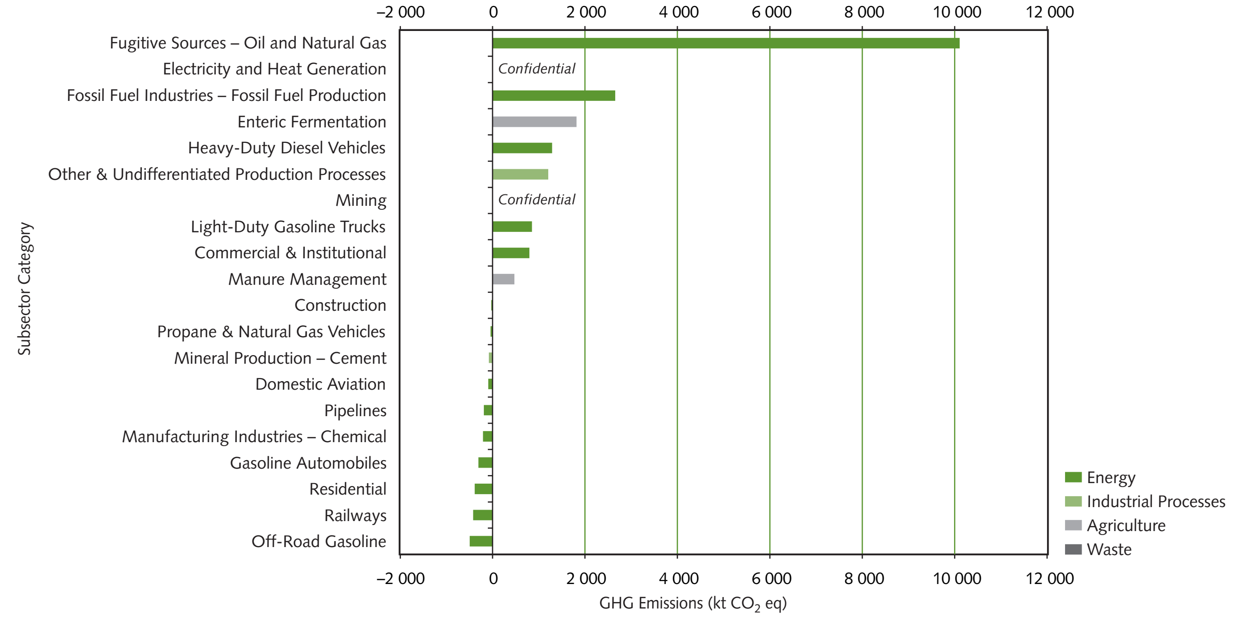
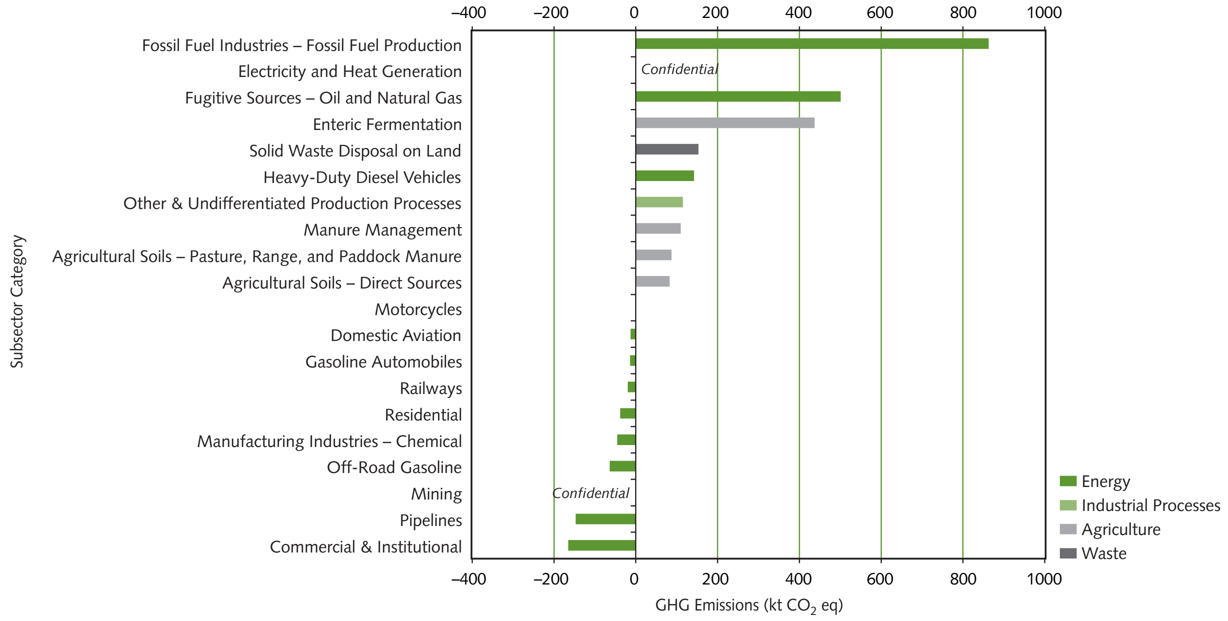


FIGURE A11-16: Saskatchewan Short-Term Emission Trends, 2003–2004



A11.9 ALBERTA

TABLE A11-9: Trends in GHG Emissions and GHG Intensity, Alberta

	1990	1995	2000	2003	2004
Total GHG (Mt)	**168.17**	**197.17**	**222.50**	**230.22**	**234.51**
Growth Since 1990	N/A	17.2%	32.3%	36.9%	39.4%
Annual Change	N/A	2.7%	4.2%	3.5%	1.9%
GDP Expense – Annual Change	N/A	2.5%	6.3%	2.9%	3.6%
GHG Intensity (Mt/$B GDP)	**2.18**	**2.14**	**1.92**	**1.83**	**1.80**
Annual Change	N/A	0.2%	−1.9%	0.6%	−1.7%

Note:
N/A = not applicable

The province of Alberta generated 12.6% of Canada's GDP in 2004, with 10% of the total population. Between 1990 and 2004, GDP and GHG output increased 69.4% and 39.4% to $130.6 billion and 234.5 Mt, respectively (Table A11-9). The short-term trends show a 1.9% growth in total GHG emissions, while observing a 3.6% increase in economic output and a 4.3% decrease in HDDs since the previous year.

Alberta, known for its abundant fossil fuel–based natural resources, provided 64% of Canada's primary energy production in 2004. Not surprisingly, the province's total GHG emissions are dominated by emissions related to the electricity generation, fossil fuel industries (including emissions from natural gas transmissions and fugitive emission sources), and the transport sector. With 86.5% of the provincial total from the Energy Sector, the remaining sources are a combination of the Agriculture (7.1%) and Industrial Processes (5.4%) sectors.

A11.9.1 LONG-TERM TRENDS (1990–2004)

Long-term emissions growth has contributed an additional 66.3 Mt to the provincial total, predominantly driven by increases from fossil fuel industries (17.7 Mt), electricity and heat generation (12.5 Mt), mining (8.7 Mt), fugitive sources from the oil and natural gas industry (6.4 Mt), HDDVs (4.5 Mt), LDGTs (2.8 Mt), and pipelines (1.8 Mt), all of which are constituents of the Energy Sector. Other and undifferentiated production processes (4.2 Mt) and enteric fermentation (2.5 Mt) emissions have also increased since 1990. Decreases over the long term have been limited to combustion emissions from manufacturing industries (1.2 Mt) and gasoline automobiles (1.0 Mt).

Agricultural emissions from enteric fermentation, manure management, and agricultural soils grew by 33.5% between 1990 and 2004. Emissions from enteric fermentation and manure management increased by 41% and 37%, respectively, while emissions from agricultural soils increased by 22%. The main factors contributing to the increased emissions were higher beef cattle and swine populations and greater use of synthetic nitrogen fertilizers.

Long-term emission trends in Alberta are illustrated in Figure A11-17.

A11.9.2 SHORT-TERM TRENDS (2003–2004)

The one-year growth of 1.9% was the result of increases in emissions from fossil fuel production (2.2 Mt), other and undifferentiated industrial production processes (1.7 Mt), and HDDVs (0.6 Mt), which were partially offset by decreases in electricity and heat generation (2.1 Mt). Overall, combustion emissions from the fossil fuel industry decreased by 4.7% (2.2 Mt), while a 0.7% (0.2 Mt) decrease in fugitive emissions from the oil and gas category was observed.

Agricultural short-term trends showed increases in N_2O by 6% and in CH_4 by 5%. These short-term changes in emissions were due mainly to increases in beef cattle population, synthetic nitrogen fertilizer consumption, and crop production.

Short-term emission trends in Alberta are illustrated in Figure A11-18.

FIGURE A11-17: Alberta Long-Term Emission Trends, 1990–2004

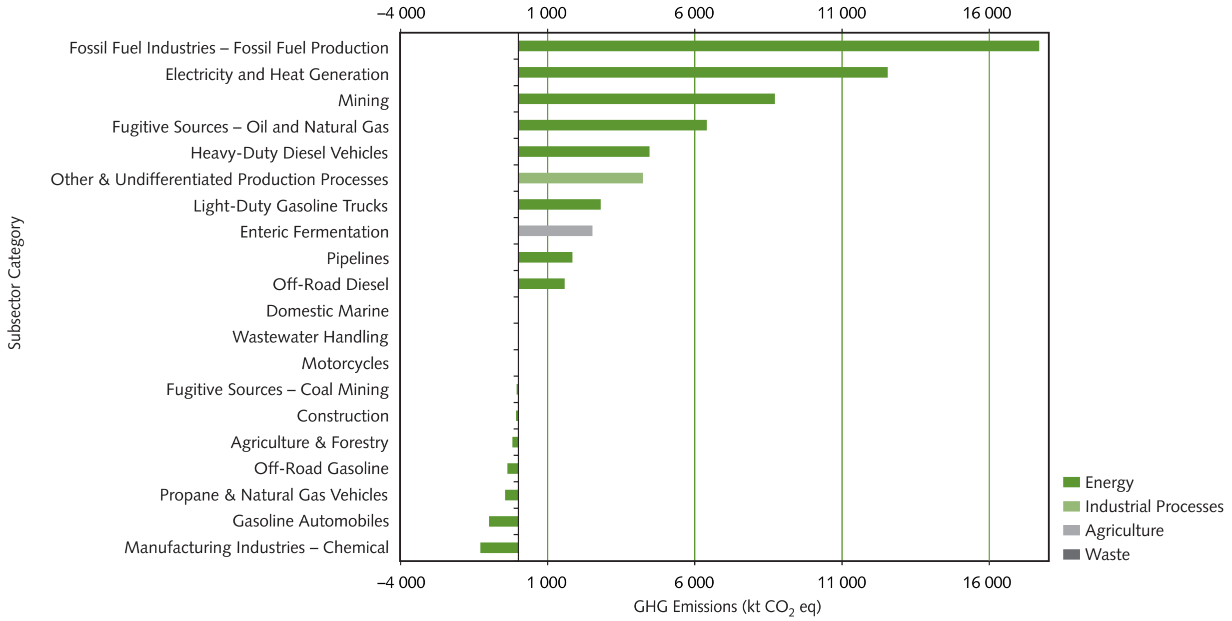
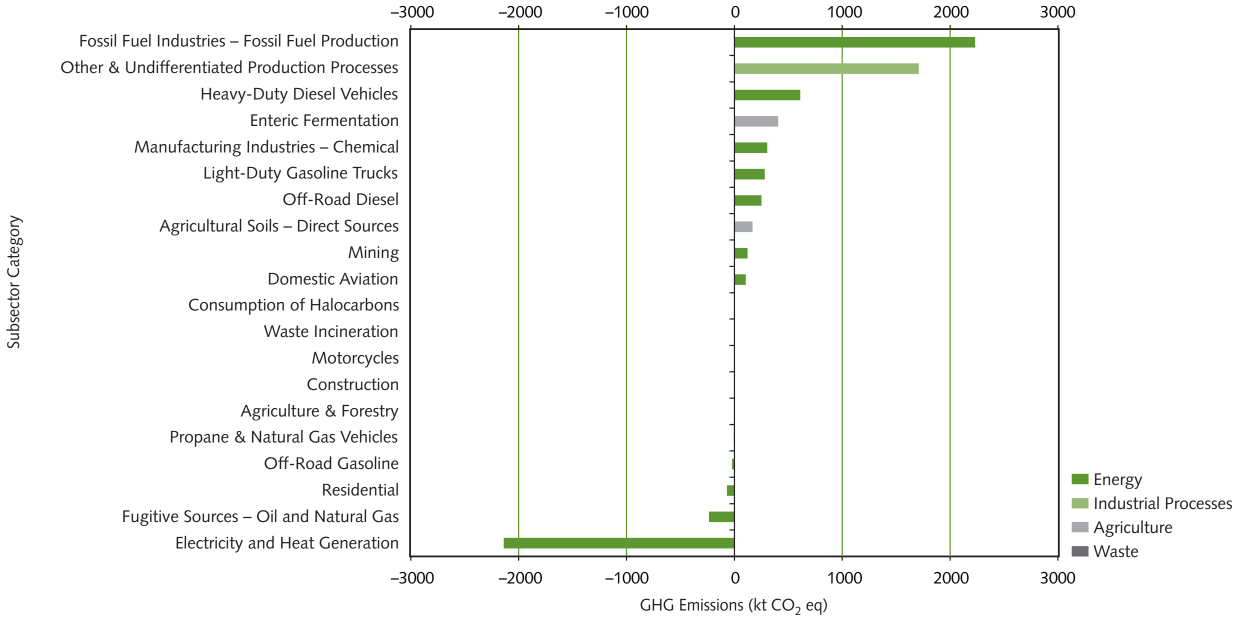


FIGURE A11-18: Alberta Short-Term Emission Trends, 2003–2004



A11.10 BRITISH COLUMBIA

TABLE A11-10: Trends in GHG Emissions and GHG Intensity, British Columbia

	1990	1995	2000	2003	2004
Total GHG (Mt)	**51.47**	**59.46**	**63.70**	**63.81**	**66.84**
Growth Since 1990	N/A	15.5%	23.8%	24.0%	29.9%
Annual Change	N/A	7.5%	1.9%	3.4%	4.7%
GDP Expense – Annual Change	N/A	2.8%	4.6%	3.2%	2.5%
GHG Intensity (Mt/$B GDP)	**0.61**	**0.60**	**0.56**	**0.52**	**0.53**
Annual Change	N/A	4.6%	–2.6%	0.2%	2.2%

Note:
N/A = not applicable

In 2004, British Columbia's 4.2 million residents generated a total of 66.8 Mt of GHGs (Table A11-10) and contributed $125.0 billion to the country's GDP. This represents 8.9% of Canada's total GHG emissions and 12.0% of the total GDP. Between 1990 and 2004, the province's total emissions increased 15.4 Mt or 30%, while GDP and population increased 48% and 28%, respectively. British Columbia's annual generation rate increased from 15.6 t GHGs per person in 1990 to 15.9 t GHGs per person in 2004, and its GHG per GDP equalled 534 kt per billion dollars in 2004. In the short term (2003–2004), total emission output increased 3 Mt, or 4.7%. The province's annual HDDs decreased by 13.2% between 1990 and 2004 and by 5.0% since 2003.

A review of British Columbia's sector-specific emissions shows 83% of GHG emissions arising from the Energy Sector, while the Waste, Agriculture, and Industrial Processes sectors contribute 8.8%, 3.8%, and 4.7%, respectively. Within the Energy Sector, stationary sources represent 41%, transportation sources represent 48%, and fugitive emissions make up the remaining 11%, predominantly from oil and natural gas operations.

A11.10.1 LONG-TERM TRENDS (1990–2004)

This province's Energy Sector and its subsectors contributed the greatest to changes in annual GHG emissions in the long term. Nine of the top 10 long-term growth subsectors are in the Energy Sector, and four of those are represented by transportation, a subsector that has registered over 40% growth since 1990. Increases from LDGTs, HDDVs, domestic aviation, and off-road diesel vehicles have been offset by reductions from railways, gasoline automobiles, and alternatively fuelled vehicles. Fugitive emissions from oil and natural gas increased 2.7 Mt, or 96%, between 1990 and 2004, while combustion emissions from the fossil fuel industries increased 2.2 Mt, or 56%. Emissions from solid waste disposal operations increased by 1.0 Mt between 1990 and 2004.

There were 27% increases in CH_4 emissions from enteric fermentation and 11% increases in N_2O emissions from manure management and agricultural soils from 1990 to 2004, due mainly to the increase in beef cattle population.

Long-term emission trends in British Columbia are illustrated in Figure A11-19.

A11.10.2 SHORT-TERM TRENDS (2003–2004)

In the short term, eight of the top 10 growth subsectors belong to the Energy Sector, with five of them related to transportation emissions. Electricity and heat generation emissions increased by 0.5 Mt (38%) from 2003, while mining emissions increased by 186%. However, the single greatest short-term increase is from solid waste disposal operations (0.7 Mt). The Waste Sector sources have increased a total of over 21% since 1990 and 14% since 2003. British Columbia's portion of emissions from the Waste Sector (8.8%) surpasses those of the remaining provinces/territories, with over 96% of this sector's total coming from solid waste disposal on land. Much of this is the result of the landfilling of wood waste by British Columbia's large forest industry.

The short-term trend in Agriculture showed an increase of 6% in CH_4 emissions between 2003 and 2004. This short-term increase was due mainly to the increase in the beef cattle population.

Short-term emission trends in British Columbia are illustrated in Figure A11-20.

FIGURE A11-19: British Columbia Long-Term Emission Trends, 1990–2004

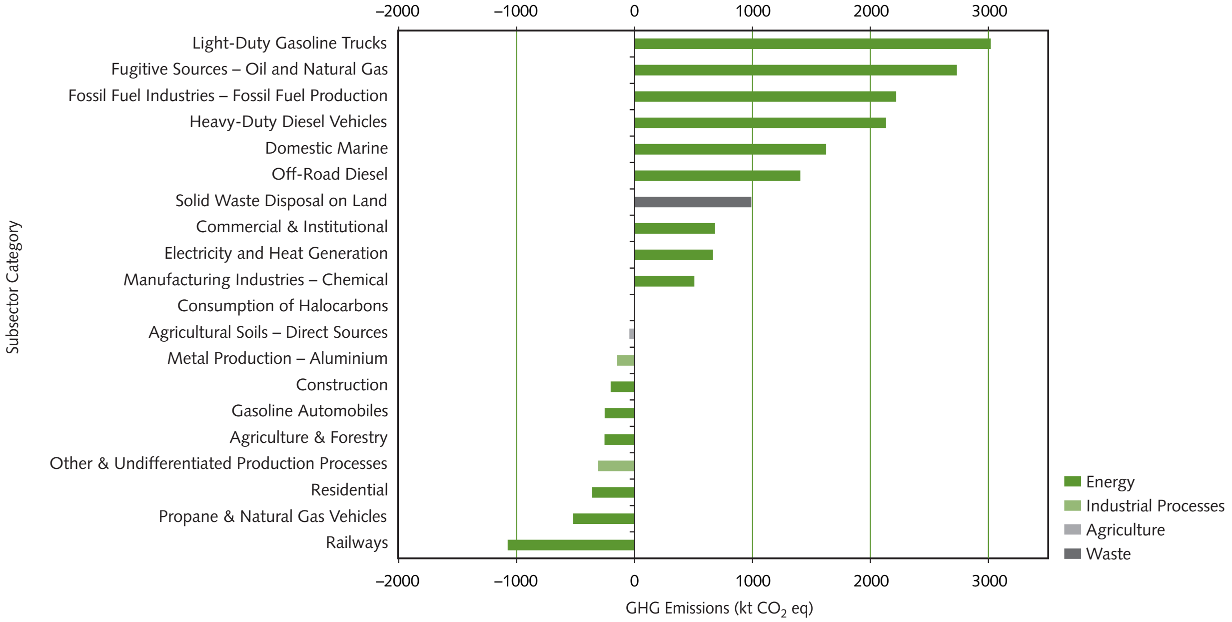
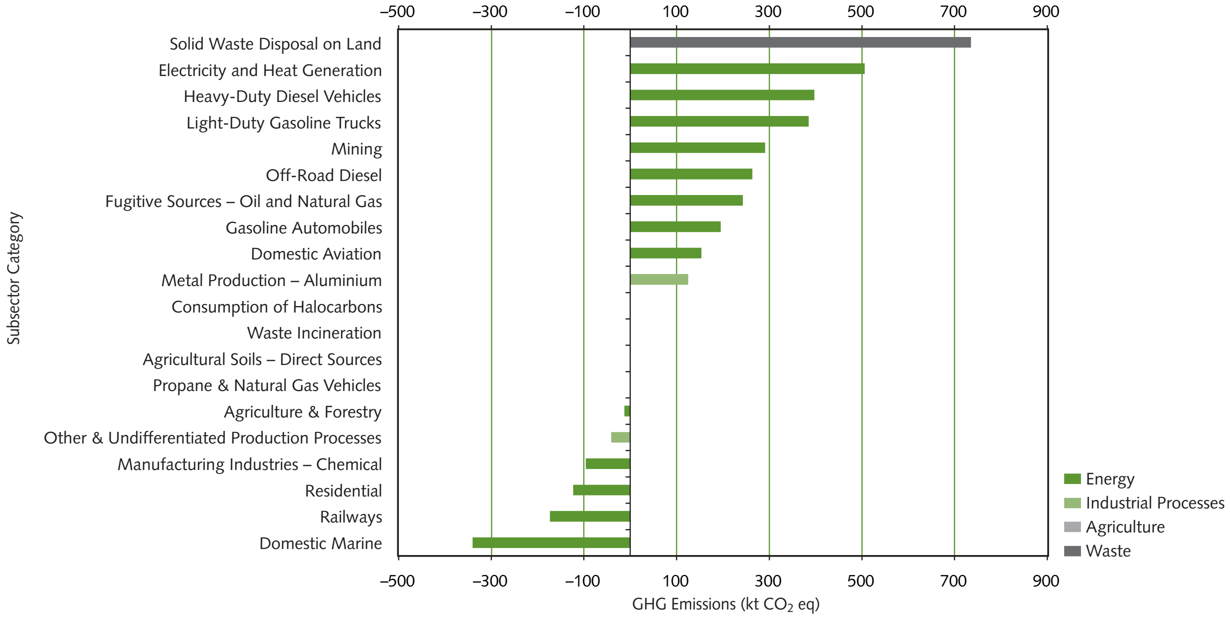


FIGURE A11-20: British Columbia Short-Term Emission Trends, 2003–2004



A11.11 YUKON, NORTHWEST TERRITORIES, AND NUNAVUT

TABLE A11-11: Trends in GHG Emissions and GHG Intensity, Total Territories

	1990	1995	2000	2003	2004
Total GHG (Mt)	**2.06**	**2.26**	**2.02**	**2.05**	**2.02**
Growth Since 1990	N/A	9.9%	–2.2%	–0.6%	–1.8%
Annual Change	N/A	7.0%	12.5%	–6.0%	–1.2%
GDP Expense – Annual Change	N/A	5.7%	5.1%	12.4%	5.8%
GHG Intensity (Mt/$B GDP)	**0.63**	**0.67**	**0.49**	**0.39**	**0.36**
Annual Change	N/A	1.2%	7.1%	–16.4%	–6.6%

Note:
N/A = not applicable

Together, Canada's territories contributed 2.0 Mt (Table A11-11) or 0.3% to the national GHG total and $5.6 billion to the national GDP in 2004. Over 97% of the territories' total emissions are from the Energy Sector.

TABLE A11-12: Trends in GHG Emissions, Yukon

	1990	1995	2000	2003	2004
Total GHG Emissions (Mt)	**0.52**	**0.46**	**0.40**	**0.43**	**0.42**
Growth Since 1990	N/A	–10.0%	–21.7%	–16.3%	–18.9%
Annual Change	N/A	10.9%	–8.3%	3.4%	–3.1%

Note:
N/A = not applicable

Yukon, with a GHG emissions total for 2004 of 0.4 Mt (Table A11-12), has shown a 19% reduction since 1990, most of which is due to reductions in combustion emissions from the off-road diesel transportation and electricity and heat generation subsectors. While total emissions went down, there was an increase in emissions from the HDDV and the agriculture subsectors of the Energy Sector. These two subsectors have shown growth since the early 1990s.

Since 1990, Yukon's population has increased almost 23%; per capita, Yukon residents are each attributed 5.8 t GHGs annually, very low compared with the Canadian average.

TABLE A11-13: Trends in GHG Emissions, Northwest Territories and Nunavut

	1990	1995	2000	2003	2004
Total GHG Emissions (Mt)	**1.54**	**1.80**	**1.61**	**1.62**	**1.61**
Growth Since 1990	N/A	16.6%	4.4%	4.7%	4.0%
Annual Change	N/A	6.0%	19.3%	–8.2%	–0.7%

Note:
N/A = not applicable

The Northwest Territories and Nunavut generated approximately 1.6 Mt total GHGs in 2004 (Table A11-13). This is a 4% increase since 1990, which has been driven almost entirely by increases from the transportation and electricity and heat generation subsectors, and specifically the contributions from HDDVs and off-road sources. Since 1990, the combined population of these regions has increased 12% to over 31 000, while GHG emissions per capita registered 51 t in 2004, a 7.5% decrease over 1990.

As a whole, HDDs for the three territories for 2004 show an overall decrease of approximately 4% compared with 1990 and 4% more than in 2003.

Long-term emission trends in Yukon and in the Northwest Territories and Nunavut are illustrated in Figures A11-21 and A11-22, respectively. Short-term emission trends in Yukon and in the Northwest Territories and Nunavut are illustrated in Figures A11-23 and A11-24, respectively.

FIGURE A11-21: Yukon Long-Term Emission Trends, 1990–2004

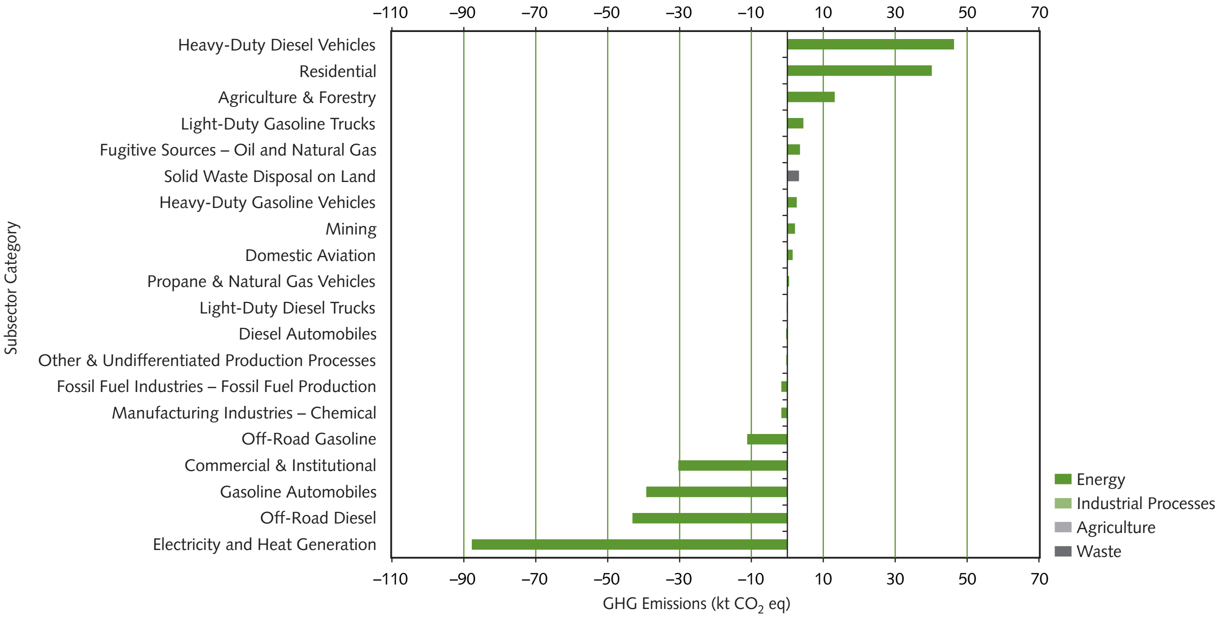


FIGURE A11-22: Northwest Territories and Nunavut Long-Term Emission Trends, 1990–2004

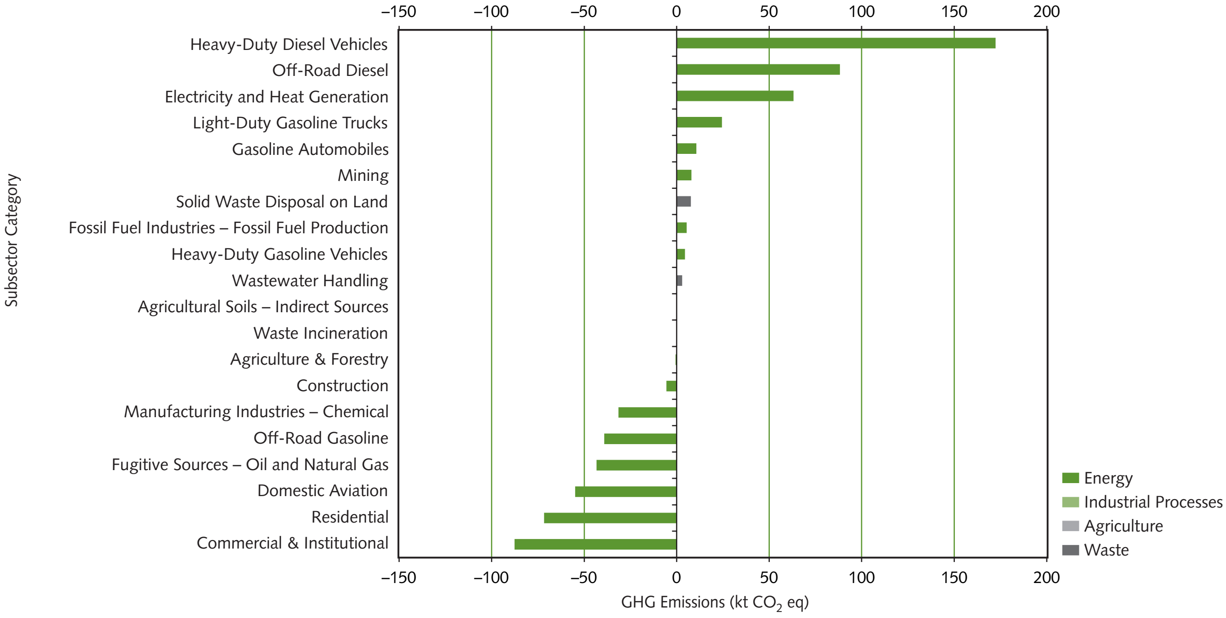


FIGURE A11-23: Yukon Short-Term Emission Trends, 2003–2004

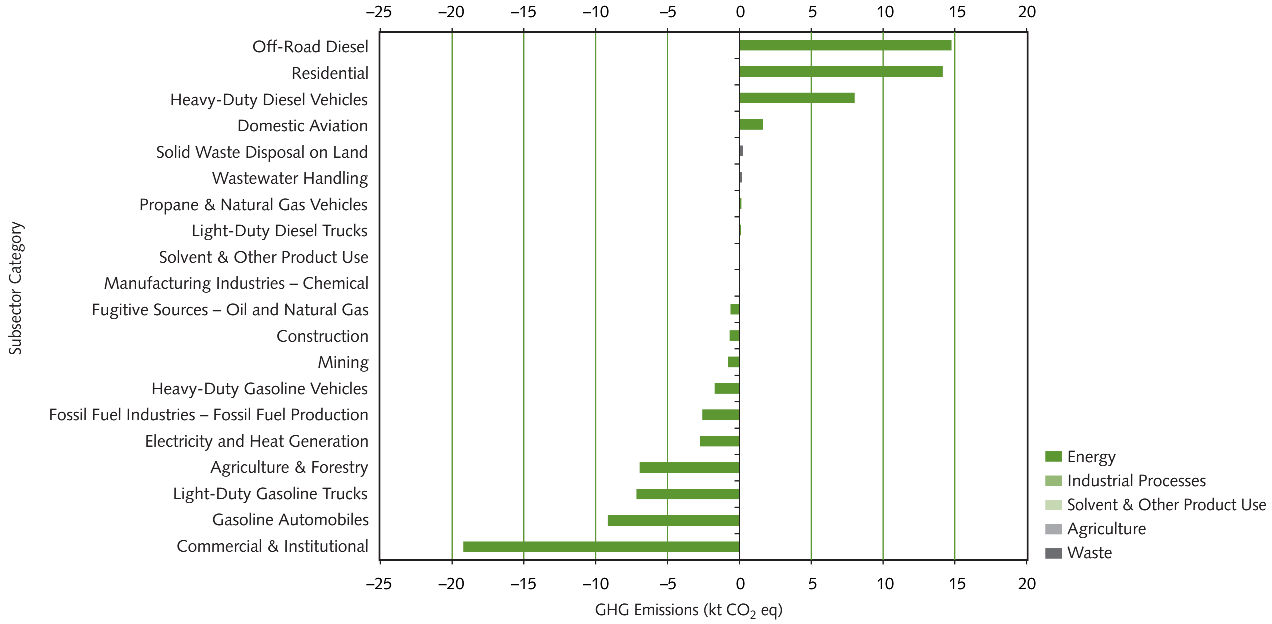
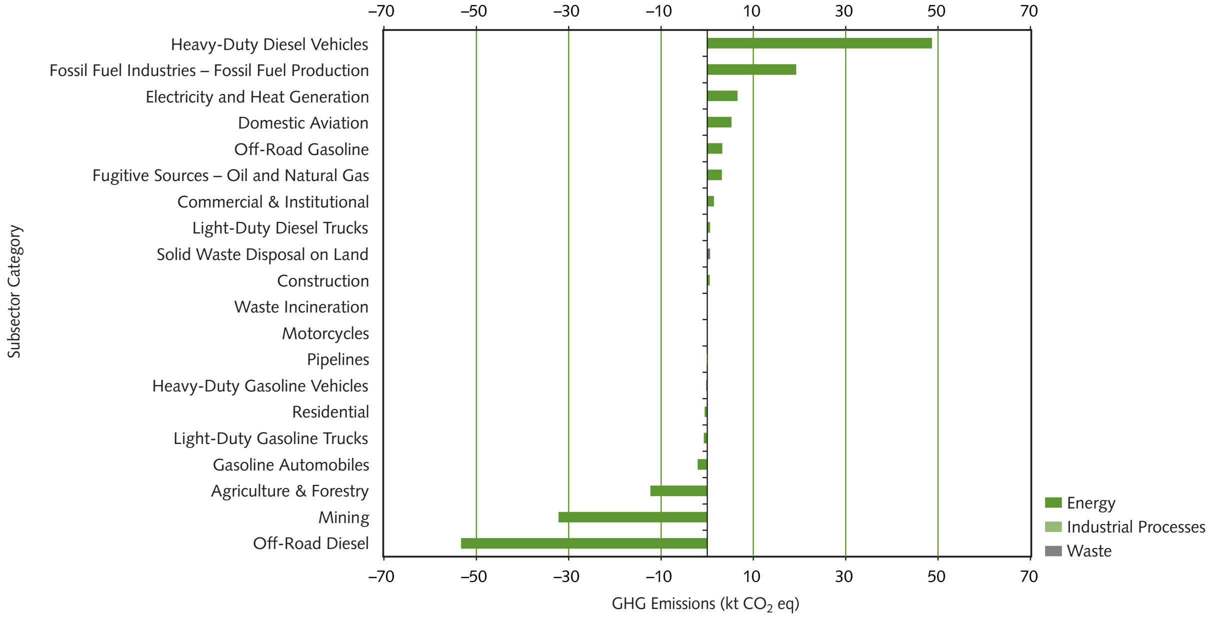


FIGURE A11-24: Northwest Territories and Nunavut Short-Term Emission Trends, 2003–2004



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ANNEX 12: PROVINCIAL/TERRITORIAL GREENHOUSE GAS EMISSION TABLES, 1990–2004

Summary tables illustrating GHG emissions by province/territory, sector, and year are included in Annex 12. Although the UNFCCC reporting guidelines require that only national-level detail be reported, provincial- and territorial-level detail is important due to the regional differences in emission levels and trends. Note that provincial and territorial emission estimates may not necessarily sum to the national totals due to rounding and suppression of confidential data. Provincial and territorial emission totals do not include:

1. HFCs (e.g., fugitive releases from AC and refrigeration systems);
2. PFCs (used during the fabrication of semiconductors);
3. CO_2 from limestone and soda ash use; and
4. emissions associated with ammonia production.

TABLE A12-1: Greenhouse Gas Category Description

GHG Source/Sink Categories	
ENERGY	
a. **Stationary Combustion Sources**	
Electricity and Heat Generation	Emissions from fuels consumed by:
Electricity Generation	Utility and industry electricity generation
Heat Generation	Steam generation (for sale)
Fossil Fuel Industries	Emissions from fuels consumed by:
Petroleum Refining and Upgrading	Petroleum refining industry and the heavy oil and bitumen upgrading industry
Fossil Fuel Production	Natural gas production and some conventional and unconventional oil production industries (some refining is included)
Mining	Emissions from commercial fuel sold to:
	Metal and non-metal mines, stone quarries, and gravel pits
	Oil and gas extraction industries
	Mineral exploration and contract drilling operation
Manufacturing Industries	Emissions from fuels consumed by the following industries:
	Iron and steel (steel foundries, casting and rolling mills)
	Non-ferrous metals (aluminium, magnesium, and other production)
	Chemical (fertilizer manufacturing, organic and inorganic chemical manufacturing)
	Pulp and paper (primarily pulp, paper and paper product manufacturers)
	Cement production
	Other manufacturing industries not listed (such as automobile manufacturing, textiles, food and beverage industries)
Construction	Emissions from fuels consumed by the construction industry – buildings, highways, etc.
Commercial & Institutional	Emissions from fuels consumed by:
	Service industries related to mining, communication, wholesale and retail trade, finance and insurance, real estate, education, etc.
	Federal, provincial, and municipal establishments
	National Defence and Canadian Coast Guard
	Train stations, airports, and warehouses
Residential	Emissions from fuels consumed for personal residences (homes, apartment hotels, condominiums, and farm houses)
Agriculture & Forestry	Emissions from fuels consumed by:
	Forestry and logging service industry
	Agriculture, hunting and trapping industry (excluding food processing, farm machinery manufacturing and repair)
b. **Transportation**	Emissions resulting from the combustion and/or fugitive releases due to moving passengers, freight, and commodities throughout Canada
Domestic Aviation	Emissions resulting from the consumption of fossil fuels by Canadian-registered airlines flying domestically
Road Transportation	Emissions resulting from the consumption of fossil fuels by vehicles licensed to operate on roads
Railways	Emissions resulting from the consumption of fossil fuels by Canadian railways
Domestic Marine	Emissions resulting from the consumption of fossil fuels by Canadian-registered marine vessels fuelled domestically
Others – Off-Road	Emissions resulting from the consumption of fossil fuels by combustion devices not licensed to operate on roads
Others – Pipelines	Emissions resulting from the transportation and distribution of crude oil, natural gas, and other products
c. **Fugitive Sources**	Intentional and unintentional releases of GHGs from the following activities:
Coal Mining	Underground and surface mining
Oil and Natural Gas	Conventional and unconventional oil and gas exploration, production, processing, transportation, and distribution
INDUSTRIAL PROCESSES	Emissions resulting from the following process activities:
a. **Mineral Products**	Production of cement and lime; use of soda ash, limestone & dolomite, and magnesite
b. **Chemical Industry**	Production of ammonia, nitric acid, and adipic acid
c. **Metal Production**	Production of aluminium, iron and steel; magnesium production and casting
d. **Consumption of Halocarbons and SF$_6$**	Use of HFCs and/or PFCs in air conditioning units, refrigeration units, fire extinguishers, aerosol cans, solvents, foam blowing, semiconductor manufacturing and electronics industry; use of SF$_6$ in electrical equipment and semiconductors
e. **Other & Undifferentiated Production**	Non-energy use of fossil fuels
SOLVENT & OTHER PRODUCT USE	Emissions resulting from the use of N$_2$O as anaesthetic and propellant
AGRICULTURE	Emissions resulting from:
a. **Enteric Fermentation**	Livestock enteric fermentation
b. **Manure Management**	Livestock waste management
c. **Agricultural Soils**	
Direct Sources	Direct N$_2$O emissions from synthetic fertilizer, manure on cropland, crop residue, tillage, summerfallow, and cultivation of organic soils
Manure on Pasture, Range, and Paddock	Direct N$_2$O emissions from manure deposited on pasture, range, and paddock
Indirect Sources	Indirect N$_2$O emissions from volatilization and leaching of animal manure nitrogen, synthetic fertilizer nitrogen, and crop residue nitrogen
WASTE	Emissions resulting from:
a. **Solid Waste Disposal on Land**	Municipal waste management sites (landfills) and wood waste landfills
b. **Wastewater Handling**	Domestic and industrial wastewater treatment
c. **Waste Incineration**	Municipal solid waste and sewage sludge incineration
LAND USE, LAND-USE CHANGE AND FORESTRY	Emissions and removals resulting from:
a. **Forest Land**	Managed forests and lands converted to forests; includes growth, natural and anthropogenic disturbances
b. **Cropland**	Mineral and organic cropland soils management, liming, woody biomass (CO$_2$), lands converted to cropland
c. **Grassland**	Managed grasslands, lands converted to grasslands (CO$_2$)
d. **Wetlands**	Lands converted to wetlands (peatlands, flooded lands) and wetlands remaining wetlands (peatlands only)
e. **Settlements**	Urban trees and forest and grassland conversion to built-up lands (settlements, transport infrastructure, oil & gas infrastructure)

TABLE A12-2: 1990–2004 Greenhouse Gas Emissions Summary for Newfoundland and Labrador

kt CO_2 eq

GHG Source Category	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
TOTAL	**10 100**	**8 870**	**8 830**	**8 860**	**7 870**	**8 780**	**8 860**	**9 370**	**11 800**	**9 420**	**9 160**	**9 950**	**12 000**	**11 300**	**10 500**
ENERGY	**8 840**	**7 670**	**7 630**	**7 680**	**6 680**	**7 590**	**7 690**	**8 190**	**10 700**	**8 280**	**8 100**	**8 900**	**11 000**	**10 300**	**9 470**
a. Stationary Combustion Sources	**5 420**	**4 540**	**4 530**	**4 550**	**3 650**	**4 500**	**4 490**	**4 940**	**5 400**	**3 990**	**4 260**	**5 060**	**5 890**	**5 610**	**4 960**
Electricity and Heat Generation	1 610	1 280	1 480	1 340	716	1 250	1 160	1 210	1 020	936	919	X	X	X	X
Fossil Fuel Industries	1 000	1 000	860	1 100	570	940	1 100	1 300	2 300	1 200	1 300	1 300	1 900	1 700	1 500
Mining	1 060	716	685	614	907	900	927	1 050	895	641	885	X	X	X	X
Manufacturing Industries	497	386	310	330	299	315	269	282	211	252	241	257	283	290	301
Construction	33.4	23.7	27.2	22.4	17.7	17.6	14.5	14.8	13.1	12.3	10.4	19.2	27.8	26.3	25.2
Commercial & Institutional	326	317	307	329	341	321	312	364	306	316	325	385	445	515	476
Residential	820	760	800	800	740	690	670	690	610	580	550	580	620	580	490
Agriculture & Forestry	25.1	41.9	60.5	55.7	54.3	57.4	59.0	75.5	76.0	69.5	47.8	X	X	X	X
b. Transportation[1]	**3 400**	**3 100**	**3 100**	**3 100**	**3 000**	**3 100**	**3 200**	**3 300**	**3 300**	**3 400**	**3 600**	**3 600**	**3 600**	**3 800**	**3 700**
Domestic Aviation	470	350	400	340	330	360	360	350	320	300	370	360	320	420	440
Road Transportation	1 900	1 900	1 850	1 900	1 950	1 890	1 870	1 870	1 870	1 960	2 010	2 000	2 070	2 150	2 060
Light-Duty Gasoline Vehicles	772	744	744	749	751	720	701	683	655	666	647	639	650	654	610
Light-Duty Gasoline Trucks	565	568	590	614	635	629	633	638	645	696	698	703	730	769	736
Heavy-Duty Gasoline Vehicles	74.6	75.3	78.3	81.4	83.9	82.8	74.6	56.5	67.9	47.2	44.4	36.2	38.8	35.9	33.8
Motorcycles	6.77	6.05	5.49	5.35	5.18	4.62	4.52	4.33	4.24	4.27	4.27	4.20	3.58	3.41	2.69
Light-Duty Diesel Vehicles	3.51	3.23	3.05	2.87	2.68	2.39	2.20	2.06	1.93	1.98	1.75	1.89	1.98	2.09	2.02
Light-Duty Diesel Trucks	13.8	12.6	9.42	8.16	7.14	5.37	4.11	6.00	4.34	6.99	7.07	10.5	11.9	14.8	15.7
Heavy-Duty Diesel Vehicles	459	484	422	435	464	442	452	482	487	535	608	609	632	673	656
Propane & Natural Gas Vehicles	1.4	1.7	1.4	5.8	1.5	2.4	2.3	2.6	1.4	4.2	1.0	1.0	0.34	0.31	0.32
Railways	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Domestic Marine	710	660	610	540	470	560	610	620	650	690	690	620	580	420	650
Others	400	200	200	300	300	300	300	400	400	400	500	600	600	800	600
Off-Road Gasoline	70	70	70	60	40	40	40	30	30	40	70	80	70	40	30
Off-Road Diesel	300	200	200	300	300	200	300	400	400	400	500	500	600	700	500
Pipelines	–	–	–	–	–	–	–	–	–	–	–	–	–	34.9	36.1
c. Fugitive Sources[2]	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**2 050**	**915**	**252**	**241**	**1 450**	**927**	**764**
Coal Mining	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Oil and Natural Gas	–	–	–	–	–	–	–	–	2 050	915	252	241	1 450	927	764
INDUSTRIAL PROCESSES[3]	**75.3**	**59.0**	**64.9**	**67.1**	**75.7**	**81.0**	**76.6**	**91.0**	**87.6**	**88.7**	**22.4**	**22.3**	**25.4**	**29.3**	**23.4**
a. Mineral Products	**57**	**44**	**51**	**53**	**61**	**66**	**62**	**75**	**74**	**68**	**–**	**–**	**–**	**–**	**–**
Cement Production	57	44	51	53	61	66	62	75	74	68	–	–	–	–	–
Lime Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
b. Chemical Industry	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Nitric Acid Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Adipic Acid Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
c. Metal Production	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Iron and Steel Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Aluminium Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
SF_6 Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
d. Consumption of Halocarbons and SF_6	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
e. Other & Undifferentiated Production[4]	**19**	**15**	**14**	**14**	**14**	**15**	**15**	**16**	**14**	**21**	**22**	**22**	**25**	**29**	**23**
SOLVENT & OTHER PRODUCT USE	**8.7**	**8.7**	**8.7**	**8.7**	**8.7**	**8.5**	**8.4**	**8.3**	**8.1**	**8.0**	**8.0**	**7.9**	**7.8**	**7.8**	**7.8**
AGRICULTURE	**49**	**49**	**50**	**49**	**48**	**49**	**49**	**47**	**44**	**44**	**44**	**44**	**45**	**45**	**44**
a. Enteric Fermentation	**18.0**	**18.1**	**18.4**	**18.0**	**17.8**	**18.1**	**17.9**	**17.8**	**17.5**	**18.5**	**19.4**	**20.4**	**20.6**	**20.1**	**19.9**
b. Manure Management	**14**	**14**	**14**	**13**	**13**	**13**	**13**	**12**	**11**	**10**	**9.7**	**9.0**	**8.9**	**8.8**	**8.8**
c. Agricultural Soils	**17**	**17**	**18**	**18**	**17**	**18**	**18**	**17**	**16**	**15**	**15**	**15**	**16**	**16**	**16**
Direct Sources	9.9	9.8	10	10	10	11	11	10	9.4	9.0	8.8	8.6	9.4	10	9.3
Pasture, Range, and Paddock Manure	2.0	2.0	2.1	2.0	2.0	2.0	2.0	2.0	1.9	2.0	2.1	2.2	2.2	2.1	2.1
Indirect Sources	5	5	5	5	5	5	5	5	5	4	4	4	4	4	4
WASTE	**1 100**	**1 100**	**1 100**	**1 100**	**1 100**	**1 000**	**1 000**	**1 000**	**1 000**	**990**	**980**	**980**	**970**	**950**	**950**
a. Solid Waste Disposal on Land	**1 100**	**1 100**	**1 000**	**1 000**	**1 000**	**1 000**	**1 000**	**1 000**	**970**	**960**	**950**	**940**	**930**	**920**	**920**
b. Wastewater Handling	**19**	**24**	**22**	**22**	**23**	**20**	**27**	**26**	**28**	**35**	**33**	**34**	**34**	**34**	**34**
c. Waste Incineration	**–**	**–**	**8.5**	**–**	**–**	**0.0**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**

Notes:

1 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

2 Fugitive emissions from refineries and the bitumen industry are reported only at the national level.

3 Emissions associated with the use of mineral products and consumption of halocarbons and SF_6 are reported only at the national level.

4 Emissions from ammonia production are included in the category Other & Undifferentiated Production.

X Indicates confidential data.

Totals may not add due to rounding.

TABLE A12-3: 2004 Greenhouse Gas Emissions Summary for Newfoundland and Labrador

GHG Source Category	Greenhouse Gases								
	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	TOTAL
Global Warming Potential			21		310				
Unit	*kt*	*kt*	*kt CO_2 eq*	*kt*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*
TOTAL	**9 000**	**57**	**1 200**	**0.98**	**310**	**N/A**	**N/A**	**N/A**	**10 500**
ENERGY	**8 970**	**10**	**200**	**0.8**	**300**	**–**	**–**	**–**	**9 470**
a. Stationary Combustion Sources	**4 730**	**9**	**200**	**0.2**	**50**	**–**	**–**	**–**	**4 960**
Electricity and Heat Generation	X	X	X	X	X	–	–	–	X
Fossil Fuel Industries	1 500	3	70	0.04	10	–	–	–	1 500
Mining	X	X	X	X	X	–	–	–	X
Manufacturing Industries	299	0.01	0.2	0.01	2	–	–	–	301
Construction	25.1	0.00	0.01	0.00	0.09	–	–	–	25.2
Commercial & Institutional	473	0.01	0.1	0.01	3	–	–	–	476
Residential	359	6	100	0.06	20	–	–	–	490
Agriculture & Forestry	X	X	X	X	X	–	–	–	X
b. Transportation[1]	**3 530**	**0.3**	**5**	**0.7**	**200**	**–**	**–**	**–**	**3 700**
Domestic Aviation	431	0.02	0.3	0.04	10	–	–	–	440
Road Transportation	1 980	0.15	3.2	0.23	72	–	–	–	2 060
Light-Duty Gasoline Vehicles	587	0.04	0.78	0.07	22	–	–	–	610
Light-Duty Gasoline Trucks	693	0.07	1.6	0.14	42	–	–	–	736
Heavy-Duty Gasoline Vehicles	32.2	0.00	0.10	0.00	1.5	–	–	–	33.8
Motorcycles	2.63	0.00	0.04	0.00	0.02	–	–	–	2.69
Light-Duty Diesel Vehicles	1.98	0.00	0.00	0.00	0.04	–	–	–	2.02
Light-Duty Diesel Trucks	15.4	0.00	0.01	0.00	0.3	–	–	–	15.7
Heavy-Duty Diesel Vehicles	650	0.03	0.7	0.02	6	–	–	–	656
Propane & Natural Gas Vehicles	0.32	0.00	0.00	0.00	0.00	–	–	–	0.32
Railways	–	–	–	–	–	–	–	–	–
Domestic Marine	580	0.03	0.7	0.2	70	–	–	–	650
Others	530	0.06	1	0.2	60	–	–	–	600
Off-Road Gasoline	30	0.04	0.8	0.00	0.2	–	–	–	30
Off-Road Diesel	470	0.02	0.5	0.2	60	–	–	–	500
Pipelines	34.5	0.00	0.04	0.01	2	–	–	–	36.1
c. Fugitive Sources[2]	**720**	**2.3**	**48**	**–**	**–**	**–**	**–**	**–**	**764**
Coal Mining	–	–	–	–	–	–	–	–	–
Oil and Natural Gas	720	2.3	48	–	–	–	–	–	764
INDUSTRIAL PROCESSES[3]	**23.4**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**23.4**
a. Mineral Products	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Cement Production	–	–	–	–	–	–	–	–	–
Lime Production	–	–	–	–	–	–	–	–	–
b. Chemical Industry	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Nitric Acid Production	–	–	–	–	–	–	–	–	–
Adipic Acid Production	–	–	–	–	–	–	–	–	–
c. Metal Production	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Iron and Steel Production	–	–	–	–	–	–	–	–	–
Aluminium Production	–	–	–	–	–	–	–	–	–
SF_6 Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	–	–
d. Consumption of Halocarbons and SF_6	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
e. Other & Undifferentiated Production[4]	**23**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**23**
SOLVENT & OTHER PRODUCT USE	**–**	**–**	**–**	**0.03**	**7.8**	**–**	**–**	**–**	**7.8**
AGRICULTURE	**–**	**1.14**	**23.8**	**0.07**	**20**	**–**	**–**	**–**	**44**
a. Enteric Fermentation	**–**	**0.95**	**19.9**	**–**	**–**	**–**	**–**	**–**	**19.9**
b. Manure Management	**–**	**0.19**	**3.9**	**0.02**	**4.8**	**–**	**–**	**–**	**8.8**
c. Agricultural Soils	**–**	**–**	**–**	**0.05**	**16**	**–**	**–**	**–**	**16**
Direct Sources	–	–	–	0.03	9.3	–	–	–	9.3
Pasture, Range, and Paddock Manure	–	–	–	0.01	2.1	–	–	–	2.1
Indirect Sources	–	–	–	0.01	4	–	–	–	4
WASTE	**–**	**44**	**930**	**0.05**	**20**	**–**	**–**	**–**	**950**
a. Solid Waste Disposal on Land	**–**	**44**	**920**	**–**	**–**	**–**	**–**	**–**	**920**
b. Wastewater Handling	**–**	**0.86**	**18**	**0.05**	**20**	**–**	**–**	**–**	**34**
c. Waste Incineration	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**

Notes:

1 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

2 Fugitive emissions from refineries and the bitumen industry are reported only at the national level.

3 Emissions associated with the use of mineral products and consumption of halocarbons and SF_6 are reported only at the national level.

4 Emissions from ammonia production are included in the category Other & Undifferentiated Production.

X Indicates confidential data.

Totals may not add due to rounding.

N/A = not available.

TABLE A12-4: 1990–2004 Greenhouse Gas Emissions Summary for Prince Edward Island

	kt CO_2 eq														
GHG Source Category	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
TOTAL	**2100**	**2060**	**2070**	**2050**	**2050**	**2020**	**2150**	**2180**	**2150**	**2140**	**2290**	**2170**	**2200**	**2300**	**2310**
ENERGY	**1460**	**1430**	**1420**	**1420**	**1410**	**1360**	**1480**	**1520**	**1470**	**1470**	**1620**	**1540**	**1530**	**1610**	**1630**
a. Stationary Combustion Sources	**749**	**713**	**708**	**709**	**676**	**649**	**693**	**747**	**668**	**620**	**751**	**696**	**686**	**743**	**719**
Electricity and Heat Generation	102	92.2	51.7	74.8	58.8	39.1	27.4	37.1	11.1	19.5	56.0	X	X	X	X
Fossil Fuel Industries	0.29	–	1.4	1.7	1.1	1.7	1.7	1.7	2.6	0.59	2.1	4.2	–	–	0.02
Mining	0.77	0.77	1.07	–	–	0.61	1.38	1.38	1.53	2.25	4.94	X	X	X	X
Manufacturing Industries	54.6	69.6	76.6	79.4	79.8	71.5	90.9	110.0	90.8	56.2	133	124	119	137	138
Construction	11.1	10.2	9.77	8.96	8.80	6.53	5.83	5.29	6.64	5.97	6.81	5.39	5.98	4.36	6.42
Commercial & Institutional	161	157	160	158	161	180	184	192	177	171	198	197	212	242	244
Residential	400	360	380	360	340	310	330	350	330	320	320	300	310	300	290
Agriculture & Forestry	19.1	19.6	27.5	28.0	27.4	40.6	47.2	50.8	49.3	44.2	32.1	X	X	X	X
b. Transportation[1]	**710**	**720**	**710**	**710**	**730**	**710**	**780**	**770**	**800**	**850**	**870**	**840**	**850**	**870**	**910**
Domestic Aviation	13	10	7.2	7.2	6.9	5.6	8.5	9.0	8.4	8.2	7.6	7.4	7.3	9.7	10
Road Transportation	540	537	537	546	567	579	594	611	646	684	672	662	685	701	733
Light-Duty Gasoline Vehicles	286	273	264	258	256	254	248	252	249	275	259	255	264	262	265
Light-Duty Gasoline Trucks	146	149	154	160	170	179	192	200	215	240	242	244	263	273	287
Heavy-Duty Gasoline Vehicles	21.0	24.3	27.9	31.6	35.7	39.9	42.1	39.2	48.7	28.1	24.9	21.0	22.6	19.7	19.4
Motorcycles	1.06	1.10	0.99	0.97	0.97	1.00	1.13	1.16	0.63	0.76	0.62	0.61	0.62	0.54	0.51
Light-Duty Diesel Vehicles	2.76	2.74	2.76	2.79	2.85	2.90	2.73	2.69	2.68	2.83	2.64	2.88	2.84	2.95	2.94
Light-Duty Diesel Trucks	2.25	1.91	1.58	1.39	1.30	1.08	0.96	0.97	0.99	1.83	1.83	1.90	1.81	1.97	2.16
Heavy-Duty Diesel Vehicles	80.3	84.5	85.1	90.2	101	100	106	113	128	133	140	135	130	141	156
Propane & Natural Gas Vehicles	1.1	1.1	0.91	0.76	0.15	0.91	1.2	1.4	0.76	2.2	0.70	1.6	0.04	0.05	0.04
Railways	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Domestic Marine	90	110	130	110	91	63	110	72	66	74	85	85	79	85	100
Others	70	60	40	40	70	70	70	80	80	90	100	90	80	70	60
Off-Road Gasoline	10	9	8	10	20	10	20	10	8	8	10	10	9	9	5
Off-Road Diesel	60	50	30	30	50	60	50	60	70	80	90	80	70	60	60
Pipelines	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
c. Fugitive Sources[2]	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Coal Mining	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Oil and Natural Gas	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
INDUSTRIAL PROCESSES[3]	**2.82**	**2.68**	**3.10**	**3.24**	**3.53**	**2.96**	**2.96**	**2.96**	**2.82**	**3.18**	**2.85**	**2.58**	**2.47**	**2.47**	**2.52**
a. Mineral Products	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Cement Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lime Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
b. Chemical Industry	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Nitric Acid Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Adipic Acid Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
c. Metal Production	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Iron and Steel Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Aluminium Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
SF_6 Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
d. Consumption of Halocarbons and SF_6	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
e. Other & Undifferentiated Production[4]	**2.8**	**2.7**	**3.1**	**3.2**	**3.5**	**3.0**	**3.0**	**3.0**	**2.8**	**3.2**	**2.8**	**2.6**	**2.5**	**2.5**	**2.5**
SOLVENT & OTHER PRODUCT USE	**2.0**	**2.0**	**2.0**	**2.0**	**2.0**	**2.0**	**2.0**	**2.1**	**2.0**	**2.1**	**2.1**	**2.1**	**2.1**	**2.1**	**2.1**
AGRICULTURE	**460**	**450**	**470**	**460**	**470**	**480**	**500**	**500**	**510**	**500**	**490**	**460**	**490**	**510**	**510**
a. Enteric Fermentation	**150**	**146**	**147**	**147**	**147**	**147**	**148**	**148**	**150**	**148**	**143**	**138**	**137**	**137**	**138**
b. Manure Management	**60**	**58**	**58**	**57**	**58**	**58**	**58**	**58**	**59**	**58**	**56**	**56**	**56**	**56**	**56**
c. Agricultural Soils	**250**	**240**	**270**	**260**	**260**	**280**	**290**	**290**	**300**	**290**	**300**	**270**	**300**	**320**	**310**
Direct Sources	160	160	180	170	170	190	200	200	210	200	200	180	210	220	220
Pasture, Range, and Paddock Manure	24	24	24	24	24	24	24	24	25	24	23	22	22	22	22
Indirect Sources	60	60	60	60	60	70	70	70	70	70	70	70	70	70	70
WASTE	**170**	**170**	**170**	**170**	**170**	**170**	**170**	**170**	**170**	**170**	**170**	**170**	**170**	**170**	**170**
a. Solid Waste Disposal on Land	**150**	**150**	**150**	**150**	**150**	**150**	**150**	**150**	**150**	**150**	**150**	**150**	**150**	**160**	**160**
b. Wastewater Handling	**5.7**	**5.8**	**5.8**	**5.8**	**6.0**	**5.9**	**5.8**	**6.0**	**6.0**	**5.7**	**6.0**	**6.0**	**6.0**	**6.0**	**6.0**
c. Waste Incineration	**9.1**	**9.1**	**8.5**	**9.1**	**9.1**	**9.1**	**9.1**	**9.2**	**9.2**	**9.2**	**9.4**	**9.2**	**9.2**	**9.2**	**9.2**

Notes:

1 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

2 Fugitive emissions from refineries and the bitumen industry are reported only at the national level.

3 Emissions associated with the use of mineral products and consumption of halocarbons and SF_6 are reported only at the national level.

4 Emissions from ammonia production are included in the category Other & Undifferentiated Production.

X Indicates confidential data.

Totals may not add due to rounding.

TABLE A12-5: 2004 Greenhouse Gas Emissions Summary for Prince Edward Island

GHG Source Category	Greenhouse Gases								
	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	TOTAL
Global Warming Potential			21		310				
Unit	*kt*	*kt*	*kt CO_2 eq*	*kt*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*
TOTAL	**1550**	**17**	**360**	**1.3**	**400**	**N/A**	**N/A**	**N/A**	**2310**
ENERGY	**1540**	**2**	**40**	**0.2**	**50**	**–**	**–**	**–**	**1630**
a. Stationary Combustion Sources	**677**	**2**	**30**	**0.03**	**8**	**–**	**–**	**–**	**719**
Electricity and Heat Generation	X	X	X	X	X	–	–	–	X
Fossil Fuel Industries	0.02	0.00	0.00	0.00	0.00	–	–	–	0.02
Mining	X	X	X	X	X	–	–	–	X
Manufacturing Industries	137	0.01	0.1	0.00	0.9	–	–	–	138.0
Construction	6.4	0.00	0.00	0.00	0.02	–	–	–	6.42
Commercial & Institutional	243	0.00	0.05	0.00	1	–	–	–	244
Residential	253	2	30	0.02	6	–	–	–	290
Agriculture & Forestry	X	X	X	X	X	–	–	–	X
b. Transportation[1]	**859**	**0.07**	**2**	**0.2**	**50**	**–**	**–**	**–**	**910**
Domestic Aviation	9.85	0.00	0.02	0.00	0.3	–	–	–	10
Road Transportation	702	0.06	1.3	0.10	30	–	–	–	733
Light-Duty Gasoline Vehicles	255	0.02	0.40	0.03	10	–	–	–	265
Light-Duty Gasoline Trucks	269	0.03	0.63	0.06	17	–	–	–	287
Heavy-Duty Gasoline Vehicles	18.5	0.00	0.06	0.00	0.85	–	–	–	19.4
Motorcycles	0.50	0.00	0.01	0.00	0.00	–	–	–	0.51
Light-Duty Diesel Vehicles	2.87	0.00	0.00	0.00	0.07	–	–	–	2.94
Light-Duty Diesel Trucks	2.11	0.00	0.00	0.00	0.05	–	–	–	2.16
Heavy-Duty Diesel Vehicles	154	0.01	0.2	0.01	1	–	–	–	156
Propane & Natural Gas Vehicles	0.04	0.00	0.00	0.00	0.00	–	–	–	0.04
Railways	–	–	–	–	–	–	–	–	–
Domestic Marine	92.0	0.01	0.1	0.03	10	–	–	–	100
Others	55	0.01	0.2	0.02	6	–	–	–	60
Off-Road Gasoline	5	0.01	0.1	0.00	0.03	–	–	–	5
Off-Road Diesel	50	0.00	0.05	0.02	6	–	–	–	60
Pipelines	–	–	–	–	–	–	–	–	–
c. Fugitive Sources[2]	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Coal Mining	–	–	–	–	–	–	–	–	–
Oil and Natural Gas	–	–	–	–	–	–	–	–	–
INDUSTRIAL PROCESSES[3]	**2.52**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**2.52**
a. Mineral Products	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Cement Production	–	–	–	–	–	–	–	–	–
Lime Production	–	–	–	–	–	–	–	–	–
b. Chemical Industry	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Nitric Acid Production	–	–	–	–	–	–	–	–	–
Adipic Acid Production	–	–	–	–	–	–	–	–	–
c. Metal Production	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Iron and Steel Production	–	–	–	–	–	–	–	–	–
Aluminium Production	–	–	–	–	–	–	–	–	–
SF_6 Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	–	–
d. Consumption of Halocarbons and SF_6	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
e. Other & Undifferentiated Production[4]	**2.5**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**2.5**
SOLVENT & OTHER PRODUCT USE	**–**	**–**	**–**	**0.01**	**2.1**	**–**	**–**	**–**	**2.1**
AGRICULTURE	**–**	**7.90**	**166**	**1.1**	**340**	**–**	**–**	**–**	**510**
a. Enteric Fermentation	**–**	**6.56**	**138**	**–**	**–**	**–**	**–**	**–**	**138**
b. Manure Management	**–**	**1.3**	**28**	**0.09**	**28**	**–**	**–**	**–**	**56**
c. Agricultural Soils	**–**	**–**	**–**	**1.0**	**310**	**–**	**–**	**–**	**310**
Direct Sources	–	–	–	0.70	220	–	–	–	220
Pasture, Range, and Paddock Manure	–	–	–	0.07	22	–	–	–	22
Indirect Sources	–	–	–	0.2	70	–	–	–	70
WASTE	**7.7**	**7.5**	**160**	**0.02**	**6**	**–**	**–**	**–**	**170**
a. Solid Waste Disposal on Land	**–**	**7.4**	**160**	**–**	**–**	**–**	**–**	**–**	**160**
b. Wastewater Handling	**–**	**0.08**	**1.7**	**0.01**	**4**	**–**	**–**	**–**	**6.0**
c. Waste Incineration	**7.7**	**–**	**–**	**0.01**	**1**	**–**	**–**	**–**	**9.2**

Notes:

1 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

2 Fugitive emissions from refineries and the bitumen industry are reported only at the national level.

3 Emissions associated with the use of mineral products and consumption of halocarbons and SF_6 are reported only at the national level.

4 Emissions from ammonia production are included in the category Other & Undifferentiated Production.

X Indicates confidential data.

Totals may not add due to rounding.

N/A = not available.

TABLE A12-6: 1990–2004 Greenhouse Gas Emissions Summary for Nova Scotia

GHG Source Category	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
	kt CO_2 eq														
TOTAL	**19 700**	**19 600**	**20 100**	**19 900**	**19 400**	**19 300**	**19 400**	**19 900**	**20 000**	**20 400**	**21 500**	**20 700**	**20 100**	**22 600**	**23 000**
ENERGY	**17 800**	**17 700**	**18 200**	**18 100**	**17 600**	**17 300**	**17 500**	**18 100**	**18 000**	**18 500**	**19 700**	**19 100**	**18 400**	**20 800**	**21 300**
a. Stationary Combustion Sources	**11 500**	**11 400**	**12 100**	**11 900**	**11 400**	**11 200**	**11 500**	**12 200**	**12 100**	**12 400**	**13 600**	**13 200**	**12 400**	**14 300**	**14 600**
Electricity and Heat Generation	6 830	7 000	7 380	7 310	7 120	6 900	7 100	7 530	7 800	8 060	8 830	X	X	X	X
Fossil Fuel Industries	710	800	790	910	600	700	730	710	700	570	1 000	1 000	1 300	1 700	1 200
Mining	35.5	32.5	31.8	22.3	29.7	33.4	38.5	41.0	46.8	48.1	53.7	X	X	X	X
Manufacturing Industries	716	625	637	642	767	874	805	761	782	802	661	509	691	629	589
Construction	50.0	36.9	31.6	25.8	30.1	35.4	28.6	29.6	36.0	32.0	28.2	37.3	55.0	52.1	54.7
Commercial & Institutional	810	794	948	789	735	817	809	946	756	865	922	1 070	1 040	1 280	1 990
Residential	2 200	2 000	2 100	2 100	2 000	1 700	1 800	1 900	1 800	1 800	1 800	1 900	1 800	1 900	1 300
Agriculture & Forestry	107	191	237	154	148	203	227	250	222	209	237	X	X	X	X
b. Transportation[1]	**5 100**	**4 900**	**4 900**	**5 100**	**5 200**	**5 300**	**5 100**	**5 200**	**5 400**	**5 800**	**5 700**	**5 500**	**5 600**	**6 200**	**6 400**
Domestic Aviation	400	400	360	380	370	380	360	340	350	360	350	320	350	380	490
Road Transportation	3 610	3 410	3 520	3 620	3 550	3 820	3 820	3 780	3 740	4 160	4 100	4 010	4 120	4 290	4 360
Light-Duty Gasoline Vehicles	1 680	1 560	1 570	1 610	1 540	1 650	1 580	1 550	1 370	1 600	1 460	1 480	1 500	1 510	1 490
Light-Duty Gasoline Trucks	936	906	955	1 010	1 010	1 120	1 150	1 160	1 230	1 390	1 440	1 340	1 400	1 470	1 500
Heavy-Duty Gasoline Vehicles	136	129	133	138	133	144	141	121	137	87.7	96.4	69.2	69.5	69.1	67.5
Motorcycles	12.0	11.5	11.0	11.1	9.90	9.78	12.4	8.74	10.2	9.79	9.32	8.10	8.09	7.89	7.63
Light-Duty Diesel Vehicles	26.3	25.1	26.0	27.0	26.2	28.5	28.1	28.0	25.0	29.0	28.1	30.2	32.4	36.1	38.0
Light-Duty Diesel Trucks	20.8	16.9	15.1	12.9	11.2	9.64	8.33	9.60	8.32	12.0	15.9	15.1	18.2	22.4	26.5
Heavy-Duty Diesel Vehicles	790	757	797	800	826	854	896	894	951	1 010	1 040	1 060	1 080	1 170	1 220
Propane & Natural Gas Vehicles	7.4	7.4	6.7	8.1	2.9	5.2	6.4	8.8	5.0	14	4.1	5.0	3.9	4.0	4.1
Railways	70	50	60	60	60	50	30	40	40	60	80	70	80	200	100
Domestic Marine	610	700	610	600	630	570	570	600	660	720	670	540	500	680	770
Others	400	400	400	400	600	500	300	500	600	500	600	600	600	600	600
Off-Road Gasoline	70	60	50	50	200	50	40	70	200	40	50	90	50	20	20
Off-Road Diesel	300	300	300	400	400	400	300	400	300	500	500	500	600	600	600
Pipelines	–	–	–	–	–	–	–	–	–	–	–	–	–	12.0	30.0
c. Fugitive Sources[2]	**1 170**	**1 340**	**1 210**	**1 080**	**972**	**835**	**835**	**692**	**513**	**338**	**331**	**352**	**352**	**346**	**343**
Coal Mining	1 000	1 000	1 000	1 000	1 000	800	800	700	500	300	300	300	300	300	300
Oil and Natural Gas	–	–	5.08	5.63	5.94	5.86	5.67	5.35	5.56	4.87	81	82	83	76	73
INDUSTRIAL PROCESSES[3]	**272**	**226**	**172**	**170**	**201**	**311**	**262**	**187**	**335**	**319**	**286**	**195**	**285**	**323**	**301**
a. Mineral Products	**170**	**150**	**100**	**110**	**150**	**230**	**190**	**120**	**220**	**230**	**220**	**130**	**220**	**230**	**240**
Cement Production	170	150	100	110	150	230	190	120	220	230	220	130	220	230	240
Lime Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
b. Chemical Industry	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Nitric Acid Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Adipic Acid Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
c. Metal Production	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**6.02**	**0.88**	**–**	**–**	**–**	**–**
Iron and Steel Production	–	–	–	–	–	–	–	–	–	6.02	0.88	–	–	–	–
Aluminium Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
SF_6 Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
d. Consumption of Halocarbons and SF_6	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
e. Other & Undifferentiated Production[4]	**100**	**77**	**68**	**59**	**56**	**77**	**70**	**71**	**110**	**88**	**69**	**62**	**68**	**97**	**66**
SOLVENT & OTHER PRODUCT USE	**14**	**14**	**14**	**14**	**14**	**14**	**14**	**14**	**14**	**14**	**14**	**14**	**14**	**14**	**14**
AGRICULTURE	**510**	**510**	**520**	**510**	**520**	**520**	**530**	**520**	**510**	**500**	**500**	**480**	**490**	**500**	**500**
a. Enteric Fermentation	**211**	**211**	**210**	**211**	**212**	**211**	**212**	**213**	**205**	**201**	**196**	**191**	**190**	**190**	**190**
b. Manure Management	**97**	**97**	**95**	**95**	**95**	**95**	**96**	**96**	**95**	**94**	**92**	**90**	**89**	**88**	**87**
c. Agricultural Soils	**210**	**200**	**210**	**200**	**220**	**220**	**220**	**210**	**210**	**210**	**210**	**200**	**210**	**220**	**220**
Direct Sources	120	110	120	120	130	130	130	120	120	120	120	120	130	140	130
Pasture, Range, and Paddock Manure	32	32	32	32	32	32	32	32	30	29	29	28	28	27	28
Indirect Sources	50	50	60	50	60	60	60	60	60	50	60	50	60	60	60
WASTE	**1 200**	**1 200**	**1 200**	**1 200**	**1 100**	**1 100**	**1 100**	**1 100**	**1 100**	**1 100**	**1 000**	**1 000**	**980**	**960**	**910**
a. Solid Waste Disposal on Land	**1 100**	**1 100**	**1 100**	**1 100**	**1 100**	**1 100**	**1 100**	**1 100**	**1 000**	**1 000**	**980**	**950**	**940**	**910**	**860**
b. Wastewater Handling	**36**	**32**	**33**	**33**	**40**	**34**	**38**	**35**	**35**	**40**	**35**	**36**	**35**	**35**	**35**
c. Waste Incineration	**21**	**17**	**16**	**13**	**12**	**11**	**10**	**10**	**9**	**13**	**12**	**12**	**11**	**12**	**13**

Notes:

1 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

2 Fugitive emissions from refineries and the bitumen industry are reported only at the national level.

3 Emissions associated with the use of mineral products and consumption of halocarbons and SF_6 are reported only at the national level.

4 Emissions from ammonia production are included in the category Other & Undifferentiated Production.

X Indicates confidential data.

Totals may not add due to rounding.

TABLE A12-7: 2004 Greenhouse Gas Emissions Summary for Nova Scotia

GHG Source Category	Greenhouse Gases								
	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	TOTAL
Global Warming Potential			21		310				
Unit	*kt*	*kt*	*kt CO_2 eq*	*kt*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*
TOTAL	**20 700**	**78**	**1 600**	**2.2**	**690**	**N/A**	**N/A**	**N/A**	**23 000**
ENERGY	**20 300**	**30**	**500**	**1**	**400**	**–**	**–**	**–**	**21 300**
a. Stationary Combustion Sources	**14 300**	**9**	**200**	**0.3**	**90**	**–**	**–**	**–**	**14 600**
Electricity and Heat Generation	X	X	X	X	X	–	–	–	X
Fossil Fuel Industries	1 100	1	30.0	0.02	6	–	–	–	1 200
Mining	X	X	X	X	X	–	–	–	X
Manufacturing Industries	577	0.07	2	0.03	10	–	–	–	589
Construction	54.4	0.00	0.02	0.00	0.3	–	–	–	54.7
Commercial & Institutional	1 980	0.02	0.5	0.03	10	–	–	–	1 990
Residential	1 110	8	200	0.09	30	–	–	–	1 300
Agriculture & Forestry	X	X	X	X	X	–	–	–	X
b. Transportation[1]	**6 060**	**0.5**	**10**	**0.9**	**300**	**–**	**–**	**–**	**6 400**
Domestic Aviation	479	0.02	0.3	0.05	10	–	–	–	490
Road Transportation	4 200	0.32	6.7	0.50	150	–	–	–	4 360
Light-Duty Gasoline Vehicles	1 440	0.10	2.0	0.18	55	–	–	–	1 490
Light-Duty Gasoline Trucks	1 410	0.15	3.1	0.27	84	–	–	–	1 500
Heavy-Duty Gasoline Vehicles	64.4	0.01	0.19	0.01	3.0	–	–	–	67.5
Motorcycles	7.46	0.01	0.13	0.00	0.05	–	–	–	7.63
Light-Duty Diesel Vehicles	37.2	0.00	0.02	0.00	0.8	–	–	–	38.0
Light-Duty Diesel Trucks	25.9	0.00	0.01	0.00	0.6	–	–	–	26.5
Heavy-Duty Diesel Vehicles	1 210	0.06	1	0.04	10	–	–	–	1 220
Propane & Natural Gas Vehicles	4.08	0.00	0.03	0.00	0.02	–	–	–	4.1
Railways	108	0.01	0.1	0.04	10	–	–	–	100
Domestic Marine	730	0.06	1	0.1	40	–	–	–	770
Others	550	0.08	2	0.2	60	–	–	–	600
Off-Road Gasoline	20	0.02	0.5	0.00	0.1	–	–	–	20
Off-Road Diesel	500	0.03	0.5	0.2	60	–	–	–	600
Pipelines	29.1	0.03	0.61	0.00	0.2	–	–	–	30.0
c. Fugitive Sources[2]	**7.3**	**16**	**340**	**–**	**–**	**–**	**–**	**–**	**343**
Coal Mining	–	10	300	–	–	–	–	–	300
Oil and Natural Gas	7.3	3.1	66	–	–	–	–	–	73.0
INDUSTRIAL PROCESSES[3]	**301**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**301**
a. Mineral Products	**240**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**240**
Cement Production	240	–	–	–	–	–	–	–	240
Lime Production	–	–	–	–	–	–	–	–	–
b. Chemical Industry	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Nitric Acid Production	–	–	–	–	–	–	–	–	–
Adipic Acid Production	–	–	–	–	–	–	–	–	–
c. Metal Production	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Iron and Steel Production	–	–	–	–	–	–	–	–	–
Aluminium Production	–	–	–	–	–	–	–	–	–
SF_6 Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	–	–
d. Consumption of Halocarbons and SF_6	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
e. Other & Undifferentiated Production[4]	**66**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**66**
SOLVENT & OTHER PRODUCT USE	**–**	**–**	**–**	**0.05**	**14**	**–**	**–**	**–**	**14**
AGRICULTURE	**–**	**10.8**	**227**	**0.87**	**270**	**–**	**–**	**–**	**500**
a. Enteric Fermentation	**–**	**9.07**	**190**	**–**	**–**	**–**	**–**	**–**	**190**
b. Manure Management	**–**	**1.7**	**36**	**0.16**	**51**	**–**	**–**	**–**	**87**
c. Agricultural Soils	**–**	**–**	**–**	**0.70**	**220**	**–**	**–**	**–**	**220**
Direct Sources	–	–	–	0.43	130	–	–	–	130
Pasture, Range, and Paddock Manure	–	–	–	0.09	28	–	–	–	28
Indirect Sources	–	–	–	0.2	60	–	–	–	60
WASTE	**11**	**41**	**870**	**0.1**	**30**	**–**	**–**	**–**	**910**
a. Solid Waste Disposal on Land	**–**	**41**	**860**	**–**	**–**	**–**	**–**	**–**	**860**
b. Wastewater Handling	**–**	**0.28**	**5.9**	**0.09**	**30**	**–**	**–**	**–**	**35**
c. Waste Incineration	**11**	**–**	**–**	**0.01**	**2**	**–**	**–**	**–**	**13**

Notes:

1 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

2 Fugitive emissions from refineries and the bitumen industry are reported only at the national level.

3 Emissions associated with the use of mineral products and consumption of halocarbons and SF_6 are reported only at the national level.

4 Emissions from ammonia production are included in the category Other & Undifferentiated Production.

X Indicates confidential data.

Totals may not add due to rounding.

N/A = not available.

TABLE A12-8: 1990–2004 Greenhouse Gas Emissions Summary for New Brunswick

kt CO_2 eq

GHG Source Category	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
TOTAL	**16 400**	**15 800**	**16 500**	**15 700**	**17 000**	**17 400**	**17 200**	**19 500**	**20 400**	**19 500**	**20 700**	**23 100**	**21 900**	**21 500**	**24 100**
ENERGY	**14 700**	**14 100**	**14 700**	**13 900**	**15 200**	**15 600**	**15 300**	**17 700**	**18 500**	**17 600**	**18 800**	**21 100**	**19 900**	**19 500**	**22 300**
a. **Stationary Combustion Sources**	**10 600**	**9 990**	**10 500**	**9 630**	**10 700**	**11 100**	**10 600**	**12 900**	**13 500**	**12 300**	**13 200**	**15 600**	**14 400**	**14 000**	**16 600**
Electricity and Heat Generation	6 000	5 450	6 100	5 130	6 230	6 850	6 060	8 340	9 460	8 200	8 560	X	X	X	X
Fossil Fuel Industries	1 100	1 100	1 100	1 200	1 300	1 000	1 400	1 300	1 200	1 300	1 600	2 800	3 200	3 000	2 700
Mining	127	82.4	96.3	103	115	117	153	121	98.5	97.2	134	X	X	X	X
Manufacturing Industries	1 420	1 410	1 370	1 410	1 390	1 460	1 420	1 350	1 220	1 250	1 340	1 290	1 240	1 250	1 230
Construction	68.5	53.1	53.3	34.7	41.4	40.9	40.0	48.9	39.0	36.6	39.9	26.4	18.6	12.5	10.9
Commercial & Institutional	587	655	507	461	505	555	495	593	504	491	614	580	494	604	969
Residential	1 200	1 200	1 200	1 200	1 100	920	930	960	840	820	850	730	740	760	740
Agriculture & Forestry	53.9	65.0	81.4	87.4	86.9	131.0	110.0	119.0	104.0	101.0	65.8	X	X	X	X
b. **Transportation**[1]	**4 100**	**4 100**	**4 200**	**4 300**	**4 500**	**4 500**	**4 700**	**4 800**	**5 000**	**5 300**	**5 600**	**5 500**	**5 500**	**5 400**	**5 600**
Domestic Aviation	76	73	72	68	79	83	87	140	140	150	160	150	130	140	140
Road Transportation	3 280	3 200	3 250	3 360	3 530	3 540	3 650	3 710	3 750	4 040	3 920	3 820	3 960	3 970	4 010
Light-Duty Gasoline Vehicles	1 570	1 500	1 490	1 490	1 500	1 430	1 450	1 450	1 470	1 480	1 350	1 370	1 400	1 360	1 360
Light-Duty Gasoline Trucks	704	713	754	795	847	849	911	945	942	1 040	1 050	1 070	1 110	1 110	1 140
Heavy-Duty Gasoline Vehicles	102	104	111	118	126	126	137	110	126	69.3	85.4	68.7	85.8	85.5	96.5
Motorcycles	6.68	6.48	6.45	6.47	6.77	6.48	7.00	7.14	7.62	7.36	7.87	8.46	8.25	8.30	8.10
Light-Duty Diesel Vehicles	18.7	18.2	18.5	18.7	19.0	18.2	18.6	18.9	19.1	18.0	17.8	18.4	19.9	20.8	21.9
Light-Duty Diesel Trucks	21.1	16.8	14.0	12.4	11.5	10.4	8.86	16.1	14.5	18.5	15.6	16.5	17.0	18.0	18.4
Heavy-Duty Diesel Vehicles	847	837	850	910	1 010	1 090	1 100	1 150	1 160	1 390	1 390	1 270	1 310	1 360	1 370
Propane & Natural Gas Vehicles	5.0	5.2	5.2	8.7	4.0	8.1	8.2	10	9.1	16	6.8	8.0	1.6	1.4	1.3
Railways	100	100	100	100	100	100	100	100	200	200	200	300	300	300	300
Domestic Marine	270	260	290	280	300	300	310	310	330	360	400	430	400	370	440
Others	300	400	400	400	500	500	500	500	600	600	800	900	800	700	700
Off-Road Gasoline	10	10	10	20	10	10	10	20	20	10	70	70	40	100	60
Off-Road Diesel	300	400	400	400	500	400	500	500	600	500	800	800	700	600	700
Pipelines	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
c. **Fugitive Sources**[2]	**1.46**	**1.36**	**0.97**	**1.00**	**0.90**	**0.71**	**0.74**	**0.48**	**0.74**	**0.74**	**29.8**	**31.2**	**31.2**	**31.2**	**31.2**
Coal Mining	1	1	1	1	0.9	0.7	0.7	0.5	0.7	0.7	0.6	0.4	0.4	0.4	0.4
Oil and Natural Gas	–	–	–	–	–	–	–	–	–	–	29.3	30.7	30.7	30.7	30.7
INDUSTRIAL PROCESSES[3]	**152**	**170**	**178**	**191**	**132**	**254**	**247**	**246**	**240**	**236**	**226**	**260**	**296**	**285**	**298**
a. **Mineral Products**	**76**	**77**	**79**	**85**	**88**	**91**	**88**	**92**	**92**	**96**	**100**	**92**	**95**	**84**	**92**
Cement Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lime Production	80	80	80	90	90	90	90	90	90	100	100	90	90	80	90
b. **Chemical Industry**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Nitric Acid Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Adipic Acid Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
c. **Metal Production**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Iron and Steel Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Aluminium Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
SF_6 Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
d. **Consumption of Halocarbons and SF_6**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
e. **Other & Undifferentiated Production**[4]	**75**	**92**	**100**	**110**	**44**	**160**	**160**	**150**	**150**	**140**	**120**	**170**	**200**	**200**	**210**
SOLVENT & OTHER PRODUCT USE	**11**	**11**	**11**	**11**	**11**	**11**	**11**	**11**	**11**	**11**	**11**	**11**	**11**	**11**	**11**
AGRICULTURE	**460**	**440**	**480**	**450**	**440**	**440**	**450**	**450**	**460**	**460**	**470**	**460**	**480**	**490**	**490**
a. **Enteric Fermentation**	**170**	**169**	**168**	**165**	**163**	**162**	**162**	**164**	**161**	**165**	**160**	**159**	**158**	**158**	**158**
b. **Manure Management**	**72**	**72**	**72**	**70**	**70**	**70**	**71**	**73**	**74**	**75**	**76**	**77**	**76**	**75**	**75**
c. **Agricultural Soils**	**210**	**200**	**240**	**210**	**200**	**210**	**220**	**220**	**220**	**220**	**230**	**220**	**240**	**260**	**250**
Direct Sources	130	120	160	140	130	130	140	140	140	140	150	140	160	170	170
Pasture, Range, and Paddock Manure	26	26	26	25	25	25	25	25	25	25	24	24	23	23	23
Indirect Sources	50	50	60	50	50	50	50	60	60	60	60	60	60	70	60
WASTE	**1 100**	**1 100**	**1 100**	**1 100**	**1 100**	**1 200**	**1 200**	**1 200**	**1 200**	**1 200**	**1 200**	**1 200**	**1 200**	**1 200**	**1 100**
a. **Solid Waste Disposal on Land**	**1 100**	**1 100**	**1 100**	**1 100**	**1 100**	**1 100**	**1 100**	**1 100**	**1 200**	**1 200**	**1 200**	**1 200**	**1 100**	**1 100**	**1 000**
b. **Wastewater Handling**	**49**	**44**	**47**	**47**	**42**	**46**	**42**	**45**	**45**	**48**	**46**	**46**	**46**	**46**	**46**
c. **Waste Incineration**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**

Notes:

1 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

2 Fugitive emissions from refineries and the bitumen industry are reported only at the national level.

3 Emissions associated with the use of mineral products and consumption of halocarbons and SF_6 are reported only at the national level.

4 Emissions from ammonia production are included in the category Other & Undifferentiated Production.

X Indicates confidential data.

Totals may not add due to rounding.

TABLE A12-9: 2004 Greenhouse Gas Emissions Summary for New Brunswick

GHG Source Category	Greenhouse Gases								
	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	TOTAL
Global Warming Potential			21		310				
Unit	*kt*	*kt*	*kt CO_2 eq*	*kt*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*
TOTAL	**21 900**	**69**	**1 400**	**2.4**	**750**	**N/A**	**N/A**	**N/A**	**24 100**
ENERGY	**21 600**	**10**	**200**	**1**	**400**	**–**	**–**	**–**	**22 300**
a. Stationary Combustion Sources	**16 300**	**9**	**200**	**0.4**	**100**	**–**	**–**	**–**	**16 600**
Electricity and Heat Generation	X	X	X	X	X	–	–	–	X
Fossil Fuel Industries	2 700	0.05	1	0.03	9	–	–	–	2 700
Mining	X	X	X	X	X	–	–	–	X
Manufacturing Industries	1 200	0.2	4	0.08	30	–	–	–	1 230
Construction	10.8	0.00	0.00	0.00	0.05	–	–	–	10.9
Commercial & Institutional	962	0.01	0.3	0.02	7	–	–	–	969
Residential	536	8	200	0.1	30	–	–	–	740
Agriculture & Forestry	X	X	X	X	X	–	–	–	X
b. Transportation[1]	**5 300**	**0.4**	**9**	**0.9**	**300**	**–**	**–**	**–**	**5 600**
Domestic Aviation	133	0.01	0.1	0.01	4	–	–	–	140
Road Transportation	3 870	0.30	6.2	0.44	140	–	–	–	4 010
Light-Duty Gasoline Vehicles	1 300	0.09	2.0	0.17	51	–	–	–	1 360
Light-Duty Gasoline Trucks	1 070	0.11	2.4	0.21	66	–	–	–	1 140
Heavy-Duty Gasoline Vehicles	92.0	0.01	0.27	0.01	4.2	–	–	–	96.5
Motorcycles	7.91	0.01	0.13	0.00	0.05	–	–	–	8.10
Light-Duty Diesel Vehicles	21.4	0.00	0.01	0.00	0.5	–	–	–	21.9
Light-Duty Diesel Trucks	18.0	0.00	0.01	0.00	0.4	–	–	–	18.4
Heavy-Duty Diesel Vehicles	1 360	0.07	1	0.04	10	–	–	–	1 370
Propane & Natural Gas Vehicles	1.30	0.00	0.01	0.00	0.01	–	–	–	1.3
Railways	256	0.01	0.3	0.1	30	–	–	–	300
Domestic Marine	396	0.02	0.5	0.1	40	–	–	–	440
Others	650	0.09	2	0.2	70	–	–	–	700
Off-Road Gasoline	50	0.06	1	0.00	0.4	–	–	–	60
Off-Road Diesel	590	0.03	0.6	0.2	70	–	–	–	700
Pipelines	–	–	–	–	–	–	–	–	–
c. Fugitive Sources[2]	**0.01**	**1.5**	**31**	**–**	**–**	**–**	**–**	**–**	**31.2**
Coal Mining	–	0.02	0.4	–	–	–	–	–	0.4
Oil and Natural Gas	0.01	1.5	31	–	–	–	–	–	30.7
INDUSTRIAL PROCESSES[3]	**298**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**298**
a. Mineral Products	**92**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**92**
Cement Production	–	–	–	–	–	–	–	–	–
Lime Production	90	–	–	–	–	–	–	–	90
b. Chemical Industry	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Nitric Acid Production	–	–	–	–	–	–	–	–	–
Adipic Acid Production	–	–	–	–	–	–	–	–	–
c. Metal Production	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Iron and Steel Production	–	–	–	–	–	–	–	–	–
Aluminium Production	–	–	–	–	–	–	–	–	–
SF_6 Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	–	–
d. Consumption of Halocarbons and SF_6	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
e. Other & Undifferentiated Production[4]	**210**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**210**
SOLVENT & OTHER PRODUCT USE	**–**	**–**	**–**	**0.04**	**11**	**–**	**–**	**–**	**11**
AGRICULTURE	**–**	**9.08**	**191**	**0.95**	**290**	**–**	**–**	**–**	**490**
a. Enteric Fermentation	**–**	**7.50**	**158**	**–**	**–**	**–**	**–**	**–**	**158**
b. Manure Management	**–**	**1.6**	**33**	**0.14**	**42**	**–**	**–**	**–**	**75**
c. Agricultural Soils	**–**	**–**	**–**	**0.81**	**250**	**–**	**–**	**–**	**250**
Direct Sources	–	–	–	0.53	170	–	–	–	170
Pasture, Range, and Paddock Manure	–	–	–	0.08	23	–	–	–	23
Indirect Sources	–	–	–	0.2	60	–	–	–	60
WASTE	**–**	**49**	**1 000**	**0.08**	**20**	**–**	**–**	**–**	**1 100**
a. Solid Waste Disposal on Land	**–**	**48**	**1 000**	**–**	**–**	**–**	**–**	**–**	**1 000**
b. Wastewater Handling	**–**	**1.1**	**22**	**0.08**	**20**	**–**	**–**	**–**	**46**
c. Waste Incineration	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**

Notes:

1 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

2 Fugitive emissions from refineries and the bitumen industry are reported only at the national level.

3 Emissions associated with the use of mineral products and consumption of halocarbons and SF_6 are reported only at the national level.

4 Emissions from ammonia production are included in the category Other & Undifferentiated Production.

X Indicates confidential data.

Totals may not add due to rounding.

N/A = not available.

TABLE A12-10: 1990–2004 Greenhouse Gas Emissions Summary for Quebec

	kt CO_2 eq														
GHG Source Category	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
TOTAL	**86 600**	**81 100**	**81 800**	**82 100**	**84 600**	**83 700**	**84 400**	**85 100**	**86 900**	**86 500**	**87 500**	**85 700**	**88 300**	**93 000**	**91 800**
ENERGY	**58 700**	**53 800**	**55 500**	**55 700**	**58 400**	**57 600**	**58 700**	**59 200**	**60 400**	**60 300**	**61 200**	**59 100**	**61 300**	**66 300**	**66 200**
a. Stationary Combustion Sources	**30 000**	**26 600**	**27 600**	**27 000**	**28 000**	**27 200**	**28 400**	**28 100**	**27 800**	**27 200**	**28 300**	**26 600**	**27 500**	**31 200**	**30 300**
Electricity and Heat Generation	1 510	526	946	295	502	396	425	459	1 560	1 170	580	642	581	1 870	1 640
Fossil Fuel Industries	3 700	3 000	3 100	3 300	3 600	3 300	3 500	3 400	3 500	3 300	3 600	3 600	3 600	3 800	3 900
Mining	734	805	730	798	736	824	825	870	760	759	921	836	935	935	446
Manufacturing Industries	12 100	10 900	10 900	10 600	11 200	10 900	11 500	11 500	11 300	11 000	11 100	10 000	10 000	10 300	10 900
Construction	458	399	371	289	275	188	191	225	188	191	190	191	254	297	322
Commercial & Institutional	4 270	4 180	4 500	4 650	4 730	5 070	5 000	5 000	4 670	4 710	5 720	5 760	6 520	7 910	6 920
Residential	7 000	6 400	6 600	6 700	6 700	6 300	6 700	6 300	5 600	5 900	6 000	5 300	5 400	5 800	5 800
Agriculture & Forestry	293	380	449	348	330	302	277	289	258	264	261	226	258	345	312
b. Transportation[1]	**28 000**	**27 000**	**28 000**	**28 000**	**30 000**	**30 000**	**30 000**	**31 000**	**32 000**	**33 000**	**32 000**	**32 000**	**33 000**	**35 000**	**35 000**
Domestic Aviation	960	780	790	710	780	800	800	700	740	730	770	830	1 400	1 400	1 400
Road Transportation	24 000	23 200	24 000	24 600	25 700	26 400	26 900	27 400	28 100	28 600	28 000	27 800	28 900	29 300	30 500
Light-Duty Gasoline Vehicles	13 800	12 800	13 100	13 400	13 700	13 600	13 400	13 100	13 300	13 200	12 900	12 800	13 100	13 000	13 400
Light-Duty Gasoline Trucks	3 310	3 370	3 740	4 100	4 460	4 710	4 980	5 150	5 450	6 080	6 130	6 220	6 520	6 700	7 040
Heavy-Duty Gasoline Vehicles	521	508	542	573	603	620	849	796	844	625	625	626	628	623	631
Motorcycles	44.6	40.8	41.5	42.8	45.4	46.9	49.0	50.5	55.1	59.4	63.8	68.3	64.0	65.0	63.2
Light-Duty Diesel Vehicles	248	232	238	242	245	242	238	231	229	223	227	231	238	239	247
Light-Duty Diesel Trucks	95.2	85.6	78.9	73.7	74.4	76.1	74.6	83.8	94.1	96.2	112	90.8	87.7	85.1	82.0
Heavy-Duty Diesel Vehicles	5 900	5 980	6 060	6 110	6 560	7 090	7 270	8 000	8 100	8 350	7 970	7 780	8 210	8 490	8 960
Propane & Natural Gas Vehicles	110	110	120	86	55	46	36	45	51	35	36	56	35	31	39
Railways	600	600	600	600	600	600	400	500	700	900	800	800	800	800	800
Domestic Marine	1 400	1 400	1 400	1 100	1 300	910	930	1 100	1 600	1 300	1 400	1 600	1 400	1 000	1 400
Others	1 000	900	800	1 000	2 000	1 000	900	1 000	1 000	1 000	1 000	1 000	800	2 000	1 000
Off-Road Gasoline	400	400	300	400	300	200	200	400	200	200	200	400	300	800	200
Off-Road Diesel	1 000	500	500	900	1 000	1 000	600	600	800	800	1 000	500	200	1 000	900
Pipelines	26.2	28.2	30.8	26.6	27.4	24.5	18.1	26.1	16.4	25.2	108	203	331	357	251
c. Fugitive Sources[2]	**281**	**315**	**320**	**326**	**385**	**396**	**404**	**406**	**439**	**441**	**444**	**450**	**450**	**450**	**450**
Coal Mining	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Oil and Natural Gas	281	315	320	326	385	396	404	406	439	441	444	450	450	450	450
INDUSTRIAL PROCESSES[3]	**12 900**	**13 200**	**12 100**	**12 000**	**11 900**	**11 400**	**10 800**	**10 700**	**10 600**	**10 200**	**10 500**	**10 600**	**10 900**	**10 600**	**9 800**
a. Mineral Products	**1 600**	**1 400**	**1 300**	**1 400**	**1 600**	**1 700**	**1 500**	**1 600**	**1 600**	**1 600**	**1 600**	**1 500**	**1 600**	**1 600**	**1 700**
Cement Production	1 300	1 100	1 100	1 100	1 300	1 500	1 300	1 200	1 200	1 200	1 200	1 200	1 200	1 200	1 200
Lime Production	300	300	300	300	300	200	200	400	400	400	400	400	400	500	500
b. Chemical Industry	**15**	**14**	**15**	**15**	**14**	**15**	**14**	**14**	**13**	**14**	**15**	**14**	**15**	**15**	**17**
Nitric Acid Production	15	14	15	15	14	15	14	14	13	14	15	14	15	15	17
Adipic Acid Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
c. Metal Production	**10 200**	**11 300**	**9 920**	**10 300**	**9 710**	**8 820**	**8 530**	**8 370**	**8 430**	**7 580**	**7 640**	**7 730**	**7 950**	**7 640**	**6 900**
Iron and Steel Production	1.15	1.16	7.66	8.80	6.24	6.71	7.88	5.78	8.03	6.57	11.7	12.1	8.30	8.29	29.5
Aluminium Production	7 810	8 510	8 240	8 770	8 170	7 480	7 690	7 630	7 540	6 750	6 400	6 440	6 400	6 420	5 920
SF_6 Used in Magnesium Smelters and Casters	2 370	2 760	1 670	1 510	1 530	1 340	837	731	875	825	1 230	1 280	1 540	1 210	950
d. Consumption of Halocarbons and SF_6[4]	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
e. Other & Undifferentiated Production[5]	**1 100**	**610**	**810**	**350**	**610**	**870**	**690**	**670**	**520**	**950**	**1 200**	**1 300**	**1 300**	**1 300**	**1 100**
SOLVENT & OTHER PRODUCT USE	**110**	**110**	**110**	**110**	**110**	**110**	**110**	**110**	**110**	**110**	**110**	**110**	**110**	**110**	**110**
AGRICULTURE	**7 200**	**6 800**	**6 800**	**6 800**	**6 800**	**7 000**	**7 100**	**7 100**	**7 000**	**7 000**	**6 800**	**7 000**	**7 100**	**7 100**	**7 300**
a. Enteric Fermentation	**2 630**	**2 560**	**2 520**	**2 530**	**2 570**	**2 640**	**2 680**	**2 680**	**2 590**	**2 540**	**2 490**	**2 520**	**2 560**	**2 570**	**2 680**
b. Manure Management	**1 300**	**1 300**	**1 300**	**1 300**	**1 300**	**1 300**	**1 400**	**1 400**	**1 400**	**1 400**	**1 400**	**1 400**	**1 400**	**1 400**	**1 400**
c. Agricultural Soils	**3 200**	**2 900**	**3 000**	**3 000**	**2 900**	**3 000**	**3 000**	**3 000**	**3 100**	**3 100**	**3 000**	**3 100**	**3 100**	**3 100**	**3 200**
Direct Sources	2 000	1 800	1 900	1 900	1 800	1 900	1 900	1 900	1 900	2 000	1 800	1 900	2 000	1 900	2 000
Pasture, Range, and Paddock Manure	330	320	320	330	330	340	340	340	330	320	310	320	320	330	350
Indirect Sources	800	800	800	800	800	800	800	800	800	800	800	800	900	800	900
WASTE	**7 700**	**7 200**	**7 300**	**7 500**	**7 400**	**7 600**	**7 700**	**8 100**	**8 700**	**9 000**	**8 900**	**8 800**	**8 900**	**9 000**	**8 400**
a. Solid Waste Disposal on Land	**7 200**	**6 700**	**6 900**	**7 000**	**7 000**	**7 200**	**7 300**	**7 600**	**8 300**	**8 500**	**8 500**	**8 400**	**8 500**	**8 600**	**8 000**
b. Wastewater Handling	**300**	**280**	**300**	**300**	**310**	**310**	**330**	**320**	**320**	**340**	**330**	**330**	**340**	**340**	**350**
c. Waste Incineration	**170**	**180**	**160**	**150**	**140**	**130**	**120**	**92**	**88**	**82**	**84**	**85**	**94**	**100**	**110**

Notes:

1 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

2 Fugitive emissions from refineries and the bitumen industry are reported only at the national level.

3 Emissions associated with the use of mineral products and consumption of halocarbons and SF_6 are reported only at the national level.

4 Only SF_6 emissions from magnesium smelters are included. Information on SF_6 use in casters is confidential for this province.

5 Emissions from ammonia production are included in the category Other & Undifferentiated Production.

Totals may not add due to rounding.

TABLE A12-11: 2004 Greenhouse Gas Emissions Summary for Quebec

GHG Source Category	Greenhouse Gases								
	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	TOTAL
Global Warming Potential			21		310				
Unit	*kt*	*kt*	*kt CO_2 eq*	*kt*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*
TOTAL	**70 200**	**610**	**13 000**	**19**	**5 800**	**N/A**	**2 120**	**980**	**91 800**
ENERGY	**63 400**	**60**	**1 000**	**5**	**2 000**	**–**	**–**	**–**	**66 200**
a. **Stationary Combustion Sources**	**29 300**	**30**	**700**	**1**	**300**	**–**	**–**	**–**	**30 300**
Electricity and Heat Generation	1 630	0.04	0.88	0.04	10	–	–	–	1 640
Fossil Fuel Industries	3 900	0.07	1	0.05	20	–	–	–	3 900
Mining	443	0.02	0.3	0.01	3	–	–	–	446
Manufacturing Industries	10 800	0.6	10	0.3	100	–	–	–	10 900
Construction	320	0.01	0.1	0.01	2	–	–	–	322
Commercial & Institutional	6 870	0.1	2	0.1	40	–	–	–	6 920
Residential	5 030	30	700	0.4	100	–	–	–	5 800
Agriculture & Forestry	307	0.01	0.1	0.01	5	–	–	–	312
b. **Transportation**[1]	**34 100**	**3**	**60**	**4**	**1 000**	**–**	**–**	**–**	**35 000**
Domestic Aviation	1 370	0.08	2	0.1	40	–	–	–	1 400
Road Transportation	29 500	2.1	45	3.1	980	–	–	–	30 500
Light-Duty Gasoline Vehicles	12 900	0.85	18	1.6	480	–	–	–	13 400
Light-Duty Gasoline Trucks	6 650	0.65	14	1.2	380	–	–	–	7 040
Heavy-Duty Gasoline Vehicles	602	0.09	1.8	0.09	28	–	–	–	631
Motorcycles	61.8	0.05	1.0	0.00	0.37	–	–	–	63.2
Light-Duty Diesel Vehicles	241	0.01	0.1	0.02	5	–	–	–	247
Light-Duty Diesel Trucks	80.1	0.00	0.05	0.01	2	–	–	–	82.0
Heavy-Duty Diesel Vehicles	8 870	0.4	9	0.3	80	–	–	–	8 960
Propane & Natural Gas Vehicles	38.3	0.04	1	0.00	0.2	–	–	–	39
Railways	731	0.04	0.8	0.3	90	–	–	–	800
Domestic Marine	1 330	0.1	2	0.2	50	–	–	–	1 400
Others	1 200	0.5	10	0.3	100	–	–	–	1 000
Off-Road Gasoline	200	0.2	5	0.00	1	–	–	–	200
Off-Road Diesel	800	0.04	0.9	0.3	100	–	–	–	900
Pipelines	244	0.24	5.1	0.01	2.0	–	–	–	251.0
c. **Fugitive Sources**[2]	**0.11**	**21**	**450**	**–**	**–**	**–**	**–**	**–**	**450**
Coal Mining	–	–	–	–	–	–	–	–	–
Oil and Natural Gas	0.11	21	450	–	–	–	–	–	450
INDUSTRIAL PROCESSES[3]	**6 680**	**–**	**–**	**0.05**	**16.5**	**–**	**2 120**	**979**	**9 800**
a. **Mineral Products**	**1 700**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**1 700**
Cement Production	1 200	–	–	–	–	–	–	–	1 200
Lime Production	500	–	–	–	–	–	–	–	500
b. **Chemical Industry**	**–**	**–**	**–**	**0.05**	**16.5**	**–**	**–**	**–**	**17**
Nitric Acid Production	–	–	–	0.05	17	–	–	–	17
Adipic Acid Production	–	–	–	–	–	–	–	–	–
c. **Metal Production**	**3 800**	**–**	**–**	**–**	**–**	**–**	**2 120**	**979**	**6 900**
Iron and Steel Production	29.5	–	–	–	–	–	–	–	29.5
Aluminium Production	3 800	–	–	–	–	–	2 120	–	5 920
SF_6 Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	950	950
d. **Consumption of Halocarbons and SF_6**[4]	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
e. **Other & Undifferentiated Production**[5]	**1 100**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**1 100**
SOLVENT & OTHER PRODUCT USE	**–**	**–**	**–**	**0.37**	**110**	**–**	**–**	**–**	**110**
AGRICULTURE	**–**	**167**	**3 510**	**12**	**3 800**	**–**	**–**	**–**	**7 300**
a. **Enteric Fermentation**	**–**	**128**	**2 680**	**–**	**–**	**–**	**–**	**–**	**2 680**
b. **Manure Management**	**–**	**39**	**820**	**2.0**	**610**	**–**	**–**	**–**	**1 400**
c. **Agricultural Soils**	**–**	**–**	**–**	**10**	**3 200**	**–**	**–**	**–**	**3 200**
Direct Sources	–	–	–	6.3	2 000	–	–	–	2 000
Pasture, Range, and Paddock Manure	–	–	–	1.1	350	–	–	–	350
Indirect Sources	–	–	–	3	900	–	–	–	900
WASTE	**81**	**390**	**8 100**	**0.8**	**300**	**–**	**–**	**–**	**8 400**
a. **Solid Waste Disposal on Land**	**–**	**380**	**8 000**	**–**	**–**	**–**	**–**	**–**	**8 000**
b. **Wastewater Handling**	**–**	**5.2**	**110**	**0.8**	**200**	**–**	**–**	**–**	**350**
c. **Waste Incineration**	**81**	**0.06**	**1**	**0.09**	**30**	**–**	**–**	**–**	**110**

Notes:

1 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

2 Fugitive emissions from refineries and the bitumen industry are reported only at the national level.

3 Emissions associated with the use of mineral products and consumption of halocarbons and SF_6 are reported only at the national level.

4 Only SF_6 emissions from magnesium smelters are included. Information on SF_6 use in casters is confidential for this province.

5 Emissions from ammonia production are included in the category Other & Undifferentiated Production.

Totals may not add due to rounding.

N/A = not available.

TABLE A12-12: 1990–2004 Greenhouse Gas Emissions Summary for Ontario

GHG Source Category	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
	kt CO_2 eq														
TOTAL	**177 000**	**176 000**	**179 000**	**171 000**	**173 000**	**176 000**	**184 000**	**189 000**	**189 000**	**193 000**	**203 000**	**195 000**	**201 000**	**209 000**	**203 000**
ENERGY	**134 000**	**132 000**	**136 000**	**128 000**	**129 000**	**132 000**	**139 000**	**146 000**	**149 000**	**157 000**	**167 000**	**161 000**	**165 000**	**174 000**	**164 000**
a. Stationary Combustion Sources	**84 500**	**84 200**	**86 000**	**77 400**	**76 400**	**77 700**	**83 400**	**88 000**	**90 100**	**94 700**	**104 000**	**100 000**	**103 000**	**111 000**	**99 400**
Electricity and Heat Generation	26 600	27 900	27 600	18 500	16 200	19 100	20 900	26 000	33 700	35 800	42 800	40 700	40 600	45 800	35 100
Fossil Fuel Industries	6 700	6 000	6 500	6 700	6 200	6 000	6 400	6 300	6 500	6 200	6 600	6 500	8 300	8 100	7 700
Mining	501	675	811	553	651	678	680	658	528	459	469	405	413	411	448
Manufacturing Industries	22 800	21 500	21 100	20 700	21 900	21 200	21 600	22 000	21 100	21 300	20 900	19 600	20 600	20 700	21 300
Construction	573	527	559	337	421	373	444	492	451	477	439	391	522	550	547
Commercial & Institutional	9 170	9 670	10 200	10 200	9 930	9 860	10 900	11 400	10 300	11 500	13 200	13 600	12 900	14 100	14 100
Residential	17 000	17 000	18 000	19 000	20 000	19 000	21 000	20 000	17 000	18 000	19 000	18 000	19 000	21 000	19 000
Agriculture & Forestry	781	894	1 110	997	940	1 150	1 130	1 050	936	959	902	761	834	987	968
b. Transportation[1]	**48 000**	**47 000**	**48 000**	**50 000**	**51 000**	**53 000**	**54 000**	**56 000**	**57 000**	**60 000**	**61 000**	**59 000**	**61 000**	**61 000**	**63 000**
Domestic Aviation	1 600	1 400	1 200	1 200	1 200	1 300	1 400	1 600	1 700	1 700	1 600	1 300	1 200	1 600	1 800
Road Transportation	37 900	36 800	38 000	39 500	40 600	41 800	42 400	44 400	44 000	46 400	47 300	49 300	50 600	52 400	53 800
Light-Duty Gasoline Vehicles	21 000	20 200	20 200	20 400	20 500	20 000	19 500	19 800	19 200	19 400	19 000	20 000	20 200	20 100	20 100
Light-Duty Gasoline Trucks	7 690	7 960	8 480	9 120	9 740	10 100	10 700	11 600	11 700	13 400	14 000	15 100	15 800	16 500	17 100
Heavy-Duty Gasoline Vehicles	888	922	983	1 050	1 120	1 160	1 200	1 220	1 270	1 010	1 030	1 000	1 020	992	987
Motorcycles	85.1	81.5	80.3	80.7	77.8	72.7	68.5	70.8	71.5	68.4	69.9	68.9	66.7	64.7	61.8
Light-Duty Diesel Vehicles	211	200	195	191	186	176	183	185	183	190	197	220	238	258	276
Light-Duty Diesel Trucks	163	124	110	101	92.1	85.9	72.1	89.5	66.9	108	118	132	145	157	171
Heavy-Duty Diesel Vehicles	7 350	6 610	6 920	7 580	8 270	9 390	9 770	10 700	10 800	11 600	12 500	12 400	12 900	14 000	14 700
Propane & Natural Gas Vehicles	540	660	1 100	1 000	590	800	830	710	630	610	390	420	270	290	340
Railways	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	1 000	1 000
Domestic Marine	940	940	890	690	710	660	710	820	810	680	630	680	660	580	640
Others	6 000	6 000	6 000	6 000	7 000	7 000	8 000	8 000	9 000	10 000	10 000	6 000	7 000	5 000	5 000
Off-Road Gasoline	1 000	1 000	900	800	800	1 000	1 000	1 000	2 000	2 000	2 000	600	700	600	600
Off-Road Diesel	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	3 000	3 000	4 000	3 000	3 000	2 000	2 000
Pipelines	2 270	2 400	3 250	3 410	3 460	4 050	4 360	4 240	4 060	4 110	3 630	2 520	3 080	2 510	2 090
c. Fugitive Sources[2]	**1 340**	**1 380**	**1 420**	**1 430**	**1 460**	**1 480**	**1 510**	**1 540**	**1 570**	**1 640**	**1 700**	**1 810**	**1 800**	**1 800**	**1 790**
Coal Mining	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Oil and Natural Gas	1 340	1 380	1 420	1 430	1 460	1 480	1 510	1 540	1 570	1 640	1 700	1 810	1 800	1 800	1 790
INDUSTRIAL PROCESSES[3]	**26 100**	**26 400**	**26 700**	**25 200**	**26 700**	**27 500**	**28 200**	**26 600**	**22 400**	**19 400**	**18 800**	**17 200**	**18 400**	**17 700**	**21 400**
a. Mineral Products	**3 400**	**3 100**	**3 200**	**3 200**	**3 600**	**3 900**	**3 800**	**3 900**	**4 000**	**4 100**	**4 200**	**4 000**	**4 000**	**4 100**	**4 300**
Cement Production	2 300	2 000	2 100	2 100	2 500	2 800	2 800	3 000	3 000	3 100	3 300	3 300	3 200	3 300	3 400
Lime Production	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	900	800	800	800	800
b. Chemical Industry	**11 000**	**10 000**	**10 000**	**9 200**	**11 000**	**11 000**	**12 000**	**10 000**	**5 100**	**1 800**	**980**	**880**	**1 300**	**1 200**	**3 200**
Nitric Acid Production	83	78	82	83	78	85	79	77	71	77	82	81	87	84	93
Adipic Acid Production	10 700	10 000	9 950	9 080	11 000	10 700	11 500	9 890	5 070	1 750	900	804	1 250	1 090	3 090
c. Metal Production	**7 780**	**9 120**	**9 200**	**8 840**	**8 230**	**8 590**	**8 480**	**8 430**	**8 930**	**9 250**	**9 510**	**8 330**	**8 470**	**8 280**	**9 340**
Iron and Steel Production	7 060	8 310	8 490	8 160	7 520	7 850	7 730	7 540	7 670	7 880	7 880	7 270	7 100	7 030	8 130
Aluminium Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
SF_6 Used in Magnesium Smelters and Casters	720	809	712	672	711	734	748	891	1 260	1 370	1 620	1 060	1 370	1 240	1 210
d. Consumption of Halocarbons and SF_6	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
e. Other & Undifferentiated Production[4]	**4 100**	**4 100**	**4 300**	**4 000**	**3 800**	**4 200**	**4 400**	**4 200**	**4 400**	**4 200**	**4 100**	**3 900**	**4 600**	**4 200**	**4 600**
SOLVENT & OTHER PRODUCT USE	**160**	**160**	**160**	**160**	**160**	**160**	**170**	**170**	**170**	**170**	**180**	**180**	**180**	**180**	**190**
AGRICULTURE	**10 000**	**10 000**	**9 800**	**9 600**	**9 700**	**10 000**	**10 000**	**9 800**	**9 900**	**9 800**	**9 500**	**9 500**	**9 600**	**10 000**	**10 000**
a. Enteric Fermentation	**3 670**	**3 640**	**3 590**	**3 480**	**3 510**	**3 640**	**3 710**	**3 660**	**3 560**	**3 450**	**3 420**	**3 450**	**3 470**	**3 570**	**3 670**
b. Manure Management	**1 600**	**1 600**	**1 600**	**1 600**	**1 600**	**1 600**	**1 600**	**1 600**	**1 600**	**1 600**	**1 600**	**1 600**	**1 600**	**1 700**	**1 700**
c. Agricultural Soils	**5 000**	**4 700**	**4 600**	**4 600**	**4 700**	**4 800**	**4 600**	**4 500**	**4 700**	**4 700**	**4 500**	**4 400**	**4 500**	**4 700**	**4 800**
Direct Sources	3 100	2 900	2 800	2 900	2 900	3 000	2 800	2 800	2 900	3 000	2 800	2 700	2 800	2 900	2 900
Pasture, Range, and Paddock Manure	590	580	570	550	560	580	590	580	560	540	530	540	540	570	590
Indirect Sources	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000
WASTE	**6 100**	**6 700**	**6 900**	**7 100**	**7 200**	**6 900**	**6 600**	**7 000**	**7 000**	**7 100**	**7 100**	**7 100**	**7 300**	**7 500**	**7 400**
a. Solid Waste Disposal on Land	**5 600**	**6 200**	**6 400**	**6 600**	**6 700**	**6 500**	**6 100**	**6 500**	**6 600**	**6 700**	**6 600**	**6 600**	**6 800**	**7 000**	**7 000**
b. Wastewater Handling	**350**	**350**	**360**	**360**	**360**	**370**	**370**	**380**	**380**	**380**	**390**	**400**	**410**	**410**	**420**
c. Waste Incineration	**130**	**140**	**140**	**110**	**100**	**110**	**100**	**73**	**73**	**69**	**73**	**76**	**45**	**49**	**54**

Notes:

1 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

2 Fugitive emissions from refineries and the bitumen industry are reported only at the national level.

3 Emissions associated with the use of mineral products and consumption of halocarbons and SF_6 are reported only at the national level.

4 Emissions from ammonia production are included in the category Other & Undifferentiated Production.

Totals may not add due to rounding.

TABLE A12-13: 2004 Greenhouse Gas Emissions Summary for Ontario

GHG Source Category	Greenhouse Gases								
	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	TOTAL
Global Warming Potential			21		310				
Unit	*kt*	*kt*	*kt CO_2 eq*	*kt*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*
TOTAL	**175 000**	**670**	**14 000**	**41**	**13 000**	**N/A**	**N/A**	**1 200**	**203 000**
ENERGY	**158 000**	**100**	**3 000**	**10**	**3 000**	**–**	**–**	**–**	**164 000**
a. Stationary Combustion Sources	**98 100**	**30**	**600**	**2**	**700**	**–**	**–**	**–**	**99 400**
Electricity and Heat Generation	34 800	1.5	32.0	0.6	200	–	–	–	35 100
Fossil Fuel Industries	7 600	0.1	3	0.08	30	–	–	–	7 700
Mining	444	0.01	0.2	0.01	4	–	–	–	448
Manufacturing Industries	21 100	0.9	20	0.6	200	–	–	–	21 300
Construction	544	0.01	0.2	0.01	4	–	–	–	547
Commercial & Institutional	14 000	0.3	5	0.3	90	–	–	–	14 100
Residential	18 600	20	500	0.6	200	–	–	–	19 000
Agriculture & Forestry	960	0.02	0.4	0.02	7	–	–	–	968
b. Transportation[1]	**60 200**	**8**	**200**	**8**	**2 000**	**–**	**–**	**–**	**63 000**
Domestic Aviation	1 750	0.09	2	0.2	50	–	–	–	1 800
Road Transportation	51 700	5.0	100	6.3	1 900	–	–	–	53 800
Light-Duty Gasoline Vehicles	19 300	1.4	29	2.4	750	–	–	–	20 100
Light-Duty Gasoline Trucks	16 100	1.8	38	3.2	1 000	–	–	–	17 100
Heavy-Duty Gasoline Vehicles	940	0.13	2.8	0.14	44	–	–	–	987
Motorcycles	60.4	0.05	1.0	0.00	0.37	–	–	–	61.8
Light-Duty Diesel Vehicles	270	0.01	0.2	0.02	6	–	–	–	276
Light-Duty Diesel Trucks	167	0.01	0.1	0.01	4	–	–	–	171
Heavy-Duty Diesel Vehicles	14 600	0.7	20	0.4	100	–	–	–	14 700
Propane & Natural Gas Vehicles	317	0.9	20	0.01	2	–	–	–	340
Railways	1 320	0.07	2	0.5	200	–	–	–	1 000
Domestic Marine	616	0.05	1	0.08	20	–	–	–	640
Others	4 800	3	60	0.9	300	–	–	–	5 000
Off-Road Gasoline	600	0.7	20	0.01	4	–	–	–	600
Off-Road Diesel	2 100	0.1	2	0.9	300	–	–	–	2 000
Pipelines	2 030	2.0	43	0.06	20	–	–	–	2 090
c. Fugitive Sources[2]	**0.80**	**85**	**1 800**	**–**	**–**	**–**	**–**	**–**	**1 790**
Coal Mining	–	–	–	–	–	–	–	–	–
Oil and Natural Gas	0.80	85	1 800	–	–	–	–	–	1 790
INDUSTRIAL PROCESSES[3]	**17 000**	**–**	**–**	**10.3**	**3 190**	**–**	**–**	**1 210**	**21 400**
a. Mineral Products	**4 300**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**4 300**
Cement Production	3 400	–	–	–	–	–	–	–	3 400
Lime Production	800	–	–	–	–	–	–	–	800
b. Chemical Industry	**–**	**–**	**–**	**10.3**	**3 190**	**–**	**–**	**–**	**3 200**
Nitric Acid Production	–	–	–	0.30	93	–	–	–	93
Adipic Acid Production	–	–	–	9.98	3 090	–	–	–	3 090
c. Metal Production	**8 100**	**–**	**–**	**–**	**–**	**–**	**–**	**1 210**	**9 340**
Iron and Steel Production	8 130	–	–	–	–	–	–	–	8 130
Aluminium Production	–	–	–	–	–	–	–	–	–
SF_6 Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	1 210	1 210
d. Consumption of Halocarbons and SF_6	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
e. Other & Undifferentiated Production[4]	**4 600**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**4 600**
SOLVENT & OTHER PRODUCT USE	**–**	**–**	**–**	**0.60**	**190**	**–**	**–**	**–**	**190**
AGRICULTURE	**–**	**212**	**4 460**	**18**	**5 700**	**–**	**–**	**–**	**10 000**
a. Enteric Fermentation	**–**	**175**	**3 670**	**–**	**–**	**–**	**–**	**–**	**3 670**
b. Manure Management	**–**	**37**	**780**	**2.9**	**910**	**–**	**–**	**–**	**1 700**
c. Agricultural Soils	**–**	**–**	**–**	**15**	**4 800**	**–**	**–**	**–**	**4 800**
Direct Sources	–	–	–	9.4	2 900	–	–	–	2 900
Pasture, Range, and Paddock Manure	–	–	–	1.9	590	–	–	–	590
Indirect Sources	–	–	–	4	1 000	–	–	–	1 000
WASTE	**45**	**330**	**7 000**	**1**	**400**	**–**	**–**	**–**	**7 400**
a. Solid Waste Disposal on Land	**–**	**330**	**7 000**	**–**	**–**	**–**	**–**	**–**	**7 000**
b. Wastewater Handling	**–**	**1.5**	**32**	**1**	**400**	**–**	**–**	**–**	**420**
c. Waste Incineration	**45**	**–**	**–**	**0.03**	**9**	**–**	**–**	**–**	**54**

Notes:

1 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

2 Fugitive emissions from refineries and the bitumen industry are reported only at the national level.

3 Emissions associated with the use of mineral products and consumption of halocarbons and SF_6 are reported only at the national level.

4 Emissions from ammonia production are included in the category Other & Undifferentiated Production.

Totals may not add due to rounding.

N/A = not available.

TABLE A12-14: 1990–2004 Greenhouse Gas Emissions Summary for Manitoba

GHG Source Category	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
	kt CO_2 eq														
TOTAL	**18 000**	**17 600**	**17 700**	**17 700**	**18 100**	**19 000**	**19 700**	**19 300**	**19 600**	**19 500**	**20 200**	**18 900**	**19 500**	**19 400**	**20 000**
ENERGY	**12 400**	**12 000**	**12 000**	**11 900**	**12 100**	**12 700**	**13 100**	**12 600**	**12 700**	**12 600**	**13 100**	**12 000**	**12 400**	**12 000**	**12 300**
a. Stationary Combustion Sources	**4 840**	**4 520**	**4 290**	**4 170**	**4 080**	**4 210**	**4 620**	**4 300**	**4 840**	**4 600**	**5 350**	**4 570**	**4 890**	**4 380**	**4 380**
Electricity and Heat Generation	570	418	417	284	323	219	340	244	962	546	993	X	X	X	X
Fossil Fuel Industries	0.14	0.02	0.04	0.03	0.03	0.04	0.02	0.02	0.01	0.03	0.03	0.03	0.33	0.01	0.01
Mining	73.1	75.7	57.6	27.8	8.12	12.5	10.5	12.1	33.9	27.4	29.4	X	X	X	X
Manufacturing Industries	1 050	953	766	703	777	821	840	808	914	1 080	1 140	1 060	1 210	1 090	1 210
Construction	63.1	45.4	50.5	38.2	40.8	33.8	31.9	45.0	84.8	76.0	62.2	61.4	68.6	78.9	82.7
Commercial & Institutional	1 410	1 430	1 480	1 530	1 430	1 590	1 670	1 650	1 490	1 470	1 680	1 590	1 710	1 590	1 590
Residential	1 600	1 600	1 500	1 500	1 400	1 500	1 600	1 400	1 300	1 300	1 400	1 200	1 300	1 300	1 300
Agriculture & Forestry	42.9	47.3	52.0	101	77.4	76.7	110	98.3	71.6	86.5	62.8	X	X	X	X
b. Transportation[1]	**7 200**	**7 000**	**7 200**	**7 300**	**7 500**	**8 000**	**8 000**	**7 700**	**7 300**	**7 500**	**7 200**	**6 800**	**6 900**	**7 000**	**7 300**
Domestic Aviation	330	300	280	280	340	370	380	390	330	360	360	350	360	400	340
Road Transportation	4 160	4 220	4 260	4 220	4 410	4 550	4 560	4 540	4 570	4 680	4 590	4 610	4 710	4 770	4 990
Light-Duty Gasoline Vehicles	1 990	1 970	1 910	1 810	1 790	1 750	1 660	1 540	1 540	1 510	1 440	1 430	1 440	1 440	1 460
Light-Duty Gasoline Trucks	867	932	982	1 010	1 080	1 130	1 230	1 250	1 300	1 430	1 440	1 450	1 510	1 540	1 600
Heavy-Duty Gasoline Vehicles	194	211	224	231	246	258	204	255	250	228	238	236	236	237	241
Motorcycles	7.31	7.61	7.28	6.69	6.52	6.30	3.75	5.05	4.98	3.92	3.54	2.89	2.76	2.35	2.16
Light-Duty Diesel Vehicles	20.3	20.1	19.3	18.0	17.5	16.6	16.8	15.5	15.5	15.3	14.7	15.0	15.7	16.3	17.2
Light-Duty Diesel Trucks	30.9	30.0	30.6	31.7	33.4	35.4	37.2	30.3	28.4	31.7	34.5	32.2	35.9	37.7	43.2
Heavy-Duty Diesel Vehicles	992	989	1 030	1 090	1 160	1 250	1 330	1 320	1 320	1 350	1 380	1 400	1 450	1 470	1 600
Propane & Natural Gas Vehicles	61	64	60	27	71	97	83	120	110	110	36	31	20	22	21
Railways	600	500	500	500	600	600	500	400	400	300	300	200	90	200	300
Domestic Marine	–	–	0.30	–	–	–	–	–	–	–	–	–	–	0.29	0.11
Others	2 000	2 000	2 000	2 000	2 000	3 000	3 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000
Off-Road Gasoline	300	300	400	400	400	500	400	400	400	400	400	400	400	400	400
Off-Road Diesel	900	700	600	600	600	800	800	700	700	600	700	700	700	800	900
Pipelines	847	976	1 220	1 260	1 200	1 300	1 300	1 200	959	1 060	828	543	658	450	432
c. Fugitive Sources[2]	**421**	**430**	**445**	**455**	**459**	**476**	**506**	**526**	**536**	**536**	**563**	**568**	**570**	**571**	**573**
Coal Mining	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Oil and Natural Gas	421	430	445	455	459	476	506	526	536	536	563	568	570	571	573
INDUSTRIAL PROCESSES[3]	**504**	**430**	**328**	**333**	**330**	**328**	**332**	**338**	**343**	**502**	**535**	**520**	**470**	**453**	**468**
a. Mineral Products	**200**	**160**	**60**	**65**	**67**	**69**	**67**	**70**	**70**	**64**	**69**	**61**	**63**	**57**	**63**
Cement Production	140	99	–	–	–	–	–	–	–	–	–	–	–	–	–
Lime Production	60	60	60	60	70	70	70	70	70	60	70	60	60	60	60
b. Chemical Industry	**21**	**20**	**21**	**21**	**24**	**27**	**30**	**29**	**27**	**29**	**31**	**30**	**33**	**32**	**35**
Nitric Acid Production	21	20	21	21	24	27	30	29	27	29	31	30	33	32	35
Adipic Acid Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
c. Metal Production	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Iron and Steel Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Aluminium Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
SF_6 Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
d. Consumption of Halocarbons and SF_6	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
e. Other & Undifferentiated Production[4]	**280**	**250**	**250**	**250**	**240**	**230**	**230**	**240**	**250**	**410**	**440**	**430**	**370**	**360**	**370**
SOLVENT & OTHER PRODUCT USE	**17**	**17**	**17**	**17**	**17**	**17**	**17**	**17**	**17**	**17**	**17**	**17**	**17**	**17**	**18**
AGRICULTURE	**4 400**	**4 500**	**4 700**	**4 700**	**5 000**	**5 200**	**5 500**	**5 600**	**5 800**	**5 600**	**5 700**	**5 600**	**5 700**	**6 100**	**6 400**
a. Enteric Fermentation	**1 530**	**1 550**	**1 650**	**1 660**	**1 720**	**1 850**	**1 960**	**2 050**	**2 050**	**1 990**	**1 980**	**2 040**	**2 100**	**2 210**	**2 450**
b. Manure Management	**560**	**570**	**600**	**610**	**630**	**680**	**720**	**750**	**760**	**750**	**760**	**810**	**860**	**880**	**940**
c. Agricultural Soils	**2 300**	**2 400**	**2 500**	**2 400**	**2 600**	**2 600**	**2 800**	**2 800**	**2 900**	**2 900**	**2 900**	**2 700**	**2 800**	**3 000**	**3 000**
Direct Sources	1 300	1 400	1 400	1 400	1 500	1 500	1 600	1 600	1 700	1 600	1 600	1 500	1 500	1 700	1 600
Pasture, Range, and Paddock Manure	280	280	300	300	310	340	360	380	380	360	360	370	380	400	450
Indirect Sources	700	700	800	800	800	800	900	900	900	900	900	900	900	1 000	900
WASTE	**610**	**660**	**680**	**700**	**710**	**730**	**750**	**770**	**780**	**800**	**820**	**840**	**860**	**870**	**910**
a. Solid Waste Disposal on Land	**560**	**620**	**630**	**650**	**670**	**690**	**710**	**720**	**740**	**750**	**780**	**790**	**810**	**830**	**860**
b. Wastewater Handling	**45**	**44**	**45**	**45**	**45**	**45**	**44**	**45**	**45**	**46**	**46**	**46**	**46**	**46**	**46**
c. Waste Incineration	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**

Notes:

1 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

2 Fugitive emissions from refineries and the bitumen industry are reported only at the national level.

3 Emissions associated with the use of mineral products and consumption of halocarbons and SF_6 are reported only at the national level.

4 Emissions from ammonia production are included in the category Other & Undifferentiated Production.

X Indicates confidential data.

Totals may not add due to rounding.

TABLE A12-15: 2004 Greenhouse Gas Emissions Summary for Manitoba

GHG Source Category	Greenhouse Gases								
	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	TOTAL
Global Warming Potential			21		310				
Unit	*kt*	*kt*	*kt CO_2 eq*	*kt*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*
TOTAL	**11 700**	**210**	**4 400**	**13**	**4 000**	**N/A**	**N/A**	**N/A**	**20 000**
ENERGY	**11 300**	**30**	**600**	**1**	**400**	**–**	**–**	**–**	**12 300**
a. Stationary Combustion Sources	**4 280**	**3**	**60**	**0.1**	**40**	**–**	**–**	**–**	**4 380**
Electricity and Heat Generation	X	X	X	X	X	–	–	–	X
Fossil Fuel Industries	–	0.00	0.00	0.00	0.01	–	–	–	0.01
Mining	X	X	X	X	X	–	–	–	X
Manufacturing Industries	1 200	0.04	0.9	0.03	9	–	–	–	1 210
Construction	82.2	0.00	0.03	0.00	0.5	–	–	–	82.7
Commercial & Institutional	1 580	0.03	0.6	0.03	10	–	–	–	1 590
Residential	1 180	3	50	0.05	20	–	–	–	1 300
Agriculture & Forestry	X	X	X	X	X	–	–	–	X
b. Transportation[1]	**6 960**	**1**	**30**	**1**	**300**	**–**	**–**	**–**	**7 300**
Domestic Aviation	331	0.03	0.7	0.03	10	–	–	–	340
Road Transportation	4 800	0.42	8.9	0.57	180	–	–	–	4 990
Light-Duty Gasoline Vehicles	1 400	0.12	2.4	0.18	56	–	–	–	1 460
Light-Duty Gasoline Trucks	1 500	0.16	3.4	0.30	94	–	–	–	1 600
Heavy-Duty Gasoline Vehicles	229	0.03	0.68	0.03	11	–	–	–	241
Motorcycles	2.11	0.00	0.04	0.00	0.01	–	–	–	2.16
Light-Duty Diesel Vehicles	16.8	0.00	0.01	0.00	0.4	–	–	–	17.2
Light-Duty Diesel Trucks	42.2	0.00	0.02	0.00	1.0	–	–	–	43.2
Heavy-Duty Diesel Vehicles	1 590	0.08	2	0.05	10	–	–	–	1 600
Propane & Natural Gas Vehicles	20.7	0.03	0.6	0.00	0.1	–	–	–	21
Railways	238	0.01	0.3	0.1	30	–	–	–	300
Domestic Marine	0.11	0.00	0.00	0.00	0.00	–	–	–	0.11
Others	1 600	0.9	20	0.3	100	–	–	–	2 000
Off-Road Gasoline	400	0.5	10	0.01	3	–	–	–	400
Off-Road Diesel	760	0.04	0.8	0.3	100	–	–	–	900
Pipelines	420	0.42	8.9	0.01	3	–	–	–	432
c. Fugitive Sources[2]	**25**	**26**	**550**	**–**	**–**	**–**	**–**	**–**	**573**
Coal Mining	–	–	–	–	–	–	–	–	–
Oil and Natural Gas	25	26	550	–	–	–	–	–	573
INDUSTRIAL PROCESSES[3]	**433**	**–**	**–**	**0.11**	**34.9**	**–**	**–**	**–**	**468**
a. Mineral Products	**63**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**63**
Cement Production	–	–	–	–	–	–	–	–	–
Lime Production	60	–	–	–	–	–	–	–	60
b. Chemical Industry	**–**	**–**	**–**	**0.11**	**34.9**	**–**	**–**	**–**	**35**
Nitric Acid Production	–	–	–	0.11	35	–	–	–	35
Adipic Acid Production	–	–	–	–	–	–	–	–	–
c. Metal Production	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Iron and Steel Production	–	–	–	–	–	–	–	–	–
Aluminium Production	–	–	–	–	–	–	–	–	–
SF_6 Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	–	–
d. Consumption of Halocarbons and SF_6	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
e. Other & Undifferentiated Production[4]	**370**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**370**
SOLVENT & OTHER PRODUCT USE	**–**	**–**	**–**	**0.06**	**18**	**–**	**–**	**–**	**18**
AGRICULTURE	**–**	**136**	**2 860**	**11**	**3 500**	**–**	**–**	**–**	**6 400**
a. Enteric Fermentation	**–**	**116**	**2 450**	**–**	**–**	**–**	**–**	**–**	**2 450**
b. Manure Management	**–**	**20**	**410**	**1.7**	**530**	**–**	**–**	**–**	**940**
c. Agricultural Soils	**–**	**–**	**–**	**9.6**	**3 000**	**–**	**–**	**–**	**3 000**
Direct Sources	–	–	–	5.1	1 600	–	–	–	1 600
Pasture, Range, and Paddock Manure	–	–	–	1.5	450	–	–	–	450
Indirect Sources	–	–	–	3	900	–	–	–	900
WASTE	**–**	**41**	**870**	**0.1**	**40**	**–**	**–**	**–**	**910**
a. Solid Waste Disposal on Land	**–**	**41**	**860**	**–**	**–**	**–**	**–**	**–**	**860**
b. Wastewater Handling	**–**	**0.46**	**9.6**	**0.1**	**40**	**–**	**–**	**–**	**46**
c. Waste Incineration	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**

Notes:

1 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

2 Fugitive emissions from refineries and the bitumen industry are reported only at the national level.

3 Emissions associated with the use of mineral products and consumption of halocarbons and SF_6 are reported only at the national level.

4 Emissions from ammonia production are included in the category Other & Undifferentiated Production.

X Indicates confidential data.

Totals may not add due to rounding.

N/A = not available.

TABLE A12-16: 1990–2004 Greenhouse Gas Emissions Summary for Saskatchewan

	kt CO_2 eq														
GHG Source Category	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
TOTAL	**42 700**	**42 500**	**47 300**	**50 800**	**54 500**	**57 000**	**58 700**	**61 200**	**61 500**	**62 000**	**63 700**	**63 500**	**64 700**	**66 500**	**69 100**
ENERGY	**35 000**	**34 600**	**38 900**	**41 900**	**45 100**	**47 500**	**47 800**	**50 100**	**50 600**	**51 200**	**52 800**	**52 600**	**54 100**	**54 900**	**56 400**
a. Stationary Combustion Sources	**19 500**	**18 700**	**21 700**	**23 700**	**25 600**	**26 500**	**25 700**	**26 100**	**26 900**	**27 300**	**27 100**	**27 600**	**28 400**	**28 700**	**29 800**
Electricity and Heat Generation	10 400	10 600	12 100	12 400	13 300	13 900	14 000	14 900	15 100	14 900	14 700	X	X	X	X
Fossil Fuel Industries	3 800	2 200	2 900	4 400	5 200	5 900	4 500	4 600	5 400	5 800	5 500	5 800	6 200	5 500	6 400
Mining	965	978	969	1 700	1 810	1 690	1 320	1 900	1 810	1 660	2 000	X	X	X	X
Manufacturing Industries	856	1 430	2 270	1 170	1 530	1 300	1 570	1 060	1 120	967	934	792	713	694	649
Construction	70.3	56.7	80.3	71.2	65.4	73.0	87.1	56.1	65.3	86.8	49.6	40.7	39.0	37.6	42.6
Commercial & Institutional	1 010	1 010	926	1 480	1 310	1 210	1 420	1 200	1 250	1 590	1 710	1 590	2 030	1 970	1 810
Residential	2 100	2 200	2 100	2 100	2 100	2 100	2 500	2 100	1 900	2 000	2 000	2 000	2 000	1 800	1 800
Agriculture & Forestry	302	274	303	333	327	328	387	349	292	339	281	X	X	X	X
b. Transportation[1]	**9 500**	**9 600**	**10 000**	**11 000**	**11 000**	**11 000**	**12 000**	**12 000**	**11 000**	**12 000**	**11 000**	**9 900**	**10 000**	**10 000**	**10 000**
Domestic Aviation	210	180	180	160	150	170	170	150	170	140	110	120	130	120	110
Road Transportation	4 380	4 750	5 430	5 410	5 610	5 490	5 810	6 580	5 960	6 190	6 150	5 420	6 000	6 330	6 510
Light-Duty Gasoline Vehicles	1 590	1 600	1 900	1 770	1 640	1 480	1 450	1 500	1 370	1 370	1 280	1 040	1 240	1 300	1 280
Light-Duty Gasoline Trucks	1 030	1 100	1 400	1 400	1 410	1 400	1 560	1 680	1 500	1 750	1 730	1 400	1 740	1 850	1 880
Heavy-Duty Gasoline Vehicles	193	242	356	406	460	507	517	595	590	480	479	363	444	470	475
Motorcycles	1.88	2.01	2.56	2.61	3.03	3.03	2.75	5.77	5.62	6.37	6.79	6.44	6.84	7.58	7.04
Light-Duty Diesel Vehicles	14.3	14.3	16.7	15.1	13.3	11.2	13.2	13.2	12.5	13.0	12.6	11.0	14.2	16.1	17.1
Light-Duty Diesel Trucks	75.7	86.6	83.5	86.3	99.4	99.1	108	122	110	102	120	120	126	126	137
Heavy-Duty Diesel Vehicles	1 410	1 640	1 600	1 660	1 930	1 940	2 120	2 610	2 310	2 420	2 480	2 450	2 400	2 550	2 690
Propane & Natural Gas Vehicles	65	64	80	62	52	50	44	59	59	48	27	31	19	14	17
Railways	600	300	400	400	500	500	600	600	500	400	400	300	300	200	200
Domestic Marine	–	–	–	–	–	–	–	–	–	–	0.02	0.04	0.01	0.01	0.01
Others	4 000	4 000	4 000	5 000	5 000	5 000	5 000	4 000	5 000	5 000	4 000	4 000	4 000	4 000	4 000
Off-Road Gasoline	1 000	1 000	400	600	800	800	800	400	700	600	700	1 000	800	800	700
Off-Road Diesel	1 000	1 000	1 000	2 000	2 000	2 000	2 000	2 000	1 000	1 000	1 000	1 000	1 000	1 000	2 000
Pipelines	1 640	1 780	2 430	2 460	2 270	2 600	2 570	2 500	2 660	2 790	2 410	1 720	2 000	1 590	1 450
c. Fugitive Sources[2]	**6 060**	**6 300**	**6 970**	**7 680**	**8 400**	**9 490**	**10 400**	**12 300**	**12 400**	**12 400**	**14 500**	**15 100**	**15 300**	**15 700**	**16 200**
Coal Mining	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Oil and Natural Gas	6 050	6 290	6 960	7 660	8 380	9 480	10 400	12 300	12 300	12 400	14 500	15 100	15 300	15 700	16 200
INDUSTRIAL PROCESSES[3]	**280**	**378**	**310**	**521**	**529**	**232**	**975**	**1 200**	**1 300**	**1 310**	**1 280**	**1 360**	**1 330**	**1 280**	**1 400**
a. Mineral Products	**83**	**61**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Cement Production	83	61	–	–	–	–	–	–	–	–	–	–	–	–	–
Lime Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
b. Chemical Industry	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Nitric Acid Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Adipic Acid Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
c. Metal Production	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Iron and Steel Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Aluminium Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
SF_6 Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
d. Consumption of Halocarbons and SF_6	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
e. Other & Undifferentiated Production[4]	**200**	**320**	**310**	**520**	**530**	**230**	**980**	**1 200**	**1 300**	**1 300**	**1 300**	**1 400**	**1 300**	**1 300**	**1 400**
SOLVENT & OTHER PRODUCT USE	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**
AGRICULTURE	**6 800**	**6 900**	**7 400**	**7 700**	**8 200**	**8 600**	**9 200**	**9 100**	**8 900**	**8 700**	**8 900**	**8 700**	**8 500**	**9 500**	**10 000**
a. Enteric Fermentation	**2 930**	**3 020**	**3 330**	**3 440**	**3 520**	**3 780**	**3 940**	**3 850**	**3 770**	**3 680**	**3 740**	**3 900**	**4 010**	**4 310**	**4 750**
b. Manure Management	**810**	**840**	**920**	**930**	**960**	**1 000**	**1 000**	**1 000**	**1 000**	**990**	**1 000**	**1 100**	**1 100**	**1 200**	**1 300**
c. Agricultural Soils	**3 100**	**3 000**	**3 200**	**3 400**	**3 700**	**3 800**	**4 200**	**4 300**	**4 100**	**4 100**	**4 100**	**3 800**	**3 400**	**4 000**	**4 300**
Direct Sources	1 600	1 500	1 500	1 600	1 800	1 800	2 100	2 100	2 000	2 000	2 100	1 800	1 500	1 900	1 900
Pasture, Range, and Paddock Manure	560	570	630	650	670	720	750	740	720	700	710	740	760	820	910
Indirect Sources	1 000	900	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000
WASTE	**620**	**630**	**650**	**670**	**680**	**700**	**720**	**740**	**700**	**710**	**730**	**740**	**750**	**760**	**920**
a. Solid Waste Disposal on Land	**570**	**590**	**600**	**620**	**640**	**650**	**670**	**690**	**650**	**660**	**680**	**690**	**700**	**720**	**870**
b. Wastewater Handling	**50**	**49**	**50**	**50**	**48**	**50**	**49**	**49**	**49**	**47**	**49**	**49**	**49**	**49**	**49**
c. Waste Incineration	**0.52**	**0.52**	**0.52**	**0.02**	**0.02**	**0.04**	**0.02**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**

Notes:

1 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

2 Fugitive emissions from refineries and the bitumen industry are reported only at the national level.

3 Emissions associated with the use of mineral products and consumption of halocarbons and SF_6 are reported only at the national level.

4 Emissions from ammonia production are included in the category Other & Undifferentiated Production.

X Indicates confidential data.

Totals may not add due to rounding.

TABLE A12-17: 2004 Greenhouse Gas Emissions Summary for Saskatchewan

GHG Source Category	Greenhouse Gases								
	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	TOTAL
Global Warming Potential			21		310				
Unit	*kt*	*kt*	*kt CO_2 eq*	*kt*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*
TOTAL	**41 400**	**1 000**	**22 000**	**19**	**5 900**	**N/A**	**N/A**	**N/A**	**69 100**
ENERGY	**40 000**	**800**	**20 000**	**2**	**600**	**–**	**–**	**–**	**56 400**
a. Stationary Combustion Sources	**29 300**	**20**	**300**	**0.7**	**200**	**–**	**–**	**–**	**29 800**
Electricity and Heat Generation	X	X	X	X	X	–	–	–	X
Fossil Fuel Industries	6 100	10	300	0.2	50	–	–	–	6 400
Mining	X	X	X	X	X	–	–	–	X
Manufacturing Industries	640	0.05	1	0.03	8	–	–	–	649
Construction	42.3	0.00	0.02	0.00	0.3	–	–	–	42.6
Commercial & Institutional	1 800	0.03	0.7	0.04	10	–	–	–	1 810
Residential	1 710	2	30	0.05	10	–	–	–	1 800
Agriculture & Forestry	X	X	X	X	X	–	–	–	X
b. Transportation[1]	**10 000**	**3**	**60**	**1**	**400**	**–**	**–**	**–**	**10 000**
Domestic Aviation	106	0.01	0.3	0.01	3	–	–	–	110
Road Transportation	6 290	0.57	12	0.68	210	–	–	–	6 510
Light-Duty Gasoline Vehicles	1 230	0.12	2.6	0.15	47	–	–	–	1 280
Light-Duty Gasoline Trucks	1 760	0.21	4.5	0.37	120	–	–	–	1 880
Heavy-Duty Gasoline Vehicles	453	0.06	1.3	0.07	21	–	–	–	475
Motorcycles	6.88	0.01	0.12	0.00	0.04	–	–	–	7.04
Light-Duty Diesel Vehicles	16.7	0.00	0.01	0.00	0.4	–	–	–	17.1
Light-Duty Diesel Trucks	133	0.00	0.08	0.01	3	–	–	–	137
Heavy-Duty Diesel Vehicles	2 670	0.1	3	0.08	20	–	–	–	2 690
Propane & Natural Gas Vehicles	16.1	0.03	0.6	0.00	0.1	–	–	–	17
Railways	156	0.01	0.2	0.06	20	–	–	–	200
Domestic Marine	0.01	0.00	0.00	0.00	0.00	–	–	–	0.01
Others	3 500	2	50	0.6	200	–	–	–	4 000
Off-Road Gasoline	700	0.8	20	0.01	4	–	–	–	700
Off-Road Diesel	1 400	0.07	1	0.6	200	–	–	–	2 000
Pipelines	1 410	1.4	30	0.04	10	–	–	–	1 450
c. Fugitive Sources[2]	**720**	**740**	**15 000**	**–**	**–**	**–**	**–**	**–**	**16 200**
Coal Mining	–	0.7	10	–	–	–	–	–	10
Oil and Natural Gas	720	730	15 000	–	–	–	–	–	16 200
INDUSTRIAL PROCESSES[3]	**1 400**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**1 400**
a. Mineral Products	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Cement Production	–	–	–	–	–	–	–	–	–
Lime Production	–	–	–	–	–	–	–	–	–
b. Chemical Industry	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Nitric Acid Production	–	–	–	–	–	–	–	–	–
Adipic Acid Production	–	–	–	–	–	–	–	–	–
c. Metal Production	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Iron and Steel Production	–	–	–	–	–	–	–	–	–
Aluminium Production	–	–	–	–	–	–	–	–	–
SF_6 Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	–	–
d. Consumption of Halocarbons and SF_6	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
e. Other & Undifferentiated Production[4]	**1 400**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**1 400**
SOLVENT & OTHER PRODUCT USE	**–**	**–**	**–**	**0.05**	**15**	**–**	**–**	**–**	**15**
AGRICULTURE	**–**	**242**	**5 080**	**17**	**5 200**	**–**	**–**	**–**	**10 000**
a. Enteric Fermentation	**–**	**226**	**4 750**	**–**	**–**	**–**	**–**	**–**	**4 750**
b. Manure Management	**–**	**16**	**330**	**3.1**	**950**	**–**	**–**	**–**	**1 300**
c. Agricultural Soils	**–**	**–**	**–**	**14**	**4 300**	**–**	**–**	**–**	**4 300**
Direct Sources	–	–	–	6.3	1 900	–	–	–	1 900
Pasture, Range, and Paddock Manure	–	–	–	2.9	910	–	–	–	910
Indirect Sources	–	–	–	5	1 000	–	–	–	1 000
WASTE	**–**	**42**	**890**	**0.1**	**30**	**–**	**–**	**–**	**920**
a. Solid Waste Disposal on Land	**–**	**41**	**870**	**–**	**–**	**–**	**–**	**–**	**870**
b. Wastewater Handling	**–**	**0.87**	**18**	**0.1**	**30**	**–**	**–**	**–**	**49**
c. Waste Incineration	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**

Notes:

1 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

2 Fugitive emissions from refineries and the bitumen industry are reported only at the national level.

3 Emissions associated with the use of mineral products and consumption of halocarbons and SF_6 are reported only at the national level.

4 Emissions from ammonia production are included in the category Other & Undifferentiated Production.

X Indicates confidential data.

Totals may not add due to rounding.

N/A = not available.

TABLE A12-18: 1990–2004 Greenhouse Gas Emissions Summary for Alberta

GHG Source Category	kt CO_2 eq														
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
TOTAL	**168 000**	**171 000**	**178 000**	**183 000**	**192 000**	**197 000**	**202 000**	**205 000**	**206 000**	**213 000**	**222 000**	**223 000**	**222 000**	**230 000**	**235 000**
ENERGY	**146 000**	**148 000**	**155 000**	**159 000**	**167 000**	**171 000**	**175 000**	**176 000**	**179 000**	**185 000**	**194 000**	**194 000**	**195 000**	**201 000**	**203 000**
a. **Stationary Combustion Sources**	**96 200**	**98 800**	**104 000**	**105 000**	**109 000**	**112 000**	**112 000**	**111 000**	**112 000**	**120 000**	**127 000**	**126 000**	**130 000**	**136 000**	**136 000**
Electricity and Heat Generation	40 200	42 100	45 300	46 000	49 600	49 200	48 400	51 200	51 800	50 100	52 100	53 500	53 000	54 900	52 700
Fossil Fuel Industries	32 000	34 000	36 000	36 000	36 000	36 000	35 000	32 000	34 000	44 000	46 000	47 000	47 000	47 000	50 000
Mining	2 400	1 430	1 200	3 200	2 880	3 340	4 280	3 920	3 450	3 450	5 500	5 890	7 520	11 000	11 100
Manufacturing Industries	9 410	9 600	9 370	8 270	8 920	9 950	9 940	10 500	10 000	9 670	9 610	7 890	7 760	7 820	8 120
Construction	236	202	244	212	206	189	216	211	136	166	172	168	170	158	158
Commercial & Institutional	4 950	4 760	4 410	4 540	4 570	5 520	4 970	5 020	4 640	4 580	5 290	4 750	5 720	6 070	6 100
Residential	6 600	6 600	6 400	6 600	7 300	7 600	8 700	7 700	7 400	7 500	8 300	7 200	8 000	8 200	8 100
Agriculture & Forestry	468	458	560	574	358	335	410	380	341	348	361	286	301	270	266
b. **Transportation**[1]	**23 000**	**21 000**	**21 000**	**22 000**	**24 000**	**25 000**	**26 000**	**29 000**	**30 000**	**30 000**	**30 000**	**32 000**	**31 000**	**32 000**	**33 000**
Domestic Aviation	1 100	920	980	1 000	1 000	1 000	1 100	1 200	1 300	1 300	1 300	1 400	1 400	1 300	1 400
Road Transportation	14 400	13 600	13 900	13 900	15 800	16 000	16 100	17 500	17 900	18 100	18 800	19 700	19 600	19 900	20 900
Light-Duty Gasoline Vehicles	5 620	5 140	5 080	4 950	5 200	5 040	4 630	4 780	4 970	4 810	4 690	4 970	4 940	4 630	4 630
Light-Duty Gasoline Trucks	3 650	3 520	3 670	3 770	4 180	4 270	4 250	4 690	4 840	5 490	5 610	6 040	6 270	6 160	6 450
Heavy-Duty Gasoline Vehicles	650	694	788	871	1 030	1 110	1 100	1 180	1 320	989	1 130	1 070	1 060	1 090	1 120
Motorcycles	25.3	24.4	22.8	23.9	25.7	23.5	21.7	23.6	26.6	25.0	25.5	26.1	24.5	24.2	23.7
Light-Duty Diesel Vehicles	52.0	46.2	43.9	40.7	40.2	36.2	33.8	36.3	38.1	38.3	36.7	43.1	47.6	52.4	58.6
Light-Duty Diesel Trucks	87.1	70.3	61.4	57.5	60.3	54.2	52.3	104	85.3	95.3	158	188	223	233	279
Heavy-Duty Diesel Vehicles	3 650	3 490	3 580	3 900	4 740	4 920	5 470	6 250	6 240	6 300	6 840	7 080	6 840	7 500	8 110
Propane & Natural Gas Vehicles	630	630	700	320	510	510	550	480	430	340	270	270	210	190	180
Railways	2 000	2 000	2 000	2 000	2 000	1 000	1 000	1 000	1 000	1 000	2 000	2 000	2 000	2 000	2 000
Domestic Marine	0.30	–	0.61	0.61	0.30	0.61	0.30	–	–	–	0.00	0.02	0.02	0.01	0.01
Others	5 000	5 000	5 000	6 000	6 000	7 000	8 000	9 000	9 000	9 000	8 000	9 000	8 000	8 000	8 000
Off-Road Gasoline	1 000	1 000	1 000	1 000	700	600	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000
Off-Road Diesel	3 000	2 000	2 000	2 000	3 000	3 000	4 000	4 000	5 000	4 000	5 000	4 000	4 000	4 000	4 000
Pipelines	1 270	1 360	1 920	2 100	2 600	2 670	2 780	3 160	3 250	3 210	2 670	3 420	3 470	3 090	3 110
c. **Fugitive Sources**[2]	**27 200**	**28 100**	**30 400**	**31 700**	**33 000**	**34 700**	**36 800**	**36 600**	**36 800**	**35 600**	**36 400**	**35 500**	**33 600**	**33 800**	**33 600**
Coal Mining	200	200	300	300	300	300	300	300	300	200	200	200	200	200	200
Oil and Natural Gas	27 000	27 900	30 100	31 400	32 700	34 400	36 500	36 300	36 500	35 300	36 200	35 400	33 500	33 600	33 400
INDUSTRIAL PROCESSES[3]	**8 080**	**8 550**	**8 250**	**8 950**	**9 440**	**9 520**	**10 300**	**11 200**	**10 300**	**10 300**	**10 200**	**10 200**	**9 580**	**10 900**	**12 700**
a. **Mineral Products**	**850**	**620**	**700**	**730**	**830**	**930**	**850**	**1 100**	**1 100**	**1 100**	**1 100**	**1 100**	**1 200**	**1 100**	**1 200**
Cement Production	740	510	590	610	700	800	730	950	940	1 000	960	940	1 000	1 000	1 100
Lime Production	100	100	100	100	100	100	100	100	100	100	100	200	100	100	100
b. **Chemical Industry**	**660**	**650**	**660**	**660**	**650**	**660**	**670**	**670**	**660**	**670**	**670**	**670**	**680**	**670**	**680**
Nitric Acid Production	660	650	660	660	650	660	670	670	660	670	670	670	680	670	680
Adipic Acid Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
c. **Metal Production**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Iron and Steel Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Aluminium Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
SF_6 Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
d. **Consumption of Halocarbons and SF_6**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
e. **Other & Undifferentiated Production**[4]	**6 600**	**7 300**	**6 900**	**7 600**	**8 000**	**7 900**	**8 800**	**9 400**	**8 500**	**8 500**	**8 400**	**8 500**	**7 700**	**9 100**	**11 000**
SOLVENT & OTHER PRODUCT USE	**38**	**39**	**40**	**40**	**41**	**41**	**42**	**43**	**44**	**44**	**45**	**46**	**47**	**48**	**48**
AGRICULTURE	**13 000**	**13 000**	**13 000**	**13 000**	**14 000**	**15 000**	**15 000**	**15 000**	**16 000**	**16 000**	**17 000**	**17 000**	**16 000**	**16 000**	**17 000**
a. **Enteric Fermentation**	**6 070**	**6 260**	**6 490**	**6 650**	**7 040**	**7 470**	**7 670**	**7 730**	**7 920**	**8 100**	**8 400**	**8 730**	**8 650**	**8 180**	**8 590**
b. **Manure Management**	**1 700**	**1 800**	**1 800**	**1 900**	**2 000**	**2 100**	**2 100**	**2 100**	**2 200**	**2 300**	**2 300**	**2 400**	**2 400**	**2 300**	**2 400**
c. **Agricultural Soils**	**4 700**	**4 700**	**4 600**	**5 000**	**5 100**	**5 200**	**5 400**	**5 400**	**5 600**	**5 800**	**5 900**	**5 600**	**5 200**	**5 400**	**5 800**
Direct Sources	2 200	2 100	2 000	2 200	2 200	2 200	2 300	2 300	2 300	2 500	2 500	2 200	1 900	2 200	2 300
Pasture, Range, and Paddock Manure	1 200	1 200	1 300	1 300	1 400	1 400	1 500	1 500	1 600	1 600	1 700	1 700	1 700	1 600	1 700
Indirect Sources	1 000	1 000	1 000	1 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000
WASTE	**1 500**	**1 600**	**1 500**	**1 500**	**1 600**	**1 600**	**1 600**	**1 600**	**1 800**	**1 900**	**1 900**	**2 000**	**2 000**	**2 100**	**2 200**
a. **Solid Waste Disposal on Land**	**1 400**	**1 500**	**1 400**	**1 400**	**1 500**	**1 500**	**1 500**	**1 500**	**1 700**	**1 800**	**1 800**	**1 900**	**1 900**	**2 000**	**2 100**
b. **Wastewater Handling**	**100**	**110**	**100**	**97**	**110**	**99**	**120**	**100**	**98**	**120**	**100**	**100**	**98**	**99**	**100**
c. **Waste Incineration**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**

Notes:

1 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

2 Fugitive emissions from refineries and the bitumen industry are reported only at the national level.

3 Emissions associated with the use of mineral products and consumption of halocarbons and SF_6 are reported only at the national level.

4 Emissions from ammonia production are included in the category Other & Undifferentiated Production.

Totals may not add due to rounding.

TABLE A12-19: 2004 Greenhouse Gas Emissions Summary for Alberta

GHG Source Category	Greenhouse Gases								
	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	TOTAL
Global Warming Potential			21		310				
Unit	*kt*	*kt*	*kt CO_2 eq*	*kt*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*
TOTAL	**184 000**	**1 900**	**40 000**	**35**	**11 000**	**N/A**	**N/A**	**N/A**	**235 000**
ENERGY	**172 000**	**1 000**	**30 000**	**8**	**2 000**	**–**	**–**	**–**	**203 000**
a. Stationary Combustion Sources	**133 000**	**100**	**2 000**	**3**	**900**	**–**	**–**	**–**	**136 000**
Electricity and Heat Generation	52 400	1.6	34	0.9	300	–	–	–	52 700
Fossil Fuel Industries	47 000	100	2 000	1	400	–	–	–	50 000
Mining	11 000	0.2	4.0	0.2	70	–	–	–	11 100
Manufacturing Industries	8 040	0.4	8	0.2	70	–	–	–	8 120
Construction	156	0.00	0.06	0.01	2	–	–	–	158
Commercial & Institutional	6 060	0.1	2	0.1	40	–	–	–	6 100
Residential	8 010	2	50	0.2	50	–	–	–	8 100
Agriculture & Forestry	265	0.01	0.1	0.01	2	–	–	–	266
b. Transportation[1]	**31 500**	**6**	**100**	**5**	**2 000**	**–**	**–**	**–**	**33 000**
Domestic Aviation	1 400	0.08	2	0.1	40	–	–	–	1 400
Road Transportation	20 100	1.8	37	2.2	700	–	–	–	20 900
Light-Duty Gasoline Vehicles	4 450	0.38	7.9	0.57	180	–	–	–	4 630
Light-Duty Gasoline Trucks	6 040	0.69	15	1.3	390	–	–	–	6 450
Heavy-Duty Gasoline Vehicles	1 070	0.15	3.1	0.16	49	–	–	–	1 120
Motorcycles	23.2	0.02	0.39	0.00	0.14	–	–	–	23.7
Light-Duty Diesel Vehicles	57.3	0.00	0.03	0.00	1	–	–	–	58.6
Light-Duty Diesel Trucks	273	0.01	0.2	0.02	6	–	–	–	279
Heavy-Duty Diesel Vehicles	8 030	0.4	8	0.2	70	–	–	–	8 110
Propane & Natural Gas Vehicles	181	0.1	2	0.00	1	–	–	–	180
Railways	2 190	0.1	3	0.9	300	–	–	–	2 000
Domestic Marine	0.01	0.00	0.00	0.00	0.00	–	–	–	0.01
Others	7 800	4	90	2	500	–	–	–	8 000
Off-Road Gasoline	1 000	1	20	0.02	6	–	–	–	1 000
Off-Road Diesel	3 800	0.2	4	2	500	–	–	–	4 000
Pipelines	3 030	3.0	64	0.08	30	–	–	–	3 110
c. Fugitive Sources[2]	**7 200**	**1 300**	**26 000**	**–**	**–**	**–**	**–**	**–**	**33 600**
Coal Mining	–	9	200	–	–	–	–	–	200
Oil and Natural Gas	7 200	1 200	26 000	–	–	–	–	–	33 400
INDUSTRIAL PROCESSES[3]	**12 000**	**–**	**–**	**2.21**	**684**	**–**	**–**	**–**	**12 700**
a. Mineral Products	**1 200**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**1 200**
Cement Production	1 100	–	–	–	–	–	–	–	1 100
Lime Production	100	–	–	–	–	–	–	–	100
b. Chemical Industry	**–**	**–**	**–**	**2.21**	**684**	**–**	**–**	**–**	**680**
Nitric Acid Production	–	–	–	2.2	680	–	–	–	680
Adipic Acid Production	–	–	–	–	–	–	–	–	–
c. Metal Production	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Iron and Steel Production	–	–	–	–	–	–	–	–	–
Aluminium Production	–	–	–	–	–	–	–	–	–
SF_6 Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	–	–
d. Consumption of Halocarbons and SF_6	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
e. Other & Undifferentiated Production[4]	**11 000**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**11 000**
SOLVENT & OTHER PRODUCT USE	**–**	**–**	**–**	**0.16**	**48**	**–**	**–**	**–**	**48**
AGRICULTURE	**–**	**437**	**9 170**	**24**	**7 600**	**–**	**–**	**–**	**17 000**
a. Enteric Fermentation	**–**	**409**	**8 590**	**–**	**–**	**–**	**–**	**–**	**8 590**
b. Manure Management	**–**	**28**	**580**	**5.8**	**1 800**	**–**	**–**	**–**	**2 400**
c. Agricultural Soils	**–**	**–**	**–**	**19**	**5 800**	**–**	**–**	**–**	**5 800**
Direct Sources	–	–	–	7.6	2 300	–	–	–	2 300
Pasture, Range, and Paddock Manure	–	–	–	5.5	1 700	–	–	–	1 700
Indirect Sources	–	–	–	6	2 000	–	–	–	2 000
WASTE	**–**	**98**	**2 100**	**0.3**	**100**	**–**	**–**	**–**	**2 200**
a. Solid Waste Disposal on Land	**–**	**98**	**2 100**	**–**	**–**	**–**	**–**	**–**	**2 100**
b. Wastewater Handling	**–**	**–**	**–**	**0.3**	**100**	**–**	**–**	**–**	**100**
c. Waste Incineration	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**

Notes:

1 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

2 Fugitive emissions from refineries and the bitumen industry are reported only at the national level.

3 Emissions associated with the use of mineral products and consumption of halocarbons and SF_6 are reported only at the national level.

4 Emissions from ammonia production are included in the category Other & Undifferentiated Production.

Totals may not add due to rounding.

N/A = not available.

TABLE A12-20: 1990–2004 Greenhouse Gas Emissions Summary for British Columbia

GHG Source Category	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
	kt CO_2 eq														
TOTAL	**51 500**	**51 000**	**50 300**	**53 000**	**55 300**	**59 500**	**61 500**	**60 300**	**60 400**	**62 500**	**63 700**	**63 200**	**61 700**	**63 800**	**66 800**
ENERGY	**41 400**	**40 600**	**39 800**	**42 100**	**44 100**	**47 800**	**50 100**	**48 600**	**49 500**	**51 300**	**52 400**	**52 700**	**51 300**	**53 200**	**55 200**
a. Stationary Combustion Sources	**19 100**	**17 800**	**16 500**	**18 000**	**18 100**	**20 200**	**21 800**	**19 400**	**20 000**	**21 900**	**22 800**	**22 900**	**21 200**	**21 900**	**22 600**
Electricity and Heat Generation	1 170	1 040	1 270	2 340	2 180	2 700	768	1 190	1 870	1 300	2 480	3 070	1 180	1 330	1 840
Fossil Fuel Industries	4 000	3 200	2 000	1 100	2 100	2 900	5 000	3 300	4 100	5 700	4 400	3 800	4 700	6 100	6 200
Mining	253	225	271	336	202	163	449	344	324	228	316	233	271	156	447
Manufacturing Industries	5 990	5 460	4 990	5 340	5 500	6 250	6 860	6 420	6 030	6 580	7 190	7 400	6 500	6 590	6 500
Construction	304	268	317	340	283	198	207	126	100	85.8	75.6	70.4	73.5	81.3	100
Commercial & Institutional	2 820	3 070	3 180	3 560	3 290	3 360	3 400	3 290	2 880	2 960	3 390	3 440	4 130	3 430	3 500
Residential	4 300	4 200	4 100	4 600	4 400	4 400	4 900	4 500	4 400	4 700	4 600	4 500	4 300	4 100	3 900
Agriculture & Forestry	323	375	374	374	205	155	191	270	253	263	315	357	126	80.9	68.2
b. Transportation[1]	**19 000**	**19 000**	**20 000**	**20 000**	**21 000**	**23 000**	**23 000**	**24 000**	**24 000**	**24 000**	**24 000**	**24 000**	**24 000**	**25 000**	**27 000**
Domestic Aviation	1 100	1 000	1 000	900	1 000	1 200	1 200	1 300	1 300	1 500	1 400	1 100	1 400	1 400	1 500
Road Transportation	12 400	12 500	12 600	13 100	13 900	14 300	14 400	15 000	15 600	15 500	15 400	15 400	15 500	16 000	17 000
Light-Duty Gasoline Vehicles	5 380	5 320	5 270	5 360	5 410	5 320	5 210	5 400	5 450	5 330	5 100	5 030	4 940	4 930	5 130
Light-Duty Gasoline Trucks	2 770	2 970	3 180	3 480	3 770	3 980	4 170	4 550	4 850	5 150	5 180	5 170	5 260	5 410	5 790
Heavy-Duty Gasoline Vehicles	352	417	485	567	647	713	720	667	827	622	596	524	516	507	525
Motorcycles	39.0	38.9	39.5	39.2	40.1	39.7	39.0	43.0	44.9	47.3	46.3	44.4	41.4	41.6	41.8
Light-Duty Diesel Vehicles	74.5	71.6	68.5	66.7	63.9	59.2	65.9	65.9	69.4	71.5	64.5	67.5	70.7	76.9	85.5
Light-Duty Diesel Trucks	78.5	59.7	49.1	42.8	39.8	36.8	33.8	41.0	39.7	26.3	60.2	71.7	86.0	96.7	115
Heavy-Duty Diesel Vehicles	2 920	2 840	2 880	3 010	3 290	3 530	3 710	3 840	3 840	3 950	4 060	4 150	4 350	4 650	5 050
Propane & Natural Gas Vehicles	780	770	580	490	620	570	410	400	480	310	330	320	290	260	260
Railways	1 000	1 000	2 000	2 000	2 000	2 000	2 000	1 000	1 000	1 000	1 000	1 000	900	600	400
Domestic Marine	1 000	1 100	1 100	1 100	1 200	1 200	1 100	1 000	1 000	1 100	1 200	1 600	1 900	3 000	2 700
Others	3 000	3 000	3 000	3 000	4 000	4 000	5 000	5 000	5 000	5 000	5 000	5 000	4 000	5 000	5 000
Off-Road Gasoline	400	400	400	500	600	600	600	700	600	600	700	600	600	700	700
Off-Road Diesel	2 000	2 000	2 000	2 000	2 000	2 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000
Pipelines	846	1 090	1 040	1 110	1 240	1 370	1 490	1 430	1 560	1 390	1 630	1 840	1 340	1 050	1 120
c. Fugitive Sources[2]	**3 320**	**3 480**	**3 630**	**3 920**	**4 510**	**4 980**	**5 260**	**5 330**	**5 340**	**5 190**	**5 270**	**5 730**	**5 890**	**5 840**	**6 090**
Coal Mining	500	500	400	500	500	600	600	700	600	500	500	500	500	500	500
Oil and Natural Gas	2 830	3 000	3 270	3 450	3 990	4 410	4 630	4 670	4 780	4 700	4 790	5 210	5 370	5 320	5 570
INDUSTRIAL PROCESSES[3]	**3 090**	**3 180**	**3 060**	**3 530**	**3 770**	**4 000**	**3 450**	**3 700**	**3 750**	**3 940**	**3 970**	**2 970**	**2 880**	**3 020**	**3 170**
a. Mineral Products	**770**	**670**	**740**	**780**	**870**	**950**	**910**	**1 100**	**1 100**	**1 300**	**1 300**	**1 200**	**1 300**	**1 200**	**1 300**
Cement Production	610	510	570	590	690	760	730	860	870	1 100	1 100	1 000	1 100	1 100	1 100
Lime Production	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
b. Chemical Industry	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Nitric Acid Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Adipic Acid Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
c. Metal Production	**1 510**	**1 650**	**1 640**	**1 650**	**1 620**	**1 690**	**1 750**	**1 800**	**2 060**	**1 870**	**1 820**	**1 270**	**1 060**	**1 230**	**1 360**
Iron and Steel Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Aluminium Production	1 510	1 650	1 640	1 650	1 620	1 690	1 750	1 800	2 060	1 870	1 820	1 270	1 060	1 230	1 360
SF_6 Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
d. Consumption of Halocarbons and SF_6[4]	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
e. Other & Undifferentiated Production[5]	**810**	**860**	**670**	**1 100**	**1 300**	**1 400**	**790**	**850**	**630**	**810**	**880**	**490**	**550**	**540**	**500**
SOLVENT & OTHER PRODUCT USE	**50**	**51**	**52**	**54**	**55**	**57**	**58**	**59**	**60**	**60**	**61**	**61**	**62**	**63**	**63**
AGRICULTURE	**2 100**	**2 100**	**2 100**	**2 100**	**2 200**	**2 300**	**2 300**	**2 300**	**2 100**	**2 200**	**2 200**	**2 300**	**2 300**	**2 400**	**2 500**
a. Enteric Fermentation	**1 060**	**1 080**	**1 110**	**1 090**	**1 120**	**1 190**	**1 220**	**1 200**	**1 160**	**1 190**	**1 190**	**1 200**	**1 240**	**1 280**	**1 350**
b. Manure Management	**380**	**380**	**390**	**390**	**400**	**410**	**420**	**420**	**420**	**430**	**430**	**440**	**450**	**460**	**480**
c. Agricultural Soils	**660**	**590**	**650**	**650**	**650**	**650**	**670**	**690**	**540**	**610**	**590**	**650**	**620**	**650**	**670**
Direct Sources	280	230	260	270	260	250	260	280	170	220	200	240	220	230	230
Pasture, Range, and Paddock Manure	190	190	190	190	190	210	210	210	200	210	210	210	220	220	240
Indirect Sources	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
WASTE	**4 900**	**5 100**	**5 200**	**5 200**	**5 200**	**5 300**	**5 600**	**5 700**	**5 000**	**5 000**	**5 100**	**5 100**	**5 200**	**5 100**	**5 900**
a. Solid Waste Disposal on Land	**4 700**	**4 900**	**5 000**	**5 000**	**5 000**	**5 100**	**5 400**	**5 400**	**4 800**	**4 800**	**4 800**	**4 900**	**5 000**	**4 900**	**5 700**
b. Wastewater Handling	**130**	**130**	**140**	**140**	**130**	**140**	**140**	**150**	**150**	**150**	**150**	**150**	**150**	**150**	**150**
c. Waste Incineration	**66**	**71**	**70**	**70**	**70**	**70**	**70**	**71**	**71**	**70**	**70**	**67**	**69**	**68**	**68**

Notes:

1 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

2 Fugitive emissions from refineries and the bitumen industry are reported only at the national level.

3 Emissions associated with the use of mineral products and consumption of halocarbons and SF_6 are reported only at the national level.

4 Only SF_6 emissions from magnesium smelters are included. Information on SF_6 use in casters is confidential for this province.

5 Emissions from ammonia production are included in the category Other & Undifferentiated Production.

Totals may not add due to rounding.

TABLE A12-21: 2004 Greenhouse Gas Emissions Summary for British Columbia

GHG Source Category	Greenhouse Gases								
	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	TOTAL
Global Warming Potential			21		310				
Unit	*kt*	*kt*	*kt CO_2 eq*	*kt*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*
TOTAL	**52 800**	**500**	**10 000**	**8.8**	**2 700**	**N/A**	**908**	**0**	**66 800**
ENERGY	**50 500**	**200**	**3 000**	**5**	**1 000**	**–**	**–**	**–**	**55 200**
a. Stationary Combustion Sources	**21 900**	**20**	**400**	**0.8**	**200**	**–**	**–**	**–**	**22 600**
Electricity and Heat Generation	1 820	0.22	4.7	0.04	10	–	–	–	1 840
Fossil Fuel Industries	5 900	10	300	0.1	40	–	–	–	6 200
Mining	445	0.00	0.09	0.01	2	–	–	–	447
Manufacturing Industries	6 370	0.8	20	0.4	100	–	–	–	6 500
Construction	99.5	0.00	0.04	0.00	0.6	–	–	–	100
Commercial & Institutional	3 480	0.06	1	0.07	20	–	–	–	3 500
Residential	3 740	8	200	0.2	50	–	–	–	3 900
Agriculture & Forestry	67.7	0.00	0.02	0.00	0.5	–	–	–	68.2
b. Transportation[1]	**25 200**	**4**	**80**	**4**	**1 000**	**–**	**–**	**–**	**27 000**
Domestic Aviation	1 460	0.08	2	0.1	40	–	–	–	1 500
Road Transportation	16 300	1.5	32	2.2	670	–	–	–	17 000
Light-Duty Gasoline Vehicles	4 900	0.41	8.6	0.70	220	–	–	–	5 130
Light-Duty Gasoline Trucks	5 400	0.61	13	1.2	380	–	–	–	5 790
Heavy-Duty Gasoline Vehicles	501	0.07	1.5	0.07	23	–	–	–	525
Motorcycles	40.9	0.03	0.69	0.00	0.25	–	–	–	41.8
Light-Duty Diesel Vehicles	83.5	0.00	0.05	0.01	2	–	–	–	85.5
Light-Duty Diesel Trucks	112	0.00	0.06	0.01	3	–	–	–	115
Heavy-Duty Diesel Vehicles	5 000	0.2	5	0.1	50	–	–	–	5 050
Propane & Natural Gas Vehicles	254	0.2	4	0.01	2	–	–	–	260
Railways	352	0.02	0.4	0.1	40	–	–	–	400
Domestic Marine	2 520	0.2	4	0.4	100	–	–	–	2 700
Others	4 600	2	40	1	400	–	–	–	5 000
Off-Road Gasoline	700	0.8	20	0.01	5	–	–	–	700
Off-Road Diesel	2 800	0.1	3	1	300	–	–	–	3 000
Pipelines	1 090	1.1	23	0.03	9	–	–	–	1 120
c. Fugitive Sources[2]	**3 400**	**130**	**2 700**	**–**	**–**	**–**	**–**	**–**	**6 090**
Coal Mining	–	20	500	–	–	–	–	–	500
Oil and Natural Gas	3 400	100	2 200	–	–	–	–	–	5 570
INDUSTRIAL PROCESSES[3]	**2 260**	**–**	**–**	**–**	**–**	**–**	**908**	**0.02**	**3 170**
a. Mineral Products	**1 300**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**1 300**
Cement Production	1 100	–	–	–	–	–	–	–	1 100
Lime Production	200	–	–	–	–	–	–	–	200
b. Chemical Industry	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Nitric Acid Production	–	–	–	–	–	–	–	–	–
Adipic Acid Production	–	–	–	–	–	–	–	–	–
c. Metal Production	**450**	**–**	**–**	**–**	**–**	**–**	**908**	**0.02**	**1 360**
Iron and Steel Production	–	–	–	–	–	–	–	–	–
Aluminium Production	450	–	–	–	–	–	908	–	1 360
SF_6 Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	–	–
d. Consumption of Halocarbons and SF_6[4]	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
e. Other & Undifferentiated Production[5]	**500**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**500**
SOLVENT & OTHER PRODUCT USE	**–**	**–**	**–**	**0.20**	**63**	**–**	**–**	**–**	**63**
AGRICULTURE	**–**	**71.2**	**1 500**	**3.3**	**1 000**	**–**	**–**	**–**	**2 500**
a. Enteric Fermentation	**–**	**64.4**	**1 350**	**–**	**–**	**–**	**–**	**–**	**1 350**
b. Manure Management	**–**	**6.8**	**140**	**1.1**	**340**	**–**	**–**	**–**	**480**
c. Agricultural Soils	**–**	**–**	**–**	**2.2**	**670**	**–**	**–**	**–**	**670**
Direct Sources	–	–	–	0.75	230	–	–	–	230
Pasture, Range, and Paddock Manure	–	–	–	0.77	240	–	–	–	240
Indirect Sources	–	–	–	0.6	200	–	–	–	200
WASTE	**57**	**270**	**5 700**	**0.5**	**100**	**–**	**–**	**–**	**5 900**
a. Solid Waste Disposal on Land	**–**	**270**	**5 700**	**–**	**–**	**–**	**–**	**–**	**5 700**
b. Wastewater Handling	**–**	**1.0**	**22**	**0.4**	**100**	**–**	**–**	**–**	**150**
c. Waste Incineration	**57**	**–**	**–**	**0.04**	**10**	**–**	**–**	**–**	**68**

Notes:

1 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

2 Fugitive emissions from refineries and the bitumen industry are reported only at the national level.

3 Emissions associated with the use of mineral products and consumption of halocarbons and SF_6 are reported only at the national level.

4 Only SF_6 emissions from magnesium smelters are included. Information on SF_6 use in casters is confidential for this province.

5 Emissions from ammonia production are included in the category Other & Undifferentiated Production.

Totals may not add due to rounding.

N/A = not available.

TABLE A12-22: 1990–2004 Greenhouse Gas Emissions Summary for Yukon

kt CO_2 eq

GHG Source Category	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
TOTAL	**515**	**488**	**506**	**421**	**419**	**464**	**526**	**497**	**410**	**440**	**404**	**400**	**417**	**431**	**418**
ENERGY	**504**	**476**	**494**	**409**	**407**	**450**	**512**	**484**	**397**	**426**	**390**	**386**	**403**	**417**	**403**
a. Stationary Combustion Sources	**196**	**166**	**153**	**129**	**126**	**159**	**196**	**175**	**124**	**139**	**127**	**130**	**139**	**149**	**131**
Electricity and Heat Generation	96.0	58.8	54.0	30.9	28.0	54.8	104	89.1	33.1	26.6	17.4	14.9	17.6	10.9	8.2
Fossil Fuel Industries	3.1	15	16	14	13	13	11	13	14	14	13	9.8	7.0	4.0	1.4
Mining	3.07	3.12	0.26	0.54	1.65	8.78	12.30	3.92	2.84	5.66	4.41	4.83	6.96	6.03	5.23
Manufacturing Industries	1.67	1.13	1.11	1.67	0.85	0.79	0.25	0.53	–	0.00	–	0.03	–	–	–
Construction	1.42	1.11	0.57	–	1.68	4.38	3.52	2.67	1.56	2.27	2.29	1.44	1.43	2.51	1.83
Commercial & Institutional	70.7	67.6	60.9	55.8	49.3	51.5	37.3	35.7	33.4	39.6	53.6	51.8	54.0	59.6	40.4
Residential	20	15	12	22	27	17	22	25	32	41	36	33	36	46	60
Agriculture & Forestry	0.57	3.95	8.46	5.08	5.68	7.64	5.96	5.96	7.67	10.6	0.98	14.4	15.2	20.7	13.7
b. Transportation[1]	**310**	**310**	**340**	**270**	**270**	**290**	**310**	**300**	**270**	**280**	**260**	**250**	**260**	**260**	**270**
Domestic Aviation	21	19	16	17	19	21	24	16	23	21	23	16	15	21	23
Road Transportation	183	183	196	196	239	248	244	190	226	254	232	214	220	207	197
Light-Duty Gasoline Vehicles	80.3	80.0	83.8	84.6	75.6	75.7	69.8	65.9	74.5	69.7	52.3	52.3	50.4	50.3	41.1
Light-Duty Gasoline Trucks	34.5	36.7	41.0	44.0	41.7	42.2	41.1	42.2	52.3	55.1	43.9	44.8	44.6	46.1	38.9
Heavy-Duty Gasoline Vehicles	5.73	6.38	7.40	8.19	7.96	8.08	8.04	8.25	10.1	14.3	11.4	10.4	10.2	10.1	8.38
Motorcycles	0.38	0.39	0.40	0.41	0.37	0.38	0.34	0.32	0.40	0.40	0.32	0.32	0.33	0.32	0.27
Light-Duty Diesel Vehicles	0.96	0.96	1.00	1.00	0.88	0.89	0.81	0.79	0.88	0.84	0.65	0.68	0.69	0.73	0.63
Light-Duty Diesel Trucks	1.20	0.99	0.91	0.76	1.30	1.43	1.34	0.72	0.94	0.66	0.95	0.86	0.98	0.86	0.97
Heavy-Duty Diesel Vehicles	58.8	56.2	58.9	54.9	105	115	120	70.0	85.4	112	122	104	111	97.2	105
Propane & Natural Gas Vehicles	1.5	1.5	2.9	2.3	5.9	4.0	2.2	1.9	1.7	1.6	0.68	1.0	1.5	1.9	2.0
Railways	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Domestic Marine	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Others	100	100	100	60	20	20	40	100	20	6	4	20	20	30	50
Off-Road Gasoline	20	10	8	9	8	10	10	9	9	6	4	5	4	5	4
Off-Road Diesel	90	90	100	50	9	7	30	90	10	–	–	20	20	30	50
Pipelines	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
c. Fugitive Sources[2]	**–**	**2.96**	**4.68**	**6.59**	**5.42**	**4.79**	**4.13**	**5.03**	**4.71**	**4.99**	**4.02**	**3.24**	**6.25**	**4.13**	**3.51**
Coal Mining	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Oil and Natural Gas	–	2.96	4.68	6.59	5.42	4.79	4.13	5.03	4.71	4.99	4.02	3.24	6.25	4.13	3.51
INDUSTRIAL PROCESSES[3]	**0.85**	**0.56**	**0.85**	**0.42**	**0.28**	**2.26**	**1.83**	**0.85**	**0.42**	**0.81**	**0.71**	**0.61**	**0.99**	**0.75**	**0.49**
a. Mineral Products	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Cement Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lime Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
b. Chemical Industry	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Nitric Acid Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Adipic Acid Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
c. Metal Production	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Iron and Steel Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Aluminium Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
SF_6 Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
d. Consumption of Halocarbons and SF_6	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
e. Other & Undifferentiated Production[4]	**0.9**	**1**	**0.9**	**0**	**0**	**2**	**2**	**0.9**	**0.4**	**0.81**	**0.71**	**0.61**	**0.99**	**0.75**	**0.48**
SOLVENT & OTHER PRODUCT USE	**0.42**	**0.44**	**0.45**	**0.46**	**0.45**	**0.46**	**0.47**	**0.48**	**0.47**	**0.46**	**0.46**	**0.45**	**0.45**	**0.46**	**0.47**
AGRICULTURE	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
a. Enteric Fermentation	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
b. Manure Management	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
c. Agricultural Soils	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Direct Sources	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pasture, Range, and Paddock Manure	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Indirect Sources	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
WASTE	**10**	**11**	**11**	**11**	**11**	**12**	**12**	**12**	**12**	**12**	**13**	**13**	**13**	**13**	**14**
a. Solid Waste Disposal on Land	**7.0**	**7.3**	**7.5**	**7.7**	**7.9**	**8.1**	**8.3**	**8.6**	**8.8**	**9.0**	**9.3**	**9.5**	**9.8**	**10**	**10**
b. Wastewater Handling	**3.2**	**3.3**	**3.5**	**3.5**	**3.4**	**3.5**	**3.4**	**3.6**	**3.5**	**3.3**	**3.2**	**3.1**	**3.1**	**3.3**	**3.5**
c. Waste Incineration	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**

Notes:

1 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

2 Fugitive emissions from refineries and the bitumen industry are reported only at the national level.

3 Emissions associated with the use of mineral products and consumption of halocarbons and SF_6 are reported only at the national level.

4 Emissions from ammonia production are included in the category Other & Undifferentiated Production.

Totals may not add due to rounding.

TABLE A12-23: 2004 Greenhouse Gas Emissions Summary for Yukon

GHG Source Category	Greenhouse Gases								
	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	TOTAL
Global Warming Potential			21		310				
Unit	*kt*	*kt*	*kt CO_2 eq*	*kt*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*
TOTAL	**388**	**0.77**	**16**	**0.05**	**14**	**N/A**	**N/A**	**N/A**	**418**
ENERGY	**387**	**0.2**	**3**	**0.04**	**10**	**–**	**–**	**–**	**403**
a. Stationary Combustion Sources	**127**	**0.1**	**2**	**0.01**	**2**	**–**	**–**	**–**	**131**
Electricity and Heat Generation	7.82	0.00	0.01	0.00	0.4	–	–	–	8.18
Fossil Fuel Industries	1.3	0.00	0.04	0.00	0.0	–	–	–	1.4
Mining	5.12	0.00	0.00	0.00	0.1	–	–	–	5.23
Manufacturing Industries	–	–	–	–	–	–	–	–	–
Construction	1.82	0.00	0.00	0.00	0.01	–	–	–	1.83
Commercial & Institutional	39.9	0.00	0.01	0.00	0.4	–	–	–	40.4
Residential	57.0	0.1	2	0.00	0.6	–	–	–	60
Agriculture & Forestry	13.7	0.00	0.00	0.00	0.05	–	–	–	13.7
b. Transportation[1]	**258**	**0.02**	**0.5**	**0.04**	**10**	**–**	**–**	**–**	**270**
Domestic Aviation	21.9	0.00	0.07	0.00	0.7	–	–	–	23
Road Transportation	192	0.02	0.31	0.02	5.3	–	–	–	197
Light-Duty Gasoline Vehicles	39.5	0.00	0.07	0.01	1.6	–	–	–	41.1
Light-Duty Gasoline Trucks	36.5	0.00	0.09	0.01	2.3	–	–	–	38.9
Heavy-Duty Gasoline Vehicles	7.99	0.00	0.02	0.00	0.37	–	–	–	8.38
Motorcycles	0.27	0.00	0.00	0.00	0.00	–	–	–	0.27
Light-Duty Diesel Vehicles	0.62	0.00	0.00	0.00	0.01	–	–	–	0.63
Light-Duty Diesel Trucks	0.94	0.00	0.00	0.00	0.02	–	–	–	0.97
Heavy-Duty Diesel Vehicles	104	0.01	0.1	0.00	0.9	–	–	–	105
Propane & Natural Gas Vehicles	2.01	0.00	0.01	0.00	0.01	–	–	–	2.0
Railways	–	–	–	–	–	–	–	–	–
Domestic Marine	–	–	–	–	–	–	–	–	–
Others	44	0.01	0.1	0.02	5	–	–	–	50
Off-Road Gasoline	4	0.00	0.09	0.00	0.03	–	–	–	4
Off-Road Diesel	40	0.00	0.04	0.02	5	–	–	–	50
Pipelines	–	–	–	–	–	–	–	–	–
c. Fugitive Sources[2]	**2.9**	**0.03**	**0.60**	**–**	**–**	**–**	**–**	**–**	**3.51**
Coal Mining	–	–	–	–	–	–	–	–	–
Oil and Natural Gas	2.9	0.03	0.60	–	–	–	–	–	3.51
INDUSTRIAL PROCESSES[3]	**0.49**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**0.49**
a. Mineral Products	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Cement Production	–	–	–	–	–	–	–	–	–
Lime Production	–	–	–	–	–	–	–	–	–
b. Chemical Industry	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Nitric Acid Production	–	–	–	–	–	–	–	–	–
Adipic Acid Production	–	–	–	–	–	–	–	–	–
c. Metal Production	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Iron and Steel Production	–	–	–	–	–	–	–	–	–
Aluminium Production	–	–	–	–	–	–	–	–	–
SF_6 Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	–	–
d. Consumption of Halocarbons and SF_6	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
e. Other & Undifferentiated Production[4]	**0.48**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**0.48**
SOLVENT & OTHER PRODUCT USE	**–**	**–**	**–**	**0.00**	**0.47**	**–**	**–**	**–**	**0.47**
AGRICULTURE	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
a. Enteric Fermentation	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
b. Manure Management	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
c. Agricultural Soils	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Direct Sources	–	–	–	–	–	–	–	–	–
Pasture, Range, and Paddock Manure	–	–	–	–	–	–	–	–	–
Indirect Sources	–	–	–	–	–	–	–	–	–
WASTE	**–**	**0.61**	**13**	**0.00**	**1**	**–**	**–**	**–**	**14**
a. Solid Waste Disposal on Land	**–**	**0.49**	**10**	**–**	**–**	**–**	**–**	**–**	**10**
b. Wastewater Handling	**–**	**0.12**	**2.5**	**0.00**	**1**	**–**	**–**	**–**	**3.5**
c. Waste Incineration	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**

Notes:

1 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

2 Fugitive emissions from refineries and the bitumen industry are reported only at the national level.

3 Emissions associated with the use of mineral products and consumption of halocarbons and SF_6 are reported only at the national level.

4 Emissions from ammonia production are included in the category Other & Undifferentiated Production.

Totals may not add due to rounding.

N/A = not available.

TABLE A12-24: 1990–2004 Greenhouse Gas Emissions Summary for Northwest Territories and Nunavut

	kt CO_2 eq														
GHG Source Category	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
TOTAL	1540	1500	1310	1580	1700	1800	1670	1700	1560	1350	1610	2160	1760	1620	1600
ENERGY	1520	1470	1290	1560	1670	1770	1640	1670	1530	1320	1580	2120	1720	1580	1570
a. Stationary Combustion Sources	908	949	812	913	978	1110	816	925	749	639	823	1010	902	805	788
Electricity and Heat Generation	215	215	186	197	198	371	351	348	326	302	293	302	258	271	278
Fossil Fuel Industries	180	110	16	31	20	23	14	3.80	3.10	3.30	170	320	280	170	190
Mining	50.8	55.6	41.4	65.9	152	103	44.4	49.3	63.8	68.9	76.6	103	103	90.9	58.7
Manufacturing Industries	31.6	21.1	23.1	8.53	14.2	20.5	18.4	9.63	0.28	–	–	0.02	–	0.07	0.18
Construction	7.59	7.32	7.76	6.87	4.04	20.4	0.85	0.57	0.44	0.92	0.67	0.91	1.61	1.46	2.01
Commercial & Institutional	250	341	332	371	392	454	197	339	214	172	163	153	127	161	162
Residential	170	190	190	230	190	120	190	180	140	92	120	110	110	95	95
Agriculture & Forestry	2.34	9.70	12.4	2.22	1.99	–	–	–	–	0.01	0.01	20.3	22.7	14.1	1.76
b. Transportation[1]	550	450	420	580	650	620	790	740	780	670	740	1100	810	760	760
Domestic Aviation	170	170	180	200	220	180	200	210	170	110	110	210	140	110	110
Road Transportation	120	100	100	77.0	105	149	144	153	150	206	232	222	269	288	334
Light-Duty Gasoline Vehicles	27.9	24.1	23.6	25.5	27.9	27.1	22.2	26.5	25.4	39.5	45.0	50.1	41.9	40.6	38.5
Light-Duty Gasoline Trucks	12.0	11.0	11.5	13.2	15.4	15.8	14.1	18.0	17.8	31.2	37.8	42.8	37.1	37.2	36.5
Heavy-Duty Gasoline Vehicles	1.99	1.92	2.08	2.47	2.93	3.08	2.75	3.32	3.46	6.34	8.01	8.18	7.01	6.76	6.51
Motorcycles	0.13	0.12	0.11	0.12	0.14	0.13	0.11	0.14	0.14	0.21	0.27	0.26	0.21	0.21	0.20
Light-Duty Diesel Vehicles	0.33	0.29	0.28	0.30	0.32	0.31	0.27	0.32	0.30	0.47	0.56	0.65	0.57	0.59	0.59
Light-Duty Diesel Trucks	1.52	1.05	0.92	0.45	0.64	1.09	1.04	1.18	1.10	0.95	1.32	1.18	1.91	2.11	2.73
Heavy-Duty Diesel Vehicles	75.1	59.5	58.9	32.7	51.7	97.4	102	102	100	125	138	117	179	199	247
Propane & Natural Gas Vehicles	1.5	1.5	2.9	2.3	5.9	4.0	2.2	1.9	1.7	1.6	0.68	1.0	1.5	1.9	2.0
Railways	3	2	2	2	2	2	1	3	2	3	3	4	4	3	3
Domestic Marine	–	0.30	0.61	0.61	–	71	90	12	31	8.4	10	17	9.7	–	–
Others	300	200	100	300	300	200	400	400	400	300	400	600	400	400	300
Off-Road Gasoline	60	60	60	90	80	70	70	90	40	30	30	20	10	20	30
Off-Road Diesel	200	100	70	200	200	100	300	300	400	300	400	600	400	300	300
Pipelines	–	–	–	–	2.57	–	–	–	5.14	4.84	5.80	6.19	3.73	3.01	2.95
c. Fugitive Sources[2]	63.0	67.5	57.7	61.3	41.4	41.3	38.6	6.2	4.9	4.9	9.4	11	14	17	20
Coal Mining	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Oil and Natural Gas	63.0	67.5	57.7	61.3	41.4	41.3	38.6	6.2	4.9	4.9	9.4	11	14	17	20
INDUSTRIAL PROCESSES[3]	2.88	10.7	0.85	0.42	0.28	2.26	1.83	0.85	0.42	2.46	4.23	5.41	5.42	5.38	5.38
a. Mineral Products	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cement Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lime Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
b. Chemical Industry	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Nitric Acid Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Adipic Acid Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
c. Metal Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Iron and Steel Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Aluminium Production	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
SF_6 Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
d. Consumption of Halocarbons and SF_6	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
e. Other & Undifferentiated Production[4]	2.9	11	0.85	0.42	0.28	2.3	1.8	0.85	0.42	2.5	4.2	5.4	5.4	5.4	5.4
SOLVENT & OTHER PRODUCT USE	0.89	0.92	0.94	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.1	1.1
AGRICULTURE	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
a. Enteric Fermentation	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
b. Manure Management	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
c. Agricultural Soils	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Direct Sources	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pasture, Range, and Paddock Manure	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Indirect Sources	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
WASTE	21	23	23	24	25	25	27	27	27	29	29	30	31	31	32
a. Solid Waste Disposal on Land	16	17	17	18	18	19	19	20	20	21	21	22	23	23	24
b. Wastewater Handling	5.4	6.8	6.3	6.0	7.4	6.6	7.7	7.4	7.0	7.7	7.8	8.0	8.1	8.2	8.4
c. Waste Incineration	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Notes:

1 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

2 Fugitive emissions from refineries and the bitumen industry are reported only at the national level.

3 Emissions associated with the use of mineral products and consumption of halocarbons and SF_6 are reported only at the national level.

4 Emissions from ammonia production are included in the category Other & Undifferentiated Production.

Totals may not add due to rounding.

TABLE A12-25: 2004 Greenhouse Gas Emissions Summary for Northwest Territories and Nunavut

GHG Source Category	Greenhouse Gases								
	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	TOTAL
Global Warming Potential			21		310				
Unit	*kt*	*kt*	*kt CO_2 eq*	*kt*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*
TOTAL	**1500**	**2.3**	**49**	**0.19**	**58**	**N/A**	**N/A**	**N/A**	**1600**
ENERGY	**1490**	**0.9**	**20**	**0.2**	**50**	**–**	**–**	**–**	**1570**
a. Stationary Combustion Sources	**759**	**0.7**	**20**	**0.04**	**10**	**–**	**–**	**–**	**788**
Electricity and Heat Generation	268	0.01	0.23	0.03	9	–	–	–	278
Fossil Fuel Industries	180	0.5	10	0.01	1	–	–	–	190
Mining	58.4	0.00	0.01	0.00	0.3	–	–	–	58.7
Manufacturing Industries	0.18	0.00	0.00	–	–	–	–	–	0.18
Construction	1.99	0.00	0.00	0.00	0.01	–	–	–	2.01
Commercial & Institutional	161	0.00	0.05	0.00	1	–	–	–	162
Residential	88.8	0.2	5	0.00	1	–	–	–	95
Agriculture & Forestry	1.75	0.00	0.00	0.00	0.01	–	–	–	1.76
b. Transportation[1]	**716**	**0.07**	**2**	**0.1**	**40**	**–**	**–**	**–**	**760**
Domestic Aviation	107	0.01	0.2	0.01	3	–	–	–	110
Road Transportation	328	0.02	0.44	0.02	6.3	–	–	–	334
Light-Duty Gasoline Vehicles	37.0	0.00	0.07	0.00	1.5	–	–	–	38.5
Light-Duty Gasoline Trucks	34.2	0.00	0.08	0.01	2.2	–	–	–	36.5
Heavy-Duty Gasoline Vehicles	6.21	0.00	0.02	0.00	0.29	–	–	–	6.51
Motorcycles	0.20	0.00	0.00	0.00	0.00	–	–	–	0.20
Light-Duty Diesel Vehicles	0.58	0.00	0.00	0.00	0.01	–	–	–	0.59
Light-Duty Diesel Trucks	2.67	0.00	0.00	0.00	0.06	–	–	–	2.73
Heavy-Duty Diesel Vehicles	245	0.01	0.3	0.01	2	–	–	–	247
Propane & Natural Gas Vehicles	2.01	0.00	0.01	0.00	0.01	–	–	–	2.0
Railways	2.81	0.00	0.00	0.00	0.4	–	–	–	3
Domestic Marine	–	–	–	–	–	–	–	–	–
Others	280	0.04	0.9	0.1	30	–	–	–	300
Off-Road Gasoline	20	0.03	0.6	0.00	0.2	–	–	–	30
Off-Road Diesel	250	0.01	0.3	0.1	30	–	–	–	300
Pipelines	2.82	0.00	0.00	0.00	0.1	–	–	–	2.95
c. Fugitive Sources[2]	**18**	**0.10**	**2.0**	**–**	**–**	**–**	**–**	**–**	**19.7**
Coal Mining	–	–	–	–	–	–	–	–	–
Oil and Natural Gas	18	0.10	2.0	–	–	–	–	–	19.7
INDUSTRIAL PROCESSES[3]	**5.38**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**5.38**
a. Mineral Products	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Cement Production	–	–	–	–	–	–	–	–	–
Lime Production	–	–	–	–	–	–	–	–	–
b. Chemical Industry	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Nitric Acid Production	–	–	–	–	–	–	–	–	–
Adipic Acid Production	–	–	–	–	–	–	–	–	–
c. Metal Production	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Iron and Steel Production	–	–	–	–	–	–	–	–	–
Aluminium Production	–	–	–	–	–	–	–	–	–
SF_6 Used in Magnesium Smelters and Casters	–	–	–	–	–	–	–	–	–
d. Consumption of Halocarbons and SF_6	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
e. Other & Undifferentiated Production[4]	**5.4**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**5.4**
SOLVENT & OTHER PRODUCT USE	**–**	**–**	**–**	**0.00**	**1.1**	**–**	**–**	**–**	**1.1**
AGRICULTURE	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
a. Enteric Fermentation	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
b. Manure Management	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
c. Agricultural Soils	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Direct Sources	–	–	–	–	–	–	–	–	–
Pasture, Range, and Paddock Manure	–	–	–	–	–	–	–	–	–
Indirect Sources	–	–	–	–	–	–	–	–	–
WASTE	**–**	**1.4**	**30**	**0.01**	**2**	**–**	**–**	**–**	**32**
a. Solid Waste Disposal on Land	**–**	**1.1**	**24**	**–**	**–**	**–**	**–**	**–**	**24**
b. Wastewater Handling	**–**	**0.29**	**6.1**	**0.01**	**2**	**–**	**–**	**–**	**8.4**
c. Waste Incineration	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**

Notes:

1 Emissions from fuel ethanol are reported within the gasoline transportation subcategories.

2 Fugitive emissions from refineries and the bitumen industry are reported only at the national level.

3 Emissions associated with the use of mineral products and consumption of halocarbons and SF_6 are reported only at the national level.

4 Emissions from ammonia production are included in the category Other & Undifferentiated Production.

Totals may not add due to rounding.

N/A = not available.

ANNEX 13: EMISSION FACTORS

This annex summarizes the development and selection of emission factors used to prepare the national GHG inventory.

A13.1 FUEL COMBUSTION

A13.1.1 NATURAL GAS AND NGLs

A13.1.1.1 CO_2

CO_2 emission factors for fossil fuel combustion are primarily dependent on the properties of the fuel and, to a lesser extent, the combustion technology.

For natural gas, there are two major qualities of fuel combusted in Canada: marketable fuel (processed for commercial sale) and non-marketable fuel (unprocessed for internal use). Emission factors have been developed for these two categories (Table A13-1) based on data from the chemical analysis of representative natural gas samples (McCann, 2000) and an assumed fuel combustion efficiency of 99.5% (IPCC/OECD/IEA, 1997). The emission factor for marketable fuel matches closely with previous factors based on energy contents reported in Statistics Canada's RESD (Jaques, 1992). The factor for non-marketable natural gas is higher than that for marketable fuels due to its raw nature, which includes ethane, propane, and butane in addition to methane in the fuel mix.

NGL (ethane, propane, butane) emission factors were developed based on chemical analysis data for marketable fuels (McCann, 2000) and an assumed fuel combustion efficiency of 99.5% (IPCC/OECD/IEA, 1997). The emission factors are lower than those developed on the assumption of pure fuels (Jaques, 1992) due to the presence of impurities in the fuels.

A13.1.1.2 CH_4

Emissions of CH_4 from fuel combustion are technology dependent. Sectoral emission factors (Table A13-1) have been developed based on technologies typically used in Canada. The factors were developed based on a review of emission factors for combustion technologies (SGA, 2000). The emission factor for producer consumption of natural gas was developed based on a technology split for the upstream oil and gas industry (CAPP, 1999) and technology-specific emission factors from the U.S. EPA report AP-42 (EPA, 1996).

A13.1.1.3 N_2O

Emissions of N_2O from fuel combustion are technology dependent. Emission factors (Table A13-1) have been developed based on technologies typically used in Canada. The factors were developed from a review of emission factors for and an analysis of combustion technologies (SGA, 2000).

TABLE A13-1: Emission Factors for Natural Gas and NGLs

Source	Emission Factors		
	CO_2	CH_4	N_2O
Natural Gas	*g/m³*	*g/m³*	*g/m³*
Electric Utilities	1891[1]	0.49[2]	0.049[2]
Industrial	1891[1]	0.037[2]	0.033[2]
Producer Consumption	2389[1]	6.5[3,4]	0.06[2]
Pipelines	1891[1]	1.9[2]	0.05[2]
Residential, Commercial, Agriculture	1891[1]	0.037[2]	0.035[2]
NGLs	*g/L*	*g/L*	*g/L*
Ethane	976[1]	N/A	N/A
Propane	1500[1]	0.024[2]	0.108[2]
Butane	1730[1]	0.024[2]	0.108[2]

Notes:

1 Adapted from McCann (2000).

2 SGA (2000).

3 EPA (1996).

4 CAPP (1999).

N/A = not applicable

A13.1.2 REFINED PETROLEUM PRODUCTS

A13.1.2.1 CO_2

CO_2 emission factors for fossil fuel combustion are primarily dependent on the properties of the fuel and, to a lesser extent, the combustion technology.

Emission factors have been developed for each major class of refined petroleum product (Table A13-2) based on standard fuel properties and an assumed fuel combustion efficiency of 98.5% (Jaques, 1992).

The composition of petroleum coke is process specific. Factors have been developed for both coker-derived and catalytic cracker–derived cokes. Average factors have been developed based on data provided by industry (Nyboer, 1996). Industry factors were provided by industry on a mass basis and were converted to a volumetric basis for comparability with the national energy data using the density of coke provided by Statistics Canada (#57-003).

A13.1.2.2 CH_4

Emissions of CH_4 from fuel combustion are technology dependent. Emission factors have been developed (Table A13-2) based on technologies typically used in Canada. The factors were developed from a review of emission factors for and an analysis of combustion technologies (SGA, 2000).

An emission factor for petroleum coke could not be found in the literature due to a lack of research in this area. It was assumed to be the same as that for heavy fuel oil used in industry.

An emission factor for refinery fuel gas (still gas) is not available, according to the SGA (2000) study.

A13.1.2.3 N_2O

Emissions of N_2O from fuel combustion are technology dependent. Emission factors have been developed (Table A13-2) based on technologies typically used in Canada. The factors were developed from a review of emission factors for and an analysis of combustion technologies (SGA, 2000).

An emission factor for petroleum coke could not be found, so it was assumed to be the same as that for heavy fuel oil used in industry.

TABLE A13-2: Emission Factors for Refined Petroleum Products

Source	Emission Factors		
	CO_2	CH_4	N_2O
Light Fuel Oil	*g/L*	*g/L*	*g/L*
Electric Utilities	2830[1]	0.18[2]	0.031[2]
Industry	2830[1]	0.006[2]	0.031[2]
Producer Consumption	2830[1]	0.006[2]	0.031[2]
Residential	2830[1]	0.026[2]	0.006[2]
Other Small Combustion	2830[1]	0.026[2]	0.031[2]
Heavy Fuel Oil	*g/L*	*g/L*	*g/L*
Electric Utilities	3090[1]	0.034[2]	0.064[2]
Industry	3090[1]	0.12[2]	0.064[2]
Producer Consumption	3090[1]	0.12[2]	0.064[2]
Residential, etc.	3090[1]	0.057[2]	0.064[2]
Kerosene	*g/L*	*g/L*	*g/L*
Electric Utilities	2550[1]	0.006[2]	0.031[2]
Industry	2550[1]	0.006[2]	0.031[2]
Producer Consumption	2550[1]	0.006[2]	0.031[2]
Residential, etc.	2550[1]	0.026[2]	0.006[2]
Other Small Combustion	2550[1]	0.026[2]	0.031[2]
Diesel	*g/L*	*g/L*	*g/L*
Electric Utilities	2730[1]	0.133[2]	0.4[2]
Producer Consumption	2730[1]	0.133[2]	0.4[2]
Petroleum Coke	*g/L*	*g/L*	*g/L*
Petroleum Coke Others	4200[3]	0.12[2]	0.064[2]
Producer Consumption	4200[3]	0.12[2]	0.064[2]
Coke from Catalytic Crackers	3800[3]	0.12[2]	0.064[2]
	g/m^3	*g/m^3*	*g/m^3*
Still Gas	2000[1]	N/A[2]	0.002[2]

Notes:

1 Jaques (1992).

2 SGA (2000).

3 Nyboer (1996).

N/A = not available

A13.1.3 COAL AND COAL PRODUCTS

A13.1.3.1 CO_2

CO_2 emission factors for coal combustion are dependent on the properties of the fuel and, to a lesser extent, the combustion technology.

Coal emission factors (Table A13-3) have been developed for each province based on the rank of the coal and the region of supply. Emission factors have been developed based on data from chemical analysis of coal samples for electric utilities, which comprise the vast majority of coal consumption, and a fuel combustion efficiency of 99.0% (Jaques, 1992). The factors for coal were reviewed in 1999 because the supply and quality of coal used may change over time. Based on this review, it was determined that updated factors should be used for the more recent years. The factors for the year 1990 are based on supply and quality data from 1988 (Jaques, 1992). For 1998 to the present, factors are based on 1998 coal quality and supply (McCann, 2000). The factors for 1991–1997 are based on both studies. In order to address the change in emission factors introduced by the 2000 study, a linear interpolation method was used to derive coal-specific emission factors for 1991–1997 using the 1990 (Jaques, 1992) and 1998 (McCann, 2000) emission factors as the endpoints.

Coke and coke oven gas emission factors were developed based on industry data (Jaques, 1992). The emission factors for coke represent coke use in the cement, non-ferrous metal, and other manufacturing industries.

A13.1.3.2 CH_4

Emissions of CH_4 from fuel combustion are technology dependent. Emission factors for sectors (Table A13-4) have been developed based on technologies typically used in Canada. The factors were developed from a review of emission factors for and an analysis of combustion technologies (SGA, 2000).

A13.1.3.3 N_2O

Emissions of N_2O from fuel combustion are technology dependent. Emission factors for sectors (Table A13-4) have been developed based on technologies typically used in Canada. The factors were developed from a review of emission factors for and an analysis of combustion technologies (SGA, 2000).

A13.1.4 MOBILE COMBUSTION

A13.1.4.1 CO_2

CO_2 emission factors for mobile combustion are dependent on fuel properties and are the same as those used for stationary combustion for all fuels (Table A13-5).

A13.1.4.2 CH_4

Emissions of CH_4 from fuel combustion are technology dependent. Emission factors for sectors have been developed (Table A13-5) based on technologies typically used in Canada. The factors were developed from a review of emission factors for and an analysis of combustion technologies (SGA, 2000).

A13.1.4.3 N_2O

Emissions of N_2O from fuel combustion are technology dependent. Emission factors for sectors have been developed (Table A13-5) based on technologies typically used in Canada. The factors were developed from a review of emission factors for and an analysis of combustion technologies (SGA, 2000).

TABLE A13-3: CO$_2$ Emission Factors for Coal and Coal Products

Province	CO$_2$ Emission Factors								
Coals	1990	1991	1992	1993	1994	1995	1996	1997	1998–2004
					g/kg				
Newfoundland and Labrador									
Canadian Bituminous[1]	2300[2]	2294	2287	2281	2274	2268	2262	2255	2249[3]
Anthracite	2390[2]	2390	2390	2390	2390	2390	2390	2390	2390[3]
Prince Edward Island									
Canadian Bituminous[1]	2300[2]	2294	2287	2281	2274	2268	2262	2255	2249[3]
Nova Scotia									
Canadian Bituminous	2300[2]	2294	2287	2281	2274	2268	2262	2255	2249[3]
U.S. Bituminous	2330[2]	2325	2320	2314	2309	2304	2299	2293	2288[3]
New Brunswick									
Canadian Bituminous	2230[2]	2201	2172	2142	2113	2084	2055	2026	1996[3]
U.S. Bituminous	2500[2]	2476	2453	2429	2405	2382	2358	2334	2311[3]
Quebec									
Canadian Bituminous[1]	2300[2]	2294	2287	2281	2274	2268	2262	2255	2249[3]
U.S. Bituminous	2500[2]	2480	2461	2441	2421	2402	2382	2362	2343[3]
Anthracite	2390[2]	2390	2390	2390	2390	2390	2390	2390	2390[3]
Ontario									
Canadian Bituminous	2520[2]	2487	2454	2420	2387	2354	2321	2287	2254[3]
U.S. Bituminous	2500[2]	2492	2483	2475	2466	2458	2449	2441	2432[3]
Sub-Bituminous[4]	2520[2]	2422	2323	2225	2126	2028	1930	1831	1733[3]
Lignite	1490[2]	1488	1486	1485	1483	1481	1479	1478	1476[3]
Anthracite	2390[2]	2390	2390	2390	2390	2390	2390	2390	2390[3]
Manitoba									
Canadian Bituminous	2520[2]	2486	2453	2419	2386	2352	2319	2285	2252[3]
U.S. Bituminous[5]	NO	NO	NO	NO	2387	2387	NO	NO	NO
Sub-Bituminous	2520[2]	2422	2323	2225	2126	2028	1930	1831	1733[3]
Lignite	1520[2]	1508	1496	1484	1472	1460	1448	1436	1424[3]
Anthracite	2390[2]	2390	2390	2390	2390	2390	2390	2390	2390[3]
Saskatchewan									
Canadian Bituminous[6]	1700[2]	1719	1738	1757	1776	1795	1814	1833	1852[3]
Sub-Bituminous[5]	NO	NO	NO	NO	1747	1747	NO	NO	NO
Lignite	1340[2]	1351	1362	1373	1384	1394	1405	1416	1427[3]
Alberta									
Canadian Bituminous	1700[2]	1719	1738	1757	1776	1795	1814	1833	1852[3]
Sub-Bituminous	1740[2]	1743	1746	1749	1753	1756	1759	1762	1765[3]
Anthracite	2390[2]	2390	2390	2390	2390	2390	2390	2390	2390[3]
British Columbia									
Canadian Bituminous	1700[2]	1747	1793	1840	1886	1933	1979	2026	2072[3]
All Provinces					g/kg				
Coke	2480[2]	2480	2480	2480	2480	2480	2480	2480	2480[3]
					g/m^3				
Coke Oven Gas	1600[2]	1600	1600	1600	1600	1600	1600	1600	1600[3]

Notes:

1 Assumed same source of Canadian bituminous for Newfoundland and Labrador, Prince Edward Island, Nova Scotia, and Quebec.

2 Jaques (1992).

3 Adapted from McCann (2000).

4 Represents both domestic and imported sub-bituminous.

5 Used Canada weighted average for 1990.

6 Assumed same source of Canadian bituminous for Saskatchewan and Alberta.

NO = not occurring

TABLE A13-4: CH_4 and N_2O Emission Factors for Coals[1]

Source	Emission Factors	
	CH_4	N_2O
	g/kg	*g/kg*
Electric Utilities	0.022	0.032
Industry	0.03	0.02
Residential	4	0.02
Coke	N/A	0.02
	g/m^3	*g/m^3*
Coke Oven Gas	0.037	0.035

Notes:

1 SGA (2000).

N/A = not available

TABLE A13-5: Emission Factors for Energy Mobile Combustion Sources

Use	Emission Factors		
	CO_2	CH_4	N_2O
	g/L fuel	*g/L fuel*	*g/L fuel*
On-Road Transport			
Gasoline Vehicles			
Light-Duty Gasoline Vehicles (LDGVs)			
Tier 1, Three-Way Catalyst	2360[1]	0.12[2]	0.26[2]
Tier 0, New Three-Way Catalyst	2360[1]	0.32[2]	0.25[2]
Tier 0, Aged Three-Way Catalyst	2360[1]	0.32[2]	0.58[2]
Oxidation Catalyst	2360[1]	0.42[2]	0.2[2]
Non-Catalyst	2360[1]	0.52[2]	0.028[2]
Light-Duty Gasoline Trucks (LDGTs)			
Tier 1, Three-Way Catalyst	2360[1]	0.22[2]	0.41[2]
Tier 0, New Three-Way Catalyst	2360[1]	0.41[2]	0.45[2]
Tier 0, Aged Three-Way Catalyst	2360[1]	0.41[2]	1[2]
Oxidation Catalyst	2360[1]	0.44[2]	0.2[2]
Non-Catalyst	2360[1]	0.56[2]	0.028[2]
Heavy-Duty Gasoline Vehicles (HDGVs)			
Three-Way Catalyst	2360[1]	0.17[2]	1[2]
Non-Catalyst	2360[1]	0.29[2]	0.046[2]
Uncontrolled	2360[1]	0.49[2]	0.08[2]
Motorcycles			
Non-Catalytic Controlled	2360[1]	1.4[2]	0.046[2]
Uncontrolled	2360[1]	2.3[2]	0.046[2]
Diesel Vehicles			
Light-Duty Diesel Vehicles (LDDVs)			
Advance Control	2730[1]	0.05[2]	0.2[2]
Moderate Control	2730[1]	0.07[2]	0.2[2]
Uncontrolled	2730[1]	0.1[2]	0.2[2]
Light-Duty Diesel Trucks (LDDTs)			
Advance Control	2730[1]	0.07[2]	0.2[2]
Moderate Control	2730[1]	0.07[2]	0.2[2]
Uncontrolled	2730[1]	0.08[2]	0.2[2]
Heavy-Duty Diesel Vehicles (HDDVs)			
Advance Control	2730[1]	0.12[2]	0.08[2]
Moderate Control	2730[1]	0.13[2]	0.08[2]
Uncontrolled	2730[1]	0.15[2]	0.08[2]
Natural Gas Vehicles	1.89[3]	0.022[2]	6×10^{-5}[2]
Propane Vehicles	1500[3]	0.52[2]	0.028[2]
Off-Road Vehicles			
Other Gasoline Vehicles	2360[1]	2.7[2]	0.05[2]
Other Diesel Vehicles	2730[1]	0.14[2]	1.1[2]
Diesel Rail Transportation	2730[1]	0.15[2]	1.1[2]
Marine Transportation			
Gasoline Boats	2360[1]	1.3[2]	0.06[2]
Diesel Ships	2730[1]	0.15[2]	1.00[2]
Light Fuel Oil Ships	2830[1]	0.3[2]	0.07[2]
Heavy Fuel Oil Ships	3090[1]	0.3[2]	0.08[2]
Air Transportation			
Conventional Aircraft	2330[1]	2.19[2]	0.23[2]
Jet Aircraft	2550[1]	0.08[2]	0.25[2]

Notes:

1 Jaques (1992).

2 SGA (2000).

3 Adapted from McCann (2000).

A13.2 FUGITIVE EMISSION FACTORS: COAL MINING

Fugitive emissions from coal mining are predominantly CH_4. These emissions result from the release of entrained CH_4 from coal formation during mining. The emission factors have been developed (Table A13-6) based on mine-specific and basin-specific data (King, 1994). The development of the factors is described in the fugitive emissions section (Section 3.3) of the inventory report.

TABLE A13-6: Emission Factors for Fugitive Sources — Coal Mining

Province	Method	Coal Type	Emission Factors *t CH_4/kt coal*
Nova Scotia	Underground	Bituminous	13.79
Nova Scotia	Surface	Bituminous	0.13
New Brunswick	Surface	Bituminous	0.13
Saskatchewan	Surface	Lignite	0.06
Alberta	Surface	Bituminous	0.45
Alberta	Underground	Bituminous	1.76
Alberta	Surface	Sub-Bituminous	0.19
British Columbia	Surface	Bituminous	0.58
British Columbia	Underground	Bituminous	4.1

Source:

Adapted from King (1994).

A13.3 INDUSTRIAL PROCESSES

A13.3.1 MINERAL, CHEMICAL, AND METAL INDUSTRIES

Emissions from industrial processes are process and technology specific. The development of the factors for each source (Table A13-7) is described in the Industrial Processes chapter of the inventory report (Chapter 4).

TABLE A13-7: Emission Factors for Industrial Process Sources

Source	Description	Emission Factors			
		CO_2	N_2O	CF_4	C_2F_6
Mineral Use			*g/kg feed*		
Limestone Use	In iron and steel, glass, non-ferrous metal production, pulp & paper mills, and other chemical uses	418	–	–	–
Dolomite Use	In iron and steel	468	–	–	–
Soda Ash Use	In glass manufacturing	415	–	–	–
Magnesite Use	Calcination of magnesite in magnesium production	506	–	–	–
Mineral Products			*g/kg product*		
Cement Production	Limestone calcination	507	–	–	–
Lime Production	Limestone calcination (high-calcium lime)	750	–	–	–
	Limestone calcination (dolomitic lime)	860	–	–	–
Chemical Industry			*kg/t product*		
Ammonia Production	From natural gas reforming, which produces the hydrogen needed	1560	–	–	–
Nitric Acid Production	Plants with catalytic converters	–	0.66	–	–
	Plants with extended absorption for NO_x (type 1)	–	9.4	–	–
	Plants with extended absorption for NO_x (type 2)	–	12	–	–
			kg/kg product		
Adipic Acid Production	Plants without abatement	–	0.303	–	–
Metal Production			*kg/t product*		
Primary Aluminium	Electrolysis process — cell technology				
	Side-worked pre-baked	1600	–	1.4	0.336
	Centre-worked pre-baked	1600	–	0.2–0.4	0.034–0.068
	Horizontal stud Søderberg	1700	–	0.6–0.7	0.054–0.063
	Vertical stud Søderberg	1700	–	0.4–0.6	0.024–0.036
			g/kg feed (coke)		
Iron and Steel Production	Iron ore reduction with coke	2479	–	–	–
			kg/t steel		
	Steel production in EAFs	4.58	–	–	–

Sources:

CO_2 Emission Factors:

Limestone Use — ORTECH Corporation (1994).

Dolomite Use — AMEC (2006).

Soda Ash Use — DOE/EIA (1993).

Magnesite Use — AMEC (2006).

Lime Production — IPCC (2000).

Cement Production — IPCC/OECD/IEA (1997).

Ammonia Production — Faith *et al*. (1975); Jaques (1992).

Primary Aluminium Production — AAC (2002).

Iron and Steel — Jaques (1992); IPCC (2000).

N_2O Emission Factors:

Nitric Acid — Collis (1992).

Adipic Acid Production — Thiemens and Trogler (1991).

CF_4 and C_2F_6 Emission Factors:

Primary Aluminium Production — AAC (2002).

A13.3.2 CONSUMPTION OF HALOCARBONS

The use of HFCs in AC, refrigeration, aerosols, foam blowing, and total flooding systems can result in HFC emissions. Emission factors used to estimate 1995 HFC emissions are given in Table A13-8. Section 4.9.2.2 of Chapter 4 shows the emission factors used to develop 1996–2004 HFC and 1995–2004 PFC emission estimates.

TABLE A13-8: Emission Factors for Consumption of HFCs in 1995

Application	HFC Emission Factors
	kg loss/kg consumed
Aerosols	0.8
Foams	1
AC OEM	0.04
AC Service	1
Refrigeration	0.1
Total Flooding Systems	0.35

Source:

IPCC/OECD/IEA (1997)

A13.3.3 NON-ENERGY USE OF FOSSIL FUELS

A13.3.3.1 CO_2

The use of fossil fuels as feedstocks or for other non-energy uses may result in emissions during the life of manufactured products. Industry-average emission factors (Table A13-9) have been developed based on the total potential CO_2 emission rates (McCann, 2000) and the IPCC default percentages of carbon stored in products (IPCC/OECD/IEA, 1997).

TABLE A13-9: Emission Factors for Hydrocarbon Non-Energy Products

Description	CO_2 Emission Factor
	g/L feedstock
Ethane Use	197
Butane Use	349
Propane Use	303
Petrochemical Distillate Use for Feedstocks	500
Naphtha Used for Various Products	625
Petroleums Used for Lubricants	1410
Petroleums Used for Other Products	1450
	g/m³
Natural Gas Used for Chemical Products	1522

Sources:

IPCC/OECD/IEA (1997); McCann (2000); Cheminfo Services (2005)

A13.4 SOLVENT AND OTHER PRODUCT USE

N_2O emissions can result from its use as an anaesthetic and propellant. The development of the emission factors shown in Table A13-10 is described in the Solvent and Other Product Use chapter of the inventory report (Chapter 5).

TABLE A13-10: Emission Factors for Solvent and Other Product Use

Product	Application	N_2O Emission Factors
		g/capita
N_2O Use	Anaesthetic Usage	46.2
	Propellant Usage	2.38

Source:

Senes Consultants Limited (1994)

A13.5 AGRICULTURE

Emissions from agriculture result from enteric fermentation, manure management, and agricultural soil management (see Table A13-11 to Table A13-15).

Methodologies for generating these emission estimates are detailed in Section A3.4 of Annex 3.

TABLE A13-11: CH_4 Emission Factors for Livestock and Manure

Animal Type	Emission Factors	
	Enteric Fermentation	**Manure Management**
	kg CH_4/head per year	*kg CH_4/head per year*
Cattle		
Bulls	94[1]	3.2[2]
Dairy Cows	See Table A13-12	See Table A13-12
Beef Cows	90[1]	3.5[2]
Dairy Heifers	73[1]	15.4[2]
Beef Heifers	75[1]	2.8[2]
Heifers for Slaughter	63[1]	1.8[2]
Steers	56[1]	2.0[2]
Calves	40[1]	1.1[2]
Pigs		
Starters	1.5[3]	1.8[2]
Growers	1.5[3]	5.1[2]
Finishers	1.5[3]	7.9[2]
Sows	1.5[3]	6.3[2]
Boars	1.5[3]	6.4[2]
Other Livestock		
Sheep	8[3]	0.3[2]
Lambs	8[3]	0.2[2]
Goats	5[3]	0.3[2]
Horses	18[3]	2.3[2]
Bison	55[3]	2.0[2]
Poultry		
Chickens	NE	0.02[2]
Hens	NE	0.03[2]
Turkeys	NE	0.08[2]

Notes:

1 Sources of emission factors (Tier 2) are country specific (Boadi *et al.*, 2004).

2 Sources of emission factors (Tier 2) are country specific (Marinier *et al.*, 2004).

3 Source of emission factors is IPCC/OECD/IEA (1997).

NE = not estimated.

TABLE A13-12: Enteric Fermentation and Manure Management Emission Factors for Dairy Cattle from 1990 to 2004

Year	Enteric Fermentation $EF(_{EF})_T$[1] *kg CH_4/head/year*	Manure Management $EF(_{EF})_T$[2] *kg CH_4/head/year*
1990	116.9	25.7
1991	117.7	25.9
1992	120.3	26.5
1993	122.3	26.9
1994	123.0	27.1
1995	123.8	27.3
1996	125.6	27.4
1997	126.1	27.7
1998	128.0	27.9
1999	130.1	28.2
2000	132.1	29.0
2001	132.9	29.3
2002	135.2	29.6
2003	135.3	29.7
2004	134.8	29.6

Notes:

1 Emission factors are derived from Boadi *et al.* (2004) following Good Practice Guidance provided by IPCC (2000) with modifications to capture changes in milk productivity.

2 Emission factors are derived following Good Practice Guidance provided by IPCC (2006).

TABLE A13-13: Nitrogen Excretion Rate by Animal Type

Animal Type	Average Manure Nitrogen Excretion per 1000 kg Live Animal Mass per Day[1]	Nitrogen Excretion (N_{EX}) *kg N/head-year*
Non-Dairy Cattle	0.34	58.1
Dairy Cattle	0.45	108.2
Poultry	1.02	0.5
Sheep and Lambs	0.42	4.1
Swine	0.52	11.6
Goats	0.45	10.5
Horses	0.30	49.3
Bisons	0.34	58.1

Note:

1 ASAE Standards (ASAE, 2003).

TABLE A13-14: Percentage of Manure Nitrogen Handled by Animal Waste Management Systems

Animal Type	Liquid Systems	Solid Storage and Drylot	Pasture and Paddock	Other Systems
Non-Dairy Cattle	1	47	48	4
Dairy Cattle	42	40	18	0
Poultry	10	88	2	0
Sheep and Lambs	0	38	62	0
Swine	96	3	0	1
Other (Goats, Horses, and Bison)	0	42	58	0

Source:

Marinier *et al.* (2004).

TABLE A13-15: Percentage of Manure Nitrogen Lost as N_2O by Animal Type[1]

Animal Type	Liquid Systems	Solid Storage and Drylot	Pasture and Paddock	Other Systems
Non-Dairy Cattle	0.1	2.0	2.0	0.5
Dairy Cattle	0.1	2.0	2.0	0.5
Poultry	0.1	2.0	1.0[2]	0.5
Sheep and Lambs	0.1	2.0	2.0	0.5
Swine	0.1	2.0	2.0	0.5
Other (Goats, Horses, and Bison)	0.1	2.0	1.0[2]	0.5

Notes:

1 IPCC/OECD/IEA (1997), except where otherwise noted.

2 IPCC (2006).

A13.6 BIOMASS COMBUSTION

A13.6.1 CO_2

Emissions of CO_2 from the combustion of biomass (whether for energy use, from prescribed burning, or from wildfires) are not included in national inventory totals. These emissions are estimated and recorded as a loss of biomass stock in the LULUCF Sector.

The emissions related to energy use are reported as memo items in the CRF as required by the UNFCCC. Emissions from this source are primarily dependent on the characteristics of the fuel being combusted. The methodology for deriving the emission factors (Table A13-6) is described in the biomass combustion section of the inventory report (see Section 3.4.2).

CO_2 emissions occur during forest wildfires and from controlled burning during forest conversion activities. The carbon emitted as CO_2 (CO_2-C) during forest fires is considered in the forest carbon balance, while the CO_2-C emitted during controlled burns is reported under the new land-use categories. There is no unique CO_2 emission factor applicable to all fires, as the proportion of CO_2-C emitted for each pool can be specific to the pool, the types of forest and disturbance, and the ecological zone (see Section A3.5.2 in Annex 3).

A13.6.2 CH_4

Emissions of CH_4 from biomass fuel combustion are technology dependent. The emission factors (Table A13-16) were derived from a review of emission factors for combustion technologies (SGA, 2000). The factors are from the U.S. EPA AP-42 Supplement B (EPA, 1996).

Emissions of carbon as CH_4 (CH_4-C) from wildfires and controlled burning are always equal to 1/90th of CO_2-C emissions.

A13.6.3 N_2O

Emissions of N_2O from biomass fuel combustion are technology dependent. The emission factors (Table A13-16) were developed from a review of emission factors for combustion technologies and an analysis of combustion technologies typically used in Canada (SGA, 2000). The factors are from the U.S. EPA AP-42 Supplement B (EPA, 1996).

N_2O emissions from wildfires and controlled burning are equal to 0.017% vol/vol of CO_2 emissions. Since both gases have the same molecular weight, the same ratio can be applied on a mass basis (see Section A3.5.2 in Annex 3).

TABLE A13-16: Emission Factors for Biomass

Source	Description	Emission Factors		
		CO_2 g/kg fuel	CH_4 g/kg fuel	N_2O g/kg fuel
Wood Fuel/Wood Waste	Industrial combustion	950	0.05	0.02
Forest Fires	Open combustion	N/A	N/A[1]	N/A[2]
Controlled Burning	Open combustion	N/A	N/A[1]	N/A[2]
Spent Pulping Liquor	Industrial combustion	1428	0.05	0.02
Stoves and Fireplaces	Residential combustion	–	–	–
Conventional Stoves		1500	15	0.16
Conventional Fireplaces and Inserts		1500	15	0.16
Stoves/Fireplaces with Advanced Technology or Catalytic Control		1500	6.9	0.16
Other Wood-Burning Equipment		1500	15	0.16

Notes:

1 Emission ratio for CH_4 is 1/90th CO_2. See Annex 3.5.

2 Emission ratio for N_2O is 0.017% CO_2. See Annex 3.5.

N/A = not applicable

CO_2 emissions from biomass combusted for energy purposes are not included in inventory totals, whereas CH_4 and N_2O emissions from these sources are inventoried under the Energy Sector. All GHG emissions including CO_2 from biomass burned in managed forests (wildfires and controlled burning) are reported under LULUCF and excluded from national inventory totals.

Sources:

CO_2 Emission Factors:

Wood Fuel/Wood Waste — EPA (1996).

Conventional Stoves — ORTECH (1994).

CH_4 Emission Factors:

Wood Fuel/Wood Waste — EPA (1985).

N_2O Emission Factors:

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ANNEX 14: ROUNDING PROTOCOL

A rounding protocol has been developed for the emission and removal estimates in order to provide context on their uncertainty levels. The accuracy of the data is reflected by presenting the emission and removal estimates to the appropriate number of significant figures based on the uncertainty of the specific category. The number of significant figures to which each emission source and sink category has been rounded can be found in Table A14-1. The uncertainty intervals that were used for each source category were developed using the Monte Carlo method by ICF Consulting (ICF, 2004, 2005) based on the 2001 inventory (as submitted in 2003 to the UNFCCC Secretariat), published uncertainty estimates (IPCC/OECD/IEA, 1997; IPCC, 2001), and expert opinion. The uncertainty interval for SF_6 emissions in the category Consumption of Halogens and SF_6 was taken from the study *Improving and Updating Industrial Process-Related Activity Data and Methodologies Used in Canada's Greenhouse Gas Inventory* by Cheminfo Services (2005). For a fuller description of the analysis of uncertainty in Canada's emission estimates, refer to Annex 7.

The following uncertainty interval values have been used to determine the number of significant figures to which the estimates have been rounded:

- one significant figure: equal to and greater than 50%;
- two significant figures: between 10% and 50%; and
- three significant figures: equal to and less than 10%.

The LULUCF Sector has not been formally assessed for uncertainty — new methodologies, which were not available for the 2004 ICF study, have been used to develop the estimates for the 2005 UNFCCC submission. For this sector, the number of significant figures for each category was determined by expert opinion. Some other categories are presented in the summary tables because they represent aggregations of interest, but they have also not been assessed for uncertainty because they do not represent standard IPCC categories. In these cases, the number of significant figures has been estimated on the basis of similarity with other categories whose uncertainty has been assessed.

In the ICF study, the uncertainty intervals established were based on the original, raw gas estimates and did not take into consideration the GWP uncertainties when CO_2 equivalent values were calculated. There was one exception — the case of the total CO_2 equivalent estimate for Canada. This uncertainty interval, including GWP uncertainty, was determined to be –5% to +10%. When the GWP uncertainty was not taken into consideration, the uncertainty interval was determined to be –3% to +6%. Although the GWP uncertainty does affect the uncertainty associated with Canada's total GHG emission estimate, it does not have an impact on the associated number of significant figures.

Since the effect of GWP uncertainties on individual category estimates has not been determined, for each category, the number of significant figures shown for the CO_2 equivalent estimate for each non-CO_2 gas has been left the same as that for the estimate without the GWPs.

Uncertainties have been determined for the national emission estimates, as required by IPCC Good Practice Guidance (IPCC, 2000), but not for provincial/territorial emission estimates. As there are no uncertainties established for provincial estimates, the rounding protocol used for the national emission tables has been applied to the provincial/territorial emission tables.

All calculations, including summing of emission totals, have been made using unrounded data. The rounding protocol has been applied to the estimates only after the calculations have been completed. Therefore, individual values in the tables may not add up to the subtotals and/or overall totals.

TABLE A14-1: Number of Significant Figures Applied to GHG Summary Tables

GHG Source/Sink Categories	Greenhouse Gases						
	CO_2	CH_4	N_2O	HFCs	PFCs	SF_6	TOTAL
TOTAL	**3**	**2**	**2**	**2**	**3**	**2**	**3**
ENERGY	**3**	**1**	**1**	**–**	**–**	**–**	**3**
a. Stationary Combustion Sources	**3**	**1**	**1**	**–**	**–**	**–**	**3**
Electricity and Heat Generation	3	2	1	–	–	–	3
Fossil Fuel Industries	2	1	1	–	–	–	2
Petroleum Refining	2	1	1	–	–	–	2
Fossil Fuel Production	3	1	1	–	–	–	2
Mining	3	1	1	–	–	–	3
Manufacturing Industries	3	1	1	–	–	–	3
Iron and Steel	3	1	1	–	–	–	3
Non-Ferrous Metals	3	1	1	–	–	–	3
Chemical	3	2	1	–	–	–	3
Pulp and Paper	3	1	1	–	–	–	3
Cement	3	1	1	–	–	–	3
Other Manufacturing	3	1	1	–	–	–	3
Construction	3	1	1	–	–	–	3
Commercial & Institutional	3	1	1	–	–	–	3
Residential	3	1	1	–	–	–	2
Agriculture & Forestry	3	1	1	–	–	–	3
b. Transportation	**3**	**1**	**1**	**–**	**–**	**–**	**2**
Domestic Aviation	3	1	1	–	–	–	2
Road Transportation	3	2	2	–	–	–	3
Light-Duty Gasoline Vehicles	3	2	2	–	–	–	3
Light-Duty Gasoline Trucks	3	2	2	–	–	–	3
Heavy-Duty Gasoline Vehicles	3	2	2	–	–	–	3
Motorcycles	3	2	2	–	–	–	3
Light-Duty Diesel Vehicles	3	1	1	–	–	–	3
Light-Duty Diesel Trucks	3	1	1	–	–	–	3
Heavy-Duty Diesel Vehicles	3	1	1	–	–	–	3
Propane & Natural Gas Vehicles	3	1	1	–	–	–	2
Railways	3	1	1	–	–	–	1
Domestic Marine	3	1	1	–	–	–	2
Others	2	1	1	–	–	–	1
Off-Road Gasoline	1	1	1	–	–	–	1
Off-Road Diesel	2	1	1	–	–	–	1
Pipelines	3	2	1	–	–	–	3
c. Fugitive Sources	**2**	**2**	**1**	**–**	**–**	**–**	**3**
Coal Mining	–	1	–	–	–	–	1
Oil and Natural Gas	2	2	1	–	–	–	3
Oil	3	2	–	–	–	–	2
Natural Gas	2	2	–	–	–	–	2
Venting	2	2	1	–	–	–	2
Flaring	3	3	1	–	–	–	2
INDUSTRIAL PROCESSES	**3**	**–**	**3**	**2**	**3**	**3**	**3**
a. Mineral Production	**2**	**–**	**–**	**–**	**–**	**–**	**2**
Cement	2	–	–	–	–	–	2
Lime	1	–	–	–	–	–	1
Limestone and Soda Ash Use	2	–	–	–	–	–	2
b. Chemical Industry	**2**	**–**	**3**	**–**	**–**	**–**	**2**
Ammonia Production	2	–	–	–	–	–	2
Nitric Acid Production	–	–	2	–	–	–	2
Adipic Acid Production	–	–	3	–	–	–	3
c. Metal Production	**2**	**–**	**–**	**–**	**3**	**3**	**3**
Iron and Steel Production	3	–	–	–	–	–	3
Aluminium Production	2	–	–	–	3	–	3
SF_6 Used in Magnesium Smelters and Casters	–	–	–	–	–	3	3
d. Consumption of Halocarbons and SF_6	**–**	**–**	**–**	**2**	**2**	**2**	**2**
e. Other & Undifferentiated Production	**2**	**–**	**–**	**–**	**–**	**–**	**2**
SOLVENT & OTHER PRODUCT USE	**–**	**–**	**2**	**–**	**–**	**–**	**2**
AGRICULTURE	**–**	**3**	**2**	**–**	**–**	**–**	**2**
a. Enteric Fermentation	**–**	**3**	**–**	**–**	**–**	**–**	**3**
b. Manure Management	**–**	**2**	**2**	**–**	**–**	**–**	**2**
c. Agricultural Soils	**–**	**–**	**2**	**–**	**–**	**–**	**2**
Direct Sources	–	–	2	–	–	–	2
Pasture, Range, and Paddock Manure	–	–	2	–	–	–	2
Indirect Sources	–	–	1	–	–	–	1
WASTE	**2**	**2**	**1**	**–**	**–**	**–**	**2**
a. Solid Waste Disposal on Land	**–**	**2**	**–**	**–**	**–**	**–**	**2**
b. Wastewater Handling	**–**	**2**	**1**	**–**	**–**	**–**	**2**
c. Waste Incineration	**2**	**1**	**1**	**–**	**–**	**–**	**2**
LAND USE, LAND-USE CHANGE AND FORESTRY	**2**	**2**	**2**	**–**	**–**	**–**	**2**
a. Forest Land	**2**	**2**	**2**	**–**	**–**	**–**	**2**
b. Cropland	**2**	**1**	**1**	**–**	**–**	**–**	**2**
c. Grassland	**–**	**–**	**–**	**–**	**–**	**–**	**–**
d. Wetlands	**1**	**1**	**1**	**–**	**–**	**–**	**1**
e. Settlements	**1**	**1**	**1**	**–**	**–**	**–**	**1**

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ANNEX 15: OZONE AND AEROSOL PRECURSORS

National summary tables for SO_x, NO_x, CO, and NMVOCs are included in this annex. These gases are reported to the UNECE by the Criteria Air Contaminants Division at Environment Canada under the Convention on Long-Range Transboundary Air Pollution. As recommended by the Conference of Parties to the UNFCCC (FCCC/SBSTA/2004/8), Annex I Parties should provide information on indirect GHGs such as CO, NO_x, NMVOCs, and SO_x in the NIR.

These gases do not have a direct global warming effect, but either influence the creation and destruction of tropospheric and stratospheric ozone or affect the terrestrial radiation absorption, as in the case of SO_x. These gases can impact the climate by acting as short-lived GHGs, alter atmospheric lifetimes of other GHGs, and form GHGs, as in the case of CO reacting with hydroxyl radical to form CO_2 in the atmosphere. These emissions are produced by a number of sources, which include fossil fuel combustion in the energy and transportation sectors, industrial production, biomass combustion, etc.

TABLE A15-1: Carbon Monoxide Emissions Summary for Canada

CRF Sector Categories	Carbon Monoxide														
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
	kt CO														
National Total	**15 451**	**14 362**	**14 357**	**13 489**	**13 508**	**13 595**	**12 605**	**12 154**	**11 836**	**11 342**	**10 589**	**10 359**	**10 152**	**10 140**	**10 206**
1 A 1 a Public Electricity and Heat Production	65	68	65	24	25	24	25	24	24	25	28	29	30	32	32
1 A 1 b Petroleum Refining	13	13	13	19	19	18	18	19	19	19	17	17	16	16	16
1 A 1 c Manufacture of Solid Fuels and Other Energy Industries	42	40	42	47	53	57	59	66	69	71	73	73	70	68	466
1 A 2 Manufacturing Industries and Construction	658	629	687	1 014	910	933	947	946	894	930	688	691	685	694	727
1 A 3 a ii (i) Civil Aviation (Domestic, LTO)	63	58	54	52	54	55	53	55	60	59	57	58	58	60	36
1 A 3 a ii (ii) Civil Aviation (Domestic, Cruise)	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	22
1 A 3 b Road Transportation	9 800	9 307	9 143	8 323	8 422	7 830	7 446	7 023	6 729	6 193	5 729	5 473	5 197	5 053	4 731
1 A 3 c Railways	22	22	21	21	23	23	22	23	22	20	21	21	22	20	20
1 A 3 d ii National Navigation	8	8	8	7	8	8	7	7	7	7	14	14	14	14	9
1 A 3 e Other	2 302	2 348	2 393	2 439	2 484	2 528	2 530	2 511	2 522	2 531	2 554	2 558	2 601	2 653	2 556
1 A 4 a Commercial/Institutional	5	5	5	6	6	6	6	6	6	6	8	10	11	11	11
1 A 4 b Residential	1 041	650	645	619	637	632	623	626	626	623	676	657	679	687	690
1 A 4 c Agriculture/Forestry/Fishing	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1 A 5 a Other, Stationary (Including Military)	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1 A 5 b Other, Mobile (Including Military)	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1 B 1 Fugitive Emissions from Solid Fuels	4	4	4	1	1	1	1	1	1	1	2	2	2	2	2
1 B 2 Oil and Natural Gas	19	19	20	12	13	13	13	14	15	15	53	61	71	84	146
2 A Mineral Products[1]	5	5	5	37	23	25	27	24	30	27	14	14	14	14	14.28
2 B Chemical Industry	16	16	16	21	21	21	21	21	21	21	19	20	22	23	25
2 C Metal Production	335	296	292	323	292	313	294	312	310	299	277	299	307	354	340
2 D Other Production[1]	66	75	74	132	131	123	126	126	125	129	116	115	102	99	86
2 G Other	11	11	11	13	14	12	13	13	13	13	18	16	16	16	30
3 A Paint Application	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3 B Degreasing and Dry Cleaning	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3 C Chemical Products, Manufacture and Processing	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3 D Other (Including Products Containing HMs and POPs)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4 B Manure Management[2]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4 C Rice Cultivation	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4 D 1 Direct Soil Emission	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4 F Field Burning of Agricultural Wastes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4 G Other[3]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5 B Forest and Grassland Conversion	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6 A Solid Waste Disposal on Land	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1	1	1	1	N/A
6 B Wastewater Handling	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
6 C Waste Incineration[4]	10	10	9	6	5	5	5	5	5	5	6	7	7	7	7
6 D Other Waste[5]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
7 Other	965	779	849	372	367	967	368	329	339	347	220	224	229	233	239

Notes:

1 Including product handling.

2 Including NH_3 from enteric fermentation.

3 Including particulate matter sources.

4 Excludes waste incineration for energy (this is included in 1 A 1).

5 Includes accidental fires.

Totals may not add due to rounding.

N/A = not applicable; IE = included elsewhere; LTO = landing and takeoff; HMs = heavy metals; POPs = persistent organic pollutants.

TABLE A15-2: Nitrogen Oxides Emissions Summary for Canada

CRF Sector Categories	Nitrogen Oxides														
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
	kt NO_x														
National Total	**2759**	**2685**	**2650**	**2561**	**2601**	**2608**	**2557**	**2587**	**2620**	**2571**	**2583**	**2578**	**2569**	**2559**	**2491**
1 A 1 a Public Electricity and Heat Production	249	256	245	248	250	242	252	247	251	253	283	280	281	288	242
1 A 1 b Petroleum Refining	27	26	26	23	22	23	22	22	22	22	24	23	22	22	22
1 A 1 c Manufacture of Solid Fuels and Other Energy Industries	152	147	156	175	199	210	219	250	252	264	277	286	295	305	520
1 A 2 Manufacturing Industries and Construction	163	170	168	131	133	140	128	131	130	132	112	110	115	117	121
1 A 3 a ii (i) Civil Aviation (Domestic, LTO)	72	61	57	56	55	60	63	64	73	65	58	59	58	59	6
1 A 3 a ii (ii) Civil Aviation (Domestic, Cruise)	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	60
1 A 3 b Road Transportation	1212	1139	1107	1052	1036	1006	968	949	972	922	850	831	794	753	556.03
1 A 3 c Railways	114	115	112	111	118	118	114	122	114	107	109	118	120	117	112
1 A 3 d ii National Navigation	99	93	92	85	90	90	82	81	82	78	111	110	111	112	115
1 A 3 e Other	368	377	385	393	401	409	415	419	421	422	425	420	417	413	426
1 A 4 a Commercial/Institutional	24	24	24	29	30	29	29	29	29	29	31	32	33	38	36
1 A 4 b Residential	49	46	46	45	47	46	45	46	46	45	47	46	46	46	46
1 A 4 c Agriculture/Forestry/Fishing	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1 A 5 a Other, Stationary (Including Military)	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1 A 5 b Other, Mobile (Including Military)	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1 B 1 Fugitive Emissions from Solid Fuels	16	16	15	17	17	16	17	16	17	17	17	17	17	17	13
1 B 2 Oil and Natural Gas	59	57	60	64	69	71	73	80	80	83	114	122	132	143	85
2 A Mineral Products[1]	29	27	28	34	34	35	33	33	36	33	33	33	33	35	34
2 B Chemical Industry	24	26	27	27	28	28	24	26	25	25	29	29	29	29	29
2 C Metal Production	38	40	38	18	18	18	18	18	18	19	13	12	13	14	14
2 D Other Production[1]	30	32	32	29	29	30	28	28	28	28	27	26	27	27	24
2 G Other	17	18	17	15	16	16	15	15	15	15	11	11	11	11	16
3 A Paint Application	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3 B Degreasing and Dry Cleaning	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3 C Chemical Products, Manufacture and Processing	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3 D Other (Including Products Containing HMs and POPs)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4 B Manure Management[2]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4 C Rice Cultivation	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4 D 1 Direct Soil Emission	0	0	0	0	0	0	0	0	0	0	0	0	0	0	IE
4 F Field Burning of Agricultural Wastes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4 G Other[3]	0	0	0	1	1	0	1	1	1	1	0	0	0	0	0
5 B Forest and Grassland Conversion	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6 A Solid Waste Disposal on Land	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
6 B Wastewater Handling	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
6 C Waste Incineration[4]	2	3	2	3	3	3	3	3	3	3	6	6	6	6	6
6 D Other Waste[5]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
7 Other	15	12	13	8	8	17	8	8	8	8	6	6	6	6	8

Notes:

1 Including product handling.

2 Including NH_3 from enteric fermentation.

3 Including particulate matter sources.

4 Excludes waste incineration for energy (this is included in 1 A 1).

5 Includes accidental fires.

Totals may not add due to rounding.

N/A = not applicable; IE = included elsewhere; LTO = landing and takeoff; HMs = heavy metals; POPs = persistent organic pollutants.

TABLE A15-3: Non-Methane Volatile Organic Compounds Emissions Summary for Canada

CRF Sector Categories	Volatile Organic Compounds (Non-Methane)														
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
	kt NMVOCs														
National Total	**3093**	**2848**	**2844**	**2545**	**2589**	**2729**	**2555**	**2513**	**2510**	**2449**	**2666**	**2670**	**2684**	**2705**	**2472**
1 A 1 a Public Electricity and Heat Production	2	2	2	3	3	3	3	3	3	3	2	2	3	3	4
1 A 1 b Petroleum Refining	6	6	6	3	3	3	3	3	3	3	2	2	2	2	2
1 A 1 c Manufacture of Solid Fuels and Other Energy Industries	19	20	21	22	23	24	26	26	27	25	26	27	27	28	12
1 A 2 Manufacturing Industries and Construction	76	71	76	75	74	73	73	73	71	74	61	61	59	59	49.18
1 A 3 a ii (i) Civil Aviation (Domestic, LTO)	10	9	9	9	9	10	10	10	11	11	10	10	10	10	8
1 A 3 a ii (ii) Civil Aviation (Domestic, Cruise)	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	2
1 A 3 b Road Transportation	756	702	680	602	607	557	523	482	459	441	405	379	351	328	302.6
1 A 3 c Railways	6	6	6	6	6	6	6	6	6	5	5	5	6	5	5
1 A 3 d ii National Navigation	13	12	12	11	12	12	11	11	11	11	9	9	9	9	8
1 A 3 e Other	301	305	309	313	317	321	314	303	299	297	298	292	288	285	305
1 A 4 a Commercial/Institutional	0	0	0	0	0	0	0	0	0	0	1	13	13	13	2
1 A 4 b Residential	347	145	144	137	140	139	137	138	138	138	150	94	96	97	153
1 A 4 c Agriculture/Forestry/Fishing	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1 A 5 a Other, Stationary (Including Military)	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1 A 5 b Other, Mobile (Including Military)	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1 B 1 Fugitive Emissions from Solid Fuels	2	2	1	2	2	2	2	2	2	2	1	1	1	1	1
1 B 2 Oil and Natural Gas	696	708	741	749	768	797	841	840	868	833	865	919	948	979	750
2 A Mineral Products[1]	5	5	4	4	4	3	4	4	4	4	2	2	1	1	1
2 B Chemical Industry	31	31	30	23	23	22	22	22	22	22	11	12	13	15	17
2 C Metal Production	2	2	2	3	3	4	3	3	3	3	5	5	4	5	15
2 D Other Production[1]	67	69	69	71	71	73	70	72	71	71	75	73	72	73	27
2 G Other	58	57	56	61	63	60	62	61	61	61	73	140	146	147	153
3 A Paint Application	162	166	160	132	130	139	121	130	127	123	111	104	105	107	109
3 B Degreasing and Dry Cleaning	306.21	319.15	316.07	273.74	285.03	250.36	277.94	279.04	279.09	277.73	310.29	295.47	300.7	305.13	309.79
3 C Chemical Products, Manufacture and Processing	1.23	1.23	1.26	2.09	2.15	2.09	2.13	2.11	2.12	2.12	2.56	2.46	2.53	2.59	2.83
3 D Other (Including Products Containing HMs and POPs)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4 B Manure Management[2]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4 C Rice Cultivation	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4 D 1 Direct Soil Emission	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4 F Field Burning of Agricultural Wastes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4 G Other[3]	174	165	150	14	13	174	15	13	13	13	215	198	201	205	209
5 B Forest and Grassland Conversion	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6 A Solid Waste Disposal on Land	7	5	5	5	5	7	5	5	5	5	9	7	7	7	7
6 B Wastewater Handling	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6 C Waste Incineration[4]	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
6 D Other Waste[5]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7 Other	45	37	40	23	23	46	23	21	22	22	15	15	16	16	16

Notes:

1 Including product handling.

2 Including NH_3 from enteric fermentation.

3 Including particulate matter sources.

4 Excludes waste incineration for energy (this is included in 1 A 1).

5 Includes accidental fires.

Totals may not add due to rounding.

N/A = not applicable; IE = included elsewhere; LTO = landing and takeoff; HMs = heavy metals; POPs = persistent organic pollutants.

TABLE A15-4: Sulphur Oxides Emissions Summary for Canada

CRF Sector Categories	Sulphur Oxides														
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
	kt SO_x														
National Total	**3230**	**3580**	**3086**	**2436**	**2397**	**2512**	**2429**	**2457**	**2466**	**2448**	**2352**	**2387**	**2343**	**2390**	**2304**
1 A 1 a Public Electricity and Heat Production	679	692	666	539	536	523	538	527	540	546	625	614	606	613	605
1 A 1 b Petroleum Refining	105	109	110	137	126	120	120	124	122	124	101	102	101	102	96
1 A 1 c Manufacture of Solid Fuels and Other Energy Industries	137	132	139	153	172	181	188	210	206	211	223	222	220	218	348
1 A 2 Manufacturing Industries and Construction	268	284	284	204	210	205	228	220	209	213	133	136	133	139	136
1 A 3 a ii (i) Civil Aviation (Domestic, LTO)	4	4	3	3	3	4	4	4	4	4	4	4	4	4	1
1 A 3 a ii (ii) Civil Aviation (Domestic, Cruise)	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	3
1 A 3 b Road Transportation	71	74	72	76	65	42	41	35	27	26	25	25	17	17	9
1 A 3 c Railways	5	5	5	5	5	5	5	6	5	5	4	5	5	5	5
1 A 3 d ii National Navigation	36	33	33	33	33	33	29	28	27	29	33	32	32	32	32
1 A 3 e Other	24	23	19	25	25	13	14	17	18	18	17	19	18	18	16
1 A 4 a Commercial/Institutional	19	19	20	13	13	14	13	13	13	13	21	22	23	39	39
1 A 4 b Residential	33	33	33	18	19	19	18	19	19	18	16	16	15	15	15
1 A 4 c Agriculture/Forestry/Fishing	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1 A 5 a Other, Stationary (Including Military)	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1 A 5 b Other, Mobile (Including Military)	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1 B 1 Fugitive Emissions from Solid Fuels	21	21	19	18	18	18	18	17	17	18	17	16	16	16	16.3
1 B 2 Oil and Natural Gas	253	252	264	285	291	295	295	308	308	307	245	249	253	257	137
2 A Mineral Products[1]	39	40	37	30	32	33	29	31	31	31	31	32	29	31	31
2 B Chemical Industry	4	4	5	4	4	5	3	3	3	3	5	6	5	7	6
2 C Metal Production	1475	1793	1317	855	806	969	842	857	877	844	823	860	839	847	778
2 D Other Production[1]	32	36	36	18	19	18	18	18	18	18	17	18	17	18	18
2 G Other	16	16	16	12	12	12	12	12	12	12	8	8	7	7	9
3 A Paint Application	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3 B Degreasing and Dry Cleaning	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3 C Chemical Products, Manufacture and Processing	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3 D Other (Including Products Containing HMs and POPs)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4 B Manure Management[2]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4 C Rice Cultivation	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4 D 1 Direct Soil Emission	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4 F Field Burning of Agricultural Wastes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4 G Other[3]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5 B Forest and Grassland Conversion	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6 A Solid Waste Disposal on Land	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
6 B Wastewater Handling	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
6 C Waste Incineration[4]	2	2	2	1	1	1	1	1	1	1	2	2	2	2	2
6 D Other Waste[5]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7 Other	6	7	7	4	6	5	11	9	6	6	1	1	2	2	2

Notes:

1 Including product handling.

2 Including NH_3 from enteric fermentation.

3 Including particulate matter sources.

4 Excludes waste incineration for energy (this is included in 1 A 1).

5 Includes accidental fires.

Totals may not add due to rounding.

N/A = not applicable; IE = included elsewhere; LTO = landing and takeoff; HMs = heavy metals; POPs = persistent organic pollutants.

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