Canada's Greenhouse Gas Inventory

1990–2001

Greenhouse Gas Division
Environment Canada

AUGUST 2003

Environment Canada Environnement Canada

Canada

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FOREWORD

On December 4, 1992, Canada ratified the United Nations Framework Convention on Climate Change (UNFCCC). A culmination of many months of negotiations, the Convention entered into force on March 21, 1994. Under the existing reporting guidelines, agreed to at the fifth Conference of the Parties (CoP 5) in November 1999, and most recently revised at CoP 8 for use starting in 2004, Annex I Parties are required to submit and publish an annual inventory report. This report, prepared by staff of the Greenhouse Gas Division of Environment Canada in consultation with a wide range of stakeholders, is Canada's official national greenhouse gas inventory submission to the UNFCCC. It represents the efforts of several years of continuing work and builds upon the results of previous reports, published in 1992, 1996, 1997, 1999, 2000, 2001 and 2002. In addition to the inventory data, it contains, to the extent possible, relevant supplementary information and an analysis of recent trends in emissions and removals.

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. Therefore, some degree of uncertainty about the estimates still remains, and work will continue to improve them.

On December 17, 2002, Canada ratified the Kyoto Protocol to the UN Framework Convention on Climate Change. The Kyoto Protocol, when it enters into force, legally binds Canada to a 6% reduction of 1990 emissions and stipulates that progress in achieving this reduction commitment will be measured through the use of a set of internationally agreed to emissions and removals inventory methodologies and reporting guidelines. Along with new reporting guidelines, the most recent step in the process has been the adoption of the Intergovernmental Panel on Climate Change (IPCC) Good Practice Guidance and the requirement to prepare an annual national greenhouse gas inventory report. The inventory report, by including additional information, serves as a much better tool from which to generate indicators to compare Parties' performance under the UNFCCC and can be seen as a necessary, but interim, step to a reporting system under the Kyoto Protocol. The Protocol also commits Parties to improve the quality of national and regional emissions data and to provide support to developing countries. Among a number of initiatives that form part of Canada's response to climate change, emission allocation mechanisms are being examined to link, verify, and attribute domestic emission reductions to this national emissions and removals inventory to improve Canada's ability to monitor, report, and verify our greenhouse gas emissions.

Art Jaques, P. Eng.
April 12, 2003

Chief, Greenhouse Gas Division
Environment Canada

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.

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In particular, we would 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. In addition, a special note of thanks should go to our colleagues in the Canadian Forest Service, Darcie Booth, Tony Lempriere and Brian Haddon; our colleagues at Agriculture and Agri-Food Canada, Marie Boehm, Henry Janzen and Ray Desjardins; and our colleagues in Natural Resources Canada, Neil McIlveen, Ian Hayhow, Hertsel Labib, and Michel Francoeur. 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. A special note of thanks goes to John Nyboer of Simon Fraser University for his detailed analysis of energy use in Canadian industry. Ken Olsen and Maria Wellisch managed the development of the national inventory, and Kerry Rhoades managed the production of this report.

Finally, this section would not be complete without acknowledging the long-standing contributions and leadership provided by Art Jaques, Chief of the Greenhouse Gas Division of Environment Canada.

READERS' COMMENTS

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LIST OF ACRONYMS, ABBREVIATIONS AND UNITS

AC	air conditioning
AC OEM	air conditioning original equipment manufacture
Al_2O_3	alumina
C	carbon
$CaCO_3$	calcium carbonate
CaO	lime
CAPP	Canadian Association of Petroleum Producers
CBM	Carbon Budget Model
CF_4	carbon tetrafluoride
C_2F_6	carbon hexafluoride
CFC	chlorofluorocarbon
CFS	Canadian Forest Service
CGHGI	Canada's Greenhouse Gas Inventory
CH_4	methane
CO	carbon monoxide
CO_2	carbon dioxide
CRF	Common Reporting Format
CVS	The Canadian Vehicle Survey
EPA	Environmental Protection Agency (United States)
eq	equivalent
FCR	fuel consumption ratio
g	gram
GDP	gross domestic product
GHG	greenhouse gas
GHV	gross heating value
Gt	gigatonne
GWP	global warming potential
ha	hectare
HDD	heating degree-day
HDDT	heavy-duty diesel truck
HDDV	heavy-duty diesel vehicle
HDGV	heavy-duty gasoline vehicle
HFC	hydrofluorocarbon
HNO_3	nitric acid
IPCC	Intergovernmental Panel on Climate Change
kg	kilogram
kt	kilotonne
kWh	kilowatt-hour
L	litre
lb	pound
LDDT	light-duty diesel truck
LDDV	light-duty diesel vehicle
LDGT	light-duty gasoline truck
LDGV	light-duty gasoline vehicle
LDV	light-duty vehicle
LPG	liquefied petroleum gas
LUCF	Land-Use Change and Forestry
LULUCF	Land-Use, Land-Use Change and Forestry
m	metre
m^3	cubic metre
M-GEM	Mobile Greenhouse Gas Emission Model
MARS	Monitoring, Accounting and Reporting System
MSW	municipal solid waste
Mt	megatonne
MW	megawatt
N	nitrogen
N_2	nitrogen gas
Na_3AlF_6	cryolite
Na_2CO_3	sodium carbonate
NAICS	North American Industrial Classification System
NGL	natural gas liquid
NH_3	ammonia
NH_4^+	ammonium
NHV	net heating value
NMVOC	non-methane volatile organic compound
NO	nitric oxide
NO_3^-	nitrate
N_2O	nitrous oxide
NO_x	nitrogen oxides
PFC	perfluorocarbon
PJ	petajoule
ppb	part per billion
ppbv	part per billion by volume
ppm	part per million
QA	quality assurance
QC	quality control
QRESD	*Quarterly Report on Energy Supply-Demand in Canada*
SF_6	sulphur hexafluoride
SIC	Standard Industrial Classification
SO_2	sulphur dioxide
SUV	sport utility vehicle
t	tonne
UNFCCC	United Nations Framework Convention on Climate Change
VIO	Vehicle in Operation
VOC	Volatile Organic Compound

EXECUTIVE SUMMARY

GHG 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 2003 is the 11th year that Canada has published a GHG emissions inventory. This is also the first inventory since Canada's decision to ratify the Kyoto Protocol to the UNFCCC. Once in force,[2] the Kyoto Protocol requires Canada to reduce its GHG emissions to 6% below 1990 levels over the period 2008 to 2012. Under the Protocol, Canada's National GHG Inventory will be the tool for measuring progress against this obligation. For this reason, the UNFCCC now requires Canada to move towards more rigourous and transparent reporting of its GHG emissions, calculation methodologies and verification procedures for the inventory. This year's GHG inventory has taken a significant step in that direction by aligning itself with the reporting requirements agreed to at the eighth Conference of the Parties (CoP8) in November, 2002 and which must be used for reporting in 2004.

This report is also the first in a progression towards more comprehensive reports that allow Canada to track its progress in meeting its emission reduction goals. Future reports will need to combine many sources of information on the performance of government programs, industry initiatives and actions taken by individual Canadians to reduce their GHGs. Additional detail and analysis of the data are foreseen as necessary to aid in tracking our progress in meeting our emission reduction targets. Indicators of performance will help with decisions about which approaches are most successful in significantly and predictably reducing emissions.

Therefore, this year's National Inventory Report represents an interim step towards meeting Canada's domestic GHG reporting needs and the new reporting requirements under the UNFCCC, while recognizing that additional reporting elements will need to be added once the Kyoto Protocol enters into force.

The current report includes an inventory of anthropogenic (human-induced) emissions by sources, and removals by sinks, of all GHGs not controlled by the Montreal Protocol. This Executive Summary discusses underlying trends in these emissions and presents provincial and territorial emissions for the period 1990–2001. Chapter 1, the Introduction, provides an overview of Canada's institutional arrangements for producing the inventory, a brief description of estimation methodologies, quality assurance and quality control procedures along with 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 trends in accordance with the UNFCCC Reporting Guidelines. Chapters 3 to 9 provide descriptions and additional analysis for each broad emissions category according to UNFCCC Common Reporting Format (CRF) requirements. Annexes 1 to 7 provide detailed explanations of estimation methodologies, comparisons with the Reference Approach, completeness assessments and other information relevant to Canada's emissions profile. Annexes 8 and 9 present additional trend analysis by province and by industrial sector. Finally, summary tables of GHG emissions tabulated by jurisdiction, sector, and gas are presented in Annexes 10 and 11.

DEVELOPING CANADA'S NATIONAL GREENHOUSE GAS INVENTORY

On behalf of the Government of Canada, Environment Canada develops and publishes annually Canada's Greenhouse Gas Inventory (CGHGI). The GHGs for which emissions have been estimated in the national inventory are:

- carbon dioxide (CO_2);
- methane (CH_4);

2 Although Canada has ratified the Protocol, it has not yet entered into force internationally. The Kyoto Protocol will enter into force on the ninetieth day after the date on which not less than 55 Parties to the Convention, incorporating Parties included in Annex I which accounted in total for at least 55% of the total carbon dioxide emissions for 1990 of the Parties included in Annex I, have deposited their instruments of ratification. (See Article 25 of the Kyoto Protocol.)

- nitrous oxide (N_2O);
- sulphur hexafluoride (SF_6);
- perfluorocarbons (PFCs); and
- hydrofluorocarbons (HFCs).

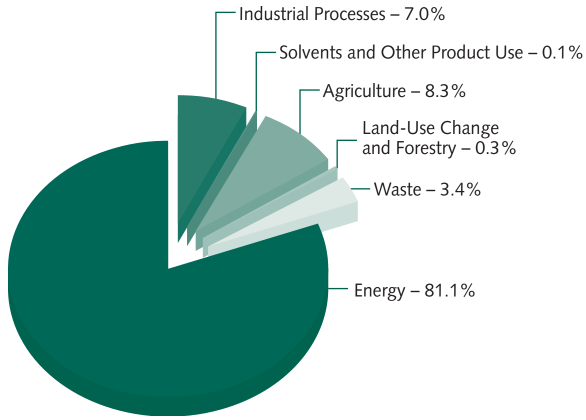
The inventory reporting format is based on international reporting methods agreed to by the UNFCCC according to the procedures of the Intergovernmental Panel on Climate Change (IPCC) in its *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 1997) and *IPCC Good Practice Guidance* (IPCC, 2000). The inventory uses an internationally agreed upon reporting format that groups emissions into the following six sectors: Energy, Industrial Processes, Solvent and Other Product Use, Agriculture, Land-Use Change and Forestry (LUCF), and Waste. Each of these categories is further subdivided within the inventory and follows, as closely as possible, the UNFCCC sector and subsector divisions.[3] Detailed descriptions of the methodologies used to estimate the sector emissions and their respective trends are provided in Chapters 3 through 9 and Annexes 2 and 3.

TREND SUMMARY

In 2001, Canadians contributed about 720 megatonnes of CO_2 equivalent (Mt CO_2 eq)[4] of GHGs to the atmosphere,[5] a decrease of 1.3% over the 730 Mt recorded in the year 2000. This is the first year-over-year decrease in emissions that has occurred in Canada since the economic recession of 1991. It is particularly significant for the fact that, in 2001, Canada was still experiencing good economic growth, evidenced by a 1.5% increase in Gross Domestic Product (GDP), leading to an improvement of Canada's GHG intensity[6] of 2.8%.

Approximately 73% of total GHG emissions in 2001 resulted from the combustion of fossil fuels. Another 8% were from fugitive sources, with the result that over 81% of emissions were from the Energy sector. A sectoral breakdown of Canada's total emissions for 2001[7] is shown in Figure S-1.

Figure S-1: Sectoral Breakdown of Canada's GHG Emissions, 2001



3 Minor differences exist between the UNFCCC and CGHGI sector designations. These are explained in footnotes throughout this report. More details can be found in Annex 1, where the CGHGI methodology is described.

4 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 1.2 of this document.

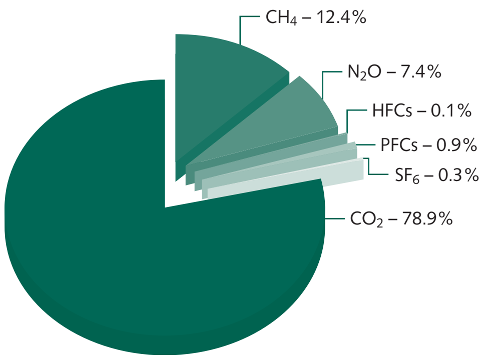
5 Unless explicitly stated otherwise, all emission estimates given in Mt represent emissions of GHG in Mt CO_2 equivalent.

6 GHG intensity is a measure of total GHG emissions divided by total GDP.

7 Due to rounding, individual percentages may not add up to 100%.

On an individual GHG basis, CO_2 contributed the largest share of 2001 emissions at 78.9% (about 566 Mt), while CH_4 accounted for 12.4% (93 Mt). N_2O accounted for 7.4% of the emissions (51 Mt), PFCs contributed 0.9% (6 Mt), and SF_6 and HFCs constituted the remainder (Figure S-2).

Figure S-2: Canada's GHG Emissions by Gas, 2001



As per reporting requirements, net CO_2 removals associated with the LUCF sector are not included in the inventory totals. The net removals are estimated to be about -36 Mt[8] for 2001. Table S-1 shows the emissions for individual gases and sectors in Canada for the year 2001.

8 Removals of CO_2 are shown as negative values.

TABLE S-1: Canada's GHG Emissions by Gas and Sector, 2001

Greenhouse Gas 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	**566,000**	**4,500**	**93,000**	**170**	**51,000**	**900**	**6,000**	**2,000**	**720,000**
ENERGY	**528,000**	**2,100**	**45,000**	**36**	**11,000**	**-**	**-**	**-**	**584,000**
a. Stationary Combustion Sources	**335,000**	**220**	**4,600**	**8**	**2,400**	**-**	**-**	**-**	**342,000**
Electricity and Heat Generation	136,000	5	100	2	770	-	-	-	137,000
Fossil Fuel Industries	64,500	120	2,400	1	420	-	-	-	67,300
Petroleum Refining	29,000	-	9	-	90	-	-	-	29,100
Fossil Fuel Production	35,500	110	2,400	1	330	-	-	-	38,200
Mining	10,200	-	4	-	78	-	-	-	10,200
Manufacturing Industries	48,500	2	35	1	350	-	-	-	48,900
Iron and Steel	5,830	-	5	-	55	-	-	-	5,890
Non Ferrous Metals	3,480	-	2	-	17	-	-	-	3,500
Chemical	6,440	-	3	-	35	-	-	-	6,470
Pulp and Paper	9,500	1	16	-	110	-	-	-	9,630
Cement	3,270	-	1	-	14	-	-	-	3,290
Other Manufacturing	20,000	-	8	-	110	-	-	-	20,100
Construction	1,000	-	-	-	8	-	-	-	1,010
Commercial & Institutional	32,700	1	13	1	210	-	-	-	32,900
Residential	39,400	94	2,000	2	520	-	-	-	41,900
Agriculture & Forestry	2,190	-	1	-	17	-	-	-	2,210
b. Transportation Combustion Sources	**178,000**	**31**	**650**	**29**	**8,900**	**-**	**-**	**-**	**187,000**
Domestic Aviation	11,800	1	12	1	360	-	-	-	12,100
Road Transportation	127,000	14	290	19	5,700	-	-	-	134,000
Gasoline Automobiles	46,400	5	96	7	2,200	-	-	-	48,700
Light-Duty Gasoline Trucks	36,400	5	100	9	2,900	-	-	-	39,400
Heavy-Duty Gasoline Vehicles	3,930	1	12	1	180	-	-	-	4,130
Motorcycles	236	-	4	-	1	-	-	-	242
Diesel Automobiles	583	-	-	-	13	-	-	-	596
Light-Duty Diesel Trucks	629	-	-	-	14	-	-	-	643
Heavy-Duty Diesel Vehicles	38,200	2	39	1	350	-	-	-	38,600
Propane & Natural Gas Vehicles	1,100	2	36	-	7	-	-	-	1,140
Railways	5,820	-	7	2	730	-	-	-	6,550
Domestic Marine	5,180	-	8	1	330	-	-	-	5,510
Others	27,600	16	330	6	1,700	-	-	-	29,700
Off-Road	17,700	6	130	5	1,700	-	-	-	19,500
Pipelines	9,970	10	210	-	81	-	-	-	10,300
c. Fugitive Sources	**15,300**	**1,900**	**39,000**	**-**	**-**	**-**	**-**	**-**	**54,800**
Coal Mining	-	47	990	-	-	-	-	-	990
Oil and Natural Gas	15,000	1,800	38,000	-	-	-	-	-	54,000
Oil	78	660	14,000	-	-	-	-	-	14,000
Natural Gas	29	1,100	24,000	-	-	-	-	-	24,000
Venting	7,800	-	-	-	-	-	-	-	7,800
Flaring	7,400	31	660	-	-	-	-	-	8,000
INDUSTRIAL PROCESSES	**38,300**	**-**	**-**	**5**	**1,600**	**900**	**6,000**	**2,000**	**49,000**
a. Mineral Production	**8,650**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**8,650**
Cement	6,490	-	-	-	-	-	-	-	6,490
Lime	1,750	-	-	-	-	-	-	-	1,750
Limestone and Soda Use	403	-	-	-	-	-	-	-	403
b. Chemical Industry	**5,920**	**-**	**-**	**5**	**1,600**	**-**	**-**	**-**	**7,520**
Ammonia Production	5,920	-	-	-	-	-	-	-	5,920
Nitric Acid Production	-	-	-	3	800	-	-	-	795
Adipic Acid Production	-	-	-	3	800	-	-	-	802
c. Metal Production	**12,100**	**-**	**-**	**-**	**-**	**-**	**6,000**	**2,000**	**20,300**
Iron and Steel Production	7,920	-	-	-	-	-	-	-	7,920
Aluminium Production	4,160	-	-	-	-	-	6,000	-	10,300
SF_6 used in Magnesium Smelters	-	-	-	-	-	-	-	2,000	2,020
d. Consumption of Halocarbons	**-**	**-**	**-**	**-**	**-**	**900**	**20**	**-**	**936**
e. Other & Undifferentiated Production	**11,700**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**11,700**
SOLVENT & OTHER PRODUCT USE	**-**	**-**	**-**	**2**	**470**	**-**	**-**	**-**	**468**
AGRICULTURE	**-300**	**1,200**	**24,000**	**120**	**36,000**	**-**	**-**	**-**	**60,000**
a. Enteric Fermentation	-	900	19,000	-	-	-	-	-	18,800
b. Manure Management	-	260	5,500	15	4,600	-	-	-	10,100
c. Agriculture Soils	-300	-	-	100	31,000	-	-	-	30,000
Direct Sources	-300	-	-	79	24,000	-	-	-	20,000
Indirect Sources	-	-	-	23	7,000	-	-	-	7,000
LAND-USE CHANGE AND FORESTRY (non-CO_2 only)[1]	**-**	**50**	**1,100**	**3**	**1,000**	**-**	**-**	**-**	**2,080**
a. Prescribed Burns	-	17	360	1	210	-	-	-	575
b. Wildfires in the Wood Production Forest	-	33	690	3	820	-	-	-	1,510
WASTE	**284**	**1,100**	**23,000**	**3**	**1,000**	**-**	**-**	**-**	**24,800**
a. Solid Waste Disposal on Land	-	1,100	23,000	-	-	-	-	-	23,100
b. Wastewater Handling	-	19	400	3	970	-	-	-	1,370
c. Waste Incineration	284	-	7	-	60	-	-	-	350
LAND-USE CHANGE AND FORESTRY[1]	**-40,000**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-40,000**
a. Changes in Forest and Woody Biomass Stocks	-40,000	-	-	-	-	-	-	-	-40,000
b. Forest and Grassland Conversion	4,000	-	-	-	-	-	-	-	4,000
c. Abandonment of Managed Lands	-3,000	-	-	-	-	-	-	-	-3,000
d. CO_2 Emissions and Removals from Soil	2,000	-	-	-	-	-	-	-	2,000

1 CO_2 emissions and removals in the LUCF sector are not included in the national totals. Non-CO_2 emissions from fires located in the National Parks are not included in the provincial/territorial totals but are reported in the national totals.

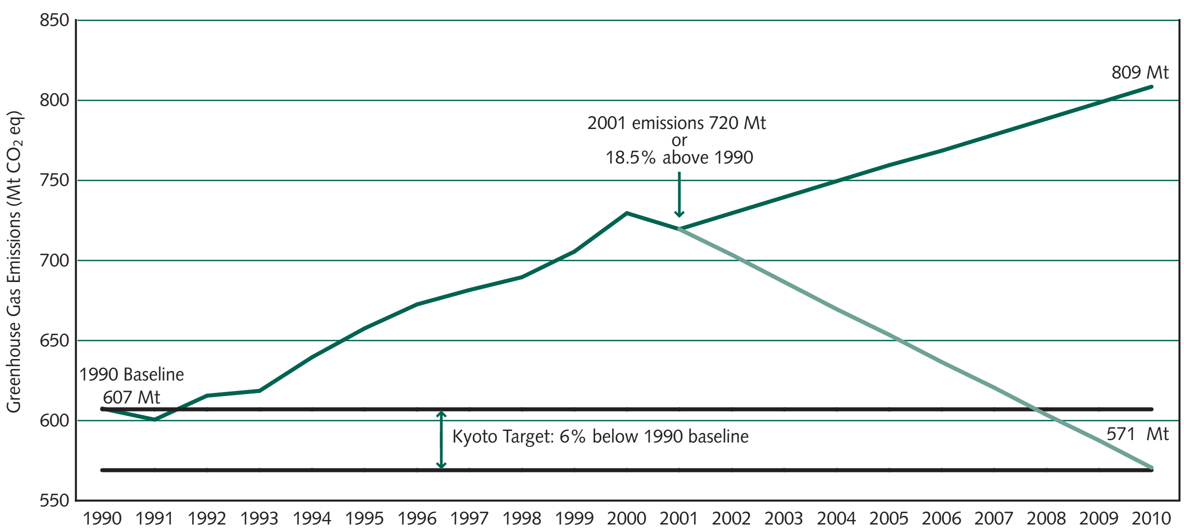
Totals may not add due to rounding.

SOURCE AND SINK CATEGORY EMISSION ESTIMATES AND TRENDS

The 1990–2001 data on Canada's GHG emissions (Table S-2) demonstrate progress in reducing emissions in many areas of the economy, but also indicate areas where more work needs to be done. Total emissions of all GHGs in 2001 were 18.5% above the 1990 level of 608 Mt. Although emissions have been rising since 1990 (Figure S-3), in 1994 emission growth peaked at over 3.5% per year and fell consistently thereafter until 1999 and 2000, when emissions rose 2.4% and 3.4% respectively. Between 2000 and 2001, emissions declined by 1.3%, representing the first decline in emissions since 1991. This decline in emissions appears to be mainly the result of a warmer than average winter, reduced energy use in some industrial sectors and declines in fuel consumption for several modes of transportation. The cumulative average annual growth of emissions over the 1990–2001 period was 1.6%.

In 2001, Canada's emissions decreased by 9.5 Mt from the 2000 level of 730 Mt. The Energy sector was responsible for most of the decrease, with emissions declining over 8.7 Mt. GHG emissions associated with manufacturing in 2001 declined by 4.1 Mt over 2000, a decrease of almost 8%. Between 2000 and 2001 transportation sector emissions declined in domestic aviation (-11.7%), heavy-duty gasoline vehicles (-5.7%), and in all diesel categories (-1.9%), reflecting reduced passenger travel and on-road shipping resulting directly or indirectly from the events of September 11, 2001.

FIGURE S-3: Canadian Emission Trend and Forecast, 1990–2010



Sources:

Actual Emission Estimates, Baseline (estimates presented in this report).

Forecast: McIlveen, N. (2002), Personal communication, Analysis and Modelling Division, Natural Resources Canada.

TABLE S-2: Canada's GHG Emission Trends by Sector

Greenhouse Gas Categories	1990	1995	2000	2001
	kt CO_2 equivalent			
TOTAL	**608,000**	**658,000**	**730,000**	**720,000**
ENERGY	**473,000**	**513,000**	**593,000**	**584,000**
a. Stationary Combustion Sources	**282,000**	**294,000**	**348,000**	**342,000**
Electricity and Heat Generation	95,300	101,000	136,000	137,000
Fossil Fuel Industries	51,500	54,700	66,900	67,300
Petroleum Refining	26,100	28,400	27,800	29,100
Fossil Fuel Production	25,400	26,300	39,100	38,200
Mining	6,190	7,860	10,390	10,250
Manufacturing Industries	54,500	52,900	53,000	48,900
Iron and Steel	6,490	7,040	7,190	5,890
Non Ferrous Metals	3,230	3,110	3,190	3,500
Chemical	7,100	8,460	7,860	6,470
Pulp and Paper	13,500	11,500	10,800	9,600
Cement	3,390	3,420	3,430	3,290
Other Manufacturing	20,800	19,400	20,500	20,100
Construction	1,880	1,180	1,080	1,010
Commercial & Institutional	25,800	29,000	33,200	32,900
Residential	44,000	44,900	45,000	41,900
Agriculture & Forestry	2,420	2,790	2,570	2,210
b. Transportation Combustion Sources	**153,000**	**169,000**	**190,000**	**187,000**
Domestic Aviation	10,700	10,900	13,700	12,100
Road Transportation	107,000	119,000	131,000	134,000
Gasoline Automobiles	53,700	51,300	48,300	48,700
Light Duty Gasoline Trucks	21,800	28,500	37,600	39,400
Heavy Duty Gasoline Vehicles	3,140	4,760	4,370	4,130
Motorcycles	230	214	239	242
Diesel Automobiles	672	594	605	596
Light Duty Diesel Trucks	591	416	645	643
Heavy Duty Diesel Vehicles	24,500	30,800	38,700	38,600
Propane & Natural Gas Vehicles	2,210	2,100	1,100	1,140
Railways	7,110	6,430	6,670	6,550
Domestic Marine	5,050	4,380	5,110	5,510
Others	23,400	28,600	33,400	29,700
Off Road	16,500	16,600	22,100	19,500
Pipelines	6,900	12,000	11,300	10,300
c. Fugitive Sources	**37,900**	**49,800**	**54,000**	**54,800**
Coal Mining	1,910	1,710	950	990
Oil and Natural Gas	36,000	48,000	53,000	54,000
Oil	8,600	13,000	14,000	14,000
Natural Gas	17,000	22,000	24,000	24,000
Venting	4,500	6,700	7,500	7,800
Flaring	5,800	6,800	7,800	8,000
INDUSTRIAL PROCESSES	**52,900**	**56,200**	**50,900**	**49,000**
a. Mineral Production	**8,160**	**7,690**	**8,700**	**8,650**
Cement	5,870	5,360	6,310	6,490
Lime	1,850	1,990	2,000	1,750
Limestone and Soda Use	-	-	-	-
b. Chemical Industry	**16,500**	**18,000**	**9,000**	**8,000**
Ammonia Production	5,010	6,480	6,850	5,920
Nitric Acid Production	780	780	800	800
Adipic Acid Production	10,700	10,700	900	800
c. Metal Production	**19,100**	**19,900**	**20,900**	**20,300**
Iron and Steel Production	7,590	8,440	8,510	7,920
Aluminum Production	8,610	9,560	10,000	10,300
SF_6 used in Magnesium Smelters	2,870	1,880	2,310	2,020
d. Consumption of Halocarbons	**-**	**510**	**940**	**940**
e. Other & Undifferentiated Production	**9,220**	**10,180**	**11,850**	**11,660**
SOLVENT & OTHER PRODUCT USE	**417**	**442**	**463**	**468**
AGRICULTURE	**59,200**	**61,100**	**60,800**	**60,000**
a. Enteric Fermentation	16,000	18,100	17,700	18,800
b. Manure Management	8,270	9,220	9,380	10,100
c. Agriculture Soils	30,000	30,000	30,000	30,000
Direct Sources	30,000	30,000	30,000	20,000
Indirect Sources	5,000	6,000	7,000	7,000
LAND USE CHANGE AND FORESTRY (non-CO_2 only)[1]	**2,260**	**4,670**	**660**	**2,080**
a. Prescribed Burns	1,560	-	580	570
b. Wildfires in the Wood Production Forest	700	4,260	-	1,510
WASTE	**20,100**	**22,000**	**24,300**	**24,800**
a. Solid Waste Disposal on Land	18,500	20,400	22,600	23,100
b. Wastewater Handling	1,220	1,300	1,360	1,370
c. Waste Incineration	-	-	-	-
LAND USE CHANGE AND FORESTRY[1]	**-100,000**	**-10,000**	**-50,000**	**-40,000**
a. Changes in Forest and Woody Biomass Stocks	-100,000	-10,000	-60,000	-40,000
b. Forest and Grassland Conversion	1,000	2,000	3,000	4,000
c. Abandonment of Managed Lands	-3,000	-3,000	-3,000	-3,000
d. CO_2 Emissions and Removals from Soil	4,000	2,000	2,000	2,000

1 CO_2 emissions and removals in the LUCF sector are not included in the national totals. Non-CO_2 emissions from fires located in the National Parks are not included in the provincial/territorial totals but are reported in the national totals.

Totals may not add due to rounding.

Emissions in the off-road sector also decreased (-11.9%) between 2000 and 2001, mainly reflecting decreases in construction and agricultural activity. In addition, emissions from pipelines decreased (-9%) due mainly to a warmer than usual winter.

Long-term trends (1990–2001) showed some declines as well. Manufacturing industry emissions declined by 5.6 Mt (-10.3%). Residential emissions also declined by almost 2.1 Mt (-4.7%), showing the effects of a warmer than usual winter. Finally, emissions from gasoline automobiles continued their decline in emissions, showing a decrease of nearly 5 Mt since 1990, (-9.3%). However, this has been more than offset by increases in emissions from the light-duty gasoline truck category (minivans and SUVs) which showed a continuing increase of 17.6 Mt (81.2%) since 1990. On average, light-duty trucks emit 40% more GHGs per kilometre than cars. Table S-2 summarises Canada's GHG emissions by sector for the years 1990–2001.

Table S-3 depicts Canada's total GHG emissions from 1990 to 2001, 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 18.5% increase in GHG emissions during the past 11 years outpaced increases in both

TABLE S-3: Canada's GHG Emissions and Accompanying Variables, 1990–2001

Year	1990	1995	2000	2001
Total GHG (Mt)[1]	**608**	**658**	**730**	**720**
Growth Since 1990	N/A	8.2%	20.1%	18.5%
Annual Change	N/A	2.7%	3.2%	-1.3%
GDP – Expense[2]	**765,311**	**833,456**	**1,012,334**	**1,027,522**
Growth Since 1990	N/A	8.9%	32.3%	34.3%
Annual Change	3.4%	2.8%	4.5%	1.5%
Average Annual Change	N/A	1.8%	3.2%	3.1%
GHG Intensity (Mt/$B GDP)	**0.79**	**0.79**	**0.72**	**0.70**
Annual Change	N/A	-0.1%	-1.3%	-2.8%
Average Annual Change	N/A	0.0%	-0.1%	-0.3%
GHG Efficiency ($GDP/kt GHG)	**1.26**	**1.27**	**1.39**	**1.43**
1990 Index	100.0%	100.6%	110.1%	113.3%
Annual Change	N/A	0.1%	1.4%	3.1%
Population (000s)[3]	**27,701**	**29,354**	**30,791**	**31,111**
Growth Since 1990	N/A	6.0%	11.2%	12.3%
GHG Per Capita (tonnes/person)	**21.9**	**22.4**	**23.7**	**23.1**
1990 Index	100%	102%	108%	106%
Annual Change	N/A	1.6%	2.4%	-2.5%
Energy Use (PJ)[4]	**9,230**	**9,695**	**10,830**	**10,836**
Growth Since 1990	N/A	5%	17%	17%
Energy Produced (PJ)[5]	**7,752**	**10,277**	**11,729**	**11,949**
Growth Since 1990	N/A	33%	51%	54%
Energy Exported (PJ)	**1,755**	**4,032**	**4,822**	**4,962**
Growth Since 1990	N/A	130%	175%	183%
Emissions Associated with Exports (Mt)	**21.5**	**42.9**	**47.5**	**47.6**
Growth Since 1990	N/A	100%	121%	122%
Annual Change	N/A	1.4%	3.0%	0.1%

Notes:

1 Environment Canada, Pollution Data branch, Canada's Greenhouse Gas Inventory 1990–2001 DRAFT.

2 Real Gross Domestic Product, (Million 1997 dollars) (http://www.statcan.ca/english/concepts/revisions_2002_05_31.pdf).

3 Source: Statistics Canada, CANSIM II Table 051-001.

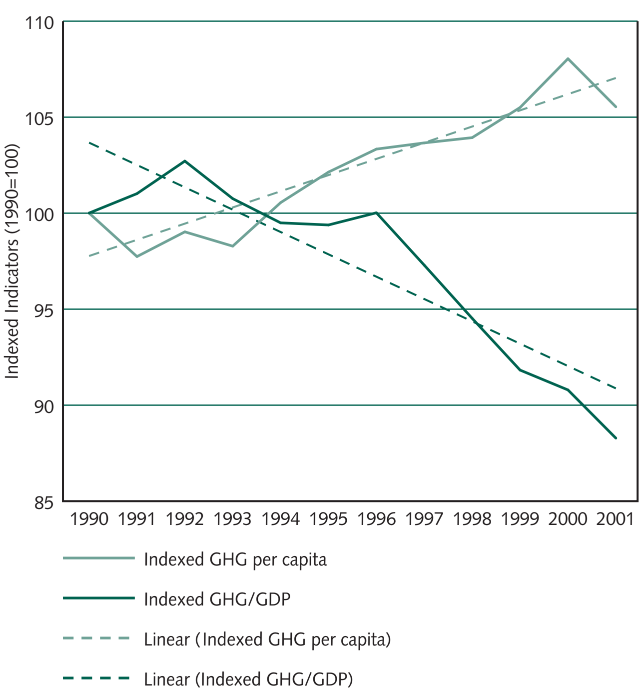
4 Statistics Canada's Quarterly Report on Energy Supply-Demand In Canada 2001, Table 1B, Line 8 (Cat. 57-003 2001Q4).

5 Natural Gas and Crude Oil only.

population (which grew 12.3%) and energy use (which rose 17%). However, the growth in total emissions was well short of the 34.3% growth in GDP between 1990 and 2001 (Statistics Canada 2002, Millions Chained 1997$). On average, GDP grew at about 2.8% per year in the mid-1990s and by 1.5% between 2000 and 2001.

GHG emissions per unit of GDP continued to decrease over the period 1990–2001, mainly due to a move away from GHG-intensive fossil fuels in the industrial, residential, and commercial sectors and to gains in energy efficiency (Figure S-4). Emissions per person in Canada have grown by 5.5% as growth in emissions has outpaced population growth. This is mainly due to increasing emissions resulting from increases in power generation and the production of fossil fuels, mainly for export.

FIGURE S-4: Trends in GHG Intensity of GDP and Population, 1990–2001



Overall, the Energy sector is responsible for 98.7% of the 112.5 Mt increase in total Canadian GHG emissions over the period 1990–2001, while representing 81% of the total GHG emissions for 2001. The greatest contributors to the increases in GHG emissions are:

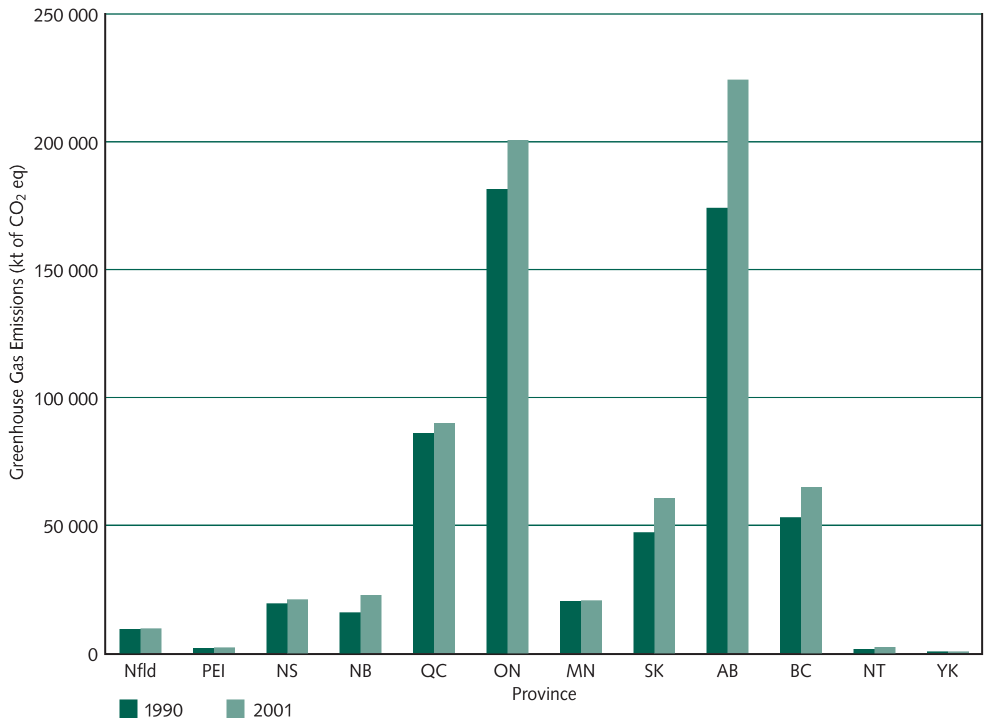
- electricity and steam generation, 41.8 Mt (37.2% of the increase);
- vehicles, 34.2 Mt (30.4% of the increase); and
- fossil fuel industries, 15.8 Mt (14.1% of the increase).

The GHG emission increase associated with electricity and steam generation is mainly the result of the use of more GHG-intensive fossil fuels and increased demand for electricity. The percentage of low or non-emitting electricity and steam generating sources has decreased from 79% of the total in 1990 to only 72% of the total in 2001. Combined with a 22% increase in total generation, the electricity sector is a significant and increasing contributor to Canada's emissions profile (Statistics Canada 2002a).

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 benefit 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 distribution of emissions and the change in these emissions between 1990 and 2001.

FIGURE S-5: Total Provincial/Territorial GHG Emissions, 1990 and 2001[9]



OTHER INFORMATION

EMISSIONS ASSOCIATED WITH THE EXPORT OF OIL AND NATURAL GAS

Growth in oil and gas exports, primarily to the United States, contributed significantly to emission growth[10] between 1990 and 2001. In this period, net oil exports grew by 309% to 991 petajoules (PJ)[11] (almost 10 times the growth rate of oil production), while net exports of natural gas increased 162% to 3971 PJ (more than twice the growth rate of natural gas production). The portion of emissions from all oil and gas production, processing and transmission activities that is attributable to exports increased from 28 Mt in 1990 to 68 Mt in 2001.[12] Overall, total energy exported has increased 139% between 1990 and 2001, while emissions associated with those exports have increased 146%.

9 Fuel combustion emissions from the fossil fuel industry category for Alberta showed a significant increase over the period 1998–1999. This is attributed not to increased sector activity or changes in practice but to inconsistencies associated with the system for reporting the underlying fuel combustion data used in the emission calculation. Additional investigations will be undertaken to correct any year-to-year inconsistencies in the underlying data and estimated emissions in line with internationally agreed good practice guidance and uncertainty management.

10 The source for all export and energy production data is Statistics Canada, Catalogue #57-003. The 1990–1995 GHG emissions associated with net exports are taken from a report prepared by Environment Canada (McCann et al., 1997), while the 1996–2000 estimates were extrapolated from this report.

11 A petajoule is a measure of the energy content of fuels.

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

TABLE S-4: Crude Oil: Production, Net Export, and GHG Emission Trends, 1990–2001

Crude Oil	1990	1995	2000	2001
Domestic Production (PJ)	**3,568**	**4,148**	**4,669**	**4,747**
Growth Since 1990	*N/A*	*16%*	*31%*	*33%*
Energy Exported (PJ)	**1,513**	**2,445**	**3,200**	**3,170**
Growth Since 1990	*N/A*	*62%*	*111%*	*110%*
Net Energy Export (PJ)	**242**	**1,047**	**1,037**	**991**
Growth Since 1990	*N/A*	*332%*	*328%*	*309%*
Emissions Associated with NET Exports (Mt CO_2 eq)	**8.8**	**17.8**	**16.5**	**15.9**
Growth Since 1990	*N/A*	*40%*	*30%*	*25%*

TABLE S-5: Natural Gas: Production, Net Export, and GHG Emission Trends, 1990–2001

Natural Gas	1990	1995	2000	2001
Domestic Production (PJ)	**4,184**	**6,129**	**7,060**	**7,202**
Growth Since 1990	*N/A*	*47%*	*69%*	*72%*
Energy Exported (PJ)	**1,537**	**3,011**	**3,846**	**4,120**
Growth Since 1990	*N/A*	*96%*	*150%*	*168%*
Net Energy Export (PJ)	**1,513**	**2,985**	**3,785**	**3,971**
Growth Since 1990	*N/A*	*97%*	*150%*	*162%*
Emissions Associated with NET Exports (Mt CO_2 eq)	**12.7**	**25.1**	**31.1**	**31.7**
Growth Since 1990	*N/A*	*98%*	*145%*	*150%*

TABLE S-6: Combined Crude Oil and Natural Gas: Production, Net Export, and GHG Emissions Trends, 1990–2001

Combined Crude Oil and Natural Gas	1990	1995	2000	2001
Domestic Production (PJ)	**7,752**	**10,277**	**11,729**	**11,949**
Growth Since 1990	*N/A*	*33%*	*51%*	*54%*
Energy Exported (PJ)	**3,050**	**5,456**	**7,046**	**7,291**
Growth Since 1990	N/A	79%	131%	139%
Net Energy Export (PJ)	**1,755**	**4,032**	**4,822**	**4,962**
Growth Since 1990	*N/A*	*130%*	*175%*	*183%*
Emissions Associated with NET Exports (Mt CO_2 eq)	**21.5**	**42.9**	**47.5**	**47.6**
Growth Since 1990	*N/A*	*238%*	*274%*	*275%*

Total Exported Crude Oil and Natural Gas	1990	1995	2000	2001
Emissions Associated with Total Crude Oil Exports (Mt CO_2 eq)	**13.9**	**24.5**	**31.9**	**31.6**
Growth Since 1990	*N/A*	*76%*	*130%*	*127%*
Emissions Associated with Total Gas Exports (Mt CO_2 eq)	**13.9**	**26.5**	**33.1**	**35.4**
Growth Since 1990	*N/A*	*91%*	*138%*	*155%*
Total	**27.8**	**51.8**	**66.3**	**68.3**
Growth Since 1990	*N/A*	*86%*	*139%*	*146%*

1 INTRODUCTION

1.1 GHG INVENTORIES AND CLIMATE CHANGE

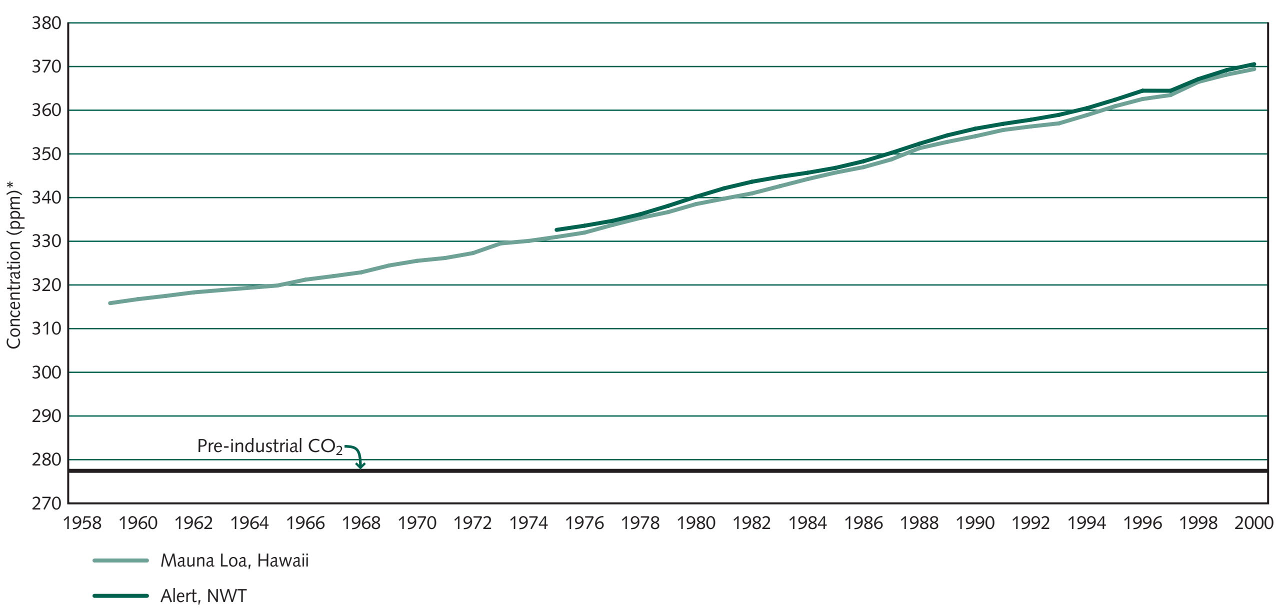
In order to understand climate change, it is important to differentiate between weather and climate. Weather is the state of the atmosphere at a given time and place and is usually reported as changes in temperature, air pressure, humidity, wind, cloudiness, and precipitation. The term weather is used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

On the other hand, climate is the average weather (usually taken over a 30-year time period) for a particular region. Climate is not the same as weather; rather, it is the average pattern of weather 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 build-up of greenhouse gases (GHGs) that trap heat and reflect it back to the Earth's surface. According to the IPCC's 3rd Assessment report, 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.

It is now well known that atmospheric concentrations of GHGs have grown significantly since pre-industrial times (Figure 1-1). 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: Global Atmospheric Concentrations of Carbon Dioxide



*ppm = parts per million

Sources:

C.D. Keeling and T.P. Whorf, Scripps Institution of Oceanography, University of California, California, U.S.A. for CO_2 measurements taken at Mauna Loa Observatory, Hawaii.

Atmospheric Environment Service, Environment Canada for carbon dioxide measurements taken at Alert, NWT, Canada. Data provided by State of the Environment Program (1999).

Canada tracks its contribution to the increase in these GHG concentrations by estimating its total national emissions of six GHGs covered by the UNFCCC and Kyoto Protocol.[13] This report provides estimates of Canada's emissions and removals of the following GHGs: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulphur hexafluoride (SF_6), perfluorocarbons (PFCs) and hydrofluorocarbons (HFCs). As specified by the UNFCCC, country estimates of GHGs relate to their human (anthropogenic) activities, and do not include emissions from naturally-occurring sources or sinks.

1.1.1 CARBON DIOXIDE (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 from natural systems, they represent only a fraction (~2%) of total global emissions. However, they are perceived to 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 Gt, almost a fourfold increase (Marland et al., 1999). Deforestation, land use, 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 ecosytems, 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 METHANE (CH_4)

In addition to CO_2, excess global CH_4 emissions resulting from anthropogenic activities are considered to have caused an increase of about 145% in atmospheric concentrations since the mid-1700s (Thompson et al., 1992). Recent atmospheric measurements of methane concentrations are shown in the figure below (Figure 1-2).

The current annual rate of accumulation of CH_4 is estimated to range between 40 and 60 Mt (~14–21 ppbv), or approximately 10% of total worldwide CH_4 emissions (Thompson et al., 1992). CH_4 emissions generated from human activities, amounting to ~360 Mt per year, 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).

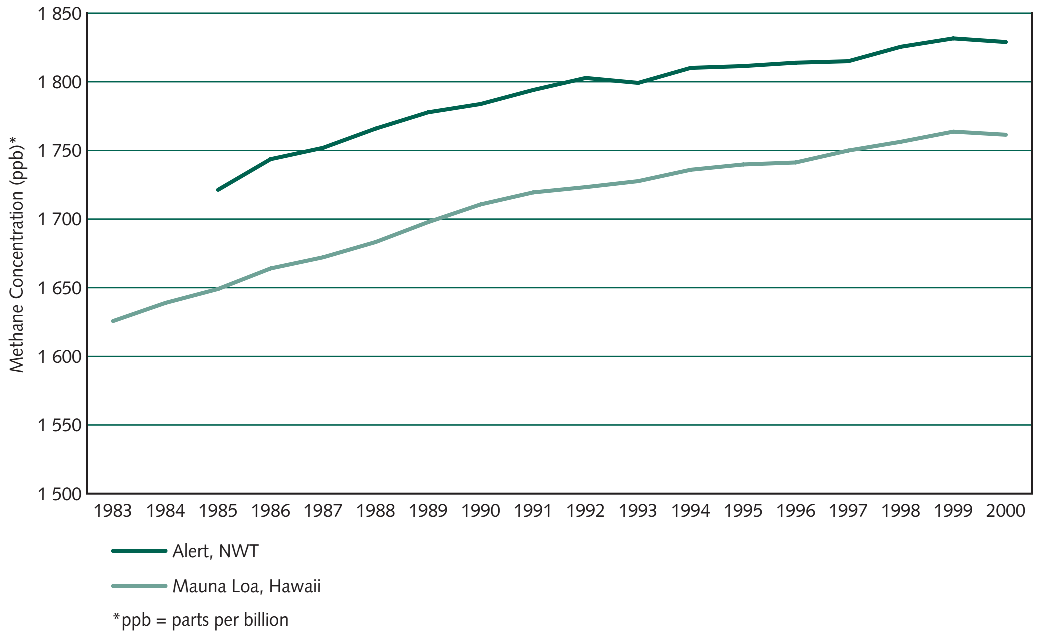
1.1.3 NITROUS OXIDE (N_2O)

At present, it has been estimated that approximately one-third of global atmospheric nitrous oxide (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 (Figure 1-3) (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).

The other two-thirds of global atmospheric N_2O comes from soil and water denitrification under anaerobic conditions.

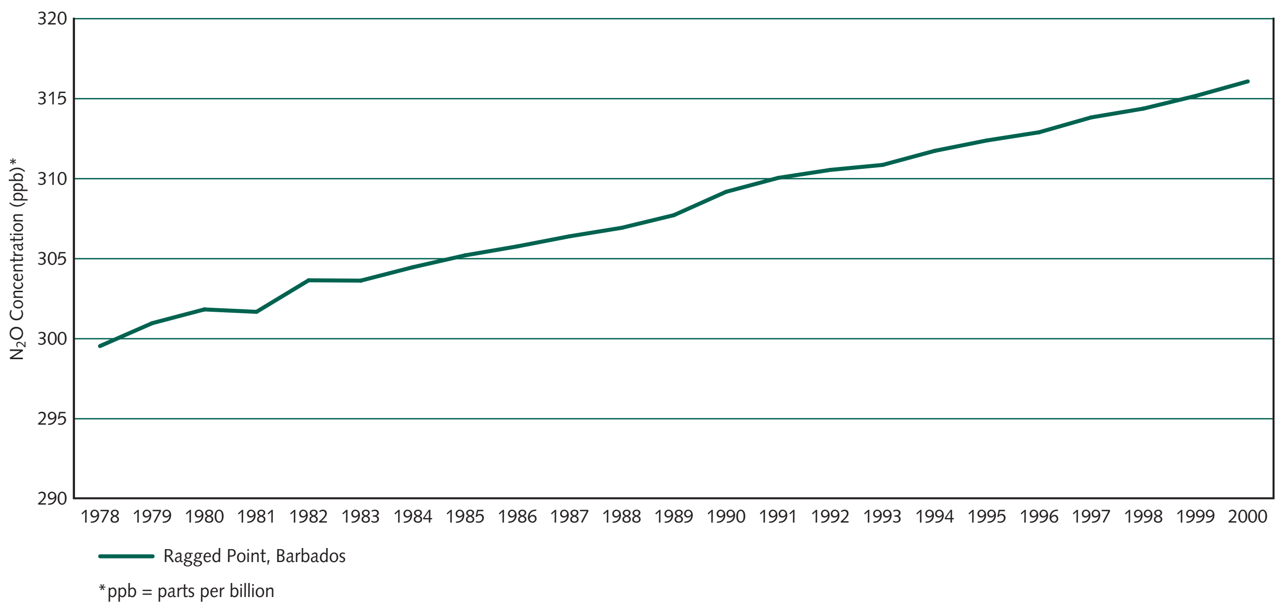
13 The UN FCCC and Kyoto Protocol do not cover the greenhouse gases (e.g. CFCs, HCFCs) that are covered under the Montreal Protocol, the international agreement whose aim is to reduce damage of the stratospheric ozone layer.

FIGURE 1-2: Global Atmospheric Concentrations of Methane



Source: E. Dlugonkencky, and P. Lang, Climate Monitoring and Diagnostics Laboratory National Oceanic and Atmospheric Administration (NOAA), Boulder Colorado, U.S.A.

FIGURE 1-3: Global Atmospheric Concentrations of Nitrous Oxide



Source: World Data Center for Greenhouse Gases, AGAGE Science team

1.1.4 HFCS, PFCS, AND SF_6

The final group of GHGs included in this report are the synthetic (not naturally-occurring), fluorinated gases of hydrofluorocarbons (HFCs), perfluorocarbon (PFCs) and sulphur hexafluoride (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 greater than 2,300 years with CF_4 estimated to last 50,000 years.

1.2 GREENHOUSE GASES AND THE USE OF GLOBAL WARMING POTENTIALS (GWPS)

To understand the emission data presented in this report, it is important to understand that the radiative forcing[14] 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, while 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 policy-makers 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., GHG) might have on the surface troposphere. The GWP of a GHG takes into account both the instantaneous radiative forcing due to an incremental concentration increase and the lifetime of the gas. The 100-year GWPs, recommended by the IPCC (Table 1-1) and required for inventory reporting under the UNFCCC (adopted at the third Conference of the Parties), are used in this report.

TABLE 1-1: Global Warming Potentials and Atmospheric Lifetimes

GHG	Formula	100-year GWP	Atmospheric Lifetime
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	$C_2H_2F_2$ (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_3H2F_6	6,300	209
HFC-245ca	C_3H3F_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-C_4F_8	8,700	3,200
Perfluoropentane	C_5F_{12}	7,500	4,100
Perfluorohexane	C_6F_{14}	7,400	3,200

GWP Source: IPCC (1996a), *1995 Summary for Policy Makers – A Report of Working Group I of the Intergovernmental Panel on Climate Change.*

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

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.

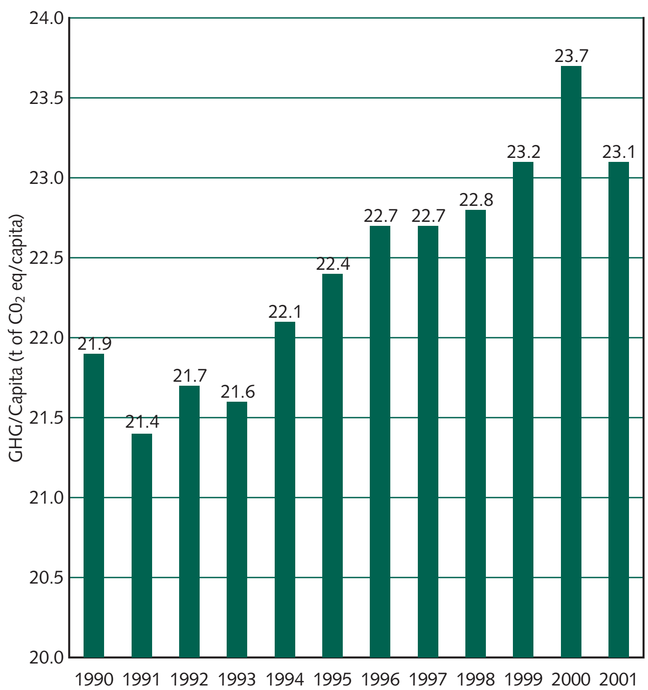
1.3 CANADA'S CONTRIBUTION

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 21.9 t CO_2 eq of GHGs per capita. Over the 11-year period from 1990 to

14 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).

2001, this has increased to 23.1 t CO_2 eq of GHGs per capita (Figure 1-1).

FIGURE 1-4: Trend in Canada's Per Capita GHG Emissions, 1990–2001



1.4 INSTITUTIONAL ARRANGEMENTS FOR INVENTORY PREPARATION

The Ministry of the Environment (Environment Canada) is responsible for monitoring and reporting on the environment in Canada. The Greenhouse Gas Division of Environment Canada is Canada's central inventory agency and, as such, prepares and compiles the national GHG inventory for Canada. Underlying data used to prepare the inventory is collected by Environment Canada from a variety of agencies, including Statistics Canada (e.g. energy data, livestock, crop production and land statistics), Natural Resources Canada (e.g. mineral production and forestry statistics), Agriculture and Agri-Food Canada (e.g. agriculture soil model results), as well as other sections of Environment Canada (e.g. landfill gas capture, HFC- and PFC-use data).

Statistics Canada and Environment Canada have legislated mandatory reporting provisions to ensure consistent reporting. The majority of the data collected by Statistics Canada (and used as activity data for the inventory) is mandatory and collected under the authority of the *Statistics Act*. To improve the accuracy of the inventory Environment Canada has established a formal agreement (Memorandum of Understanding) with Statistics Canada to allow sharing of select facility level information (which would otherwise be confidential) to improve the quality of the inventory. Environment Canada uses mandatory reporting provisions of the *Canadian Environmental Protection Act* to collect HFC- and PFC-use data. The remainder of the data collected for the inventory is reported in a non-mandatory manner.

Clear roles have been established between the two main departments active in climate change, Environment Canada (EC) and Natural Resources Canada (NRCan). These have been agreed to in a Memorandum of Understanding between the GHG Division of EC and the Analysis and Modelling Division of NRCan, where EC prepares and compiles the national GHG inventory and NRCan is responsible for preparing GHG emission forecasts. In preparation for the more stringent Kyoto Protocol reporting for agriculture, forestry and land-use change activities, the GHG Division presides over an interdepartmental committee on the Monitoring, Accounting and Reporting System (MARS) for Land-Use, Land-Use Change and Forestry (LULUCF).[15] The mandate of this committee is to coordinate the activities of Environment Canada, Natural Resources Canada (the Canadian Forest Service) and Agriculture and Agri-Food Canada, so that the necessary accounting systems can be developed which will allow Canada to meet both UNFCCC and Kyoto Protocol reporting requirements for these activities.

Prior to inventory submission to the UNFCCC, the inventory is reviewed by the Emissions and Projections Working Group (EPWG) and other selected government experts. The EPWG is used to co-ordinate emission inventory activities in Canada and is made up of provincial/territorial and federal government representatives working in the field of air pollution measurement and estimation.

15 MARS for Land Use, Land-Use Change and Forestry; See website: http://www.ec.gc.ca/pdb/ghg/mars_steering_committee_e.cfm

1.5 PROCESS FOR INVENTORY PREPARATION

The data sources 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 a spreadsheet-based emission accounting system or model. Emissions are calculated by designated inventory experts, reviewed internally and then reported according to UNFCCC guidelines in the Common Reporting Format (CRF) and the National Inventory Report (NIR). The inventory group also carries out QC procedures, documentation, uncertainty estimation, key source assessment and trends analysis.

A draft inventory is distributed in a formal review process to an interdepartmental group (Emissions and Projections Working Group). In addition, the emission estimates for the Energy, Industrial Processes, and Agriculture sectors are reviewed in detail by other government departments such as Natural Resources Canada and Agriculture and Agri-Food Canada, while the Waste sector emissions are reviewed by other experts within Environment Canada.

Comments from the review are incorporated and the initial submission is made electronically by April 15th of each year. The CRF and NIR are then further edited, translated, published and a final submission is prepared in late summer.

1.6 METHODOLOGIES AND DATA SOURCES

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

- Energy;
- Industrial processes;
- Solvent and other product use;
- Agriculture;
- Land-use change and forestry; and
- Waste.

Each of these categories is further subdivided within the inventory. The methods described have been grouped, as closely as possible, by UNFCCC sector and subsector. Note that Canada reports agricultural soils under the agriculture category rather than the land-use change and forestry category.

The methodologies contained in the Revised 1996 IPCC Guidelines and IPCC Good Practice Guidance (2000) are followed to estimate emissions and removals of each of the following direct GHGs:

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

The UNFCCC also requests emissions estimates for the following ozone and aerosol precursor gases:

- sulphur dioxide (SO_2);
- nitrogen oxides (NO_x);
- carbon monoxide (CO); and
- non-methane volatile organic compounds (NMVOCs).

For all sources except Land-Use Change and Forestry (LUCF), these gases (referred to as the Criteria Air Contaminants) are inventoried and reported separately using different methodologies from those used for the direct GHGs. These gases are reported to the United Nations Economic Commission for the Environment (UNECE) (http://webdab.emep.int/). Emissions of ozone and aerosol precursors are calculated and reported for the LUCF category within this national inventory.

Emissions of NO_x and CO from forest fires are reported in the LUCF sector to maintain the carbon balance, because accounting rules in the GHG inventory differ from those of the Criteria Air Contaminants inventory, resulting in substantially different emission estimates; to follow up on the Synthesis & Assessment report for the 2001 GHG inventory submission.

In general, an emission inventory can be defined as "a comprehensive account of air-pollutant emissions and associated data from sources within the inventory area over a specified time frame." It can be prepared "top down", "bottom up" or using a combination approach.

For the most part, Canada's national inventory is prepared using a "top down" approach, providing estimates at a provincial/territorial level of segregation. Ideally, an inventory would be compiled from the measured emissions or removals from every source and sink in the country, referred to as a "bottom-up" approach. While 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.

In general, the inventory is divided among point and area sources. Point sources refer to individual sources or facilities, whereas area sources are spacially diffuse and/or very numerous, involving gathering 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. With the exception of Ontario,[16] GHG emissions and removals have not normally been reported for regulatory or compliance purposes in Canada. About 200 entities voluntarily report their emissions in a comprehensive fashion through Canada's Voluntary Challenge and Registry (VCR). For the most part, this data is not collected in a manner which supports direct use in the national inventory.

Emissions or removals, whether for point or area sources, are usually calculated or estimated using mass-balance approaches, or stoichiometric relationships under averaged conditions. In many cases, provincial 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.

Estimates of emissions and removals associated with biological systems, as in the case of agriculture, forestry and land-use changes, are particularly challenging to develop as they require the separation of anthropogenic impacts from very large natural fluxes and stores of carbon and nitrogen. Since these emissions and removals vary considerably with respect to location and many of the processes take place over several years (versus annual increments), models can offer a more practical approach for these estimations.

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 amount of the component (e.g., carbon) contained in feed materials or fuels and that 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 plant. 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 other agencies and organizations. These values reflect the

16 The Province of Ontario has included GHGs in its list of mandatory reporting for certain sectors.

most accurate methodologies based on currently available data and include information currently being developed by the Intergovernmental Panel on Climate Change (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 is to say, in some cases a more accurate method or emission factor is 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.

1.7 KEY SOURCE CATEGORIES

For the year 2001 GHG inventory a level, trend and qualitative key source assessments were performed on the inventory according to the IPCC Tier 1 approach. The source categories used for the Key source assessment generally follow those in the CRF. However, they have been aggregated in some cases and are specific to the Canadian Inventory.

Major key sources based on the level assessment are the fuel combustion categories of public electricity and heat generation and road transport, while adipic acid production is a significant key source based on a trend assessment. Details and results of the assessments are presented in Annex 1.

1.8 QA/QC

Quality assurance/quality control (QA/QC) and verification procedures are an integral part of the preparation of the national GHG inventory. Formal QA takes place during a review by the EPWG and regular QC is performed systematically during the inventory preparation process and consists of a variety of data, calculation procedure and emission trend checks. In addition, the Greenhouse Gas Division of Environment Canada has begun scoping out its QA/QC plan as required by Intergovernmental Panel on Climate Change (IPCC) Good Practice Guidance (IPCC/OECD/IEA, 2000), developing QC procedures and building its data/information archive.

To ensure that the inventory is inline with IPCC Good Practice Guidance, the GHG Division plans to undertake further work in the following areas:

- Development of a formal QA/QC plan;
- Development of a QA/QC manual – for the inventory as a whole and by individual activity sector;
- Improved documentation and building of an archive;
- Uncertainty analysis with new QC procedures; and
- Implementation of Tier 2 QC procedures for key sources.

The methodologies used for the Canadian inventory have been evolving since the first inventory, prepared more than 10 years ago. In addition to the EPWG review, the inventory and methodologies are published on a regular basis, providing an additional opportunity for public and expert review.

Canada has also undertaken the process of identifying inventory key sources. The results of these analyses and assessments will form the foundation for future inventory improvements.

1.9 INVENTORY UNCERTAINTY

National GHG emission inventories should be accurate, complete, comparable, transparent and verifiable. However, uncertainties are an inherent part of the estimation process. Uncertainties result from many causes, including:

- Differences in the interpretation of source and sink category definitions, assumptions, units, etc.;
- Inadequate and incorrect socioeconomic activity data used to develop the emission estimates;
- Inappropriate application of emission factors to situations and conditions for which they do not apply;
- Actual empirical uncertainty of measured emission data and the basic processes leading to emissions; and,
- Lack of understanding of the emission or removal processes.

In 1994, Environment Canada completed a study of the underlying uncertainties associated with Canada's greenhouse gas (GHG) emission estimates. The result was a quantitative assessment of the reliability inherent in the 1990 inventory, as then compiled. A full discussion of the methodology used to develop uncertainties is available in the original study (McCann 1994).

The uncertainties associated with CO_2, which dominates the GHG inventory, were found to be very low. Overall, uncertainties were developed based on a stochastic model and were estimated to be about 4% for carbon dioxide (CO_2), 30% for methane (CH_4), and 40% for nitrous oxide (N_2O). It was noted that individual sector uncertainties could be even greater.

The approach taken to developing uncertainties made use of Monte Carlo stochastic computer simulations. Individual uncertainty range estimates by industry experts were skewed in some cases (i.e., not normally distributed). This necessitated the use of Monte Carlo stochastic computer simulations to develop group and then overall uncertainty estimates for each GHG. Up to 100,000 iterations were used in these simulations to provide the final estimates of uncertainty at confidence levels ranging from 85 to 95%. While the uncertainties were calculated for the 1990 inventory, many data sources and emission rates have remained the same, as have the methods used to estimate emissions. It is, therefore, still reasonable to assume that the uncertainty in the CO_2 and CH_4 emission estimates are of the same order of magnitude.

However, since the uncertainty estimates were developed for an older version of the inventory and many new sources have been added, they can only be considered approximations at this juncture. Thus, these estimates provide only rough guidance to the precision of the current inventory. Further studies of inventory uncertainty are a priority for future inventory improvement.

1.10 COMPLETENESS ASSESSMENT

The national GHG inventory, for the most part, is a complete inventory of the six GHGs required under the UNFCCC. A few minor sources are not included in the inventory such as SF_6 from electrical equipment and magnesium founderies. However, these sources are considered to be small when viewed in the context of the inventory as a whole. Further details on the completeness of the inventory can be found in the assessment of completeness (Annex 5).

2 EMISSION TRENDS, 1990–2001

2.1 SUMMARY OF EMISSION TRENDS

In the year 2001 Canada's emissions of greenhouse gases (GHGs) were 18.5% higher than they were in 1990. Between 2000 and 2001 emissions declined by 1.3%. This is the first-year-over year decline in emissions since 1991/1992. Reductions were seen mainly in the industrial and manufacturing sectors, domestic aviation, on-road vehicles used for shipping, and fugitive emissions from natural gas transmission and distribution. These reductions reflect manufacturing efficiency improvements combined with reduced production levels compared with previous years. They also reflect reduced air travel following the events of September 11, 2003 and less fuel used for space heating due to a warmer than average winter.

Growth in emissions resulted primarily from increases in fossil fuel power and steam generation and production of fossil fuels, mainly for export.

2.2 EMISSION TRENDS BY GAS

Carbon dioxide is, by far, the largest contributor to Canada's GHG emissions. Figure 2-1 shows how little the percentage contributions of the six GHGs has changed between 1990 and 2001. CO_2 has only changed in proportion from 77.7% of emissions in 1990 to 78.9% in 2001.

2.3 EMISSION TRENDS BY SOURCE

2.3.1 ENERGY SECTOR (2001 GHG EMISSIONS, 584 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 81% of total Canadian GHG emissions in 2001 (529 Mt and 55 Mt, respectively). Between 1990 and 2001, fuel combustion-related emissions increased 24.6%, while emissions from fugitive releases rose 44.4%. Five-year changes in both fuel combustion and fugitive emissions through the period 1990–2001 are shown in Table 2-1.

Figure 2-1: Canada's GHG Emissions by Gas, 1990 and 2001

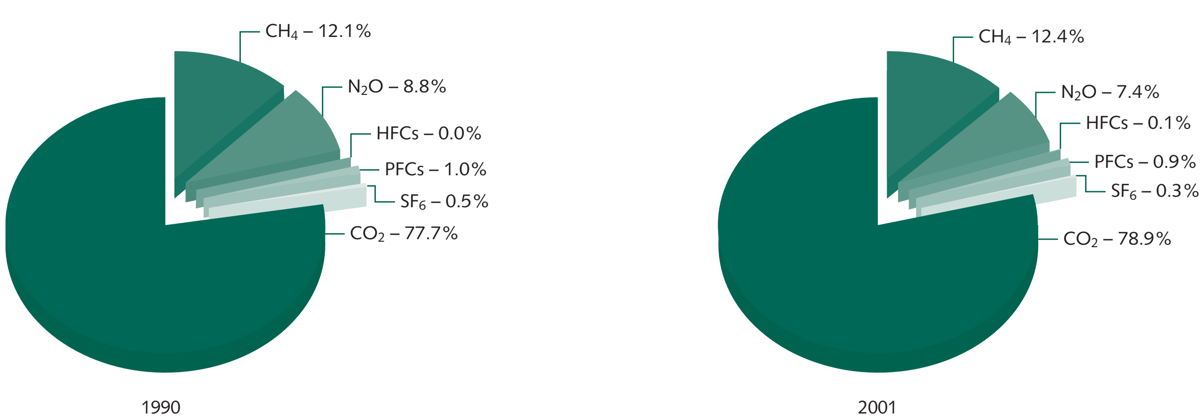


TABLE 2-1: Energy GHG Emissions by UNFCCC Sector, 1990–2001

Greenhouse Gas Sources/Sinks	Mt CO_2 Equivalent 1990	1995	2000	2001
1. Energy	**473**	**513**	**593**	**584**
A. Fuel Combustion (Sectoral Approach)	**435**	**463**	**539**	**529**
1. Energy Industries	147	156	203	204
2. Manufacturing Industries and Construction	62.6	62.0	64.4	60.1
3. Transport	153	169	190	187
4. Other Sectors	72.2	76.7	80.8	77.0
B. Fugitive Emissions from Fuels	**38**	**50**	**54**	**55**
1. Solid Fuels	1.9	1.7	0.9	1.0
2. Oil and Natural Gas	36	48	53	54

On a per gas basis for the Energy sector, CO_2 accounted for the majority of emissions in 2001 (566.2 Mt), while CH_4 contributed 93.5 Mt and N_2O accounted for 51.4 Mt. The largest contributor to emissions in the Energy sector is energy industries (fossil fuel production, electricity, and heat production), which accounted for 28.4% of energy emissions, with emissions from the transport sector close behind, with 26% of energy-related emissions.

2.3.1.1 Emissions from Fuel Combustion (2001 GHG emissions, 529 Mt)

Emissions of GHGs from fuel combustion rose from 435 Mt in 1990 to 529 Mt in 2001, a 21.7% increase. Fuel combustion emissions are divided into the following UNFCCC categories: energy industries,[17] manufacturing industries and construction, transport, and other sectors. The other sectors category comprises emissions from the residential and commercial subsectors, as well as minor contributions of stationary fuel combustion emissions from agriculture and forestry.

Table 2-1 shows the changes in the emissions of each sector in the fuel combustion category. The sector in which emissions have increased the most since 1990 is energy industries (39.2% growth in GHG emissions). This sector also produced the largest amount of emissions within the energy category for 2001, at 204 Mt. Emissions from other sectors (the main contributors being residential and commercial subsector emissions) increased 6.6% between 1990 and 2001, however, emissions from the manufacturing industries and the construction sector declined by 3.7%. A more comprehensive account of the changes in emissions is presented in the individual sectoral sections of the energy category below.

Energy Industries (2001 GHG emissions, 204 Mt)

The energy industries sector is the largest source of fuel combustion emissions and accounts for 71.6% of Canada's total GHG emissions. Fuel combustion emissions included in this sector are from stationary sources only, from the production, processing, and refining of energy (electricity generation, oil and natural gas production, refining of petroleum products, etc.). In 2001, emissions from this sector totalled 204 Mt, an increase of 39.2% from the 1990 level of 147 Mt. UNFCCC subcategories within this sector include public electricity and heat production, petroleum refining, and manufacture of solid fuels and other energy industries.

Public Electricity and Heat Production[18]

This sector accounted for 19% (137 Mt) of Canada's 2001 GHG emissions and was responsible for 37.2% of the total emissions growth between 1990 and 2001. Overall, emissions have increased almost 43.9%, or 41.8 Mt, since 1990.

Hydroelectric and coal-fired generation continue to be the major sources of Canadian electricity, accounting for 58% and 19%, respectively, of total national generation in 2001. Nuclear energy provided 13%, natural gas 6%, and oil 3%. Of this total, nearly 6% was produced by industrial, non-utility generating sources. Total annual production increased over 22% between 1990 and 2001. This rate of growth exceeds the population growth rate of 12.3% for the same

17 The UNFCCC energy industries sector is composed of the following Canadian Greenhouse Gas Inventory (CGHGI) sectors: *fossil fuel industries* and *electricity and heat generation.*

18 The public electricity and heat production sector includes emissions from utilities and industrial generation.

period, pointing to a rapid increase in per capita demand over the period.

In 2001, the dominant proportion of GHG emissions, nearly 79%, was from the use of coal (which has much higher emission intensity than natural gas), while natural gas and oil accounted for 13% and 8%, respectively (Table 2-2). The higher GHG intensity of coal is reflected in the fact that it accounted for only 19% of the total electricity generated in Canada in 2001.

TABLE 2-2: GHG Emissions from Electricity and Heat Generation, 1990–2001

Electricity Generation Source Emissions	Mt CO_2 Equivalent 1990	1995	2000	2001
Coal*	78,800	83,100	104,800	103,400
Oil	11,400	6,990	8,800	10,600
Natural Gas	4,050	9,150	16,100	16,800

* Includes coal products

The growth in emissions is directly related to rising demand for power and the increasing use of fossil fuels 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 declined in the latter part of the 1990s when nuclear facilities in Ontario were decommissioned for maintenance and rehabilitation. Although hydroelectric generation increased nearly 12.2% from 1990 to 2001, production was reduced substantially in 1997 and 1998 due to low reservoir levels (Statistics Canada, 1998). Although imports increased to meet the supply/demand gap, growth in demand was largely met by domestic generation from fossil fuels, primarily coal and natural gas. Coal-fired generation increased 43.4%, while natural gas production increased more than 267% between 1990 and 2001.[19]

Petroleum Refining and Manufacture of Solid Fuels and Other Energy Industries[20]

The petroleum refining sector includes emissions from the combustion of fossil fuels during the production of refined petroleum products. The manufacture of solid fuels and other energy industries sector encompasses fuel combustion emissions associated with the upstream oil and gas industry (including upgrading of bitumen to synthetic crude oil). As shown in Table 2-3, between 1990 and 2001, emissions from the petroleum refining sector increased almost 11% (from 26 Mt to 29 Mt), while emissions from the manufacture of solid fuels and other energy industries sector rose to 38 Mt, 50% higher than the 1990 level of 25 Mt. The combined effect for the two sectors is an increase of over 30% in this sector. 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, 1990–2001

GHG Source Category	Mt CO_2 Equivalent 1990	2000	2001	1990–2001
Petroleum Refining	26.1	27.8	29.1	11%
Manufacture of Solid Fuels and Other Energy Industries	25.4	39.1	38.2	50%
TOTAL	**51.5**	**66.9**	**67.3**	**31%**

Manufacturing Industries and Construction (2001 GHG emissions, 80.2 Mt)

Emissions from the manufacturing industries and construction sector include the combustion of fossil fuels by all manufacturing industries, the construction industry and mining.[21] In 2001, GHG emissions were 80.2 Mt, a decrease of 3.7% from the 1990 level of 83.3 Mt. Over the short term (1999–2001), emissions also decreased by 5.6% mainly due to declining emissions in the Manufacturing Industries sector.[22]

19 The most recent information for the year 2001 is not yet available from Statistics Canada.

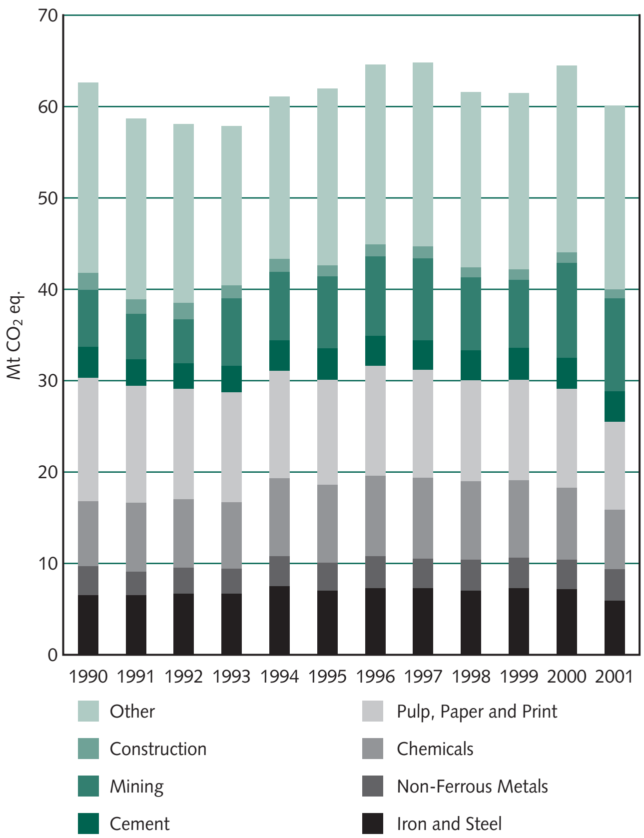
20 In the CGHGI, the fossil fuel industries category encompasses both the *petroleum refining* and *manufacture of solid fuels and other energy industries* subsectors.

21 The CGHGI categories that constitute this UNFCCC sector are *manufacturing, construction,* and *mining* (refer to Table S-1 and Table S-2).

22 Emission decreases were recorded in the Iron and Steel, Chemicals, Pulp and Paper and Other Manufacturing subsectors.

Overall, this sector was responsible for 11.1% of Canada's total GHG emissions for 2001. Figure 2-2 provides an overview of the changes in emissions for the various manufacturing industries and construction between 1990 and 2001.

FIGURE 2-2: GHG Emissions from Manufacturing Industries and Construction by Subcategory, 1990–2001



2.3.1.2 Transport (2001 GHG emissions, 187 Mt)

Transport is a large and diverse sector accounting for 26% of Canada's GHG emissions in 2001. The sector includes emissions from fuel combustion for the transport of passengers and freight in six distinct subcategories:

- Road transport;
- Aviation;
- Marine;
- Rail;
- Off-road ground transport (e.g., construction or agriculture vehicles); and
- Pipelines (pipelines, both oil and gas, represent non-vehicular transport).

From 1990 to 2001, GHG emissions from transport, driven primarily by energy used for personal transportation, rose 22.4%, or 34.2 Mt. Overall, transport was the second leading emissions-producing sector in 2001, contributing 34.2 Mt and accounting for over 30.4% of Canada's emissions growth from 1990 to 2001.

Emissions from light-duty gasoline trucks (LDGT), the subcategory that includes SUVs and vans, have increased 15.7% since 1990 (from 21.7 Mt in 1990 to over 39 Mt in 2001), while emissions from cars (light-duty gasoline vehicles, or LDGV) have decreased 9.3% (from 53.7 Mt in 1990 to 48.7 Mt in 2001) (Table 2-4).

TABLE 2-4: GHG Emissions from Transport, 1990–2001

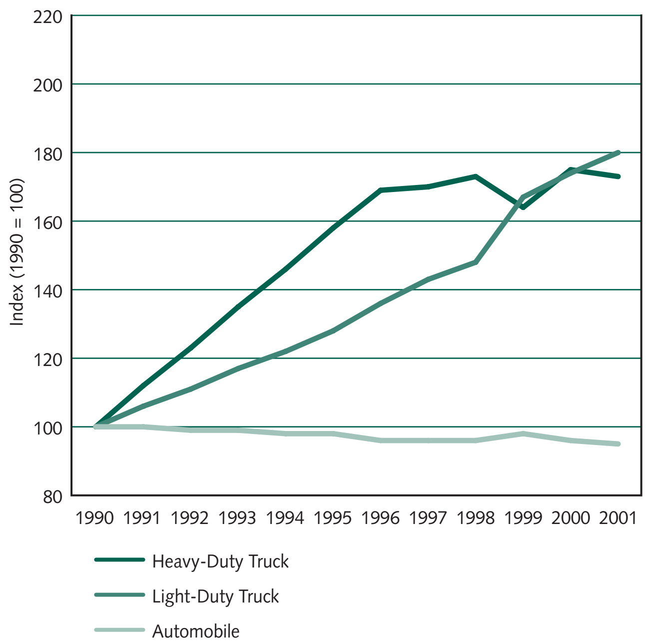
Greenhouse Gas Categories	1990	1995	2000	2001
b. Transportation	**153,186**	**168,965**	**190,329**	**187,430**
Domestic Aviation	10,738	10,860	13,723	12,121
Road Transportation	106,860	118,700	131,460	133,519
Gasoline Automobiles	53,740	51,313	48,254	48,741
Light-Duty Gasoline Trucks	21,754	28,489	37,564	39,426
Heavy-Duty Gasoline Vehicles	3,139	4,757	4,374	4,125
Motorcycles	230	214	239	242
Diesel Automobiles	672	594	605	596
Light-Duty Diesel Vehicles	591	416	645	643
Heavy-Duty Diesel Vehicles	24,524	30,815	38,676	38,606
Propane and Natural Gas Vehicles	2,210	2,100	1,104	1,140
Railways	7,111	6,430	6,668	6,554
Domestic Marine	5,049	4,375	5,107	5,513
Others	23,428	28,600	33,370	29,722
Off-Road	16,528	16,592	22,094	19,466
Pipelines	6,900	12,008	11,276	10,256

For full details of all years, please refer to Annex 10.

The growth in transport sector emissions may be due not only to the 19% increase in the total vehicle fleet, but also to a shift in light-duty vehicle purchases from cars (LDGV) to trucks (LDGT) which, on average, emit 40% more GHGs per kilometre.

Over the period 1990–2001, the increase of 17.6 Mt and 14.1 Mt for LDGT and heavy-duty diesel vehicles (HDDV), respectively, indicates the trend toward increasing use of SUVs for personal transportation and heavy-duty trucks for freight transport (Figure 2-3).

FIGURE 2-3: Trends in Vehicle Populations for Canada, 1990–2001



In 2001, emissions from HDDVs contributed nearly 38.6 Mt to Canada's total GHG emissions (an increase of 57.4% from 1990 emissions). Although emissions from heavy-duty gasoline vehicles (HDGV) were substantially lower, at 4.1 Mt for 2001, this subcategory exhibited an increase of almost 31.4% over the same period. 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[23] in the transport sector also increased between 1990 and 2001. Emissions from off-road vehicles (snowmobiles, all-terrain vehicles, excavating, construction, etc.) rose 17.8%, from 16.5 Mt to 19.5 Mt.

The pipeline emissions included in the transport sector are combustion emissions primarily from natural gas transport. Due to increasing activity in the Energy sector, these emissions rose 48.6%, from 6.9 Mt in 1990 to 10.3 Mt in 2001.

2.3.1.3 Other Sectors (2001 GHG emissions, 77 Mt)

The Other sectors category comprises fuel combustion emissions from the residential and commercial subsectors, as well as stationary fuel combustion emissions from both the agriculture and forestry sectors.[24] Overall, this category exhibited increases in GHG emissions of 6.6%, while individual subsectors within it demonstrated a variety of changes. These changes, which are reflected in Annex 10, are discussed below.

Residential and Commercial

Emissions in these subsectors arise primarily from the combustion of fuel to heat residential and commercial buildings. Fuel combustion in the residential and commercial/institutional subsectors[25] accounted for 5.8% (41.9 Mt) and 4.6% (32.9 Mt), respectively, of all GHG emissions in 2001.

As shown in Figure 2-4, residential emissions have decreased significantly between 1990 and 2001, declining 2 Mt over this period. More recently,

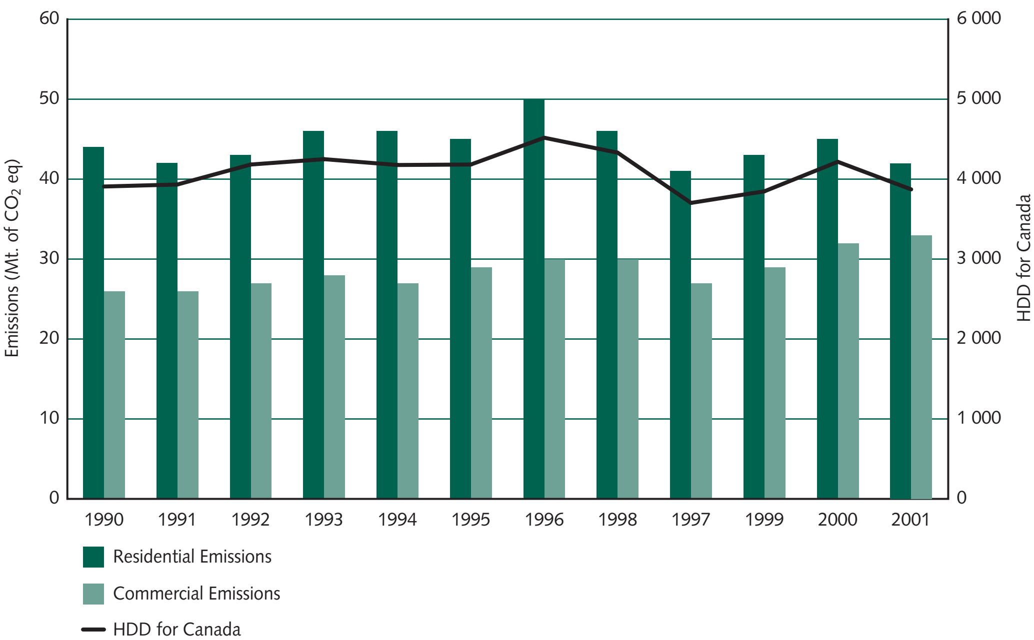
23 Off-road emissions include those from the combustion of diesel and gasoline in a variety of widely divergent activities. Examples include the use of heavy mobile equipment in the construction, mining, and logging sectors, recreational vehicles such as snowmobiles, and lawn and garden devices such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

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

25 Commercial sector emissions are based on fuel use as reported in the *Quarterly Report on Energy Supply-Demand in Canada* (Statistics Canada, Catalogue #57-003) 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.

emissions declined even more, 3.1 Mt or 6.9% between 2000 and 2001. Commercial/institutional emissions increased 27.2% between 1990 and 2001. The combined effect for the two subsectors was an increase of 5 Mt, or 4.4%. GHG emissions, particularly in the residential subsector, track heating degree-days (HDD)[26] closely (as shown in Figure 2-4). This close tracking indicates the important influence of weather on emissions on a year-to-year basis.

FIGURE 2-4: Emissions in the Residential and Commercial Sectors Relative to Heating Degree-Days, 1990–2001



Floor space in both the residential and commercial subsectors increased significantly and consistently in the same period. This upward trend was counteracted by the following two influences: fuel substitution away from petroleum products and improvements in end-use efficiency. Combined, these influences have reduced energy consumption, and thus emissions, within the residential subsector (Environment Canada, 2002).

Agriculture and Forestry

Stationary fuel combustion-related emissions from the agriculture and forestry sectors amounted to 2.2 Mt in 2001, a decrease in emissions of 8.6% since 1990.

Emission declined even more rapidly between 2000 and 2001, decreasing 13.6%.

2.3.1.4 Fugitive Emissions from Fuels (2001 GHG emissions, 54.8 Mt)

As stated above, fugitive emissions from fossil fuels are the intentional or unintentional releases of GHGs from the production, processing, transmission, storage, and delivery of fossil fuels. Released gases that are combusted before disposal (e.g., flaring of natural gases at oil and gas production 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 7.6% of Canada's total GHG emissions for 2001 and contributed 15% to the growth in emissions between 1990 and 2001.

26 Heating degree-days are calculated by determining the average, cross-Canada number of days below 18°C and multiplying this value by the corresponding number of degrees below this temperature.

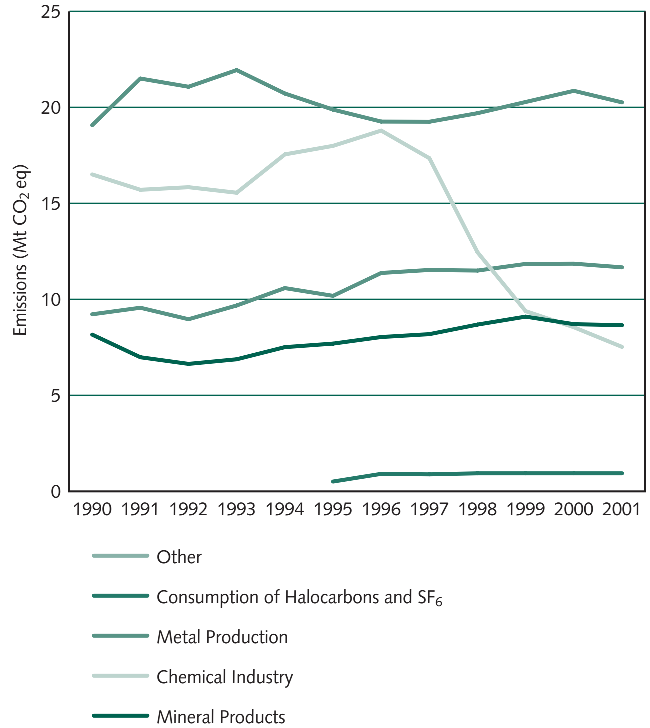
Table 2-1 summarizes the changes in fugitive emissions by the UNFCCC subcategories, solid fuels and oil and natural gas. In total, fugitive emissions grew by about 44.4% between 1990 and 2001, from 37.9 Mt to nearly 54.8 Mt, with emissions from the oil and natural gas category contributing over 96% of the total fugitive emissions in 2001. Although fugitive releases from the solid fuels sector (e.g., coal mining) decreased by almost 1 Mt (over 48%) between 1990 and 2001 due to the closing of many mines in eastern Canada, emissions from oil and natural gas increased over 49% during the same period.

This rise in emissions is largely due to the increased production of natural gas and heavy oil since 1990, resulting mainly from increasing export of oil and natural gas to the United States.

2.3.2 INDUSTRIAL PROCESSES SECTOR (2001 GHG EMISSIONS, 49 MT)

This category comprises emissions from industrial processes where GHGs are a direct by-product of those processes. In 2001, industrial process emissions accounted for approximately 6.8% of all GHG emissions, for a total of 49 Mt, and came from diverse industrial processes defined as follows: mineral products, chemicals industry, metal production,[27] consumption of halocarbons and SF_6, and other. Figure 2-5 illustrates the changes in each of these sectors over the period 1990–2001, and Table 2-5 provides a percentage breakdown of the emissions, by subcategory, for 2001.

FIGURE 2-5: GHG Emissions from Industrial Processes by Sector, 1990–2001



27 The UNFCCC Metal Production sector includes the following sectors denoted in the CGHGI's industrial processes category: ferrous metal production and aluminium and magnesium production (see Annex 8).

TABLE 2-5: GHG Emissions from Industrial Processes by Subcategory ($Mt\ CO_2$ eq), 1990–2001

Greenhouse Gas Categories	1990	1995	2000	2001
Industrial Processes				
a. Mineral Products	**8,161**	**7,691**	**8,704**	**8,650**
Cement	5,873	5,361	6,306	6,493
Lime	1,849	1,987	1,995	1,755
Limestone and Soda Use	439	343	403	403
b. Chemical Industry	**16,503**	**17,991**	**8,544**	**7,520**
Ammonia Production	5,008	6,482	6,845	5,923
Nitric Acid Production	777	782	799	795
Adipic Acid Production	10,718	10,726	900	802
c. Metal Production	**19,067**	**19,879**	**20,857**	**20,256**
Iron and Steel Production	7,585	8,440	8,511	7,920
Aluminium Production	8,611	9,561	10,032	10,315
SF_6 used in Magnesium Smelters	2,870	1,879	2,313	2,021
d. Consumption of Halocarbons	**–**	**508**	**936**	**936**
e. Other and Undifferentiated Production	**9,218**	**10,180**	**11,854**	**11,664**

Emissions from most sources within this sector declined between 1990 and 2001; overall sectoral emissions decreased by 3.9 Mt. The largest single source of emissions in 2001 was the metal production category, with nearly 20.3 Mt of emissions, as shown in Table 2-5. The other and undifferentiated production category accounts for the largest increase in emissions (about 26.5%) since 1990. These emissions are primarily from non-energy uses of fossil fuels, including the use of natural gas to produce hydrogen in the oil upgrading and refining industries, the use of natural gas liquids (NGLs) as feedstock in the chemicals industry, and the use of lubricants.

Despite a rising trend at the beginning of the decade, emissions declined significantly through 1997–2001: total emissions in 2001 were 7.4% below 1990 levels. This is due primarily to emission reductions resulting from the addition of emission abatement technology in an adipic acid production process at Canada's sole production facility based in Ontario. This technology contributed to reductions of 54.4% in the chemical industry subsector emissions over the period 1990–2001.

2.3.3 SOLVENT AND OTHER PRODUCT USE SECTOR (2001 GHG EMISSIONS, 0.5 MT)

While accounting for only 0.07% (0.5 Mt) of Canada's total GHG emissions in 2001, emissions in the solvent and other product use sector increased by 12.2% over 1990 levels. The majority of emissions in this category are related to the use of N_2O as an anaesthetic in various dental applications and as a propellant in aerosol products.

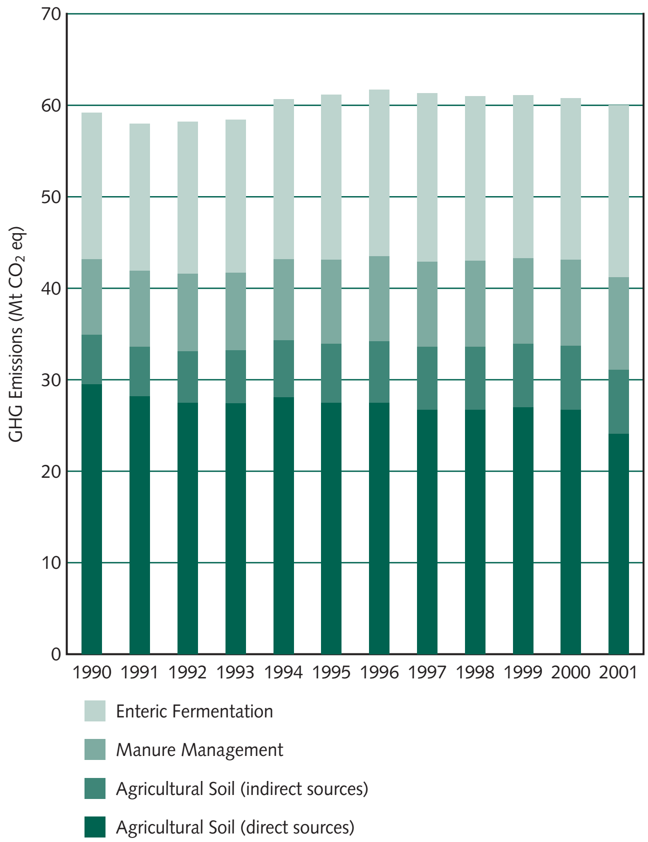
2.3.4 AGRICULTURE SECTOR (2001 GHG EMISSIONS, 60 MT)

Canada's Agriculture sector is composed of approximately 250,000 farms, 98% of which are family owned. Agricultural emissions accounted for 8.3% (or 60 Mt) of year 2001 emissions for Canada, an increase of 1.3% since 1990. All of these emissions are from non-energy sources, with N_2O accounting for approximately 60% of sectoral emissions, CH_4 for nearly 40%, and a net sink of CO_2 from agricultural soils, which was estimated to remove 0.3 Mt CO_2-eq in 2001. Emissions from all anthropogenic activities within the Agriculture sector, excluding fuel combustion, are covered in this section.

The processes that produce GHG emissions in the Agriculture sector are enteric fermentation[28] by domestic animals, manure management, fertilizer application, and cropping practices that result in GHG emissions and removals from soils. Relative changes in emissions in each of these categories are shown in Figure 2-6.

28 Enteric fermentation is a digestive process whereby carbohydrates are broken down by microorganisms into simple molecules for absorption into the bloodstream. This process results in methanogenesis in the rumen, and the methane is emitted by eructation and exhalation. Some methane is released later in the digestive process by flatulation. Animal eructation and manure methane emissions are directly proportional to animal populations. Emission estimates have been made based on animal populations and emission rates that reflect conditions in Canada.

FIGURE 2-6: GHG Emissions from Agricultural Sources, 1990–2001



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

- Livestock-related emissions due to enteric fermentation from domestic animals (i.e., digestive processes that release CH_4) and manure management (which releases CH_4 and N_2O). These emissions accounted for nearly 48% of total Agriculture's GHG emissions in 2001.
- Soil management and cropping practices contribute to N_2O emissions (due to fertilizer application and cropping practices). These sources accounted for about 52% of total Agriculture's GHG emissions in 2001. However, with increased adoption of no-till and reduction in frequency of summer-fallow, agricultural soils removed 0.3 Mt CO_2-eq from the atmosphere.

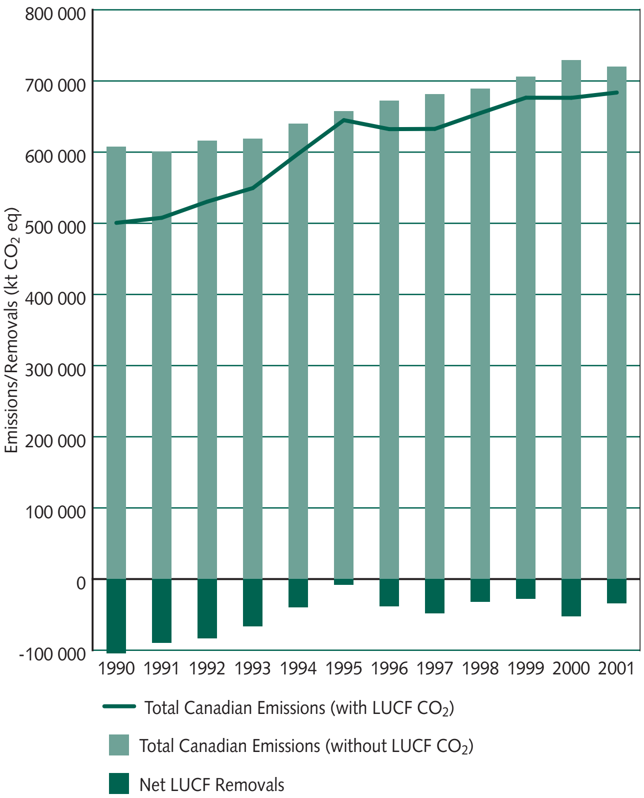
In the 1990–2001 period, livestock emissions increased 19% and soil N_2O emissions increased by 15%. Changes in agricultural practices caused soils to switch from being a source of 7.6 Mt CO_2-eq in 1990 to a sink of 0.3 Mt in 2001. Most of the increase in livestock-related emissions is attributable to increased cattle production. Uncertainty in the estimates of emissions from Agriculture is moderate to high.

In the 2001 GHG inventory for the Agriculture sector, no major changes were made to the methodologies. A new source category, emissions of CO_2 from cultivation of organic soils, was added. The emissions from this source were estimated to be 0.3 Mt CO_2-eq annually for the period 1990 to 2001.

2.3.5 LAND-USE CHANGE AND FORESTRY SECTOR (2001 GHG EMISSIONS, 2 MT)

Estimates of net CO_2 and other GHG fluxes in Canada's Land-Use Change and Forestry (LUCF) sector have been reported since 1996. In 2001, the net flux amounts to a removal of 34 Mt CO_2 eq, declining from 105 Mt in 1990. In keeping with the UNFCCC Reporting Guidelines (IPCC, 1997), CO_2 fluxes in the LUCF sector are excluded from national inventory totals. The LUCF net CO_2 removals, if included, would decrease the total Canadian GHG emissions by 5% in 2001.

FIGURE 2-7: Contribution of LUCF Sector to Canada's GHG Emission Totals, 1990–2001



In 2001 the non-CO_2 emissions alone added 2.1 Mt CO_2 eq, or 0.3%, to total Canadian emissions.

Overall, the LUCF sector, calculated as the sum of the net CO_2 flux (a removal) and non-CO_2 emissions, remained a net sink for the period 1990–2001. The general trend indicates a decline in the net removal, but the trend is not consistent and displays high interannual variability.

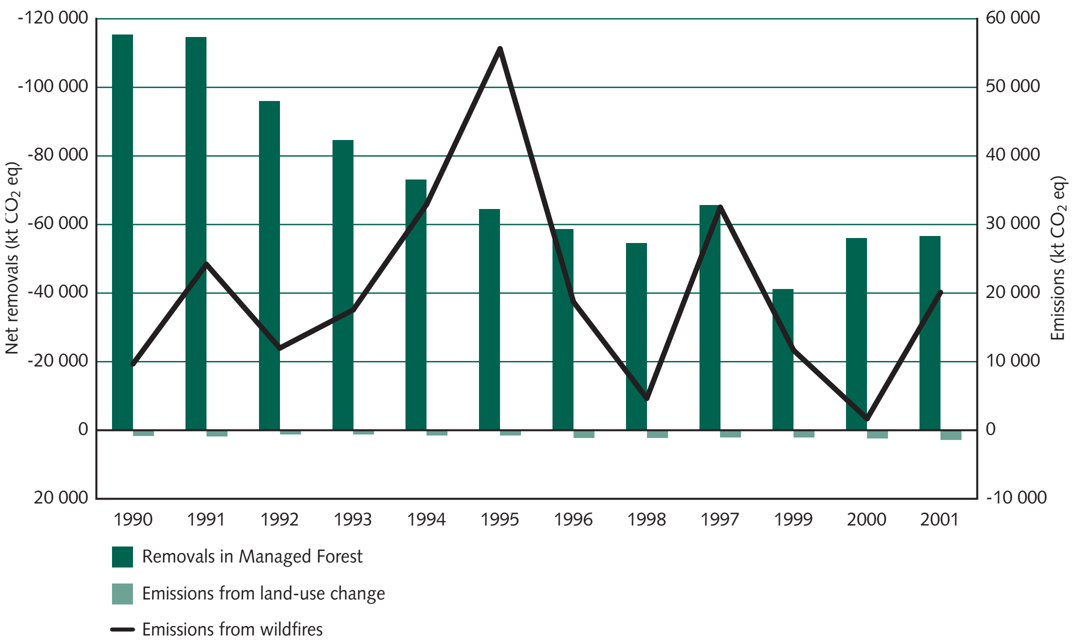
The flux estimates themselves are characterized by a high degree of uncertainty and should be treated as first approximations only. The magnitude of the net forest sink is likely to be significantly misrepresented due to the omission of several carbon stocks, notably harvested wood products and forest soils. On-going work, involving the concerted activities of several government departments and the university community, aim at improving the information sources and support the development of a comprehensive monitoring, accounting and reporting system in the LUCF sector (see Chapter 7).

In the LUCF sector, GHG emissions to the atmosphere from sources and removals by sinks are estimated and reported for four categories:

- Changes in forest and other woody biomass stocks;
- Forest and grassland conversion;
- Abandonment of managed lands; and
- CO_2 emissions and removals from soils.

Of these, the largest and most influential in terms of total emissions/removals is the first category: changes in forest and other woody biomass stocks (Figure 2-8). It generally represents more than 90% of all CO_2 removals in the LUCF sector and exerts an overriding influence on the sectoral trend. The net GHG flux reflects the difference between carbon uptake by tree growth, and emissions due to disturbances, specifically harvesting activities and wildfires. While the CO_2 uptake has declined by 8% during the decade, CO_2 releases associated with harvesting activities have increased significantly, as suggested by a steady rise in the domestic production of industrial roundwood, which peaked in 1999. The general decline in sinks over the period reflects the sensitivity of the accounting model to changes in commercial forest management. Note, however, that the Canadian forest products sector retains an estimated 45% of the carbon harvested annually (Apps et al., 1999); including this component in the calculations would significantly reduce the apparent impact of industrial activity on sinks. The frequency of wildfires and extent of commercial forest burned add considerable interannual variability to the estimates (Figure 2-8).

FIGURE 2-8: LUCF Sector Emissions and Removals by Subcategory, 1990–2001



Planned improvements include the inclusion of all carbon pools in the forest carbon accounting, incorporating the 2001 update of Canada's Forest Inventory, and spatially explicit account of fire emissions in the wood production forest (see Chapter 7).

Land-use changes comprise the remnant of the LUCF sources and sinks. Overall, land-use changes represent net GHG emissions. This sub-category includes carbon sequestration in vegetation and soils on abandoned agricultural lands reverting to natural vegetation, and emissions from these two pools upon the conversion of forests and grasslands to other land uses (see Section 7.2). CO_2 removals were stable during the 1990–2001 period, while emissions increased by 14%, for a net 41% increase in emissions, from 1.7 to 2.9 Mt CO_2. These minor contributions to LUCF sources and sinks (less than 1%) should also be weighted by the large uncertainty associated with the poor information on land-use changes in the Canadian landscape. Consequently, the impact of land-use changes may be significantly underestimated in the present inventory.

The coming years will witness significant efforts to improve the quality and availability of land-use change information in Canada. Ongoing, multi-departmental initiatives aim at facilitating the creation and exchange of consistent land cover and land-use data among the various jurisdictions, which will improve the overall ability to track and document land transfers between different uses. However, the inventory improvements which will result from these large-scale initiatives may not be realized for a few years hence.

Overall, the trends observed in the LUCF sector largely reflect changes in industrial forestry activity during the 1990s. The methodology does not include all carbon sources and sinks: forest soils and wood products, two significant carbon pools, are not accounted for in the carbon stock changes in the forest. In the future, improved land-use change information will allow a more accurate assessment of the associated emissions and removals.

2.3.6 WASTE SECTOR (2001 GHG EMISSIONS, 24.8 MT)

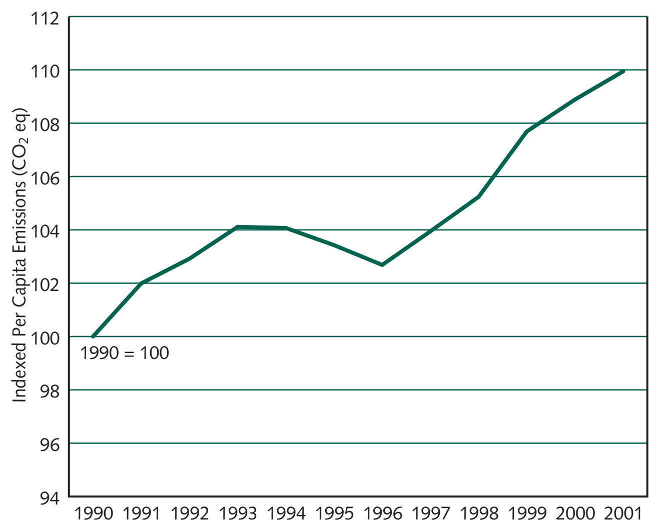
From 1990 to 2001, CO_2 equivalent emissions from waste increased 23.4%, surpassing the population growth of 12.2%. By 2001, these emissions represented 3.4% of Canadian GHG emissions, about the same percent contribution as in 1990. These emissions consist almost entirely of CH_4 produced by the decomposition of biomass in municipal solid waste (MSW). In 2001, emissions from solid waste disposal on land totalled over 23 Mt, while municipal wastewater and incinerated material derived from fossil fuel products contributed 1.4 Mt and 0.3 Mt, respectively. The tables in Annex 10 summarize the annual changes in each of the three Waste sector subcategories between 1990 and 2001.

CH_4 emissions from landfills increased by nearly 24.4% between 1990 and 2001 despite an increase in landfill gas capture and combustion of almost 33% over the same period. In 2001, there were 42 landfill gas collection systems (Environment Canada, 1999) capturing about 280 kt of CH_4, for a reduction of 5.9 Mt CO_2 eq per year. There were eight landfill gas-to-energy plants generating about 85 MW of electricity and eight more landfill gas systems feeding nearby industries.

GHG emissions from landfills are tabulated for two types of waste, MSW and wood waste landfills, both of which produce CH_4 anaerobically.[29] The CH_4 production rate at landfills 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.

Per capita emissions from this sector increased 10% from 1990 to 2001, due primarily to the increasing emissions from landfills (Figure 2-9). CH_4 capture programs at landfills have made significant contributions to reductions in emissions during this period. Trend growth exceeds population increases, since material landfilled in past decades is still contributing to CH_4 production. The decline in per capita growth observed in the mid-1990s, shown in Figure 12, is directly attributable to CH_4 capture programs at landfills.

FIGURE 2-9: Per Capita GHG Emission Trend for Waste, 1990–2001



29 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 wood products pool within the LUCF 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.

3 ENERGY (CRF SECTOR 1)

3.1 FUEL COMBUSTION (CRF 1.A)

The Fuel Combustion category includes all emissions from fuel combustion activities. Major source categories include: energy industries, manufacturing industries, transport and other (residential, commercial, etc). The general methods used to calculate emissions from fuel combustion are consistent throughout and are presented in Annex Table A8-1 (Methodology and Data for Estimating Emissions from Fuel Combustion).

3.1.1 ENERGY INDUSTRIES

3.1.1.1 Source Category Description

This category includes all emissions from stationary fuel combustion sources in the production, processing, and refining of energy. The category is subdivided into subcategories of public electricity and heat production, petroleum refining, and manufacture of solid fuels and other energy industries (which consists primarily of oil and natural gas production).

Emissions from flaring activities related to the production, processing, and refining of fossil fuels are reported as fugitive emissions.

Public Electricity and Heat Production

The electricity supply grid in Canada includes hydropower, thermal combustion-derived electricity, nuclear, wind, and tidal power. The total power generated from wind, tidal, and solar power is very small. Nuclear, hydropower, wind, solar, and tidal generation are not direct emitters of GHGs. Therefore, emission estimates are made only for thermal combustion-derived electricity.

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. (Initial heat may be produced by light fuel oil, natural gas, kerosene, or diesel oil.) Reciprocating engines use light 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

Crude oil is refined by distillation and other processes, into petroleum products such as gasoline and diesel oil. The heat required for these processes is generated by combusting either internally generated fuels (e.g. refinery fuel gas) or purchased fuels (e.g. natural gas). Carbon dioxide is also generated as a by-product during the production of hydrogen (steam reforming of natural gas). These are process-related emissions and reported accordingly under the Industrial Processes category.

Manufacture of Solid Fuels and Other Energy Industries

This sector comprises fuel combustion emissions associated with the upstream oil and gas industry (not including pipeline transmission systems) and coal mining.

3.1.1.2 Methodological Issues

Emissions for all sub sectors are calculated following the methodology described in Annex Table A8-1 and are based on national fuel consumption statistics reported in the Quarterly Report on Energy Supply and Demand (QRESD). The method is consistent with an IPCC Tier 2 method.

Public Electricity and Heat Generation

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

IPCC Inventory Guidelines 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 section regardless of whether the energy is for sale or internal use. The rationale for this is that the IPCC recognises 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 *QRESD* does distinguish industrial electricity generation data, and aggregates the data into one category titled industrial electricity generation. As a result, the GHG inventory does not allocate industrial electricity generation emissions to specific industrial subsectors, these emissions are lumped together and reported with Public Electricity and Heat generation.

Petroleum Refining

Emissions for this category are calculated using all fuel use attributed to the petroleum refining industry in the QRESD. 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. Included in this category are emissions from the use of internally generated fuels in oil sand mining and upgrading operations.

Manufacture of Solid Fuels and Other Energy Industries

Emissions for this category are calculated using natural gas, natural gas liquids, and coal fuel-use data reported for fossil fuel producers, titled *producer consumption*, in the QRESD. The fuel-use data in the QRESD includes volumes of flared fuels. However, flaring emissions are calculated and reported separately in the fugitive category. Flaring emissions reported in the fugitive category are subtracted from the data derived from the QRESD to avoid double counting of emissions. Any emissions resulting from commercial fuel purchases to the petroleum production and coal mining industries are reported within the mining sector (Section 3.1.2).

3.1.1.3 Uncertainties and Time-series Consistency

The uncertainties for the energy industry category are largely dependent on the collection procedures used for the underlying activity data, as well as how representative the emission factors are 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-market fuels (such as field uses of natural gas, and refinery fuel gas).

The estimates for the energy industries category are consistent over time and calculated using the same methodology.

3.1.1.4 QA/QC and Verification

Additional QA/QC specific to the energy industries category include comparisons of the data for the petroleum refining category against a data set developed independently by the Canadian Industrial End-use Energy and Data Analysis Center (CIEEDAC) in collaboration with the industry.

3.1.1.5 Recalculations

The underlying fuel-use data was updated by Statistics Canada and revised for the years 1999 and 2000 and estimates were recalculated accordingly. No other recalculations were made to this category.

3.1.1.6 Planned Improvements

Consideration will be given to revising the emission factors for petroleum coke and refinery fuel gas usage to better reflect current technologies and processes. Otherwise, there are no planned improvements to the methodology for this category.

3.1.2 MANUFACTURING AND CONSTRUCTION

3.1.2.1 Source Category Description

This sector comprises emissions from the combustion of fossil fuels by all mining, manufacturing and construction industries. The UNFCCC has assigned six subsectors under the manufacturing industries and construction category.

Emissions from the combustion of fuels by industries within this category for the generation of electricity or steam for sale are assigned to the Energy Industries sector. As discussed earlier (section 3.1.1), this allocation is contrary to the recommendations of the IPCC Guidelines, which ask that emissions associated with the production of electricity or heat by industries be allocated to the industries generating the emissions. Unfortunately, at present, industrial electricity generation emissions have not been allocated to the appropriate industrial subsectors because fuel-use data at this level of disaggregation are not available.

Emissions of CH_4 and N_2O from the combustion of biomass are included in the pulp and paper industrial subsector. CO_2 emissions from biomass combustion are not included in totals but are reported separately 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 process category.

3.1.2.2 Methodological Issues

Fuel combustion emissions for each subsector within the manufacturing industries and construction sector are calculated using the methodology described in Annex Table A8-1, which is consistent with an IPCC tier 2 method. Emissions generated from the use of transportation fuels (e.g., diesel and gasoline) are reported under the Transport category (Section 3.1.3). Methodological issues specific to each manufacturing subsector are identified below.

Iron and Steel

Fuel-use data for this sector were obtained from the QRESD (Statistics Canada, #57-003), reported as iron and steel (SIC 291 or NAICS 3311, 3312, and 33151). Emissions associated with the use of metallurgical coke have been allocated to the Industrial Processes section because the coke is assumed to be used as a reagent for the reduction of iron ore in blast furnaces.

Non-Ferrous Metals

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

Chemicals

All fuel-use data for this sector were obtained from the QRESD (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 category.

Pulp, Paper and Print

All fuel-use data for this sector were obtained from the QRESD (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.

Food Processing, Beverages and Tobacco

This industrial subcategory is a small energy user and fuel use from this sector is included in the other manufacturing category of the QRESD. Emissions from the food processing, beverage, and tobacco sector are included in the Other: Manufacturing Industries and Construction category.

Other: Manufacturing Industries and Construction

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

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

3.1.2.3 Uncertainties and Time-series Consistency

Uncertainties have been estimated to be in the range of 3-8% for the combustion of individual fossil fuels (McCann 1994). The underlying fuel quantities and emission factors are expected to have a low uncertainty because they are predominantly commercial fuels which have consistent properties and accurate quantity tracking.

The estimates for the manufacturing industries category are prepared in a consistent manner over time using the same methodology.

3.1.2.4 QA/QC and Verification

The underlying energy data are reported to the statistics agency (Statistics Canada) in two streams, one from distributors of fuels and the other from actual users of fuel through a fuel use consumption survey. The two data sets are compared and reconciled by Statistics Canada as a quality control measure. Furthermore, a university research center (CIEEDAC) calculates and analyses emissions based on the Industrial Consumption of Energy Survey data from

Statistics Canada. These estimates are cross-checked with the Inventory and are comparable.

3.1.2.5 Recalculations

The underlying fuel-use data was revised by Statistics Canada for the years 1999 and 2000. These estimates were recalculated accordingly. No other recalculations were made to this category.

3.1.2.6 Planned Improvements

There are no planned improvements to the methodology for this category.

3.1.3 TRANSPORT

3.1.3.1 Source Category Description

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

- Civil aviation
- Road transportation
- Railways
- Navigation
- Other transportation

3.1.3.2 Methodological Issues

Fuel combustion emissions associated with the Transport sector are calculated using various adaptations of Equation A-1. 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-GEM) (Jaques et al., 1997). This model incorporates a version of the IPCC-recommended methodology for vehicle modelling (IPCC, 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). Primarily, the model is used to further disaggregate on-road total fuel volume (QRESD) to one of 23 subcategories (Bins) per province/territory.

For on-road, M-GEM uses a Vehicle Population Profile, Fuel Consumption Ratios (FCRs), Emission Control Technology Penetration Rates and Estimated Vehicle kilometers traveled (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 sector 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 emissions factors are highly dependant upon the specific pollution control devices on each vehicle. Emission factors associated with these gases vary with vehicle type and are listed in Annex Table A7-5.

To calculate final emissions, a specific combination of emission factors (CO_2, CH_4, N_2O) are 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 equivalent. 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 Canadian studies, in particular. Specific references are included in Annex Table A7-5.

Civil Aviation

This subsector includes all emissions from domestic air transport (commercial, private, military, agricultural, etc.). Although the IPCC Guidelines call for military air transportation emissions to be reported elsewhere, they have been included here. Excluded are emissions from fuel used at airports for ground transport (reported under Other transport) and fuel used in stationary combustion applications at airports. Emissions arising from fuel sold to foreign airlines are considered to be international bunkers and are reported separately.

Methodologies follow a modified IPCC Tier 1 sectoral approach. Emissions estimates are calculated based upon the quantities of aircraft fuels consumed (IPCC, 1997). Emissions are estimated using M-GEM.
Fuel consumption data from the QRESD (Statistics

Canada, #57-003), reported as domestic air travel, are multiplied by fuel-specific emission factors. Also included are aviation gasoline and aviation turbo fuels used in the public administration and commercial/institutional categories.

Road Transport

Gasoline and Diesel

M-GEM uses a far more 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, 1997). The exception is that evaporative emissions are not listed separately, but are included with the corresponding combustion sources.

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, 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 emissions purposes, Canada, the United States, and Mexico use designations that are closely aligned to those employed for use with the U.S. 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 (LDGV);
- Light-duty gasoline trucks (LDGT);
- Heavy-duty gasoline vehicles (HDGV);
- Motorcycles;
- Light-duty diesel vehicles – automobiles (LDDV);
- Light-duty diesel trucks (LDDT); and
- Heavy-duty diesel trucks (HDDT).

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[30], more advanced technology, was introduced to LDVs in North America in 1994. However, to date, research indicates that all catalytic control units increase N_2O emissions, compared with uncontrolled vehicles (De Soete, 1989; Barton and Simpson, 1995). However, after their introduction, Tier 0 catalytic control units were also shown to have deteriorating capacity to effectively reduce N_2O emission as they aged (De Soete, 1989; 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

30 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.

those from uncontrolled vehicles (De Soete, 1989; Barton and Simpson, 1995).

Natural Gas and Propane

No breakdown by vehicle classification is available for natural gas and propane vehicles. Therefore, it was assumed that virtually all such vehicles are light duty and the vast majority are automobiles. The methodology used to evaluate road transport GHG emissions follows a detailed IPCC Tier 3 method, as outlined by the IPCC (1997).

M-GEM disaggregates vehicle data and calculates emissions of CO_2, CH_4, and N_2O from all mobile sources. However, the model was developed principally to handle the complex emission calculations for road transport.

On-Road vs. 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 QRESD (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 QRESD, on-road fuel use is a subset of all (non-rail) ground transportation fuel use. The QRESD lists data on four fuels for ground transport in Canada: gasoline, diesel fuel oil, natural gas, and propane. Emissions are calculated separately for each fuel.

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

Equation 3-1:

$$E = [EF_{Category}] \times [Fuel_{Category}]$$

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 QRESD, the two are related in the following way:

Equation 3-2:

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

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, recreational vehicles, etc.)

For the purposes of the transport sector in this inventory, it was assumed that all natural gas and propane is 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-GEM from available data. The governing equation is:

Equation 3-3:

$$Fuel_{Road\ Category} = [\text{Vehicle Population}] \times [\text{Average Distance Driven/Year}] \times [\text{Fuel Consumption Ratio}]$$

These parameters are different for each vehicle type, therefore, M-GEM 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 to 2000 (DesRosiers) have been combined with Commercial VIO data sets for 1994 to 2001 (POLK). Commercial vehicle estimates for 1989 (Environment Canada 1995) provide an anchor point for the interpolation of the intervening years 1990 to 1993. Motorcycle data were obtained from Statistics Canada (#53-219) up to and including 1998. Motorcycle data for subsequent years are presently extrapolated. This source (#53-219) provided population data for all vehicles in the Canadian territories from 1990 to 1998 and subsequent years use The Canadian Vehicle Survey (CVS, Statistics Canada #53F0004XIE). The territories are not covered by the commercial databases.

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. Light-duty gasoline automobiles and trucks 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.[31] 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.

It is important to note that emission control technology penetration in Canada did not proceed at the same pace as in the United States. The differing penetration rates were due to differences in federal new-vehicle emission standards during the 1980s. Also, in Canada, the rate of penetration is not as well documented as in the United States. In many cases, penetration has had to be inferred. The estimated rate of technology split by model year used in M-GEM was based on Canadian sales (Environment Canada, 1996), commercial data (DesRosiers, 1996), regulatory information (Government of Canada, 1997), and additional international reports (IPCC, 1997) covering information from the 1970s to the present. These data were combined with data on the age distribution of vehicles by province (Philpott, 1993), reported life (Gourley, 1997), and expected deterioration rates of catalytic converters. The final result is that the on-road mix of control devices installed in vehicles for any given year can be estimated by M-GEM.

As noted, five technology categories were assigned in the light-duty gasoline automobile and light-duty gasoline truck 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 located within Annex Table A8-1. For example, the emission rate for older automobiles equipped only with non-catalytic emission control is 0.52 g CH_4/L of gasoline. For vehicles having advanced Tier 1 technology, the rate is 0.25 g CH_4/L.

Several studies report emissions of N_2O from cars equipped with and without catalytic converters (Urban and Garbe, 1980; De Soete, 1989; Prigent and De Soete, 1989; Prigent et al., 1991; Dasch, 1992). The results of these studies are comparable for non-catalyst and oxidation catalyst-equipped vehicles, but

31 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.

differ for Tier 0 three-way aged catalysts. Consistent and systematic studies on the effect of aging on catalysts are limited (De Soete, 1989; Prigent et al., 1991). Uncontrolled engine exhaust emissions contain very little N_2O. Studies show that N_2O likely represents less than 1% (between 0.4 and 0.75%) of the overall NO_x emissions from either gasoline or diesel engines without catalytic converters. However, N_2O is produced when nitric oxide (NO) and ammonia (NH_3) react over the platinum in catalytic converters. The production of N_2O is highly temperature dependent. It was found that platinum-rhodium three-way catalysts, which decrease NO_x emissions, could increase the N_2O concentration in the exhaust during catalyst light off, yet still produce very little N_2O at medium temperatures (400–500°C). A peak of N_2O formation was observed close to the catalyst light-off temperature, and the amount of N_2O emitted was found to increase 2–4.5 times after aging. The increase in N_2O emissions appeared to be due to a shift in light-off temperature caused by aging. As a consequence, the catalyst operated in the optimum temperature range for N_2O formation (De Soete, 1989; Prigent et al., 1991).

An unpublished Environment Canada study (Barton and Simpson, 1995) reports on the measurement of emissions from 14 typical pre-1994 Canadian automobiles using the standard Federal Test Procedures. All vehicles were equipped with Tier 0 three-way converters. Average tailpipe emissions were approximately 0.7 g/L for the 10 vehicles with aged converters and 0.4 g/L for the 4 vehicles with new systems. Therefore, in M-GEM, in order to account for the effect of aged Tier 0 catalysts on emissions of N_2O, vehicles within that category have been divided. Separate classifications are used for light-duty gasoline Tier 0 vehicles equipped with aged converters and for those with new three-way catalytic converters. Vehicles of model year greater than one year old are assumed to have aged units. N_2O emission rates of 0.25 and 0.58 g/L of fuel, respectively, for new and aged three-way catalyst-equipped Tier 0 automobiles have been used in the model. These emission factors can be compared with factors of 0.046 g/L for non-catalytic conversion control technology and 0.20 g/L for vehicles with oxidation catalysts. Note that these emission factors represent values that are lower than those reported in previous inventory publications. In addition, to prepare emission factors, results from a recent survey of N_2O emission studies issued by the U.S. EPA (Michaels, 1998) have been incorporated. The same study also documented EPA tests conducted in 1998 on a small sample of newer-technology North American vehicles. These vehicles were equipped with Tier 1 aged catalytic converters. Average measured N_2O emission rates were about 50% lower, under standard conditions, than those reported for Tier 0 vehicles (Barton and Simpson, 1995). On the basis of these tests, emission factors of 0.21 g/L of fuel have been adopted for Tier 1 gasoline automobiles.

Research indicates that, under standard test conditions, light-duty gasoline trucks show consistently higher emissions of N_2O per unit of fuel consumed than light-duty gasoline automobiles. As a result, higher emission factors have been adopted for light-duty trucks, for example, the LDGT N_2O emission rates used in M-GEM are 0.39 g/L for Tier 1 types and 1.0 g/L for aged Tier 0 types.

Detailed sales information was not available for vehicles other than light-duty gasoline cars and trucks. For other categories, it was necessary to employ an estimated split of significant emission control technologies.

Fuel Consumption Ratios

Fuel Consumption Ratios (FCRs), in litres of fuel per hundred kilometres, are also available in more detail for light-duty gasoline transport than 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-GEM have been adjusted to 25% above the laboratory FCR ratings (Maples, 1993). Average FCRs for all operating vehicles within each subcategory of light-duty gasoline automobiles and trucks 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 (1997).

Vehicle Kilometers Travelled (Vkmt)

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-GEM.

Road Taxed Fuel

In an effort to improve the accuracy of M-GEM, an additional check was incorporated into the model. This check compares two estimates of off-road consumption. As indicated above, using Statistics Canada data, off-road use can be calculated as the difference between total and on-road fuel 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 tax sales data for diesel oil and gasoline (Statistics Canada, #53-218). Statistics Canada records 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 QRESD (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-GEM 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

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, 1997) methodology. Fuel consumption data from the QRESD (Statistics Canada, #57-003), reported as railways, are multiplied by fuel-specific emission factors (see Annex 7).

Navigation

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, 1997) and emission estimates are performed within M-GEM. Fuel consumption data from the QRESD (Statistics Canada, #57-003), reported as domestic marine, are multiplied by fuel-specific emission factors (see Annex 7).

Emission calculations are based on estimates of fuel use reported by registered Canadian 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.

Other Transport

This subsector comprises vehicles that are not licensed to operate on roads or highways[32] and the emissions from the combustion of fuel used to propel products in long-distance pipelines.

Off-Road Transport[33]

Non-road or off-road transport (ground, non-rail, vehicles) includes emissions from both gasoline and diesel fuel combustion. Vehicles in this subsector 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

32 Referred to as non-road or off-road vehicles.

33 The terms “non-road” and “off-road” are used interchangeably.

industries both operate significant numbers of heavy non-road vehicles and are the largest diesel oil 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-GEM and estimates are generated with country-specific emission factors (see Annex 7).

Pipeline Transport

Pipelines[34] represent the only non-vehicular transport in this sector. They use fossil fueled combustion engines to power motive compressors and other equipment which 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 electrical motors to operate pumping equipment.

Combustion-related GHG emissions associated with this equipment are not calculated by M-GEM. The methodology employed is considered an IPCC Tier 1 sectoral approach. Fuel consumption data from the QRESD (Statistics Canada, #57-003), reported as pipelines, are multiplied by fuel-specific emission factors.

3.1.3.3 Uncertainties and Time-series Consistency

Energy Data

Uncertainties for the Transport category are largely dependant on the collection procedures used for the underlying activity data, as well as how accurately the emission factors represent the fuel properties. Commercial fuel volumes and properties are generally well known. Energy values utilized to estimate emissions in the Transport sector are prepared in a consistent manner over time with the same methodology.

Vehicle Populations

The data sets contributing to the Canadian vehicle population profile have been prepared by one of two North American firms which use similar methods to identify specific model year counts from provincial vehicle registries. Each firm provides a unique dataset which, when combined, define the entire Canadian fleet, except for the Canadian territories, which 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, a process important to a successful new business establishment such as an auto parts store. Because of the continental acceptance as the industry leading data source, it is deemed the best available.

With the onset of the next generation of estimating tools, one which can accommodate enhanced vehicle class definitions, fuel types and regions, these data sets are undergoing scrutiny in an attempt to understand data undulations which defy expectations. These include, specifically, increases observed in model years which haven't been available for high volume sale for 15–20 years. Further investigations will follow. However, current vehicle populations are compiled using a consistent rationale and methods according to the best available data sets through the time series 1990–present.

3.1.3.4 QA/QC and Verification

QA/QC is performed by a GHG Division sector expert within a informal QA/QC system. The QA/QC is performed during the model preparation stage and, also, during the CGHGI team reviews.

Since M-GEM 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 between Environment Canada, Transport Canada and Natural Resources Canada to facilitate the sharing of, not only data, but knowledge and history of vehicle population data. This increased perspective fosters a better understanding of actual vehicle use and, subsequently, should promote better modeling and emissions estimating. Recently,[35] Statistics Canada, with support from Transport Canada,

34 Consisting of both oil and gas types.

35 Late 1999.

began publishing the CVS, a quarterly report which 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.

3.1.3.5 Recalculations

The underlying fuel-use data was revised for 1999 and 2000, as was the Vehicle Population Profile following the acquisition of additional data sets. Transport estimates were recalculated accordingly. A correction of fuel-use data for Yukon and NWT for the years 1990 and 1991 caused a minor[36] emissions increase in each year.

No other recalculations were made to this category.

3.1.3.6 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 current model is 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-GEM will be restructured to employ a database model which can directly appropriate data from these new data sources.

In general, future improvements will concentrate on revealing more details with respect to activity data.[37] This will include:

- Higher resolution vehicle population profiles – allowing for annual age distribution of technology penetration (presently static) and greater vehicle sub-category dissagregation.
- Increased fuel types – accommodate oxygenated and bio-based fuels with consideration for biomass content.
- Improved vehicle kilometers-travelled estimates – to better allocate fuel consumption regionally.

3.1.4 OTHER SECTORS

3.1.4.1 Source Category Description

This category consists of three subsectors, commercial/institutional, residential, and agriculture/forestry/fishing. Emissions consist primarily of fuel combustion related to space and water heating. Emissions from the use of transportation fuels in these sectors are allocated to the Transport sector (Section 3.1.3). Biomass[38] combustion is a significant source of emissions in the residential sector. The carbon dioxide emissions from biomass are reported separately as memo items and not included in Energy sector totals.

3.1.4.2 Methodological Issues

Emissions from this sector are calculated according to the methodology described in Annex Table A8-1. Methodological issues specific to subsectors are described below. Emissions from the combustion of transportation fuels are allocated to the Transport category.

Commercial/Institutional

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

Residential

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

The methodology for biomass combustion from residential firewood is detailed in the section CO_2 Emissions from Biomass (Section 3.3.2), although the CH_4 and N_2O emissions are reported here.

Agriculture/Forestry/Fishing

This category includes emissions from stationary fuel combustion in the agricultural, forestry, and fisheries industries. However, emission estimates are included for the agriculture and forestry portion of the subsector only. Fishery emissions are reported typically under either transportation or other manufacturing (i.e., food

36 < .05% National.

37 Ultimately fuel consumption.

38 Typically firewood.

processing) categories. Mobile emissions associated with this subsector were not disaggregated and are included as off-road or marine emissions reported under transport (Section 3.1.3). Emissions are based on fuel-use data reported as Agriculture and Forestry in the QRESD (Statistics Canada, #57-003).

3.1.4.3 Uncertainties and Time-series Consistency

Uncertainties have been estimated to be in the range of 3-8% for the combustion of individual fuels (McCann 1994). The underlying fuel quantities and emission factors are expected to have low uncertainties because they are predominantly commercial fuels which have consistent properties and accurate tracking.

These estimates are consistent over the time series.

3.1.4.4 QA/QC and Verification

No specific and additional QA/QC activities were performed for this category.

3.1.4.5 Recalculations

The underlying fuel-use data was revised from 1999 and 2000. These estimates were recalculated accordingly. No other recalculations were made to this category.

3.1.4.6 Planned Improvements

There are no planned improvements to the methodology for this category

3.1.5 OTHER: ENERGY – FUEL COMBUSTION ACTIVITIES

The UNFCCC Reporting Guidelines assign military fuel combustion to this subsector. However, emissions related to military vehicles have been included in the Transport category, while stationary military fuel use has been included under the institutional category (section 3.1.4) due to fuel data allocation in the QRESD (Statistics Canada, #57-003). This is a small source of emissions.

3.2 FUGITIVE EMISSIONS

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 fugitive emissions. 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.

3.2.1 SOLID FUELS

3.2.1.1 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.

3.2.1.2 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. 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 to estimate emission rates from coal mining (emission factors in Annex 7) was based on a modified procedure from the Coal Industry Advisory Board. It consists of a hybrid of IPCC Tier 3 and IPCC Tier 2-type methodologies, depending on availability of mine-specific data. It separated underground mining emission from surface mining emissions and included post-mining activity emissions within each of those activities.

Underground Mines

King 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:

$$y = 4.1 + (0.023 \times x)$$

where:

x = depth of mine in metres

y = cubic metres of CH_4 per tonne coal mined

Emissions from post-mining activities were estimated by assuming that 60% of the remaining coal CH_4 (after removal from 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/tonne (the world 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 Table A8-1.

Surface Mines

For surface mines, it was assumed that the average methane gas content of surface-mined bituminous or sub-bituminous coals was 0.4 m^3/tonne (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 out-gassing 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 7 have been so adjusted.

Emissions in the national inventory were estimated by multiplying coal production data (from Statistics Canada, #45-002) by the emission factors in Annex Table A8-1.

3.2.1.3 Uncertainties and Time-series Consistency

Uncertainties for the estimates of fugitive emissions from coal mining were estimated to be about 30% (McCann, 1994). The production data is known to a high degree of certainty, while there is significant uncertainty in the emission factors due to the limited data available.

3.2.1.4 QA/QC and Verification

No specific additional QA/QC was performed for this category.

3.2.1.5 Recalculations

No recalculations were made to this sector.

3.2.1.6 Planned Improvements

No improvements are planned for this category.

3.2.2 OIL AND NATURAL GAS

3.2.2.1 Source Category Description

The oil and natural gas sector includes fugitive emissions from conventional upstream oil and gas production, unconventional oil production, and natural gas distribution. Fuel combustion emissions from facilities in the oil and gas category (when used for energy) are included under the manufacture of solid fuels and other energy industries sector (Section 3.1.1).

This category has three main subcategories; conventional oil and gas production, unconventional oil production, and gas distribution.

Conventional Upstream Oil and Gas

This subsector includes all fugitive emissions from exploration, production, processing, and transmission of oil and natural gas. Emissions may be the result of designed equipment leakage (bleed valves, fuel gas-operated pneumatic equipment), imperfect seals on equipment (flanges and valves), accidents, spills, and deliberate vents.

The conventional upstream oil and gas subsector is vast and complex. The sources have been divided into major categories:

- *Oil and Gas Well Drilling:* 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 volatilisation of invert drilling fluids.
- *Oil and Gas Well Servicing:* Well servicing is also a minor emission source. The emissions are mainly from blow-down treatments for shallow gas wells. Emissions from venting of mud tanks and depressurisation of piping, wells, and vessels could also be a potential source; however, there are limited available data, and the source is considered 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 >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 from 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 hydrocarbon from the formation. The sources of emissions are from wells, flow lines, satellite batteries, and cleaning plants. The main source of emissions is from the venting of casing gas.
- *Gas Processing:* Natural gas is processed before entering transmission pipelines to remove 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 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 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.

Unconventional Crude Oil Production

This subsector includes emissions from oil sand open pit mining operations and heavy/bitumen oil upgrading facilities in Canada. The fugitive emissions are primarily 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 are a newly discovered phenomenon, which is currently being 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.

3.2.2.2 Methodological Issues

Conventional Oil and Gas Production

Fugitive emission estimates from the conventional upstream oil and gas industries for 1990–1996 are based on a study (Picard and Ross, 1999). A summary of the method is provided here, details are available in the report. The emission estimates result from a rigorous engineering study based on the various products, processes, and infrastructure used in the Canadian conventional upstream oil and gas industry.

Emission factors in the study were obtained from published sources (Radian International, 1997) or estimated based on industry-specific information such as the average size of a mud pit, storage tank, etc.

The activity data used in the study were for typical processing plant equipment schedules, production rates, gas-oil ratios, etc., collected from various sources, such as the Alberta Energy and Utilities Board, Natural Resources Canada, and provincial energy ministries.

The method used in the original study (Picard and Ross, 1999) is considered a rigorous IPCC Tier 3-type method.

After 1996, the estimates for fugitive emissions from the conventional upstream oil and gas industries were made in a manner that was different from that utilized for the 1990–1996 period (estimates for which are based directly on the Picard and Ross study). Emission data for 1996 were extrapolated by the changes in relevant production data for the following years. This method was used on an interim basis and will continue to be used until new data become available from a rigorous study. The data used for the extrapolations are shown in Table 3-1.

TABLE 3-1: Oil and Gas Activities and Extrapolation Data

Activity	Extrapolation Data
Flaring	Gross New Production of Natural Gas (Statistics Canada, #26-006)
Raw CO_2	Net Withdrawals of Natural Gas (Statistics Canada, #26-006)
Oil and Gas Well Drilling	Constant at 1996 levels
Oil and Gas Well Servicing	Constant at 1996 levels
Natural Gas Production	Gross New Production of Natural Gas (Statistics Canada, #26-006)
Light/Medium Oil Production	Total Production of Light and Medium Crude Oil (Statistics Canada, #26-006)
Heavy Oil Production	Total Production of Heavy Oil (Statistics Canada, #26-006)
Crude Bitumen Production	Total Production of Crude Bitumen (Statistics Canada, #26-006)
Natural Gas Processing	Net Withdrawals of Natural Gas (Statistics Canada, #26-006)
Natural Gas Transmissions	Natural Gas Transmission Pipeline Length (Statistics Canada, #57-205)
Liquid Product Transport	Constant at 1996 levels
Accidents and Equipment Failures	Constant at 1995 levels (1996 was an anomalous year)
Surface Casing, Vent Blows, and Gas Migration	Constant at 1996 levels

Unconventional 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 the Canadian Association of Petroleum Producers (CAPP) and Environment Canada (McCann, 1999). Descriptions of the methods are available in the full report. Data has been kept 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.

3.2.2.3 Uncertainties and Time-series Consistency

Uncertainties for this sector have been estimated to range from 20% for CO_2 (vented stripped CO_2) to 35% for CH_4 from natural gas distribution (McCann, 1994).

The data used in the inventory from 1990–1996 is directly from an earlier study (Picard and Ross, 1999) the data from 1997 to the present is based on an extrapolation of the emission rates determined from the earlier inventory (Picard and Ross). The uncertainty of the more recent inventory years is greater due to this inconsistency in the methods used to calculate the inventory.

3.2.2.4 QA/QC and Verification

No specific additional QA/QC was performed for this category.

3.2.2.5 Recalculations

No recalculations were made for this category.

3.2.2.6 Planned Improvements

Environment Canada is planning to conduct another detailed study of the fugitive emissions from the upstream oil and gas industry in the upcoming year. This should improve the quality of the estimates by incorporating new data and improve the time series consistency.

3.3 MEMO ITEMS

3.3.1 INTERNATIONAL BUNKER FUELS

According to the IPCC Guidelines, emissions resulting from fuels sold for international marine and air transportation should not be included in national inventory totals, but reported separately as "bunkers" or "international bunkers." In the Canadian inventory, any fuel reported by Statistics Canada as having been sold to foreign-registered marine or aviation carriers is excluded from national inventory emission totals. Therefore, all tables that do not specifically list bunkers do not include emissions from these sources.

Unfortunately, it is not clear whether or not all of the fuel sold to foreign-registered carriers in Canada is used for international transport. Conversely, 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. In Canada, modified statistical procedures may be required to track bunker fuels more accurately.

It should be noted that the accidental omission of international bunker fuel values for Gas/Diesel Oil & Residual Fuel Oil from the previous 1990–2000 submission of the Reference Approach has been corrected for all years. For the years 1999–2000, revised National Energy Data (QRESD) was also available and incorporated into the latest submission.

Aviation

Emissions have been calculated using the same methods listed in the Civil Aviation section. Fuel-use data are reported as foreign airlines in the QRESD (Statistics Canada, #57-003).

Marine

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

3.3.2 CO_2 EMISSIONS FROM BIOMASS

As per the UNFCCC Guidelines, CO_2 emissions from the combustion of biomass used to produce energy are not included in the Energy section totals and are reported separately as memo items. They are accounted for in the LUCF section 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 subsectors.

Biomass emissions have been grouped into two main sources: residential firewood, and industrial wood wastes.

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 Criteria Air Contaminants Inventory (Environment Canada, 1999). Statistics Canada and Natural Resources Canada 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:

Conventional stoves;

- non-airtight
- airtight, non-advanced technology
- masonry heaters

Stove/fireplace inserts with advanced technology or catalyst control;

- advanced technology fireplaces
- advanced technology stoves
- catalytic fireplaces
- catalytic stoves

Conventional fireplaces;

- without glass doors
- with glass doors (non-airtight)
- with airtight glass doors

Furnaces;

- wood-burning fireplaces

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 #64-202 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).

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

Industrial Wood Wastes

A limited number of data for industrial firewood and spent pulping liquor are available in the QRESD (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 QRESD 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 7).

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

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

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 OTHER ISSUES

3.4.1 COMPARISON OF SECTORAL AND REFERENCE APPROACH

The reference approach was compared with the sectoral approach as a check of combustion-related emissions. The check was performed for all years from 1990 to 2001 and is an integral part of the Common Reporting Format (CRF). (Reference Approach methodology is detailed in Annex 4.)

A direct comparison of 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 predefined comparisons used in the CRF on Table 1-A(c) are not appropriate for Canada, since they are not comparing similar emission universes. The reference approach, in theory, includes all carbon dioxide (CO_2) emissions from all fossil fuel uses (combustion and process) in a country and should be compared only with a similar set of emissions from the sectoral approach. In the CRF, the reference approach is directly compared with the sectoral fuel combustion total. This comparison produces a significant discrepancy, since the sectoral approach total does not include fossil fuel-derived CO_2 from industrial processes. In Canada, a significant amount of fossil fuel is used for feedstocks in industrial processes such as aluminium, ammonia, and ethylene production. The emissions resulting from these processes are reported as industrial processes. The Canadian reporting procedure does follow the IPCC Guidelines. When the comparison is corrected by adding the relevant industrial process data to the sectoral approach (removing it from the Reference Approach Total), the totals match within 0.1–4.2%. This is deemed a good match for Canada, considering the high uncertainty in using the default IPCC emission factors for the reference approach for Canada.

TABLE 3-2: Reconciliation of Reference Approach and Sectoral Approach

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Ammonia Production	5,008	4,936	5,111	5,692	5,813	6,482	6,524	6,675	6,610	6,847	6,845	5,923
Iron and Steel Production	7,585	8,904	9,084	8,760	8,091	8,440	8,289	8,100	8,316	8,501	8,511	7,920
Aluminium Production	2,636	3,014	3,213	3,768	3,677	3,545	3,726	3,794	3,817	3,919	3,892	4,163
Other & Undifferentiated Production	9,218	9,559	8,961	9,677	10,583	10,180	11,371	11,528	11,496	11,842	11,854	11,664
Total Adjustment Value – Industrial Processes	24,447	26,414	26,369	27,898	28,163	28,646	29,909	30,098	30,239	31,109	31,103	29,670
National Approach Value	421,905	411,758	425,723	422,945	436,117	447,878	459,857	471,074	480,525	498,276	521,818	512,570
Reference Approach Total	454,336	455,041	469,839	466,613	477,473	487,158	505,121	512,896	524,050	535,891	553,460	549,093
Difference	7.7%	10.5%	10.4%	10.3%	9.5%	8.8%	9.8%	8.9%	9.1%	7.5%	6.1%	7.1%
Adjusted Reference Approach	429,889	428,627	443,471	438,715	449,309	458,512	475,212	482,798	493,811	504,783	522,357	519,424
Adjusted Difference	1.9%	4.1%	4.2%	3.7%	3.0%	2.4%	3.3%	2.5%	2.8%	1.3%	0.1%	1.3%

The activity data used in the sectoral approach and the reference approach are from the same published source. The Canadian statistics agency, Statistics Canada, compiles and publishes a national energy balance. This report compares energy production and supply with energy demand data at a sectoral level. One of the QA/QC procedures used by Statistics Canada to develop the energy data is to ensure that sectoral energy supply equals sectoral energy demand. As a result, the reference approach does not provide a useful tool for Canada in verifying the consistency of sectoral activity data. The discrepancies between the reference and sectoral approaches are due to the energy content and emission factors, not the activity data.

In Canada, like the United States, gross heating value (GHV) is used to record the energy content of fuels, and this has been used throughout the sectoral approach to give an indication of fuel combustion activity in a particular sector. However, throughout the reference approach, GHV data were converted to net heating value (NHV), since there were no readily available GHV-based emission factors for some of the raw fuels used in the reference approach. As a result, many of the default IPCC factors were used. Many of these default factors provide a wide range of values, which can have a large impact on the emission total. For example, crude oil has two default factors listed – 20 or 21 tC/TJ. This difference alone can vary the reference approach total by 2%. For this method to provide consistent results, Canada needs to develop a method to estimate country-specific emission factors for crude oil, natural gas, and coal to be used specifically in the reference approach. This would improve the usefulness and accuracy of the reference approach. The default IPCC factors will not provide the accuracy required to achieve what has been dictated as acceptable in best practice (the 2% threshold) even when the same activity data are used.

It should be noted that the accidental omission of international bunker fuel values for Gas/Diesel Oil & Residual Fuel Oil from the previous 1990–2000 submission of the Reference Approach has been corrected for all years. For the years 1999–2000, revised National Energy Data (QRESD) was also available and incorporated into the latest submission.

3.4.2 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, and lubricants, and also as feedstocks (including the process of 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.

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 4.10.

3.4.3 CO_2 CAPTURE AND STORAGE

Carbon dioxide 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. Significant quantities of carbon dioxide releases are avoided through both of these activities, however the quantities are not known or accounted for in the inventory (imported CO_2 is also not accounted for). All current inventory estimates assume carbon dioxide originating from Canadian energy-related sources is ultimately released to the atmosphere. Emission estimates in the inventory may be revised in the future to account for these emission reductions once a proper methodology and tracking mechanism is developed.

3.4.4 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 2001, Canada exported over 40% (energy equivalent) of its gross natural gas and crude oil production. The GHG's 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 et al. (1997), integrates the author's 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.

The 1996 to 2001 emission estimates have been calculated using similar energy data from Statistics Canada, while emissions attributable to the net exports were extrapolated based on the previously mentioned 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 1996–2001 net exports to develop the emission estimates.

The emissions/sectors included within the two main fuel streams 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 natural gas liquids 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 Oils – 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 produce into gas gathering systems 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)

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

The processes addressed in this section include mineral products (production and use), ammonia production, adipic acid production, other chemical production (nitric acid), ferrous metal production, aluminium metal production, magnesium metal production, consumption of halocarbons, consumption of SF_6 and other industrial processes (non-energy use of fossil fuels not accounted for under any of the other Industrial Processes categories).

CO_2 emissions resulting from the use of fossil fuels as feedstocks for the production of any chemical products other than ammonia, nitric acid and adipic acid are reported under Other: Industrial Processes (Section 4.10).

As a quality control measure, the Industrial Processes emissions calculations are reproduced multiple times in order to ensure their correctness. Firstly, the activity data is entered into the database model for the current inventory year. The same data is then entered into a second database model and the results compared. The second database model is an archiving model which computes and stores emissions for each inventory year back to 1990. These two database models have been developed for the 2001 inventory due to a change in software and, therefore, were not used in any previous inventory preparation exercises. In the event of a discrepancy between these two models, the original model, used prior to 2001, may be used in order to identify where errors may have occurred in the emissions estimation process.

Furthermore, activity data and emissions have been checked against previous inventories in order to ensure continuity. In the event that an aberration in either activity data or emissions is identified, a further inquiry is performed to determine the source of the deviation, or where an error may have occurred. Sector-specific QA/QC and verification procedures are discussed throughout Chapter 4.

The Industrial Processes section is currently undergoing a thorough review of methodologies, as well as an update to the documentation and archiving of all references pertinent to the preparation of GHG estimates, in an attempt to enhance the quality of the GHG inventory and to comply as closely as possible with the IPCC Good Practice Guidance (IPCC/OECD/IEA, 2000).

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.

4.1 MINERAL PRODUCTS

4.1.1 SOURCE CATEGORY DESCRIPTION

This sector comprises emissions related to the production and use of non-metallic minerals, including cement, lime, limestone and soda ash. Possible emissions of GHGs associated with the production and/or use of other mineral products have not been estimated.

Cement Production

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 is heated in a high-temperature kiln, forming lime (CaO) and CO_2 in a process called calcination or calcining:

$$CaCO_3 + Heat \rightarrow CaO + CO_2$$

The lime is then combined with silica-containing materials to produce clinker (greyish-black pellets about the size of 12-mm-diameter marbles). The clinker is removed from the kiln, cooled, and pulverized, and gypsum is added to produce Portland cement. 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 category and are not considered here.

Lime Production

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 the Cement Production portion of this section.

Dolomitic limestone (or magnesite) may also be processed at high temperature to obtain dolomitic lime (and release of 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 category. Since this CO_2 is biogenic in origin, it is recorded as a change in forest stock in the LUCF section.

Limestone and Dolomite Use

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, there are two other processes requiring significant amounts of the material: metallurgical smelting and glass making.

These industries use limestone at high temperatures. Therefore, the limestone is calcined to lime, producing CO_2 by the same reaction described in the Cement Production portion of this section.

Soda Ash Production and Use

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, soap and detergents, pulp and paper manufacture, and water treatment (EIA, 1994). Based on use data supplied in the Non-Metallic Mineral Product Industries (Statistics Canada, #44 250) publication, it appears that soda ash use is restricted to the glass products manufacturing industry. CO_2 is emitted as the soda ash decomposes at high temperatures in a glass manufacturing furnace.

CO_2 may also be emitted during soda ash production, depending on the production process employed. CO_2 is generated as a by-product during production, but is usually recovered and recycled for use in the carbonation stage. According to Canadian industry, there are no emissions associated with the production of soda ash in Canada (General Chemical Canada Inc., 1995).

4.1.2 METHODOLOGICAL ISSUES

4.1.2.1 Cement Production

The emission factor for CO_2 emissions from cement production is based on the lime content of cement. It was assumed that the cement produced in Canada has an average lime content of 63.5% (Jaques, 1992). Based on this assumption and the associated calcination reaction stoichiometry, an emission factor of 500 g CO_2/kg cement produced was derived. Furthermore, it is also assumed that all the cement produced in Canada is of the Portland type (ORTECH Corporation, 1994).

Cement production and cement plant clinker capacity data are obtained from the Canadian Minerals Yearbook (NRCan, 2001). For any given year, the most recent cement production numbers provided are preliminary and are subject to revision in subsequent publications. National CO_2 emissions are estimated by applying the emission factor of 500 g CO_2/kg cement produced to the yearly national cement production. The clinker capacity data is subsequently used to estimate CO_2 emissions on a provincial/territorial level based on the percentage of total national clinker capacity attributable to each province/territory. National clinker production data is currently unavailable.

This technique is the IPCC Tier 1 method, and the emission factor is within 1% of the IPCC default value (IPCC, 1997).

4.1.2.2 Lime Production

The mass of CO_2 produced per unit of lime manufactured may be estimated from a consideration of the molecular weights and the lime content of products (ORTECH Corporation, 1991). Based on the associated calcination reaction stoichiometry, an emission factor of 790 g CO_2/kg quicklime produced was derived. It is assumed that all lime is produced from high-calcium limestone and that dolomitic lime production is negligible.

Quicklime production and lime plant calcining capacity data are from the Canadian Minerals Yearbook (NRCan, 2001). For any given year, the most recent lime production numbers provided are preliminary and are subject to revision in subsequent publications. National CO_2 emissions are estimated by applying the emission factor of 790 g CO_2/kg quicklime produced to the yearly national lime production. The calcining capacity data is subsequently used to estimate CO_2 emissions on a provincial/territorial level based on the percentage of total national calcining capacity attributable to each province/territory.

This technique is considered to be a Tier 1-type method based on the use of national production data and an average national emission factor.

4.1.2.3 Limestone and Dolomite Use

A (non-dolomitic) limestone-use emission factor of 440 g CO_2/kg of limestone used was developed (ORTECH Corporation, 1994) using the chemical process stoichiometry. No data are available on the fraction of limestone used that is dolomitic. As noted in the Lime Production portion of this section, it was assumed that all lime is produced from high-calcium limestone.

Raw limestone consumption data by the glass and metallurgical smelting industries were obtained from the Canadian Minerals Yearbook (NRCan, 2001). The most recent limestone-use data published is for 2000, therefore it is assumed that there is no change in limestone use from 2000 to 2001. National CO_2 emissions are estimated by applying the emission factor of 440 g CO_2/kg of limestone used to the yearly national limestone consumption data. 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 IPCC Good Practice Guidance (IPCC/OECD/IEA, 2000).

4.1.2.4 Soda Ash Production and Use

For each mole of soda ash used, one mole of CO_2 is emitted. The emission factor (EF) for the mass of CO_2 emitted may be estimated from a consideration of consumption data and the stoichiometry of the chemical process as follows:

$$EF = 44.01 \text{ g/mol } CO_2 / 105.99 \text{ g/mol } Na_2CO_3 = 415 \text{ kg/t } Na_2CO_3$$

Consumption information was obtained from the Non-Metallic Mineral Product Industries (Statistics Canada, #44-250) publication. Only limited-use data have been published by Statistics Canada since 1993 due to the suppression of confidential data, therefore emissions have been assumed to be constant since 1993. National CO_2 emissions are estimated by applying the emission factor of 415 g CO_2/kg of soda ash used to the national soda ash consumption data. 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 soda ash use are not addressed specifically in *IPCC Good Practice Guidance* (IPCC/OECD/IEA, 2000).

4.1.3 UNCERTAINTIES AND TIME-SERIES CONSISTENCY

The uncertainties associated with methodologies used to estimate CO_2 emissions from the production of lime and cement has been determined to be in the range of from 10% for lime production and 15% for cement production (McCann, 1994). Uncertainties associated with CO_2 emissions from limestone and soda ash use were not covered by the McCann document. The following issues with respect to activity data are the primary factors effecting uncertainties in CO_2 emissions estimates from the mineral product industries:

Cement Production – There is only sufficient data available to estimate CO_2 emissions using cement production data. Furthermore, cement production data used in estimating emissions for 2001 is preliminary and subject to revision. Emissions may not be accurate on a year-to-year basis in a situation where clinker is produced in a given year and only used for actual cement production in a subsequent year. Additionally, clinker import and export data is not currently incorporated into the emissions estimates.

Lime Production – There is insufficient data available to estimate what percentage of total lime production is attributable to the production of dolomitic lime. Furthermore, lime production data used in estimating emissions for 2001 is preliminary and subject to revision.

Limestone and Dolomite Use – The Canadian Minerals Yearbook (NRCan) publishes limestone-use data under a general heading named "other chemical uses". The exact portion of this that is contributing to CO_2 emissions remains unclear. Also, the most recent limestone-use numbers published are for 2000. In addition, limestone used by the pulp and paper industry is currently unaccounted for.

Soda Ash Use – Current activity data is not available (see explanation below).

The methodology and data sources have remained consistent over the time-series. The Canadian Minerals Yearbook (NRCan) and the Non-Metallic Mineral Product Industries (Statistics Canada, #44-250) publications have been used as activity data references for each inventory year. However, current soda ash-use data has not been available since 1993 and the format of the Non-Metallic Mineral Product Industries publication has changed as of 1996 and no longer includes data on soda ash use by industrial sector. Efforts are presently being made to acquire post-1993 unpublished soda ash-use data from Statistics Canada on both a national and provincial/territorial level. This data set will contain confidential information which will be protected.

4.1.4 QA/QC AND VERIFICATION

4.1.4.1 Cement and Lime Production

The following are inventory QA/QC and verification procedures specific to Cement and Lime Production:

Emission factor verification/comparison: The national emission factor for CO_2 emissions from lime production is consistent with the IPCC default value, while the national emission factor for cement production is within 1% of the IPCC default value (IPCC, 1997).

Activity data verification: The published cement and lime production estimates are compared to the published aggregate national plant clinker capacities and national aggregate plant calcining capacities respectively, in order to provide an indication of the reasonableness and representativeness of the activity data.

Revised data: For both lime and cement production, the Canadian Minerals Yearbook (NRCan) provides only preliminary data for the current year and the figures may be revised in subsequent years. Any differences are identified and the appropriate recalculations are made.

4.1.4.2 Limestone and Dolomite Use

The following are inventory QA/QC and verification procedures specific to Limestone and Dolomite Use:

Emission factor verification/comparison: The national emission factor for CO_2 emissions from (non-dolomitic) limestone use is consistent with the IPCC default value.

Revised data: The current Canadian Minerals Yearbook (NRCan) only provides data for the year previous to the inventory year (i.e., only 2000 use data available for the 2001 inventory and the emissions for both years are assumed equal). Therefore, it is expected that each inventory year there will be a difference in the activity data for the previous year and the appropriate emissions recalculation will be carried out.

4.1.4.3 Soda Ash Use

The following are inventory QA/QC and verification procedures specific to Soda Ash Use:

Emission factor verification/comparison: The national emission factor for CO_2 emissions from soda ash use is consistent with the IPCC default value.

4.1.5 RECALCULATIONS

4.1.5.1 Cement Production

Revised 1999 cement production data has been published in the 2001 edition of the Canadian Minerals Yearbook (NRCan). The publication reports a minor decrease in cement production which corresponds to a small decrease in CO_2 emissions. There has been no change to the cement production preliminary estimates for 2000.

4.1.5.2 Lime Production

Revised 2000 lime production data was published in the 2001 edition of the Canadian Minerals Yearbook (NRCan). The publication reports a minor decrease in production from lime which corresponds to a slight decrease in CO_2 emissions.

4.1.5.3 Limestone and Dolomite Use

The 2001 edition of the Canadian Minerals Yearbook (NRCan) published limestone-use data for 2000. 2000 emissions for this sector, which were previously assumed equal to 1999 emissions due to lack of data, have been recalculated. Reported limestone use and, therefore, the CO_2 emissions from limestone use, are down significantly in 2000.

4.1.5.4 Soda Ash Use

There have been no recalculations to CO_2 emissions related to soda ash use.

4.1.6 PLANNED IMPROVEMENTS

4.1.6.1 Cement Production

Improvements to the CO_2 emissions methodology in accordance with *IPCC Good Practice Guidance* (IPCC/OECD/IEA, 2000) are being considered. The possibility of incorporating clinker import and export data and accounting for CO_2 content in non-recycled (lost) calcined cement kiln dust in the emissions calculations will be investigated.

4.1.6.2 Lime Production

Similar to Cement Production, improvements to the CO_2 emissions methodology in accordance with *IPCC Good Practice Guidance* (IPCC/OECD/IEA, 2000) are being considered. In particular, the possibility of incorporating a correction factor for the proportion of hydrated lime into the emissions calculations is being considered.

4.1.6.3 Limestone and Dolomite Use

Improvements in estimating CO_2 emissions from limestone use may comprise the inclusion of limestone use by the pulp and paper industry to the activity data and an investigation into the limestone-use data published under the general heading "Other Chemical Uses" in the Canadian Minerals Yearbook (NRCan) to determine what portion of this data, if any, should be added to the activity data.

4.1.6.4 Soda Ash Use

As previously disclosed, efforts are presently being made to acquire post-1993 unpublished soda ash-use data from Statistics Canada on national, provincial and territorial levels.

4.2 AMMONIA PRODUCTION

4.2.1 SOURCE CATEGORY DESCRIPTION

Most of the ammonia produced in Canada is manufactured using the Haber-Bosch process. In this process, nitrogen and hydrogen react to produce ammonia. The hydrogen is usually produced by the steam reformation of natural gas. This reaction produces CO_2 as a by-product.

One of the main uses for ammonia is in the manufacture of fertilizer. A large proportion of the manufactured ammonia is produced at fertilizer plants that also produce urea. Urea production consumes much of the CO_2 that would otherwise be released to the atmosphere during ammonia manufacture. In accordance with the IPCC Guidelines, emission totals are not adjusted to account for the carbon stored in urea because it will be released to the atmosphere shortly after the fertilizer is applied to the soil.

4.2.2 METHODOLOGICAL ISSUES

An emission factor of 1.56 t CO_2/t NH_3 produced was developed using typical energy and material requirements for ammonia production in Canada (Jaques, 1992).

Total ammonia and urea production data were obtained from the publication *Industrial Chemicals and Synthetic Resins* (Statistics Canada, #46-006). Ammonia production plant capacities were obtained from the publication *Fertilizer Production Capacity Data: Canada* (CFI, 1999). Some of the hydrogen produced for ammonia production is from other chemical process by-products (Jaques, 1992), thereby eliminating the release of CO_2 from the synthesis process. The gross ammonia production was reduced accordingly. National emissions were then calculated by combining the production data with the general emission factor.

The natural gas used to produce hydrogen for ammonia production is recorded by Statistics Canada with all other non-energy uses of natural gas. The CO_2 emissions from ammonia production are, therefore, subtracted from the total non-energy fossil fuel-use emissions to avoid double counting.

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 IPCC Good Practice Guidance (IPCC/OECD/IEA, 2000).

4.2.3 UNCERTAINTIES AND TIME-SERIES CONSISTENCY

Uncertainties associated with CO_2 emissions from the production of ammonia use were not covered by the McCann document (McCann, 1994). A major factor contributing to the uncertainty in CO_2 emissions estimates associated with the production of ammonia is the adjustment made to gross ammonia production data in order to account for hydrogen produced by chemical process by-products. This hydrogen production value is only an estimate and has been assumed constant for each year.

The methodology and data sources remain consistent over the time-series. The Industrial Chemicals and Synthetic Resins (Statistics Canada, #46-006) publication has been used as the activity data source for each inventory year. The most recent plant production capacity data obtained from the Canadian Fertilizer Institute is for 1999 and has been assumed to be constant since then.

4.2.4 QA/QC AND VERIFICATION

The following are inventory QA/QC and verification procedures specific to ammonia production:

Emission factor verification/comparison: The national emission factor for CO_2 emissions from ammonia production is consistent with the IPCC default value (IPCC, 1997).

Activity data verification: The published ammonia production estimates are compared to the aggregate national ammonia plant capacities in order to provide an indication of the reasonableness and representativeness of the activity data.

Revised data: From time-to-time, Statistics Canada will make, and clearly indicate, revisions in the Industrial Chemicals and Synthetic Resins (Statistics Canada, #46-006) publication. The appropriate recalculations are made where necessary.

4.2.5 RECALCULATIONS

There have been no recalculations to CO_2 emissions related to ammonia production.

4.2.6 PLANNED IMPROVEMENTS

As previously mentioned, urea production consumes much of the CO_2 that would otherwise be released to the atmosphere during ammonia manufacture. Since a significant quantity of urea produced in Canada is exported and CO_2 trapped in urea will only be released upon its application, efforts will be made to attempt to determine the quantity of CO_2 in exported urea.

4.3 NITRIC ACID PRODUCTION

4.3.1 SOURCE CATEGORY DESCRIPTION

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

4.3.2 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 of N_2O/t of ammonia consumed in the production of HNO_3. However, subsequent investigations indicated that emissions from Canadian plants were at the low end of this range (Collis, 1992).

The following emission factors (EF) were developed:

- plants with catalytic converters – EF = 0.66 kg N_2O/kg HNO_3 produced;
- plants with extended absorption for NO_x abatement type 1 – EF = 9.4 kg N_2O/kg HNO_3 produced; and
- plants with extended absorption for NO_x abatement type 2 – EF = 12 kg N_2O/kg HNO_3 produced.

Annual national nitric acid production data were obtained from the publication Industrial Chemicals and Synthetic Resins (Statistics Canada, #46-006). All nitric acid plants in Canada, with the exception of those in Alberta, are of the catalytic converter type. For Alberta, it has been assumed that 175 kt of HNO_3 are produced by plants with extended type 1, and 30 kt HNO_3 are produced by plants with extended type 2. The remainder were from catalytic converter-type plants. Nitric acid plant capacity data are subsequently used to estimate N_2O emissions on a provincial/territorial level.

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

4.3.3 UNCERTAINTIES AND TIME-SERIES CONSISTENCY

The original uncertainty study (McCann, 1994) reports that uncertainties in the estimation of N_2O emissions associated with the production of nitric acid are in the order of ±30%.

The methodology and data sources remain consistent over the time-series. The Industrial Chemicals and Synthetic Resins (Statistics Canada, #46-006) publication has been used as the activity data source for each inventory year. Plant production capacity data has been assumed constant since 1996. The uncertainty of emissions estimates are further compounded due to the lack of annual production capacity data.

4.3.4 QA/QC AND VERIFICATION

The following are inventory QA/QC and verification procedures specific to Nitric Acid Production:

Emission factor verification/comparison: The national emission factors for N_2O emissions from nitric acid production are within the range published by the IPCC (IPCC, 1997).

Activity data verification: The published nitric acid production estimates are compared to the aggregate national nitric acid plant capacities in order to provide an indication of the reasonableness and representativeness of the activity data.

Revised data: From time-to-time, Statistics Canada will make, and clearly indicate, revisions in the Industrial Chemicals and Synthetic Resins (Statistics Canada, #46-006) publication. The appropriate recalculations are made when necessary.

4.3.5 RECALCULATIONS

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

4.3.6 PLANNED IMPROVEMENTS

Improvements to the N_2O emissions methodology in accordance with IPCC Good Practice Guidance (IPCC/OECD/IEA, 2000) are being considered. The possibility of incorporating N_2O destruction factors and abatement system utilization factors to the emissions calculations will be investigated.

4.4 ADIPIC ACID PRODUCTION

4.4.1 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.

There is one adipic acid production facility in Canada operated by DuPont and located in Maitland, Ontario. An emission abatement system was installed at the facility in 1997 at which point DuPont implemented a program of emissions monitoring to determine the performance efficiency of the abatement system.

4.4.2 METHODOLOGICAL ISSUES

The emission estimates for adipic acid production are provided by the Dupont Maitland plant, Canada's only producer of adipic acid. Emissions are estimated based upon the plant's production of adipic acid for the period 1990–1996 and based on emission monitoring data from 1997 to the present. The emission factor of 0.303 kg N_2O/kg adipic acid was applied to production data to estimate pre-1997 emissions, when no emission controls were in place.

The current technique is considered to be a Tier 3-type method as it is based on the reporting of facility-specific emissions data.

4.4.3 UNCERTAINTIES AND TIME-SERIES CONSISTENCY

The original uncertainty study (McCann, 1994) reports that the uncertainty in the estimation of N_2O emissions associated with the production of adipic acid is approximately 7.0%. This uncertainty is low with respect to N_2O emissions from other sources. This, of course, is a reflection of the methodology used up until 1996 where the emission factor of 0.303 kg N_2O/kg adipic acid was applied to production data to estimate emissions.

The data source has remained 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 DuPont based on production, whereas emissions reported from 1997 to the present are measured directly using emissions monitoring equipment.

4.4.4 QA/QC AND VERIFICATION

The following are inventory QA/QC and verification procedures specific to Adipic Acid Production:

Emission factor verification/comparison: Where used, the national emission factor for N_2O emissions from adipic acid production is within 1% of the IPCC default value (IPCC, 1997).

4.4.5 RECALCULATIONS

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

4.4.6 PLANNED IMPROVEMENTS

There are currently no improvements planned specifically for estimating N_2O emissions from adipic acid production in Canada, however a thorough review of methodologies and QA/QC activities is on-going (see Section 1.6).

4.5 FERROUS METAL PRODUCTION

4.5.1 SOURCE CATEGORY DESCRIPTION

Iron is produced through the reduction of iron oxide (ore) with metallurgical coke (as the reducing agent) in a blast furnace to produce pig iron. The metallurgical coke used in the furnace is oxidized in the process to CO_2 and emitted to the atmosphere. Some carbon is stored in the pig iron. However, this is mostly released to the atmosphere during the steel production process. Steel is made from pig iron and/or scrap steel using electric arc, basic oxygen, or cupola furnaces.

The emission estimates in this subsector do not include emissions from the production of steel in electric arc or basic oxygen-type furnaces. The emissions resulting from the oxidation of fossil fuel carbon-based anodes in these furnaces are included in the Other: Industrial Processes section of this chapter.

Emissions from the combustion of fuels such as coke oven gas are not reported in this subsector, but rather under the appropriate industrial sector in the Energy section.

CO_2 emissions from the use of petroleum coke in the ferroalloy smelting process are included under Other: Industrial Processes (Section 4.10).

4.5.2 METHODOLOGICAL ISSUES

The national and provincial/territorial metallurgical coke data are obtained from the Quarterly Report on Energy Supply and Demand (Statistics Canada, #57-003), as reported under iron and steel. Metallurgical coke data published for any given year is preliminary and subject to revision in subsequent publications. National and provincial/territorial CO_2 emissions were estimated by applying the combustion emission factor of 2.480 kg CO_2/kg metallurgical coke used as a reducing agent in the iron and steel industry.

This method is based upon the mass of reducing agent used in iron and steel production and is consistent with the IPCC Tier 1 method (IPCC, 1997).

4.5.3 UNCERTAINTIES AND TIME-SERIES CONSISTENCY

The uncertainty in the estimation of CO_2 emissions associated with the consumption of metallurgical coke is approximately 8.0% (McCann, 1994).

The methodology and data sources remain consistent over time. The *Quarterly Report on Energy Supply and Demand* (Statistics Canada, #57-003) publication has been used as the activity data source for each inventory year and reports non-energy use of metallurgical coke in the iron and steel industry on both a national and provincial/territorial level.

4.5.4 QA/QC AND VERIFICATION

The following are inventory QA/QC and verification procedures specific to Iron and Steel Production:

Emission factor verification/comparison: The national emission factor, developed based on typical Canadian fuel characteristics, is comparable to those published by the IPCC (IPCC, 1997).

Revised data: The *Quarterly Report on Energy Supply and Demand* (Statistics Canada, #57-003) is subject to revision based on Statistics Canada QA/QC activities. Appropriate recalculations are made when and where necessary.

4.5.5 RECALCULATIONS

There have been minor revisions by Statistics Canada to data for use of metallurgical coke in the iron and steel industry for 1999 and 2000. These revisions have resulted in slight increases in CO_2 emission estimates for 1999 and 2000.

4.5.6 PLANNED IMPROVEMENTS

There are, currently, no improvements planned specifically for estimating CO_2 emissions from iron and steel production in Canada, however a thorough review of methodologies and QA/QC activities is on-going (see Section 1.8).

4.6 ALUMINIUM METAL PRODUCTION

4.6.1 SOURCE CATEGORY DESCRIPTION

Primary aluminium is produced in two steps. First, bauxite ore is ground, purified, and calcined to produce alumina. 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 (Al_2O_3) 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 perfluorocarbons or PFCs. PFCs are considered potent GHGs as reflected by their high global warming potential (GWP).

As the anode is consumed, CO_2 is formed in the following reaction, provided that enough alumina is present at the anode surface:

$$Al_2O_3 + 3/2C \rightarrow 2Al + 3/2CO_2$$

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, 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 toward 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 about 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:

$Na_3AlF_6 + 3/4C \rightarrow Al + 3NaF + 3/4\ CF_4$

$Na_3AlF_6 + C \rightarrow Al + 3NaF + 1/2\ C_2F_6$

A study of PFC emissions has been conducted to measure actual outputs from a number of plants (Unisearch Associates, 1994). Data were obtained for the four representative types of aluminium smelting technologies used in Canada.

PFC emissions can be controlled by computerized alumina feeders. Sensors detect 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).

Although aluminium production consumes extremely large quantities of electrical energy, currently estimated to be 13.5 kWh per 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, which emit virtually no GHGs.

4.6.2 METHODOLOGICAL ISSUES

The following CO_2 production-based emission factors for Canadian aluminium smelting were produced (ORTECH Corporation, 1994):

Søderberg – EF = 1.83 t CO_2/t Al produced
Prebaked – EF = 1.54 t CO_2/t Al produced

It has also been possible to establish the following average PFC emission rates for all aluminium plant cell technologies employed in Canada (Unisearch Associates, 1994):

Side Worked Prebaked –
EF(CF_4) = 1.2 kg CF_4/t Al produced

EF (C_2F_6) = 0.07 kg C_2F_6/t Al produced

Centre Worked Prebaked –
EF(CF_4) = 0.3 kg CF_4/t Al produced

EF (C_2F_6) = 0.02 kg C_2F_6/t Al produced

Horizontal Stud Søderberg –
EF(CF_4) = 0.8 kg CF_4/t Al produced

EF (C_2F_6) = 0.1 kg C_2F_6/t Al produced

Vertical Stud Søderberg –
EF(CF_4) = 0.4 kg CF_4/t Al produced

EF (C_2F_6) = 0.04 kg C_2F_6/t Al produced

These PFC emission factors are based on actual plant emission tests whereby a tunable diode laser absorption spectroscopy (TDLAS) measurement technique was employed to determine CF_4 and C_2F_6 concentrations in aluminium pot gas exit stacks during anode events. The PFC emission factors disclosed above have evolved based on consultations with the Aluminium Association of Canada to reflect process improvements resulting in a decrease in PFC emissions. PFC emissions for each inventory year from 1994 to 2001 have been estimated using emission factors which have been slightly modified from those disclosed above.

Annual national aluminium production data and aluminium smelter capacity data for each facility were obtained from the Canadian Minerals Yearbook (NRCan, 2001). For any given year, the most recent aluminium production numbers provided are preliminary and are subject to revision in subsequent publications. Plant emissions were calculated by estimating individual plant production based on the reported national production and smelter capacity data, and, subsequently, applying the appropriate emission factors according to the plant cell technology or technologies employed.

This technique for estimating PFC and CO_2 emissions from aluminium production is considered to be a

Tier 2-type method as it is based on the use of cell technology-specific emission factors.

The use of petroleum coke in anodes for the production of aluminium is 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 must, therefore, be subtracted from the total non-energy emissions to avoid double counting.

4.6.3 UNCERTAINTIES AND TIME-SERIES CONSISTENCY

Quantitative uncertainties associated with CO_2 and PFC emissions from the production of aluminium have not been developed. Due to the relatively high complexity of the flow and concentration measurements in determining PFC emissions factors and the large variance in anode event parameters from plant-to-plant, it is expected that the error associated with estimating PFC emissions is high relative to CO_2 emission estimates. For example, the error associated with measuring the ambient CF_4 in the atmosphere alone is approximately 10% (Unisearch Associates, 1994).

The data source has remained consistent over the time-series, however, while the PFC emission factors have undergone minor changes to reflect process modifications resulting in a decrease in PFC emissions. The *Canadian Minerals Yearbook* (NRCan) publication has been used as an activity data and plant capacity data reference for each inventory year.

4.6.4 QA/QC AND VERIFICATION

The following are inventory QA/QC and verification procedures specific to Aluminium Production:

Emission factor verification/comparison: The national emission factors for CO_2 and PFC emissions from aluminium production are consistent with the IPCC default values (IPCC, 1997).

Activity data verification: The published aluminium production estimates are compared to the published aggregate national aluminium plant capacities in order to provide an indication of the reasonableness and representativeness of the activity data.

Revised data: The *Canadian Minerals Yearbook* (NRCan) provides only preliminary aluminium production data for the current year and the figures may be revised in subsequent years. Any differences are identified and the appropriate recalculations are made.

4.6.5 RECALCULATIONS

There have been no recalculations to either PFC or CO_2 emissions related to aluminium production.

4.6.6 PLANNED IMPROVEMENTS

Improvements to the PFC emissions methodology may be made pending a recent study regarding PFC emissions from Canadian aluminium reduction plants (Unisearch, 2001).

4.7 MAGNESIUM METAL PRODUCTION

4.7.1 SOURCE CATEGORY DESCRIPTION

SF_6 is emitted during magnesium production, 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; therefore, there are no SF_6 production-related emissions in Canada.

In 2001 there were three magnesium producers in Canada: Norsk Hydro, Timminco Metals and Métallurgie Magnola Inc. Norsk Hydro has improved its production technologies to minimize the consumption of SF_6, while production has increased over the same period.

SF_6 emissions from aluminium and magnesium foundries are not estimated in the inventory. However, they are considered a minor source in comparison with primary magnesium production.

4.7.2 METHODOLOGICAL ISSUES

SF_6 emission data for 1999, 2000 and 2001 were reported directly by the magnesium producers through a mandatory emissions reporting program known as the National Pollutant Release Inventory (NPRI). For previous years the data were provided voluntarily by telephone from the producers.

This technique is considered to be a Tier 3-type method as it is based on the reporting of facility-specific emissions data.

4.7.3 UNCERTAINTIES AND TIME-SERIES CONSISTENCY

Similarly to N_2O emissions associated with adipic acid production, SF_6 emissions attributable to the Canadian primary magnesium industry are reported directly to Environment Canada and are thought to be very accurate.

The methodology and data sources remain consistent. Emissions from the two primary magnesium smelters (Norsk Hydro and Timminco) have been reported directly to Environment Canada since 1990. SF_6 emissions from all three smelters, including Magnolia which started up in 2000, have been reported to the NPRI starting in 1999.

4.7.4 QA/QC AND VERIFICATION

No additional QA/QC or verification activities have been performed other than those outlined in Section 1.6.

4.7.5 RECALCULATIONS

There have been no recalculations to SF_6 emissions related to magnesium production.

4.7.6 PLANNED IMPROVEMENTS

There are currently no improvements planned specifically for estimating SF_6 emissions from magnesium production in Canada. However, a thorough review of methodologies and QA/QC activities is on-going (see Section 1.8).

4.8 PRODUCTION AND CONSUMPTION OF HALOCARBONS

4.8.1 SOURCE CATEGORY DESCRIPTION

The major source of emissions from consumption of halocarbons is due to the use of HFCs as replacements for chlorofluorocarbons (CFCs). HFCs were not used to any significant degree in Canada before 1995. CFCs are GHGs, but are not included under the UNFCCC since they are already controlled under the Montreal Protocol and, as a result, are not inventoried herein.

Emissions from the consumption of PFCs are minor relative to emissions of PFC by-products from aluminium production. The by-product emissions of PFCs from aluminium production are discussed in the Aluminium Metal Production section. All HFCs/PFCs consumed in Canada are imported in bulk or in products (e.g. refrigerators).

Air conditioning (AC) and refrigeration equipment represent the primary source of HFC emissions. From 1990 to 1994, emissions from HFC consumption were considered negligible since HFCs were not widely used before the ban on production and use of CFCs came into effect in 1996 (as a result of the Montreal Protocol). There is no known production of HFCs/PFCs in Canada.

4.8.2 METHODOLOGICAL ISSUES

HFC emission estimates for 1995 were based on data from an initial HFC survey conducted by Environment Canada and used a modified IPCC Tier 1 methodology. Environment Canada has since revised the HFC survey to obtain more detailed activity data. An IPCC Tier 2 methodology was used to estimate 1996–2001 HFC emissions based on detailed activity data provided by the survey. HFC activity data for 1999–2001 are currently unavailable; therefore, the emission estimates are based on 1998 activity data. No data were available for quantities of HFCs contained in imported equipment for the 1995 HFC emission estimate, so this source is not included but it is assumed to be small relative to others in the inventory.

Detailed 1995 HFC data were not available to apply an IPCC Tier 2 estimate. Instead, where applicable, the IPCC Tier 1 methodology was adapted to make a more representative estimate of actual 1995 HFC emissions for the following groups: aerosols; foams; air conditioning original equipment manufacture (AC OEM); air conditioning (AC) service; refrigeration; and total flooding system.

PFC emission estimates were based on consumption data from the 1998 PFC survey conducted by Environment Canada and used the 1996 Revised IPCC Guideline (Tier 2 methodology) and the IPCC Good Practice Guidance methodologies. PFC consumption data used to estimate 1998–2001 emissions were based on 1997 data (only 1995–1997 PFC consumption data were collected in the survey).

4.8.2.1 HFC Estimate for 1995 – Emission Factors and Assumptions

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

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 suggest a 2–5% loss rate. For Canada, a rate of 4% was assumed.

AC Service – It was assumed that most HFC use related to AC Service is related to the replacement of operating losses. It was also assumed that service HFCs replace identical HFCs, which are vented. As a result, a loss rate of 100% has been employed.

Refrigeration – It was assumed that all refrigeration in Canada falls under the IPCC Other (i.e., commercial and industrial) category, since this is the dominant emission source. It was further assumed that refrigeration HFCs represent those used for initial and subsequent recharging of equipment. Therefore:

Equation 4-1:

HFC (refrig) = Charge + Operating Loss

The IPCC considers that operating loss is approximately 0.17(charge) (IPCC, 1997). Therefore, assuming the total charge remains constant for the short term:

HFC (refrig) = 0.17(Charge) + Charge = 1.17(Charge)

or

Charge = HFC (refrig)/1.17

Assuming assembly leakage is minimal:

Emission = operating loss = 0.17(Charge)

thus,

Equation 4-2:

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

4.8.2.2 HFC/PFC Estimates for 1996–2001 – Emission Factors and Assumptions

HFC and PFC emission estimates for 1996–2000 in relation to refrigerators, freezers, and air conditioning from system assembly – during system operation and at disposal – used the IPCC Tier 2 methodology presented in the revised IPCC Guidelines (IPCC, 1997).

System Assembly

To estimate emissions from system assembly, four types of equipment categories were considered: residential refrigeration, commercial refrigeration, stationary air conditioning, and mobile air conditioning. The equation given in the revised IPCC Guidelines (as shown below) was used to estimate emissions during system assembly for each type of equipment (IPCC, 1997):

Equation 4-3:

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

where:

$E_{assembly,\ t}$ = Emissions during system manufacture and assembly in year t

$E_{charged,\ t}$ = Quantity of refrigerant charged into new system in year t

k = Assembly losses in percentage of the quantity charged

The k value was chosen from a range of values that were provided for each equipment category in the revised IPCC Guidelines (see Table 4-1) (IPCC, 1997). The HFC and PFC survey provided the quantity of refrigerant charged.

TABLE 4-1: 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 used to calculate emissions due to annual leakage. The equation given in the revised IPCC Guidelines (as shown below) was used to calculate 1996–2000 HFC and PFC emissions from annual leakage (IPCC, 1997):

Equation 4-4:

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

where:

$E_{operation,\,t}$ = Quantity of HFC/PFC emitted during system operations in year t

$E_{stock,\,t}$ = Quantity of HFC/PFC stocked in existing systems in year t

x = Annual leakage rate in percentage of total HFC/PFC charge in the stock

The amount of HFC/PFC stocked in existing systems includes the HFC/PFC in equipment manufactured in Canada, the amount of HFC/PFC in imported equipment, and the amount of HFC in converted CFC equipment and excludes the amount of HFC/PFC in exported equipment. The amount of HFC used in converted CFC equipment was estimated based on the amount of HFC used for servicing equipment. It was assumed that no leakage occurs in the year of manufacturing or conversion. HFC/PFC consumption data were provided by Environment Canada's HFC/PFC survey. The IPCC Guidelines 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 4-2 (IPCC, 1997).

TABLE 4-2: Annual Leakage Rate (x)

Category	x Values
Residential Refrigeration	1.0%
Commercial Refrigeration	17.0%
Stationary Air Conditioning	17.0%
Mobile Air Conditioning	15.0%

System Disposal

HFC emissions from system disposal were not estimated, since HFC use began only in 1995 and was assumed to be negligible.

PFC emissions from system disposal were not estimated, due to a lack of data. Also, PFC emissions from systems that have been disposed of are assumed to be insignificant due to their limited use for specialized cooling systems prior to 1995.

Foam Blowing

HFC emission estimates for 1995 used an adaptation of the IPCC Tier 1 default method (IPCC, 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, 1997).

The IPCC Tier 2 methodology presented in the revised IPCC Guidelines was used to estimate 1996–2001 HFC and PFC emissions from foam blowing (IPCC, 1997). 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, 1997). At present, there is no known PFC use in open cell foam blowing. Environment Canada's HFC survey provided consumption data on the following open cell foam production categories that release HFC emissions:

- Cushioning – Automobiles
- Cushioning – Others
- Packaging – Food
- Packaging – Others
- Other Foam Uses

Closed Cell Foam Blowing

During the production of closed cell foam, approximately 10% of the HFCs/PFCs used are emitted (IPCC, 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 4-5:

$$E_{foam,\,t} = 10\%\ E_{manufacturing,\,t} + 4.5\%\ E_{foam\_stock,\,t}$$

where:

$E_{foam,\,t}$ = Emissions from closed cell foam in year t

$E_{manufacturing,\,t}$ = Quantity of HFCs/PFCs used in manufacturing closed cell foam in year t

$E_{foam\_stock,\,t}$ = Quantity of HFCs/PFCs in stock (excluding exports) in year t

Quantities of HFCs/PFCs used in manufacturing and in stock of closed cell foam were provided by Environment Canada's HFC/PFC survey. The following are closed cell foam production categories that produce HFC emissions:

- Thermal Insulation – Home and Building
- Thermal Insulation – Pipe
- Thermal Insulation – Refrigerator and Freezer
- Thermal Insulation – Other

Fire Extinguishers

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

There are two types of fire-extinguishing equipment considered: portable fire extinguishers and total flooding systems. The IPCC Tier 2 methodology of the revised IPCC Guidelines was used to calculate 1996–2001 HFC emissions from portable fire extinguishers and total flooding systems (IPCC, 1997). At present, there is no known PFC use in fire-extinguishing equipment.

Portable Fire-Extinguishing Equipment

The IPCC Tier 2 methodology in the revised IPCC Guidelines estimated emissions as 60% of HFCs used in newly installed equipment (IPCC, 1997). The quantity of each type of HFCs was provided by Environment Canada's HFC survey.

Total Flooding Systems

The IPCC Tier 2 methodology provided in the revised IPCC Guidelines estimated emissions from total flooding systems as 35% of the HFCs used in new fire-extinguishing systems installed (IPCC, 1997). The amount of each type of HFC used in new systems was provided by Environment Canada's HFC survey.

Aerosols/Metered Dose Inhalers

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

The IPCC Tier 2 methodology presented in the revised IPCC Guidelines was used to calculate 1996–2001 HFC emissions from aerosols (IPCC, 1997). 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. To calculate the amount of each type of HFC used in aerosol produced, imported, and exported, each year's activity data were provided by Environment Canada's HFC survey.

Solvents

The IPCC Tier 2 methodology presented in the revised IPCC Guidelines was used to estimate 1996–2001 HFC and PFC emissions from solvents (IPCC, 1997). 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. To calculate the amount of each type of HFC/PFC used as solvents, each year's activity data were provided by Environment Canada's HFC/PFC survey. HFCs/PFCs used as solvents include the following categories:

- electronics industries;
- laboratory solvents; and
- general cleaning.

Semiconductor Manufacture

IPCC Tier 2b methodology provided by the IPCC Good Practice Guidance was used to estimate PFC emissions from the semiconductor manufacturing industry.

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.

Bulk PFC consumption data were provided by Environment Canada's PFC survey, and emission rates chosen for each process are shown in Table 4-3, provided by the IPCC Good Practice Guidance (Tier 2b). Currently, there is no information on emission control technologies for these processes, therefore it is assumed that 100% of PFCs are released (IPCC/OECD/IEA, 2000).

TABLE 4-3: PFC Emission Rate[1]

Process	CF_4	C_2F_6	C_3F_8	$c\text{-}C_4F_8$
Plasma Etching	0.7	0.4	0.4	0.3
Chemical Vapour Deposition Chamber	0.8	0.7	0.4	ND

ND = no data available

1 From IPCC Good Practice Guidance, Tier b (IPCC/OECD/IEA, 2000).

Electrical Equipment

The Tier 2 methodology and default emission factors presented in the IPCC Good Practice Guidance were used to estimate PFC emissions. PFC consumption data were provided by the PFC survey. The data were categorized into emissive and contained PFC emission sources. Unidentified and miscellaneous PFC uses were also categorized under emissive emission sources.

Emissive sources include the following:

- electrical environmental testing;
- gross leak testing; and
- thermal shock testing.

The method used to estimate PFC emissive emissions assumed that 50% of PFCs used for the above purposes are released during the first year and the remaining 50% are released during the second year.

PFC emissions for contained sources are associated with their use as an electronic insulator and a dielectric coolant for heat transfer in the electronics industry. PFC consumption data were provided by Environment Canada's PFC survey. The Tier 2 methodology and emission factors provided by the IPCC Good Practice Guidance were used to estimate PFC emissions from contained sources, represented by the following equation:

Equation 4-6:

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

where:

$E_{contained,\,t}$ = Emissions from contained sources

$E_{consumed,\,t}$ = Quantity of PFC sale for use or manufacturing of contained sources in year t

$E_{stock,\,t}$ = 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

4.8.3 UNCERTAINTIES AND TIME-SERIES CONSISTENCY

Quantitative uncertainties in HFC/PFC emissions estimates related to the consumption of halocarbons are not currently available. The uncertainties are expected to be high relative to GHG emissions in other industrial process sectors. A primary element of uncertainty in determining halocarbon emissions from this source is attributed to the manner in which activity data is collected. As mentioned in the previous section, the 1995 Environment Canada HFC/PFC survey was not very detailed and, therefore, an incomplete data set was used to estimate HFC/PFC emissions for that year. From 1996–1998 a more detailed survey was used to collect halocarbon activity data. However, given the high number of sources/respondents the data uncertainty for this end-use survey is compounded. In addition, current activity data beyond 1998, is not available.

The Environment Canada survey has been used for each inventory year in which halocarbon emissions were estimated (1995). The methodology and data sources remain consistent although, as previously mentioned, the format of the survey changed significantly in 1996.

4.8.4 QA/QC AND VERIFICATION

No additional QA/QC or verification activities have been performed other than those outlined in Section 1.8.

4.8.5 RECALCULATIONS

There have been no recalculations to HFC/PFC emissions related to halocarbon consumption.

4.8.6 PLANNED IMPROVEMENTS

There are, currently, no improvements planned specifically for estimating HFC/PFC emissions from HFC/PFC consumption in Canada, however a thorough review of methodologies and QA/QC activities is on-going.

4.9 PRODUCTION AND CONSUMPTION OF SF_6

4.9.1 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 1990–1996 SF_6 imports from the U.S. comprised more than 95% of total imports. However, in recent years this number has declined with an increase in SF_6 imports from Germany (Cheminfo Services, 2002).

Currently, the only source of SF_6 emissions reported is from primary magnesium production. Details on SF_6 emissions estimates from this source are found in the Magnesium Metal Production section. Other significant sources of SF_6 emissions are from magnesium product casting processes where SF_6 is used as a cover gas, and from the use of SF_6 as an insulating and arc-quenching medium in electrical equipment such as electrical switchgear, stand-alone circuit breakers and gas-insulated substations.

Planned improvements in estimating SF_6 emissions from SF_6 consumption in Canada will be comprised mainly of developing an effective methodology for estimating SF_6 emissions from the use of SF_6 in electrical equipment.

Refer to the Magnesium Metal Production section for a discussion of the methodology used to estimate SF_6 emissions from primary magnesium production.

4.10 OTHER

4.10.1 SOURCE CATEGORY DESCRIPTION

These emissions are from the non-energy use of fossil fuels and are not accounted for under any of the other Industrial Processes sectors.

A number of fossil fuels are used in this category for purposes that are considered non-energy uses. These include the use of natural gas to produce hydrogen in the oil upgrading and refining industries, the use of petroleum coke for anodes in metal production, the use of natural gas liquids (NGLs) and feedstocks in the chemicals industry, and the use of lubricants. These non-energy uses of fossil fuels result in varying degrees of oxidation of the fuel, producing CO_2 emissions.

The use of fossil fuels as feedstocks or for other non-energy uses is reported in an aggregated manner by Statistics Canada under the general category of "Non-Energy Use", for each individual fuel. In the event that CO_2 emissions resulting from non-energy fuel use are allocated to another of the Industrial Processes categories (as is the case for ammonia production and aluminium production), those emissions must be subtracted from the total non-energy emissions to avoid double-counting.

4.10.2 METHODOLOGICAL ISSUES

The use of fossil fuels as feedstocks or for other non-energy uses may result in emissions during the in-use phase of manufactured products. These emissions are process and technology specific. General emission rates have been developed based on life cycle analysis of the processes and products where these fuels are used as feedstocks. Industry-average factors have been developed based on IPCC default emission rates (IPCC, 1997) and the carbon content of Canadian fuels (McCann, 2000). The factors are presented on a gram of CO_2 emitted per unit of fossil fuel used as feedstock or non-energy product basis (see Annex 7).

Fuel quantity data for non-energy fuel usage are reported by the Quarterly Report on Energy Supply and Demand (Statistics Canada, #57-003). Fuel-use data reported for any given year is preliminary and subject to revisions in subsequent publications.

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 IPCC Good Practice Guidance (IPCC/OECD/IEA, 2000).

For certain cases, industry- and process-specific data were available. For example, the use of natural gas to produce hydrogen in the oil upgrading and refining industries is reported as natural gas transformed to refined products and natural gas inter-product transfer by the Quarterly Report on Energy Supply and Demand (Statistics Canada, #57-003). In these instances, the natural gas is assumed to undergo complete oxidation, and the appropriate combustion emission factor is applied.

4.10.3 UNCERTAINTIES AND TIME-SERIES CONSISTENCY

Uncertainties related to the estimation of CO_2 emissions are relatively small in relation to other GHGs, with confidence levels ranging from 85% to 95% (McCann, 1994). However, given the multiple activity data sources and the "catch-all" nature of the Other: Industrial Processes category, uncertainty associated with the estimation of CO_2 emissions from non-energy use of fossil fuels is expected to be relatively high.

The methodology and data sources remain consistent. The Quarterly Report on Energy Supply and Demand (Statistics Canada, #57-003) publication has been used as the non-energy fuel-use activity data source for each inventory year. It should also be mentioned that the data sources for the calculation of CO_2 from aluminium and ammonia production have remained consistent. This is relevant as CO_2 emissions from aluminium and ammonia production are subtracted from the overall non-energy fuel-use emissions in order to avoid double-counting.

4.10.4 QA/QC AND VERIFICATION

No additional or specific QA/QC was undertaken for this category.

4.10.5 RECALCULATIONS

There have been minor revisions by Statistics Canada to non-energy use data for 1999 and 2000. These revisions have resulted in slight increases in CO_2 emissions for 1999 and 2000.

4.10.6 PLANNED IMPROVEMENTS

There are currently no improvements planned specifically for estimating CO_2 emissions from the non-energy use of fossil fuels in Canada, however a thorough review of methodologies and QA/QC activities is on-going (see Section 1.6).

5 SOLVENT AND OTHER PRODUCT USE (CRF SECTOR 3)

One distinction between the sources in the Solvent and Other Product Use section and those in the Industrial Processes section is that the former are generally area sources.

5.1 N_2O FROM ANAESTHETICS AND PROPELLANTS

The majority of emissions in this section are also related to the use of N_2O as an anaesthetic and a propellant. Emissions from paint application, degreasing and dry cleaning, chemical products, manufacture and processing are not estimated.

5.1.1 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.

5.1.2 METHODOLOGICAL ISSUES

Based on population statistics and the quantity of N_2O consumed in these applications in 1990 (Fettes, 1994), an emission factor for N_2O emissions from anaesthetics was estimated on the basis of consumption patterns in Canada. This emission rate is slightly lower than the emission rate developed for the United States.

An emission factor was developed for N_2O used as a propellant based upon consumption patterns in Canada in 1990 (see Annex 7). It was assumed that all the N_2O used in propellants was emitted to the atmosphere during the year of sale.

The population data used for the emission calculations were obtained from Statistics Canada (#91-213).

5.1.3 UNCERTAINTIES AND TIME-SERIES CONSISTENCY

No information is available on the uncertainties from these sources. The estimates are calculated in a consistent manner over time, therefore the time-series should be consistent.

5.1.4 QA/QC AND VERIFICATION

No specific or additional QA/QC procedures were undertaken for this category.

5.1.5 RECALCULATIONS

No recalculations were made.

5.1.6 PLANNED IMPROVEMENTS

No improvements are planned for this category.

6 AGRICULTURE (CRF SECTOR 4)

Canada's Agriculture sector emits and removes greenhouse gases from the atmosphere. The main emission sources include methane (CH_4) and nitrous oxide (N_2O) emissions from animal production (i.e. enteric fermentation and manure management), and N_2O released from agricultural soils. Removals of CO_2 are mainly from Canada's agricultural soils. This net removal of CO_2, observed as an increase in soil carbon storage, is due to greater adoption of conservation practices such as no-till farming and the reduction of summer-fallow on the Canadian prairies.

As there is only a small amount of rice production in Canada, CH_4 emissions from rice production are considered to be negligible and are not inventoried. Similarly, field burning of agricultural residues is no longer considered a common practice in Canadian agriculture and, therefore, is not inventoried. Prescribed burning of savannas is not a relevant practice in Canada. Greenhouse gas emissions from on-farm fuel combustion are included in Chapter 3: Energy.

For each emission source category, a brief introduction, methodological issues, uncertainties and time-series consistency, quality assurance/quality control (QA/QC) and verification, recalculations and planned improvements are provided. The detailed inventory methodologies and activity data are described in Annex 3.

6.1 ENTERIC FERMENTATION

6.1.1 SOURCE CATEGORY DESCRIPTION

Large quantities of methane (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 that 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.

6.1.2 METHODOLOGICAL ISSUES

The IPCC Tier 1 methodology is used to estimate CH_4 emissions from enteric fermentation. Methane emissions are calculated for each animal category, by multiplying the animal population by the average 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 6-1. Semi-annual or quarterly data are averaged to obtain annual populations. The IPCC default emission factors for a cool climate are used for all animal categories except cattle (IPCC, 1997). Country-specific emission factors are applied to bull, beef cow, dairy heifer and beef heifer populations.

TABLE 6-1: Animal Categories and Sources of Population Data

Category	Sources/Notes
Cattle	
• Dairy Cattle	Includes dairy cows only[1]
• Non-Dairy Cattle	All other cattle Data source: Statistics Canada, Cat No. 23-603
Buffalo	Considered a negligible source in Canada
Sheep	Listed under *Other* in the CGHGI Includes lambs Data source: Statistics Canada, Cat No. 23-603
Goats	Listed under *Other* in the CGHGI Data are not available on an annual basis from Statistics Canada, No. 23-603. Therefore, data from the 1991, 1996 and 2001 farm census (Statistics Canada, No. 93-350, No. 93-356, and No. 95F0301) have been used.
Camels and Llamas	Considered a negligible source in Canada
Horses	Listed under *Other* in the CGHGI Data are not available from Statistics Canada, No. 23-603. Therefore, for horses, data from the 1991, 1996 and 2001 farm census (Statistics Canada, No. 93-350, No. 93-356, and No. 95F0301) have been used.
Mules and Asses	Considered a negligible source in Canada
Swine	All pigs Data source: Statistics Canada, Cat No. 23-603
Poultry	Yearly population data are available from Production of Poultry and Eggs (Statistics Canada, No. 23-202)
Other	See above

1 For Manure Management, includes dairy cows and dairy heifers

6.1.3 UNCERTAINTIES AND TIME-SERIES CONSISTENCY

Uncertainties associated with emission estimates from enteric fermentation result mainly from uncertainties associated with estimates of animal populations from the Census of Agriculture and uncertainties associated with emission factors.

Errors associated with the Census of Agriculture include coverage errors, non-response errors, response errors and processing errors. It is generally accepted that activity data provided from the Census have a relatively low degree of uncertainty. Due to differences in sample frequency and coverage, the quality of animal population data decreases in the following order: swine (Statistics Canada, Catalogue No. 23-603), sheep and lambs (Statistics Canada, Catalogue No. 23-603), cattle (Statistics Canada, Catalogue No. 23-603), poultry (Statistics Canada, Catalogue No. 23-202), and horses and goats (Statistics Canada, Catalogue No. 95F0301XIE).

The IPCC emission factors for North America are based on research conducted in the United States. Methane emissions can vary widely from animal to animal based on a number of factors such as the amount of food ingested, the digestion efficiency, the size of the animal, the age of the animal, and the climate. The uncertainties associated with the adopted IPCC default emission factors for Canadian conditions are expected to be moderate. Thus, the overall uncertainty associated with this source of emissions is considered to be moderate.

The same methodology and emission factors are used for the entire time series of emission estimates (1990–2001).

6.1.4 QA/QC AND VERIFICATION

The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form. Quality control checks and cross-checks have been carried out to identify data entry errors and calculation errors.

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 from grazing cattle by using sulfur hexafluoride (McCaughey et al., 1997; McCaughey et al., 1999; Boadi and Wittenberg, 2002; Boadi et al., 2002a; Boadi et al., 2002b). Methane measurements in the scientific literature are currently being compiled by the GHG Division for purposes of future comparison and verification.

6.1.5 RECALCULATIONS

No recalculations have been carried out.

6.1.6 PLANNED IMPROVEMENTS

Enteric fermentation, primarily resulting from the production of beef and dairy cattle, is a major source of emissions for Canada's Agriculture sector. As such, a higher tiered methodology should be applied for emission estimates. The adoption of a Tier 2 methodology requires specific information on animal feed intake, weight, growth rate, feeding situation, quality of feed, etc. Canada is working towards the adoption of an IPCC Tier 2 methodology for estimating CH_4 emissions for cattle. It is expected this process will take one to two years to complete.

6.2 MANURE MANAGEMENT

During the handling or management of livestock manure, both CH_4 and N_2O are emitted. The magnitude of the emissions is dependent 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, while well-aerated systems generate little CH_4 but more N_2O.

6.2.1 METHANE (CH_4) EMISSIONS

6.2.1.1 Source Category Description

Shortly after manure is excreted, it begins to decompose. If little oxygen is present, the decomposition will be mainly anaerobic and thus produce 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. Average emission rates have been developed for livestock based on the typical waste management systems and manure production rates for North America.

6.2.1.2 Methodological Issues

Methane 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 emission factor associated with the specific animal category.

The animal population data are the same as those used for the enteric fermentation emission estimates, with one exception, dairy cattle includes both dairy cows and dairy heifers. The IPCC default emission factors for a developed country with a cool climate are used for all animal categories (IPCC, 1997).

6.2.1.3 Uncertainties and Time-Series Consistency

Uncertainties associated with CH_4 emission estimates from manure management result from uncertainties associated with estimates of animal populations from the Census of Agriculture and uncertainties associated with emission factors. Uncertainties associated with estimates of animal populations from the Census of Agriculture, as noted previously, are generally low.

The IPCC emission factors for North America are based on research conducted in the United States. Methane emission factors are only related to animal categories, even though the types of manure management systems may have a greater impact on emissions. It is expected that the uncertainties associated with the emission factors adopted from the IPCC defaults for Canadian conditions would be high. Thus, the overall uncertainty associated with this source of emissions would be moderate.

The same methodology and emission factors are used for the entire time series (1990–2001).

6.2.1.4 QA/QC and Verification

The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form. Quality control checks and cross-checks have been carried out to identify data entry errors and calculation errors.

6.2.1.5 Recalculations

No recalculations have been carried out.

6.2.1.6 Planned Improvements

Manure management is a major source of CH_4 emissions for Canada's Agriculture sector. As such, according to the IPCC Good Practice Guidance (IPCC, 2000), a higher tiered methodology should be applied for these emission estimates. However, the adoption of a Tier 2 methodology requires specific information on the amount of volatile solids produced; CH_4 producing potential; and manure management systems, etc.

Canada is working towards the adoption of an IPCC Tier 2 methodology for estimating CH_4 emissions from manure management systems. It is expected this process will take several years to complete.

Direct measurements of CH_4 emissions from manure management in Canada are recent, and data are still scarce. Recent scientific advances in analytical techniques allow direct measurements of CH_4 emissions from point sources, such as lagoons, using a flux tower. However, it is estimated that it will take several years before CH_4 emissions can be reliably measured and verified from various manure management systems in Canada.

6.2.2 NITROUS OXIDE (N_2O) EMISSIONS

6.2.2.1 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 nitrogen (N_2). Generally, as the degree of aeration of the waste increases, so does the amount of N_2O produced.

In Canada, four different types of manure management or animal waste management systems (AWMS) are typically used: pasture and paddock, liquid systems, solid storage or drylot, and a miscellaneous category entitled other systems. It is assumed that no manure is burned as fuel. Table 6-2 presents Canada's breakdown of manure nitrogen by AWMS. As there is little detailed data on the distribution of manure management systems by animal category, these percentages are based on consultation with industry experts. Note that the N_2O emissions from manure in pasture and paddock systems are not included here but counted as direct N_2O emissions from agricultural soils (see Section 6.4.1.6).

TABLE 6-2: Percentage of Manure Nitrogen Handled by AWMS (N_P), %

Animal Types N_T	Liquid Systems	Solid Storage & Drylot	Other Systems	Pasture Range & Paddock
Non-Dairy Cattle	1	56	1	42
Dairy Cattle	53	27	0	20
Poultry	4	0	95	1
Sheep and Lambs	0	46	10	44
Swine	90	10	0	0
Other (goats and horses)	0	46	8	46

6.2.2.2 Methodological Issues

Nitrous oxide 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 6.1.2), with one exception. Here dairy cattle includes both dairy cows and dairy heifers. The average annual nitrogen excretion rates for domestic animals are taken from research conducted in the United States (ASAE, 1999). These excretion rates are reduced by 20% to account for the volatilisation of NH_3 and NO_x (IPCC, 1997).

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 for a developed country with a cool climate are used to estimate the percentage of 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 6-2) to come up with the fraction of nitrogen that is converted in N_2O.

6.2.2.3 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, rates of nitrogen excretion, types of animal waste management systems (AWMS), and the amount of nitrogen available for conversion into N_2O from each type of AWMS. There is a high degree of uncertainty associated with emission factors for various manure management systems, rates of nitrogen excretion, and the types of manure management systems in Canada. Uncertainties associated with estimates of animal populations from the Census of Agriculture, as noted previously, are generally low. The overall uncertainty associated with this source of emission estimates is rated as high.

The same methodology and emission factors are used for the entire time series (1990–2001).

6.2.2.4 QA/QC and Verification

The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form. Quality control checks and cross-checks have been carried out to identify data entry errors and calculation errors.

6.2.2.5 Recalculations

No recalculations have been carried out.

6.2.2.6 Planned Improvements

Over the next two years, Canada intends to conduct a waste management survey for various animal categories to verify and update the AWMS distributions listed in Table 6-2.

Direct measurements of N_2O emissions from manure management in Canada are recent, 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.

6.3 EMISSIONS OR REMOVALS FROM AGRICULTURAL SOILS

Management practices and cropping systems affect both carbon and nitrogen cycles in agricultural soils. These activities can lead to emissions or removals of CO_2 and emissions of N_2O. The impacts on CH_4 are not well understood at this time.

CO_2 emissions or removals typically result from a change in soil organic carbon which is a function of the timing and amount of land conversion from native grassland or forest to agriculture, the management practices, soil characteristics, and climate. A key challenge surrounding the estimation of the change in soil carbon is the quantification of a small annual increment relative to a large carbon pool.

Canada's CO_2 inventory for agricultural soils currently applies to cropland – agricultural land that is managed for crop production. It includes CO_2 emissions and removals from mineral soils and CO_2 emissions from organic soils and lime application.

6.3.1 CULTIVATION OF MINERAL SOILS AND LIME APPLICATION

Cultivated agricultural land in Canada includes field crop area plus summer-fallow. It has stabilized at about 45.4 million hectares, and further expansion is not expected (Dumanski et al., 1998). Approximately 80% of Canada's arable land is located in the three prairie provinces of Alberta, Saskatchewan and Manitoba.

6.3.1.1 Source Category Description

Cultivation or the application of management practices (e.g. tillage, crop rotation, fallow frequency, etc.) can lead to an increase or decrease in organic carbon stored in mineral soils. This change in soil organic carbon results in an emission or removal of CO_2 from the atmosphere. The amount of organic carbon retained in soil is a function of primary production (i.e. crop yield or crop residue) and rate of decomposition of soil organic carbon.

In Canada it is believed that CO_2 emissions from mineral soils have decreased since 1990 due to changes in farming practices which are currently removing CO_2 from the atmosphere. The primary reason for the reduced net emissions from soils is due to the increasing practice of conservation tillage such as no-till and reduction of summer-fallow in the prairies. As shown in Table 6-3, no-till farming was being practiced on over 10% of Canada's croplands in 1996 as opposed to 4% in 1991 (Statistics Canada, No. 93-350 and No. 93-356). No-till farming reduces the oxidation of soil organic carbon while intensification of cropping systems (i.e. reducing summer-fallow) increases crop residue returned to the soil. In the prairies, these two practices have been adopted simultaneously in many areas, thereby increasing the carbon stored in these soils.

TABLE 6-3: Change in Management Practice, 1991–2001

Management Practice	1991	1996	2001
No-till (million ha)	1.86	4.59	8.82
Summer-fallow (million ha)	7.92	6.26	4.68

While lime is applied both to mineral and organic soils, Canada's current methodology combines lime CO_2 estimates with those of mineral soil CO_2. Limestone or dolomite are applied to raise the alkalinity and pH of acidic soils, and the breakdown of these compounds releases CO_2 into the atmosphere.

6.3.1.2 Methodological Issues

The CENTURY model (Parton et al., 1987) was employed to estimate the CO_2 emissions and removals. This model is a general model of the plant-soil ecosystem that has been used to represent carbon and nitrogen dynamics for different types of ecosystems (grasslands, forest, crops and savannas). After calibration, it can be used to simulate the diverse and myriad complexities that affect carbon fluxes in agricultural soils.

A description of how the CENTURY model was applied to estimate CO_2 fluxes on Canada's agricultural soils can be found in Annex 3 and Smith et al. (1997a). As the 2001 data from the Census of Agriculture were not available at the time of inventory preparation, the 1997–2001 CO_2 emissions and removals are projections based on the 1996 Census of Agriculture.

Currently, results of CO_2 emissions from lime application on agricultural soils are combined with the results of CO_2 emissions or removals from mineral soil obtained from the CENTURY model (Sellers and Wellisch, 1998). Emissions of CO_2 are calculated from the respective stochiometric relationships that describe the breakdown of limestone and dolomite into CO_2 and other minerals.

6.3.1.3 Uncertainties and Time-Series Consistency

Uncertainty in the model estimates is attributed to model error and variance in input parameters. Given that the model has been calibrated to estimate reasonable average output, most of the estimate uncertainty is attributed to the variance in input parameters. Sensitivity analysis (+/- 20%) of six input variables was carried out for three major soil groups in Canada. The results showed that the level and ranking of sensitivity of each input variable was different within each soil group. On average, in descending order, the variables that were found to be the most sensitive to net CO_2 emissions were air temperature, yield, fertilizer application rate, precipitation, bulk density and clay content.

Given the high degree of spatial and temporal variability, there is a high degree of uncertainty associated with the CO_2 estimates provided by the CENTURY model. Comparisons of Century outputs with field measurements suggest that further refinements are required to improve the reliability of the model in predicting soil carbon change in response to no-till practices in the prairies (McConkey, 1998). In fact, the rate of carbon gain under carbon-conserving practices determined by Smith et al. (1997b) using the CENTURY model was lower than that observed on the prairies, but higher than that observed in eastern Canada.

6.3.1.4 QA/QC and Verification

The activity data, methodologies (schedule files and parameters) and changes to methodologies are documented and archived in both paper and electronic form. Quality control checks and cross-checks have been carried out to identify data entry errors and calculation errors.

6.3.1.5 Recalculations

No recalculations have been carried out.

6.3.1.6 Planned Improvements

Through an inter-departmental Agriculture Working Group,[39] Canada is currently evaluating a number of

39 Agriculture Working Group of the Monitoring, Accounting and Reporting System (MARS) Land Use, Land Use Change and Forestry; url: http://www.ec.gc.ca/pdb/ghg/mars_steering_committee_e.cfm

different methodologies for accounting of soil carbon stock changes associated with agricultural management practices.

Over the last five years, significant progress has been made in terms of verifying changes in soil carbon stocks associated with carbon-conserving practices, such as adoption of no-till and reduction of summer-fallow on the Canadian prairies. These results will be used for either verifying the current methodology or selecting a new methodology for soil carbon accounting.

Emissions of CO_2 from lime applications on agricultural soils were only inventoried in 1997. Over the next year, Canada will update and report emissions from lime applications separately.

6.3.2 CULTIVATION OF ORGANIC SOILS

6.3.2.1 Source Category Description

Conversion of organic soils (histosols) to agriculture is normally accompanied by artificial drainage, cultivation and liming, resulting in rapid decomposition of soil organic matter and soil subsidence. Once under cultivation, the rate of CO_2 released depends on climate, the decomposibility of organic matter, the degree of drainage and other practices such as fertilization and liming. Note that this is a new source category in Canada's GHG inventory.

6.3.2.2 Methodological Issues

An IPCC Tier 1 methodology is used to estimate CO_2 emissions from the cultivation of organic soils (histosols). The emissions are calculated by multiplying the total area of cultivated histosols by an emission factor. Areas of cultivated histosols at the provincial level are not covered in the Census of Agriculture, which is collected regularly at a five-year interval by Statistics Canada. In absence of this data, consultations with numerous soil and crop specialists across Canada have been made. Based on this consultation, the total area of cultivated organic soils in Canada (for the period 1990 to 2001) is estimated to be 29,800 ha. The IPCC default emission factor of 10 tonnes of CO_2 per ha per year for a cold climate was adopted.

6.3.2.3 Uncertainties and Time-Series Consistency

The uncertainty associated with emissions from this source is due to the uncertainties associated with the area estimates for the cultivated histosols and the IPCC default emission factor. The uncertainty associated with the area estimate is expected to be low to moderate. The uncertainty associated with the IPCC default emission factors is assumed to be moderate. Thus, the overall uncertainty associated with this source of emission estimates is expected to be moderate.

The same methodology and emission factors are used for the entire time series (1990–2001).

6.3.2.4 QA/QC and Verification

The activity data and methodologies are documented and archived in both paper and electronic form. Quality control checks and cross-checks have been carried out to identify data entry errors and calculation errors.

There are limited scientific data available on CO_2 emissions resulting from cultivation of histosols in Canada. Glenn et al. (1993) conducted a study on the CO_2 fluxes from cultivated peat soils near Farnham, Quebec, and reported 10 tonnes CO_2/ha/yr, or 2.7 tonnes C/ha/yr.

6.3.2.5 Recalculations

No recalculations have been carried out.

6.3.2.6 Planned Improvements

There are no immediate plans aimed at improving emission estimates from this source.

6.4 DIRECT SOIL EMISSIONS OF NITROUS OXIDE

Emissions of N_2O from agricultural soils are derived from direct and indirect sources. Direct sources emissions are, as their name implies, directly emitted from agricultural soils. These emissions result from nitrogen that has entered the soil from synthetic fertilisers, animal manure applied as fertiliser, manure on pasture and paddock from grazing animals, biological nitrogen fixation, crop residue decomposition and the cultivation of histosols. Emissions from indirect sources are emitted through volatilization and leaching of synthetic fertilizer and manure nitrogen. These are assumed to occur off site.

6.4.1 DIRECT NITROUS OXIDE EMISSIONS

6.4.1.1 Synthetic Nitrogen Fertilisers

Source Category Description

Synthetic fertilisers add large quantities of nitrogen to agricultural soils. This added nitrogen undergoes transformations, i.e. nitrification and denitrification, and releases N_2O emissions. Emission rates associated with fertiliser application will depend on many factors such as the quantity and type of nitrogen fertilisers, crop types, soil types, climate and other environmental conditions. The timing of release varies greatly over the year, usually peaking at the time of spring snowmelt.

Methodological Issues

The methodology used to estimate N_2O emissions is an IPCC Tier 1 methodology. Emissions are calculated by multiplying fertiliser consumption by the non-volatilised fraction (available for nitrification and denitrification) and by an emission factor.

The amount of nitrogen applied is obtained from yearly fertiliser sales data, which are available from regional fertiliser associations (Korol, 2002). These data include the amount of fertiliser nitrogen sold by retailers on or before June 30 of the inventory year. It is assumed that all fertiliser sold after June 30 is used in the next inventory year.

The amount of applied nitrogen is reduced by 10% (IPCC default) to account for losses due to volatilisation. The IPCC default emission factor of 1.25% N_2O-N/kg N is then applied for all types of nitrogen fertilisers (IPCC, 1997).

Uncertainties and Time-Series Consistency

The uncertainty of synthetic fertiliser nitrogen consumption data is considered to be low. However, the uncertainty associated with the default IPCC emission factor is expected to be high, particularly because of the high degree of spatial and temporal variability associated with this emission process. Thus, the overall uncertainty associated with this emission estimate is expected to be moderate.

The same methodology and emission factors are used for the entire time series (1990–2001).

QA/QC and Verification

The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form. Quality control checks and cross-checks have been carried out to identify data entry errors and calculation errors.

There are limited and country-specific data available. Nitrous oxide emissions associated with synthetic fertiliser nitrogen applications on agricultural soils vary widely. However at regional and national scales, there is close agreement between the aggregated, measured emission factor and the IPCC default value.

Recalculations

No recalculations have been carried out.

Planned Improvements

Determining N_2O emissions associated with synthetic fertilizer applications is a complex issue because numerous factors, including the type of crop, soil, climatic and environmental conditions are involved. A number of national research initiatives are being undertaken by Agriculture and Agri-Food Canada and BIOCAP (e.g. landscape and cropping systems networks) to gain a better understanding of the processes.

6.4.1.2 Animal Manure Applied to Soils

Source Category Description

The application of animal manure as fertiliser to soils can increase the rate of nitrification/denitrification and result in enhanced N_2O emissions from agricultural soils. Note that the manure included in this category is that treated by dry lot, liquid or other AWMS. Manure deposited on grazing land is included in Section 6.4.1.6, Manure on Pasture and Paddock.

Methodological Issues

The methodology used to estimate these N_2O emissions is the IPCC Tier 1 methodology. Emissions are calculated by multiplying the amount of manure applied to agricultural soils by the non-volatilised fraction (available for nitrification and denitrification) by an emission factor. All manure that is handled by the animal waste management systems, except for the manure on pasture and paddock from grazing animals, is assumed to be applied to agricultural soils (see Section 6.2).

The amount of manure nitrogen excreted is reduced by the IPCC default value, 20%, to account for the volatilisation of NH_3 and NO_x (IPCC, 1997). The IPCC default emission factor (1.25 N_2O-N/kg N) is adopted for Canada (IPCC, 1997).

Uncertainties and Time-Series Consistency

There is a moderate degree of uncertainty associated with emission estimates from this source. While there is a high degree of uncertainty associated with the quantity of manure nitrogen applied to agricultural soils, the uncertainty associated with the emission factor that is adopted from the IPCC default to produce emission estimates is expected to be moderate.

The same methodology and emission factors are used for the entire time series (1990–2001).

QA/QC and Verification

The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form. Quality control checks and cross-checks have been carried out to identify data entry errors and calculation errors.

There are limited and country-specific data available. Nitrous oxide emissions associated with manure applications on agricultural soils vary widely.

Recalculations

No recalculations have been carried out.

Planned Improvements

Determining N_2O emissions associated with manure applied as fertiliser is a complex issue because numerous factors including the type of crop, soil, climate and environmental conditions are involved. A number of national research initiatives are being undertaken by Agriculture and Agri-Food Canada and BIOCAP (e.g., Landscape and cropping systems networks) to gain a better understanding of the processes involved.

6.4.1.3 Nitrogen-Fixing Crops

Source Category Description

Atmospheric nitrogen fixed by nitrogen-fixing plants (such as peas, beans, alfalfa) can undergo the process of nitrification and denitrification in the same manner as nitrogen applied as synthetic fertiliser. Also, rhizobia in the plant nodules can emit N_2O as they fix nitrogen.

Methodological Issues

The methodology used for estimating emissions is an IPCC Tier 1 methodology. Emissions are calculated by multiplying the dry matter of nitrogen-fixing crops by the nitrogen content and by an N_2O emission factor.

The IPCC default value for the average dry matter fraction (i.e. 86%) is applied to wheat, barley, corn, oats, rye, peas, beans, soybean, lentils, and tame hay crops (IPCC, 1997). Silage corn, potatoes, and sugar beets are assumed to contain 30, 25, and 20% of dry mass, respectively. As annual statistics for alfalfa production are combined with tame hay production, alfalfa quantities are estimated by assuming that 60% of tame hay production is alfalfa. In addition, the crop mass of alfalfa and tame hay is assumed to be equal to the reported production. The other crop production data are obtained from Statistics Canada (No. 22-002).

The amount of nitrogen in the nitrogen-fixing plants is estimated from production data, assuming that the crop mass is twice the mass of the edible portion and that it contains 0.03 kg N/kg dry mass (IPCC, 1997). The IPCC default emission factor (1.25 N_2O-N/kg N) for the nitrogen contained in nitrogen-fixing crops is applied (IPCC, 1997).

Uncertainties and Time-Series Consistency

Uncertainties are due mainly to the those associated with the quantity of nitrogen contained in the nitrogen-fixing crops and the IPCC default emission factor. The quality of crop production data is generally high. Usually by the end of the collection period, 85% of the questionnaires have been fully completed, and the survey refusal rate is 2 to 3%. For the November Crop Production Survey, coefficients of variations at the Canada level range from 1 to 5% for the major crops. The uncertainty associated with the IPCC default emission factor for nitrogen-fixing crops is expected to be high. Therefore, the overall uncertainty associated with this source of emission estimates is expected to be high.

There has been very little scientific work in quantifying N_2O emissions associated with biological nitrogen fixation in Canada or elsewhere. The current *Revised 1996 IPCC Guidelines* accounting for this particular emission source reflect general understanding of soil nitrogen cycling, rather than actual scientific measurements. Furthermore, estimates of nitrogen contained in leguminous crops based on the IPCC Guidelines are considered to be very crude.

The same methodology and emission factors are used for the entire time series (1990–2001).

QA/QC and Verification

The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form. Quality control checks and cross-checks have been carried out to identify data entry errors and calculation errors. Environment Canada has supported a two-year research initiative, "Quantifying Nitrous Oxide Emissions Resulting from the Production of Leguminous Crops in Canada". The objective of this study is to quantify emissions of N_2O resulting from leguminous crop production in Canada. The final report, expected to be available in June 2003, should allow for some verification of the emission estimates.

Recalculations

No recalculations have been carried out.

Planned Improvements

Improvements in the estimates of nitrogen contained in leguminous crops can be made using specific harvest indices and nitrogen content information, rather than IPCC defaults. It is generally known that the harvest index for most leguminous crops except for alfalfa is about 30%. The uncertainty associated with estimates of nitrogen contained in leguminous crops can be improved by using specific harvest index and nitrogen content for a specific crop.

6.4.1.4 Crop Residue Decomposition

Source Category Description

When a crop is harvested, a portion of the crop (crop residue) is left on the field to decompose. In Canada, it is estimated that 55% of the crop mass remains on the field as residue. The remaining plant matter is a nitrogen source for nitrification and denitrification processes, and thus produces N_2O.

In some cases, the remaining residue is burned. It is assumed that the amount of burning is negligible in Canada.

Methodological Issues

Emissions are estimated using the IPCC Tier 1 methodology as follows: the amount of nitrogen contained in the crop residues from both nitrogen-fixing and non-nitrogen-fixing crops is multiplied by an N_2O emission factor.

The nitrogen content for nitrogen-fixing crop residue, 0.03 kg N/dry kg, and other crops, 0.015 kg N/dry kg, are adopted for Canada (IPCC, 1997). These nitrogen contents are multiplied by the same crop production data and dry-mass contents used to estimate N_2O emissions from biological nitrogen fixation. The crop dry mass is estimated using the average dry matter fractions from the IPCC (1997). The IPCC default emission factor of 1.25 N_2O-N/kg N (IPCC, 1997) is then applied.

Uncertainties and Time-Series Consistency

The uncertainties are due to the uncertainties associated with the quantity of nitrogen contained in the crop residues and the emission factor adopted from the IPCC Guidelines. The uncertainty associated with the quantity of nitrogen contained in the crop residues is expected to be moderate. The uncertainty associated with the IPCC default emission factor for crop residue decomposition is expected to be high. This is because the release of N_2O from crop residue decomposition would be affected by many factors, such as quantity and quality of crop residues, soil type and climatic conditions.

The overall uncertainty associated with N_2O emissions from crop residue decomposition is assumed to be moderate to high.

There has been very little scientific work quantifying emissions of N_2O associated with crop residue decomposition in Canada and elsewhere. The current Revised 1996 IPCC Guidelines accounting for this particular emission source reflect general understanding of soil nitrogen cycling, rather than actual scientific measurements. Furthermore, estimates of nitrogen contained in leguminous and non-leguminous crops based on the Revised 1996 IPCC Guidelines are considered very crude.

Improving estimates of nitrogen contained in crops can be made using specific harvest indices and nitrogen content, rather than IPCC defaults. There are a number of scientific publications on these issues in Canada. The uncertainty associated with estimates of nitrogen contained in leguminous and non-leguminous crops can be improved by using specific harvest index and nitrogen content for a specific crop, but overall improvement in terms of total emissions is expected to be relatively small.

The same methodology and emission factors are used for the entire time series (1990–2001).

QA/QC and Verification

The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form. Quality control checks and cross-checks have been carried out to identify data entry errors and calculation errors.

Recalculations

No recalculations have been carried out.

Planned Improvements

There are no immediate plans aimed at improving emission estimates from this source.

6.4.1.5 Cultivation of Organic Soils (Histosols)

Source Category Description

Cultivation of organic soils (histosols) for crop production usually involves drainage for lowering below-ground water table, soil, and increased aeration, thus speeding up 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 (IPCC, 1997). Nitrous oxide 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 collected regularly at a five-year interval by Statistics Canada. In absence of this data, consultations with numerous soil and crop specialists across Canada have been made. Based on this consultation, the total area of cultivated organic soils in Canada (for the period 1990 to 2001) is estimated to be 29,800 ha. The IPCC emission factor of 5 kg N_2O-N $ha^{-1}yr^{-1}$ is applied for Canada.

Uncertainties and Time-Series Consistency

There is a high degree of uncertainty associated with emission estimates from this source, mainly because of high uncertainties associated with the emission factor.

The same methodology and emission factors are used for the entire time series (1990–2001).

QA/QC and Verification

The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form. Quality control checks and cross-checks have been carried out to identify data entry errors and calculation errors.

Recalculations

No recalculations have been carried out.

Planned Improvements

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

6.4.1.6 Manure on Pasture and Paddock

Source Category Description

When manure is excreted on pasture and paddock from grazing animals, nitrogen in the manure undergoes transformations, i.e. 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, 1997). Emissions are calculated for each animal category by multiplying the animal population by the appropriate nitrogen excretion rate 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 research conducted in the United States (ASAE, 1999). The fraction of manure nitrogen available for conversion to N_2O is calculated as the percentage of total manure nitrogen produced on pasture and paddock multiplied by the IPCC default value of 0.02 kg N_2O-N/kg N that represents the fraction of excreted manure nitrogen converted to N_2O.

Uncertainties and Time-Series Consistency

There is a high degree of uncertainty associated with emission estimates from this source. This is due to the fact that there is a high degree of uncertainty associated with both the quantity estimate of manure nitrogen on pasture and paddock excreted by grazing animals as well as the emission factor for this process.

The same methodology and emission factors are used for the entire time series (1990–2001).

QA/QC and Verification

The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form. Quality control checks and cross-checks have been carried out to identify data entry errors and calculation errors. In general, there are very little 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

No recalculations have been carried out.

Planned Improvements

Due to recent advances in measuring N_2O fluxes using flux chambers and flux towers, it is expected that country-specific data on N_2O emissions from manure on pasture and paddock will be available over the next few years in Canada.

6.4.2 INDIRECT EMISSIONS OF NITROUS OXIDE FROM SOILS

A fraction of the fertiliser nitrogen (from both synthetic fertiliser and manure) that is applied to agricultural fields will be transported off-site either through volatilisation and subsequent re-deposition or leaching, erosion and runoff. The nitrogen that is transported from the agricultural field in this manner will provide 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.

6.4.2.1 Volatilisation and Re-deposition 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 re-deposited somewhere else, and can undergo further transformations such as nitrification and denitrification, thus resulting in N_2O emissions offsite. The quantity of this volatilized nitrogen depends on a number of factors, such as rates, 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 volatilisation and re-deposition of nitrogen from applied synthetic fertiliser and manure (IPCC, 1997). The amount of synthetic fertiliser consumption is multiplied by the fraction of nitrogen that is volatilised as NH_3 and NO_x and then by an emission factor. The amount of nitrogen applied is obtained from yearly fertiliser sales data, which are available from regional fertiliser associations (Korol, 2002). The amount of nitrogen that volatilises is assumed to be 10% of synthetic fertiliser applied and 20% of manure nitrogen applied. The same IPCC emission factor, 0.01 kg N_2O-N/kg N is applied to derive the N_2O emission estimate (IPCC, 1997).

Uncertainties and Time-Series Consistency

There is a very high degree of uncertainty associated with estimates of N_2O emissions from this source. Sources of uncertainties include: the estimates of volatilised fertiliser, manure nitrogen and the emission factor.

There is a high degree of uncertainty associated with the estimate of quantity of nitrogen lost through volatilisation of NH_3 and NO_x. The volatilised fraction of nitrogen varies greatly from negligible to very high depending on many environmental conditions, soil properties, climatic factors, etc. Emission estimates from this source may vary by up to two orders of magnitude (IPCC, 1997).

It is extremely difficult to verify how well the IPCC emission factor reflects Canadian conditions. The methodology in the Revised 1996 IPCC Guidelines for this particular source of N_2O is more conceptual, based on general principles of nitrogen cycling, rather than actual measurement of emissions. In fact, there is no established experimental protocol for determining an emission factor from volatilisation of fertiliser and manure nitrogen and subsequent re-deposition.

The same methodology and emission factors are used for the entire time series (1990–2001).

QA/QC and Verification

The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form. Quality control checks and cross-checks have been carried out to identify data entry errors and calculation errors.

Recalculations

No recalculations have been carried out.

Planned Improvements

There are no immediate plans aimed at improving emission estimates from this source.

6.4.2.2 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, runoff and erosion. The quantity 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

The IPCC methodology estimates N_2O emissions from runoff and leaching of nitrogen by assuming that 30% of the nitrogen applied as synthetic fertilizer or manure is lost by leaching or runoff and multiplies this by 0.025 kg N_2O-N/kg N leaching/runoff to obtain an emission estimate (IPCC, 1997).

For the reasons described below, it was decided to use the Canada-specific emission factor instead of the IPCC default factor. This method, which could be considered to be Tier 2, reflects low precipitation and high evaporation conditions that occur on the Canadian prairies, where more than 80% of Canada's agricultural land is located and where most fertiliser is consumed.

The emissions from runoff and leaching are estimated by assuming 15% of the nitrogen applied as synthetic fertiliser or manure is lost through leaching and runoff.

In Canada, leaching losses of nitrogen vary widely among regions. High nitrogen inputs in humid conditions may lead to greater than 100 kg N $ha^{-1}yr^{-1}$ 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 agro-ecosystems. In Ontario, Goss and Goorahoo (1995) predicted leaching losses of 0 to 37 kg N ha^{-1}, accounting for 0 to 20% of nitrogen inputs from seed, feed, fertilizer, manure, animals, biological nitrogen fixation, and atmospheric deposition. Leaching losses in most of the prairie region may be smaller because of lower precipitation and nitrogen inputs. Nyborg et al. (1995) suggested that leaching losses were minimal from a long-term experiment in central Alberta, 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. In the prairie provinces of western Canada, which account for more than 80% of fertilizer inputs and agricultural land in Canada, potential evaporation exceeds precipitation by a large margin (Reynolds et al., 1995). Therefore, leaching losses in Canada are probably lower than in many other countries with intensive agriculture.

Uncertainties and Time-Series Consistency

A very high level of uncertainty is associated with estimates of emissions from this indirect source because there is a high degree of uncertainty associated with estimates of the quantity of fertiliser- and manure-nitrogen leached from agricultural soils in a form of NO_3^- as well as the emission factor. Emission estimates from this source may vary by up to two orders of magnitude (IPCC, 1997).

The methodology of the Revised 1996 IPCC Guidelines for this particular source of N_2O emissions is more conceptual, based on general principles of nitrogen cycling, rather than actual measurement of emissions. In fact, there is no established experimental protocol for determining an emission factor from runoff, leaching and erosion.

The same methodology and emission factors are used for the entire time series (1990–2001).

QA/QC and Verification

The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form. Quality control checks and cross-checks have been carried out to identify data entry errors and calculation errors.

Recalculations

No recalculations have been carried out.

Planned Improvements

There are no immediate plans aimed at improving emission estimates from this source.

7 LAND-USE CHANGE AND FORESTRY (CRF SECTOR 5)

This chapter describes the methodology used to estimate GHG emissions and removals in Canada's managed forests and associated with changes in the way land is used. GHG fluxes to and from agricultural soils are reported in the Agriculture section. In keeping with the IPCC Guidelines, the methodology emphasizes human, or anthropogenic, impacts on the national GHG balance.

The assessment includes CO_2 emissions and removals and, in the case of forest fires, emissions of the non-CO_2 gases methane, nitrous oxide, nitrogen oxides and carbon monoxide. Please note that current accounting rules exclude CO_2 emissions and removals in the LUCF sector from the national totals reported to the UNFCCC.

Background

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 the natural biota are large fluxes, recycling in the order of 1/7 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 LUCF sector, which, from the perspective of flux estimation, distinguishes it 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 LUCF 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.

Finally, Canada's large landmass and decentralized land management systems add additional challenges to the quantitative assessment of the associated GHG emissions and removals.

The remainder of this chapter is organized into the two main activities of forest management and land-use changes.

7.1 FOREST MANAGEMENT

7.1.1 SOURCE CATEGORY DESCRIPTION

Canada's forest area (417 million hectares) is composed of a mosaic of ecosystems, or forests of different ages and species composition, exposed to various climates and disturbance regimes. Approximately 58% of this forest area is classified as timber productive forest. The portion of the timber productive forest that is non-reserved and accessible, also known as the wood production forest, is where most commercial timber management takes place (148 million hectares). The wood production forest represents 35% of Canada's total forestland (Lowe et al., 1996). The remainder of the timber productive forest is either reserved for other uses, non-accessible or subject to management restrictions. The wood production forest is the major forest area subject to the assessment of emissions and removals in the forestry sector. While included, the contribution of woodlots located on agricultural lands and urban forests are deemed very minor. Parks and reserves are currently omitted from this assessment.

7.1.2 METHODOLOGICAL ISSUES

The estimation methodology for GHG emissions and removals in the forestry sector follows closely the corresponding IPCC Guidelines (IPCC, 1997), in which the net removals or emissions are calculated as the difference between CO_2 uptake through forest tree growth, and emissions resulting from commercial forest management (harvests of industrial roundwood, firewood or fuelwood collection along with prescribed burning). Due to their predominant role in the ecology and dynamics of Canadian forests, wildfires have also been included in the GHG balance of the wood production forest. The current estimation methodology is limited to the aboveground biomass carbon pool.

The primary source of forest data is Canada's Forest Inventory (CanFI), compiled by the Canadian Forest Service from 48 forest inventories in Canadian provinces and territories. These source inventories vary in levels of detail, coverage and frequency of updates. At the time of preparation for this GHG inventory, the most recent forest inventory data available was used, including:

- For each Canadian province and territory, the mean annual volume increment in timber-productive forest with access – from the 1986 CanFI update (Gray, 1995 – Table 2);
- The areal extent of stocked and unstocked forest stands in 1990;
- For the same year, the breakdown of stocked forest in five maturity classes: regeneration, immature, mature, overmature and uneven-aged forest stands (http://nfdp.ccfm.org/framesinv_e.htm, Table 1.3).

The lack of recent forest data was partly compensated by estimating, over the decade, the annual changes in stocked areas and maturity class distribution, based on the assumption that all forest management activities took place in the forest area known as the wood production forest in 1990.

The mean annual volume increments to maturity (MAI) are derived separately for mature stands, by province or territory, forest section, site class and predominant genus or forest type. Figures are rolled up by the Canadian Forest Service to provincial/territorial, or ecozone levels before publication. These published MAI values take into account mortality and growth reduction due to non-stand replacing disturbances, competition, and disease. Because these average, long-term values are highly aggregated, they do not reflect the dynamic response of growth rates as a result of changes in forest age structure and composition. Aggregated MAI values are applied, within the wood production forest, to the forest area which is actively sequestering carbon in its aboveground biomass. This excludes the overmature forest stands, which are assumed to have, in the aboveground biomass, a net carbon sequestration rate of zero. The use of the MAI is used in combination with a biomass expansion factor derived from standing aboveground biomass at maturity. Both exclude the carbon sequestered in biomass that is shed prior to stand maturity and either decomposes or remains in the ecosystem as dead biomass or soil organic matter. Hence, this approach provides generally conservative estimates of carbon sequestration in the aboveground biomass of the Canadian wood production forest.

The National Forestry Database collects and publishes annual information on forest management activities made available by each jurisdiction, notably:

- The forest areas subject to clear-cut and other harvesting practices (http://nfdp.ccfm.org/framesinv_e.htm Table 6.1);
- Site treatments & post-harvest regeneration (http://nfdp.ccfm.org/regen/english/province_e.htm); and,
- Forest area burned by wildfires (http://nfdp.ccfm.org/framesinv_e.htm Table 3.4).

These data are generally available from 1990 up to two years (three years for forest area burned) prior to the current year.

Data on commodity production and trade are obtained from the FAO Forest Database (http://apps.fao.org/cgi-bin/nph-db.pl?subset=forestry), with the exception of market pulp data, provided directly by the Pulp and Paper Products Council (2002).

In keeping with the current IPCC default methodology, emissions from forest management activities comprise all the CO_2-C contained in harvested roundwood (equal to domestic roundwood production) and harvest residues, as well as non-CO_2 gases emitted from prescribed burns. The biomass removed from harvested sites is estimated as green volumes multiplied by specific wood densities, plus bark biomass. The quantity of harvest residues is crudely estimated as the difference between pre-harvest standing biomass and that removed from the site. This approach does not adequately address the fate of carbon stored in harvested wood products (HWP). Two alternative approaches, the atmospheric flow and stock-change methods, have been preliminarily evaluated in Canada to attempt to correctly account for HWPs. Both approaches are more spatially and temporally realistic than the current default, which does not account for emissions from HWP where or when they actually occur. Both account for carbon storage in HWP, and emissions from the decay of products harvested or imported in previous years. They differ with respect to their allocation of emissions and removals. The flow approach tracks CO_2 emissions and removals associated with the harvest, manufacturing, and consumption of wood products within national boundaries. It is similar to the general methodology for estimating fossil fuel emissions, and provides a more accurate reflection of when and where emissions and removals actually occur. The stock-change approach accounts only for the net carbon stock change in the domestic wood product reservoir, after imports and exports. The difference between the stock-change and flow accounting lies in the treatment of exported products (which are significant in Canada). In the former, carbon in exported wood products exits the domestic stock and, hence, is included with emissions to the atmosphere. A breakdown and brief discussion of each of the accounting approaches, along with implications for Canada, are contained in Annex 6. The upcoming IPCC report on Good Practice Guidance for the LUCF sector should provide clarification on the scope and calculations involved in alternative methodologies for the estimation of carbon sequestered in harvested wood products.

The impact of wildfires is accounted for directly as emissions of CO_2 (1635 g CO_2/kg biomass oxidized), CH_4 (3 g CO_2 kg^{-1} biomass oxidized), N_2O (0.24 g CO_2 kg^{-1} biomass oxidized), CO (88 g CO_2 kg^{-1} biomass oxidized) and NO_x (1.75 g CO_2 kg^{-1} biomass oxidized), and indirectly as a reduction in the area of stocked forest. Note that forestland previously burned is assumed to regenerate after 15 years, resulting in an increase in stocked forest areas. All emission factors were derived from Taylor (1996). Globally, it is estimated that wildfires consumed an average of 0.0264 kt of biomass per hectare (B. Stocks, 1990; Amiro et al., 2001). Fire severity, hence biomass consumption, varies considerably within landscapes and single fire events. Estimates of biomass consumption by wildfires will improve when fires in the wood production forest are ascribed to the appropriate ecological zones. At the time of inventory preparation, georeferenced boundaries of the wood production forest were not available, therefore the exact location of forest areas burned with respect to the wood production forest had to be inferred from surrogate data. It was assumed that all timber-productive forest lands burned within intensive protection zones corresponded to wildfires located in the wood production forest. Since the location and characteristics of disturbed forest stands are not available, it is not possible to track the changes in the composition of the wood production forest with accuracy, due to these disturbances. Since the 2001 provincial fire reports were not available at the time of inventory preparation, 2001 figures of forest area burned were derived from decadal averages and should be considered as indicative only.

In 2001, the forest area assumed to be actively sequestering carbon occupied 77% of the wood production forest or approximately 114 Mha, unevenly distributed across the country. During that period 924,000 ha of wood production forest were clear-cut harvested. The net changes in forest carbon stocks amounted to removals of nearly 40 Mt CO_2 eq.

The CRF Tables 5 and 5A do not provide the necessary space to enter non-CO_2 GHG emissions from forest fires in the wood production forest. Hence, Table 5 was modified, and an alternative table has been included under Table 5A.

7.1.3 UNCERTAINTIES AND TIME-SERIES CONSISTENCY

The methods used to estimate GHG emissions and removals in Canada's managed forests involve more steps, and require more data, parameters and assumptions than in most other inventory sectors. In many instances, data are simply not available.

Because data sources and assumptions for successive annual estimates are consistent, there is fair confidence in the trends displayed in annual figures. The fluxes themselves, however, are characterized by a high degree of uncertainty.

The UNFCCC Reporting Guidelines identify four major sources of uncertainty, which all apply to the LUCF sector. These are: definitions, methodology, activity data and underlying scientific understanding. Currently, the main source of uncertainty in the LUCF inventory sector is methodological, particularly the omission from the estimation methodology of important carbon pools such as forest soils, HWP, coarse woody debris, and litter. The nature of this source of uncertainty is such that it is not possible at this time to conduct a quantitative uncertainty assessment on emission and removal estimates. Work is underway to address these methodological deficiencies, including the development of additional scientific knowledge on carbon and other GHG dynamics of Canada's vast and diverse forests and implementation of this knowledge in an operational monitoring, accounting and reporting system.

The second most important source of uncertainty is from the use of highly aggregated forest data, notably the mean annual increments, biomass expansion factors, and harvest areas. Their coarse spatial and temporal resolutions do not allow an accurate tracking of changes in forest sources and sinks. Disaggregated data do exist, but are often confidential and difficult to obtain. In some instances, the required information is simply not documented, such as the location of disturbances with respect to forest boundaries, pre-disturbance stand characteristics, and biomass utilization rates.

The steps taken to address these uncertainties are described below as planned improvements.

7.1.4 QA/QC AND VERIFICATION

There is no formal procedure for the technical verification of inventory preparation methodology and procedures. However, the following steps have been implemented:

- As far as practicable, the data used have been published in the technical or scientific literature. Updated activity data are compared on a case by case basis to those in previous submissions.
- As far as possible, data input is through electronic procedures (links, copies, inserts), as opposed to manual data inputs. All manual data inputs are double-checked. Summary tables are created electronically.
- The formulas and links for the calculations of emissions and removals are verified for accuracy, consistency and completeness.
- Estimates and trends are compared with those of previous submissions.
- Trends in selected activity data (harvest, fires) are compared with those of emission/removal estimates.
- The treatment of missing data is documented. Missing activity data are either estimated (as in the forest area actively sequestering carbon) or projected or interpolated (e.g. area of prescribed burns).
- For each submission year (starting in 2000), all components of the inventory preparation procedures have been systematically documented and archived. Correspondence, raw data and updates, data manipulations, adoption or derivation of parameters and emission factors, assumptions and expert opinions have all been catalogued. A manual of inventory preparation procedures and methods is under development.

7.1.5 RECALCULATIONS

Significant recalculations were conducted in the 2003 submission, and were applied consistently to all annual estimates back to 1990. These recalculations affect the estimate values, but not their consistency over time.

Methodological improvements have been incorporated to the calculation of emissions associated with forest fires. All GHG emitted by all fires located in the wood production forest were accounted for, whereas previously the calculations only included the non-CO_2 emissions. The assumptions used to derive the area of forest burned in the wood production forest were simplified and allowed the direct use of data published by the Canadian Council of Forest Ministers, enhancing the calculation transparency and reliability. A decision on accounting of anthropogenic fires outside the wood production forest has been deferred until further guidance is offered by the IPCC. Recalculated estimates of fire emissions were consistently, but variably, higher than those submitted in 2002, by up to 427%, except for the year 1999. Emissions from forest fires in the wood production forest are reported in the alternative CRF Table 5A, instead of Table 5E as in previous submissions, and in the modified Table 5.

There were no recent data on the forest area assumed to be actively sequestering carbon in its biomass, i.e. the stocked forest of all age-classes, excluding the overmature class. Estimates were developed of the annual change in the area of this '1990 growing forest' since 1990, assuming that all forest management activities had taken place in this forest area. The calculations took into account forest areas burned and harvested during each inventory year, as well as forest areas regenerating after these disturbances. Published, historical data on forest disturbances were used, as well as information provided by Canadian provinces and territories on post-harvest restocking of forests. This was deemed a significant improvement over the previous estimation procedure, which assumed that the maturity-class distribution of the wood production forest had remained constant since 1990.

Mean annual volume increments were taken directly from a report published by the Canadian Forest Service, as opposed to being internally derived from various sources. These data are deemed the best available published and enhance estimate reliability. Recalculated estimates of carbon sequestration in the wood production forest were consistently higher than the 2002 estimates, but the percentage increase declined from 17% in 1990 to 7% in 2000. The absolute difference in removals is considerable, ranging from 48 Gg CO_2 (1990) to 20 Gg CO_2 (2000).

Revised and updated commodity data for the period 1990 to 2000 were obtained from the FAO website in January 2002, and incorporated in the calculations, thereby improving the accuracy.

7.1.6 PLANNED IMPROVEMENTS

Planned improvements will address the gaps identified above in the methodologies and data quality. As many involve significant changes in the inventory preparation procedures, the integration of multi-governmental initiatives and the active collaboration among the many stakeholders in the Canadian forest community, their implementation may span several years. Steps have already been taken to establish a framework for the monitoring, accounting and reporting of GHG emissions/removals in Canada's managed forests. This framework provides a means for co-ordinating, planning and integrating activities between the Canadian Forest Service and Environment Canada.

The Carbon Budget Model of the Canadian Forest Service (Kurz et al., 1993; Kurz & Apps, 1999) is being further developed and adapted as an operational tool for national forest carbon monitoring, and is expected to be the major source of information for the preparation of LUCF estimates under the Framework Convention and the Kyoto Protocol. This will better enable the incorporation of all carbon pools in the assessment of the GHG balance of Canada's managed forests. On-going scientific and technical studies, conducted in governments and universities will provide new knowledge and data that will also be integrated in the preparation of LUCF estimates. These efforts are expected to significantly enhance reporting capabilities within the next five years.

In the short term, the publication of the 2001 update of the current Canadian Forest Inventory will provide more recent data on the state of the managed forests, and allow the explicit location of wildfires in the wood production forest. In the longer term, the implementation of Canada's new National Forest Inventory (Anonymous, 1999) will allow the derivation of consistent and accurate growth rates and provide the core infrastructure for the monitoring of Canada's forests.

The compilation of forest management activities on an ecological basis (rather than by jurisdiction) will enhance data availability, significance and usefulness.

It is anticipated that the forthcoming publication by the IPCC of a report on Good Practice Guidance and Uncertainty Management for the LULUCF sector will have significant impact on the planning of inventory enhancements.

7.2 LAND-USE CHANGE

In the context of the LUCF GHG inventory, land use refers to the type of human interaction with the land. Forest management and agriculture are the most extensive land uses in Canada, covering respectively 148 and 67.5 Mha.

Land use is not to be confused with land cover, which consists of the biophysical features, i.e. geology, soil and vegetation. For example, an area "covered" by grass can be "used" as a park or a pasture. In some instances but not always, land use can be directly inferred from land cover information, e.g. urban built-up areas. In Canada, wherever extensive land management predominates, the distinction between managed and unmanaged lands on the basis of land cover information alone is problematic. Nevertheless, land cover information is often available from remotely sensed imagery and provides an essential basis for monitoring activities related to land use and land use change.

Land management refers to the various sets of practices implemented under a particular land use. For example, agricultural management practices vary greatly in their intensity, as defined by the human inputs and disturbances of land cover, with associated implications for the land GHG budget.

7.2.1 SOURCE CATEGORY DESCRIPTION

This section reports estimates of CO_2 emissions and removals associated with changes in the way land is used, specifically the conversion of natural vegetation (forest and grasslands) to agricultural and urban lands, and the abandonment or loss of agricultural lands to other land uses. Both biomass and soil carbon stocks are included in the assessment, corresponding to CRF Tables 5B (biomass emissions due to land conversion, including urbanization), 5C (removals in biomass associated with vegetation regrowth on former managed lands) and 5D (changes in soil carbon associated with both land conversion and vegetation regrowth).

7.2.2 METHODOLOGICAL ISSUES

In Canada, land management activities are decentralized and under the jurisdiction of provinces and territories. The predominant land uses, their associated policies and governance, vary greatly across the country, as do the quality, quantity and availability of information on land management systems. Different departments in the provincial, territorial and federal governments collect and compile land management information, but it is not reconciled in a way that would allow the consistent tracking of land transfers between different land uses at the national scale. The rapid evolution of GIS technology over the last two decades enabled the development of powerful tools to record, analyze, display, and archive geospatial data, but the lack of common standards also enhanced the institutional barriers to the exchange of land resource data. Emerging initiatives, such as the multi-departmental Canada Land Cover Initiative and GeoConnections, aim at resolving this situation, but their enabling effect will not be felt for a few years.

The most reliable and consistent source of land use information is arguably the Census of Agriculture, distributed and compiled every five years by Statistics Canada (http://www.statcan.ca/english/agcensus2001/about.htm). The Census provides the basis for the current approach to estimating land use change, essentially from the reported areas of total farmland in each Canadian province and territory since the 1961 edition. Data for in-between census years are linearly interpolated. In each province/territory where a net increase of total farmland has been recorded over the preceding decade, specific parameters assign the source of this new agricultural land to boreal forest, temperate forest or grasslands. Above-ground forest biomass before conversion were obtained from the Canadian Forest Service (ESSA Technologies Ltd., 1996) while IPCC default data were used for post-conversion biomass. No reduction of aboveground biomass is accounted for by the conversion of grassland to agricultural lands. In 2001, an estimated 20,000 ha of forests, predominantly temperate, were converted to agriculture, accounting for almost 90% of CO_2 emissions associated with land conversion. There is no information on biomass burning practices used for land conversion, nor on the proportion of biomass left to decay after the removal of the vegetation cover. It is assumed that 90% of all the potential changes in carbon density occurs as CO_2 emissions during the inventory year.

Where total farmland area decreased it is estimated that 42% of the lost farmland is converted to urban lands (Environment Canada, 1989). The remainder is assumed to return gradually to the original vegetation cover, using the same province-specific parameters as for the derivation of the origin of new agricultural lands. CO_2 removals are believed to occur only on lands reverting to temperate or boreal forests. The annual accumulation rates of aboveground forest biomass on abandoned lands were developed by the Canadian Forest Service (ESSA Technologies Ltd., 1996). They are considerably lower than the IPCC default values (0.21 vs 1.0 tonnes dm ha^{-1} for boreal forest; 0.95 vs. 2.0 for deciduous temperate forests), but deemed more representative of Canadian conditions. These growth rates are approximations only, since in reality they vary with previous land uses, location and site conditions, and the time elapsed since land management activities were discontinued. Hence, these rates of forest regrowth do not distinguish between land abandoned over the last 20 years vs.

that abandoned for a longer time period. The activity data suggest that the annual loss of agricultural lands has slowed down by more than half over the last two decades, from over 4,000 ha to 1,500 ha annually.

Soil carbon emissions generally result from forest or agricultural land conversion. Conversely, the regrowth of forest and grassland vegetation on abandoned managed lands results in soil carbon sequestration. Activity data and related assumptions have been described above. The acreage data for converted areas are multiplied by the estimated carbon content of the soil prior to conversion to obtain the total annual potential carbon losses. Twenty-two percent (22%) of this amount is expected to be emitted over a 25-year period (from data in Dumanski et al., 1998). It is estimated that only 50% of new urban land actually releases soil carbon. The other half is paved over and the soil carbon content remains constant. Equilibrium carbon contents were derived for pre-conversion temperate and boreal forest soils (ESSA Technologies Ltd., 1996). They include both roots and mineral soils and for this reason may overestimate the initial soil carbon contents. Pre-conversion carbon contents in grassland soils were taken from Tarnocai (1996).

Soil carbon is expected to accumulate linearly upon vegetation regrowth on abandoned farmland, over a 100-yr time horizon. The annual rates of soil carbon sequestration were obtained by dividing the difference in equilibrium soil carbon densities by 100 between the expected end point and the pre-abandonment land use. Rates of soil carbon sequestration upon vegetation regrowth are 0.33 t C $ha^{-1}yr^{-1}$ (boreal forests), 0.40 t C $ha^{-1}yr^{-1}$ (temperate forests) and 0.27 t C $ha^{-1}yr^{-1}$ (grasslands).

In 2001, 10 Mt CO_2 were emitted from both biomass and soil pools upon land conversion, 70% of which were released from soils. Where vegetation was allowed to regrow, 7 Mt CO_2 were sequestered on lands, almost equally split between aboveground biomass and soil pools.

7.2.3 UNCERTAINTIES AND TIME-SERIES CONSISTENCY

As in forest management, uncertainties in the land-use change sector stem from both methodology and data. Specifically, the net annual change in agricultural land, while a consistent and reliable indicator, may mask very different combinations of gains and losses of farmland in the vast agricultural ecumene of Canadian provinces and territories. Because of the differing rates of carbon emissions or removals, the GHG fluxes associated with a net change within a given jurisdiction will almost certainly differ from the sum of emissions resulting from land conversion and removals by regrowing vegetation. The coarseness of the spatial scale over which net land-use changes are assessed is a major source of uncertainty. A preliminary assessment of farmland gains and losses at a slightly refined level ("Census Agricultural Areas") yielded very different areal estimates. In the 1991–2001 decade, the net change in total Canadian farmland amounted to a relatively modest increase of 24,000 ha, however, the summation of farmland gains and losses in Census Agricultural Areas indicated that 159,000 ha had been created over the period, while 135,000 ha had been lost.

A second important source of uncertainty is the scarcity of reliable information on the ecosystems encroached upon by land-use changes. Any given province or territory may harbour very diverse forests and woodlands, poorly characterized by the generic labels "temperate forests" or "boreal forests". The application of a single pre- or post-disturbance carbon density to all of these certainly generates inaccuracies in the estimated emissions and removals. Moreover, different practices in the removal of vegetation cover and topsoil, as well as mitigation and remediation activities, have a significant influence on the impact of land-use changes. At the present time, these are poorly documented, if at all, and constrain the development of more accurate estimates of GHG fluxes.

Other development pressure on vegetated or cultivated lands (e.g. infrastructure development, tourism), while believed to have less impact on the Canadian landscape, are not sufficiently documented to support the development of estimates.

Because the Census of Agriculture, the provincial forest inventories and possibly other regional land-use information systems do not function in a consistent and comparable manner, it is impossible at this point to accurately track land transfers between main land uses and determine, for example, the extent to which the wood production forest is affected by land use changes.

Due to the considerable uncertainties described above, it is believed that the emissions associated with land-use changes are in all likelihood underestimated. The steps taken to address these uncertainties are described below as planned improvements.

7.2.4 QA/QC AND VERIFICATION

The QA/QC and verification procedures described in Section 7.1.4 also apply to the development of emission/removal estimates resulting from land-use changes.

7.2.5 RECALCULATIONS

Recalculations of all annual estimates from 1990 to 2001 were conducted when the 2001 edition of the Census became available in 2002. In some instances, the updated 1996–2000 activity data used in the current LUCF inventory submission differed significantly from those found in the 2000 submission, which were projected from the 1991–1996 trends. For example, the area of improved farmland in 2000 was overestimated by almost 5 Mha in the 2000 submission. As a consequence, both emissions and removals were overestimated.

7.2.6 PLANNED IMPROVEMENTS

Addressing the current gaps in land management information has been given a high priority. On-going work by Environment Canada, Natural Resources Canada, Agriculture & AgriFood Canada and Statistics Canada aim to develop a land-use change information system that would support the development of the activity data required for reporting GHG emissions and removals under the Framework Convention and the Kyoto Protocol. The emphasis is on the definition and promotion of standards, the establishment of a framework that facilitates the exchange of land-cover and land-use data among data providers and users, and the creation of additional land-cover and land-use data when necessary. Several provincial and federal departments are conducting collaborative work to develop the methodological tools and approaches to document, detect and assess the impact of deforestation activities in the Canadian landscape. These efforts are expected to significantly enhance reporting capabilities within the next five years.

In the short-term, work has been undertaken to refine the analysis of current and historical census data at a finer spatial scale, and to determine with greater accuracy the actual gains and losses of agricultural lands and their locations. This will significantly improve the assessment of corresponding land-use changes and assist in the determination of the causes, the affected ecosystems, and associated GHG fluxes. A study was conducted in 2002 to document common forest cover removal practices associated with land use changes to support better estimate derivation.

8 WASTE (CRF SECTOR 6)

This category includes emissions from the treatment and disposal of wastes. Sources include solid waste disposal on land (landfills), waste water treatment and 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. In theory, there are no net emissions if the biomass is sustainably harvested. For example, CO_2 generated from aerobic decomposition of food wastes would be consumed by the next year's crop. On the other hand, methane emissions from anaerobic decomposition of wastes are included in inventory totals.

If biomass is harvested at an unsustainable rate (i.e., faster than annual regrowth), net CO_2 emissions will appear as a loss of biomass stocks in the LUCF section.

8.1 SOLID WASTE DISPOSAL ON LAND

8.1.1 SOURCE CATEGORY DESCRIPTION

Emissions are estimated from two types of landfills in Canada:

- Municipal solid waste (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, industrial, construction, and demolition wastes are disposed of in MSW landfills.

Wood waste landfills are 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. 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 to MSW landfills.

The IPCC Guidelines provide two methodologies for estimating emissions from landfills: a default method and a first-order kinetics method, also known as the Scholl Canyon model (IPCC, 1997). 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 has 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 CH_4 and CO_2 is 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:

- *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:* Since 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. The extent to which ambient air temperatures influence the temperature of the landfill and gas generation rates depends mainly on the depth of the landfill. It has been observed that landfill temperatures fluctuate with long-term ambient temperature variations (Levelton, 1991).
- *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.

8.1.2 METHODOLOGICAL ISSUES

Methane emissions are determined by calculating the amount of methane generated from landfill waste decomposition and subtracting the methane captured through landfill gas recovery systems.

Methane 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. Landfill Gas Capture data was collected directly from the landfills with gas capture systems.

8.1.2.1 Methane Produced

The Scholl Canyon model was used to estimate emissions using the following first-order decay equation (IPCC, 1997):

Equation 8-1:

$$G_i = M_i \times k \times L_0 \times \exp^{-(k \times t_i)}$$

where:

G_i = emission rate from the *i*th section (kg CH_4/year)

k = CH_4 generation rate (1/year)

L_0 = CH_4 generation potential (kg CH_4/t of refuse)

M_i = mass of refuse in the *i*th section (Mt)

t_i = age of the *i*th 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 each year, the sum of G_i for every section of waste landfilled in past years was taken, and the captured gas was subtracted. A computerized model has been developed to estimate aggregate emissions on a regional basis in Canada.

The Waste Disposed of Each Year or the Mass of Refuse (M_i)

MSW Landfills: The amount of MSW landfilled in the years 1941 through to 1989 was estimated by Levelton (1991). For the years 1990 to present, the amount of waste landfilled has been estimated based on an Environment Canada (1996) study containing solid waste data for the year 1992. Using these data, a per capita landfilling rate for each province was calculated. These rates are adjusted for the other years based on data from the National Solid Waste Inventory (CCME, 1998). The total waste disposed of each year has been determined by multiplying the per capita landfilling rate by the provincial population as recorded by Statistics Canada (#91-213-XPB).

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). The amount of wood residue landfilled in the years 1993–2000 was estimated based on information in a study of pulp and paper mill waste (MWA consultants, 1997), a study of mill residue (SEAFOR, 1990), and an internal Canadian Pulp and Paper Association document (Reid, 1998).

Methane 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, availability of nutrients, pH, and temperature. The moisture content and temperatures are largely determined by climatic conditions at the landfills. The k values used to estimate emissions from both types of landfills originate from a study that acknowledges limitations of available data (Levelton, 1991). The k values are largely based on values determined by tests at various U.S. landfills. The U.S. k values are related to precipitation, assuming that moisture content of a landfill is a direct function of the annual precipitation. Based on both the U.S. k values and precipitation data, the average annual precipitation and mean daily temperature at Canadian landfills have been calculated and k values have been assigned to each of the provinces (Levelton, 1991).

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 (Levelton, 1991).

Wood Waste Landfills: Only 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). The lowest k value given for each of these four provinces was 0.01/year (Levelton, 1991). The lowest value has been assumed to be the most appropriate since the rate at which wood waste biodegrades is most likely slower than other types of organic MSW (such as food and paper waste). This is due to the limited quantity of nutrients in wood waste that are required by the active bacteria (Tchobanoglous et al., 1993).

Methane 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). For the years 1941 through to 1989, a value for L_0 of 165 kg CH_4/t of waste (as suggested by the U.S. EPA) has been used (Levelton, 1991). The following equation was used to calculate an L_0 value for the years since 1990 (ORTECH Corporation, 1994):

Equation 8-2:

$$L_0 = (M_c \times F_b \times S)/2$$

where:

M_c = tonnes of carbon per tonne of waste landfilled

F_b = biodegradable fraction

S = stoichiometric factor

The carbon content (M_c) in the waste on a dry basis is determined as a percentage of the waste disposed of, and is divided into two categories: biodegradable carbon and refractory carbon. Biodegradable carbon is the carbon contained in degradable items such as food, paper, and wood wastes. Refractory carbon is the carbon in items such as plastic, which degrades very slowly and is, therefore, unavailable for GHG generation.

The biodegradable fraction (F_b) has been determined by dividing the biodegradable carbon by the total carbon. The stoichiometric factor for CH_4 in Equation 8-2 above is 16/12, the ratio of the molecular mass of CH_4 to that of carbon. The product of the three variables is divided by two since it is assumed that 50% of the gas produced will be CH_4 and the other 50% will be CO_2 (Pelt et al., 1998).

Based on these considerations, an L_0 of 117 kg CH_4/t of waste was calculated. As waste disposal practices in Canada change, the L_0 value will be adjusted accordingly.

Wood Waste Landfills: Equation 8-2 generated an L_0 value of 118 kg CH_4/t of wood waste, which was used to estimate emissions from wood waste landfills by the Scholl Canyon model. The data required to calculate this value originate from several sources (SEAFOR, 1990; NRCan, 1997; MWA consultants, 1997; Reid, 1998).

Captured Landfill Gas

Some of the CH_4 that is generated in MSW landfills is captured and combusted. Through combustion, this landfill methane converts into carbon dioxide, reducing the emissions of methane. In order to calculate the net CH_4 emissions from landfills, the captured quantity is subtracted from the estimate generated by the Scholl Canyon model.

Data on the amount of landfill gas captured were collected by Environment Canada's National Office of Pollution Prevention. The captured gas data are based on estimates supplied by individual landfill operators.

8.1.3 UNCERTAINTIES AND TIME-SERIES CONSISTENCY

Uncertainties for the Solid Waste Disposal on Land category are high relative to other sources, and were estimated to be in the order of 30% (McCann, 1994). For wood waste landfill it is assumed that the uncertainties are higher, and actual emissions are most likely of the same order of magnitude as the estimates that have been produced.

Landfill gas capture data for 2001 were not available, so it was kept constant from 2000.

The estimates are calculated in a consistent manner over time.

8.1.4 QA/QC AND VERIFICATION

No specific additional QA/QC was undertaken for this source category.

8.1.5 RECALCULATIONS

No recalculations were made for this source category

8.1.6 PLANNED IMPROVEMENTS

A study is planned to review the input parameters for the Scholl Canyon model, including the decay constants, and the methane generation potentials of waste in Canada.

8.2 WASTEWATER HANDLING

8.2.1 SOURCE CATEGORY DESCRIPTION

Emissions from municipal wastewater treatment were estimated. Municipal 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 flare the produced methane. Methane emissions from aerobic systems are negligible. Both types of systems generate N_2O through the nitrification and denitrification of sewage nitrogen (IPCC, 1997).

CO_2 is also generated by both types of treatment. However, as discussed earlier, CO_2 emissions originating from the decomposition of food are not to be included with the national estimates, in accordance with IPCC Guidelines.

The emission estimation methodology for wastewater handling is divided into two areas: CH_4 from anaerobic wastewater treatment and N_2O from human sewage.

Emissions from treatment of industrial wastewater were not calculated due to a lack of data on the industries that treat their own wastewater.

8.2.2 METHODOLOGICAL ISSUES

8.2.2.1 Methane

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.

An emission factor for each province was calculated by multiplying this potential emission rate by the fraction of anaerobically treated wastewater in each province (NIMWWSC, 1981).

Emissions are calculated by multiplying the emission factors by the population of the respective province (Statistics Canada, #91-213-XPB).

8.2.2.2 Nitrous Oxide

The N_2O emissions were calculated using the IPCC default method (IPCC, 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 N 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 province (Statistics Canada, #91-213-XPB).

8.2.3 UNCERTAINTIES AND TIME-SERIES CONSISTENCY

The uncertainties for this source category are considered high due to the lack of detailed data to support a more rigorous methodology.

The estimates for this category are consistent over time since the same method and data sources were used over time.

8.2.4 QA/QC AND VERIFICATION

No specific additional QA/QC was performed for this category.

8.2.5 RECALCULATIONS

No recalculations were performed for this category.

8.2.6 PLANNED IMPROVEMENTS

No improvements are planned for this category.

8.3 WASTE INCINERATION

8.3.1 SOURCE CATEGORY DESCRIPTION

Emissions from both MSW and sewage sludge incineration are included in the inventory. Several 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.

8.3.1.1 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 IPCC Guidelines, 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.

8.3.1.2 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, Quebec, and Saskatchewan operate sewage sludge incinerators.

Only CH_4 emissions are estimated from sewage sludge incineration due to a lack of underlying emission research.

8.3.2 METHODOLOGICAL ISSUES

The emission estimation methodology is divided by waste type and gas emitted.

8.3.2.1 Carbon Dioxide Emissions

The IPCC Guidelines 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 an Environment Canada study (RIS, 1996) which contains detailed provincial incineration data for the year 1992. To estimate the amount of MSW incinerated in other years, 1992 data were extrapolated based on population growth figures (Statistics Canada, #91-213-XPB).

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 Carbon Dioxide Emissions:* Emissions were calculated on a provincial level by multiplying the amount of waste incinerated by the appropriate emission factors.

Nitrous Oxide and Methane Emissions

Emissions of N_2O from MSW incineration were estimated using the IPCC default method (IPCC, 1997). An average factor was calculated assuming that the IPCC five stokers 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.

Emissions of CH_4 are estimated based on an emission factor of 1.6 t/kt of total dried solids for fluidized beds, and 3.2 t/kt of dried solids for multiple hearth incinerators. Only CH_4 has been considered in calculating emissions from sewage sludge incineration.

8.3.3 UNCERTAINTIES AND TIME-SERIES CONSISTENCY

Uncertainties for both CO_2 and non-CO_2 emissions from this source category are relatively high due to the lack of waste incineration data and the lack of technology-specific data for incinerators.

Due to a lack of data, emissions from sewage sludge incineration are assumed to be constant since 1996.

8.3.4 QA/QC AND VERIFICATION

No specific or additional QA/QC procedures were undertaken for this source category.

8.3.5 RECALCULATIONS

No recalculations were made for this source category.

8.3.6 PLANNED IMPROVEMENTS

No improvements are planned for this category.

9 RECALCULATIONS AND IMPROVEMENTS

9.1 EXPLANATIONS AND JUSTIFICATIONS FOR RECALCULATIONS

Each year, Environment Canada reviews, and if necessary, revises and recalculates the emissions and removal estimates for all years in the inventory. This is carried out as part of continuous improvement efforts to integrate refined data or methods, incorporate new information and correct errors and omissions. A summary of the changes is presented below, while further explanation is provided in Chapters 3 through 8.

Recalculations were generally made as a result of regular updates to the underlying activity data, or due to the availability of new emission source information. No revisions were made in response to the UNFCCC's report on the centralized review of Canada's 2000 National Inventory Report, since this was not available by the time the 2001 inventory was prepared. Comments from the UNFCCC review will be incorporated once the UNFCCC review report is finalised.

Energy

All fuel combustion emission estimates were revised for 1999–2000, since Statistics Canada, the source of the fuel consumption data, revised its recent fuel-use data to reflect improvements in their internal data quality procedures.

Additionally, vehicle population data were revised for 1999–2000, resulting in a minor reallocation of carbon dioxide emissions and a slight change in methane and nitrous oxide emissions reported. Vehicle populations were revised due to the ongoing review and improvement of the mobile model inputs.

Industrial processes

As discussed in the Energy section, fuel consumption data were revised from 1999–2000. This resulted in a recalculation of the carbon dioxide emissions from the non-energy use of fossil fuels section (Chapter 4.10) and the ferrous metal production section (Chapter 4.5). Other minor revisions for 1999–2000 were made to the mineral products section (Chapter 4.1) as a result of updated activity data.

Solvent and Other Product Use

No recalculations were made.

Agriculture

Only one recalculation was made in the Agriculture section. Emissions from a new source, "CO_2 from the cultivation of organic soils", were added to the inventory for the years 1990 to 2001. This source was added to improve completeness of the inventory.

Land-Use Change and Forestry

Several methodological improvements and data updates were incorporated in the 2003 submission. In all cases, recalculations were carried out for the full 1990–2000 period. Sections 7.1.5 and 7.2.5 in this report provide further explanation, while CRF Table 8 presents the actual changes. The main recalculations included:

1. Emissions of all greenhouse gases from wildfires in the wood production forest in CRF Table 5A – Changes in Forest and Other Biomass Stocks. This generally resulted in increased CO_2 emissions in this sub-category. In previous submissions, partial fire emissions inside and outside the wood production were entered in the "Other" sub-category.
2. Replacement of internally derived mean annual volume increments by published ones, increasing CO_2 removals in the stocked, actively growing forest.
3. Estimation of annual changes in the stocked area of the wood production forest based on published information on disturbances and post-harvest restocking.

Updates of total farmland areas between 1996–2001 were implemented using data published in the 2001 edition of the Census of Agriculture, altering the estimated changes in agricultural land for this period. Data on commodity production and trade were also updated.

Waste

No recalculations were made.

9.2 IMPLICATIONS FOR EMISSION LEVELS

Overall changes in emission levels (excluding CO_2 from LUCF) due to recalculations were minor. Total emissions (excluding CO_2 from LUCF) were revised from 0.8 Mt downward in 1994 to 3.5 Mt upward in 2000.

For the Energy sector, recalculations resulted in a 3.3 and 5.2 Mt CO_2 eq increase for years 1999 and 2000, or about 0.5% of the totals (excluding CO_2 from LUCF).

For the Industrial Process sector, recalculations resulted in a 0.6 Mt CO_2 eq increase and a 0.3 Mt CO_2 eq decrease for the years 1999 and 2000. This represents less than 0.5% of the totals (excluding CO_2 from LUCF).

For the Agriculture sector, the recalculations increased the sector's emissions, for the entire period 1990–2000, by 0.3 Mt CO_2 eq. On average, this increased the sector's emission levels by less than 0.5%.

9.3 IMPLICATIONS FOR EMISSION TRENDS

Overall emission trends (excluding CO_2 from LUCF) were not affected by the recalculations (See Table 9-1). Emissions (excluding CO_2 from LUCF) in 1990 were 0.4 Mt CO_2 eq greater than the previous submission, while emissions in 2000 were 3.5 Mt CO_2 eq greater than the previous submission.

Although the 2000 data was revised slightly upward for the Energy sector, recalculations did not affect long term trends in emissions because the recalculation was only for two years.

For the Industrial Processes sector – as was the case for the Energy sector – recalculations did not affect overall trends. The 2000 data was revised downward slightly.

For the Agriculture sector, recalculations increased the sector's emissions by a small amount. As this calculation was applied to the entire period 1990–2000, emissions trends for this sector were not effected.

In the Land-Use Change and Forestry sector, the downward trend in net CO_2 removals was maintained; however, this would not be reflected in overall Canadian emission trends.

TABLE 9-1: Recalculation Summary (excluding CO_2 from LUCF)

	Sectors with Recalculations (Mt CO_2 eq)								Total Inventory (Mt CO_2 eq)	
	Energy		Industrial Processes		Agriculture		LUCF			
Year	Previous	Current	Previous	Current	Previous	Current	Previous	Current	Previous	Current
1990	472.4	472.7	52.9	52.9	58.9	59.2	2.5	2.3	607.2	607.6
1991	463.8	464.1	53.7	53.7	57.8	58.1	3.3	3.8	599.7	600.9
1992	481.6	481.6	52.5	52.5	57.9	58.2	2.6	2.4	616.1	616.3
1993	481.5	481.5	54.0	54.0	58.1	58.4	3.1	2.7	618.8	618.7
1994	497.9	497.9	56.4	56.4	60.4	60.7	4.1	4.5	641.1	640.3
1995	513.1	513.1	56.2	56.2	60.8	61.1	5.1	6.3	657.8	657.6
1996	528.1	528.1	58.4	58.4	61.4	61.7	1.6	1.8	672.0	672.5
1997	539.5	539.5	57.2	57.2	61.0	61.3	0.9	0.8	681.6	681.8
1998	548.9	548.9	53.3	53.3	60.6	60.9	3.1	2.9	689.4	689.5
1999	564.4	567.7	51.5	52.1	60.8	61.2	2.4	1.4	703.4	706.6
2000	587.4	592.6	51.2	50.9	60.5	60.8	2.4	0.6	726.2	729.7
2001	N/a	583.8	N/a	49.0	N/a	60.0	N/a	2.1	N/a	720.1

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ANNEX 1: KEY SOURCES

KEY SOURCES – METHODOLOGY

The IPCC manual on *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC/OECD/IEA, 2000) identifies as good practice the identification of key source categories of emissions. The identification practice is intended to help inventory agencies prioritize their efforts and improve overall estimates. A key source 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/OECD/IEA, 2000).

This analysis identifies key source categories for the Inventory according to IPCC approaches.

Good practice first requires that inventories be disaggregated into source categories from which key sources may be identified. Source categories are defined by levels of analyses according to the following guidelines:

- IPCC categories should be used with emissions specified in CO_2 equivalent units according to standard global warming potential (GWP).
- 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 source categories for key sources proceeds according to the IPCC Tier 1 approach. Using this method, key sources are first identified by *quantitative* methods using a predetermined cumulative emissions threshold. Second, Tier 1 key sources are determined by *qualitative* approaches. A more comprehensive Tier 2 approach is recommended if source-level uncertainty estimates are available. In this approach, the results of Tier 1 are multiplied by the relative uncertainty of the source category. Since recent Canadian inventory uncertainty analysis is not available, Tier 1 methods have been used for key source determination.

The quantitative approach identifies key sources from two perspectives. The first analyzes the emission contribution that each source makes to the national total. The second perspective analyzes the trend of emission contributions from each source to identify where the greatest absolute changes (either increases or reductions) have taken place over a given time. 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 sources (IPCC/OECD/IEA, 2000). The 95% cumulative contribution threshold has been used in this analysis to define an upper boundary for key source identification. Therefore, when source contributions are sorted greatest to least, and when these sources provide at least 95% of the cumulative total of contributions, the sources are considered quantitatively to be key.

Level contribution of each source is calculated according to Equation A-1:

Equation A-1:

$$L_{x,t} = E_{x,t}/E_t$$

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

Trend contribution of each source is calculated according to Equation A-2:

Equation A-2:

$T_{x,t} = L_{x,t} \times |\{[(E_{x,t} - E_{x,0})/E_{x,t}] - [(E_t - E_0) / E_t]\}|$

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 B-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

The qualitative approach strengthens the foregoing quantitative analysis by considering more subjective criteria to determine if a category should be listed as a key source. 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. The IPCC identifies four significant criteria for qualitative analysis. They are as follows:

- *Mitigation techniques and technologies:* Identify those sources where emissions are being reduced significantly through the use of mitigation techniques or technologies.
- *High expected emissions growth:* Identify sources with significant growth forecast.
- *High uncertainty:* Identify most uncertain sources as key to help improve the accuracy of the inventory.
- *Unexpectedly low or high emissions:* Identify calculation errors and discrepancies by doing order-of-magnitude checks. Canadian emission data are published only after review. This fourth criterion is not relevant to key source identification for Canada, since unexpectedly high or low emissions are validated before publication. As a result, emissions are not unexpectedly low or high.

This analysis uses four sources of information to help define qualitative criteria. Through published information and personal communications, these information sources provided valuable insight into qualitative key source assessment:

- The Canadian Climate Change Secretariat has published *Canada's First National Climate Change Business Plan* (CCCS, 2000) and a *Government of Canada Action Plan 2000 on Climate Change* (Government of Canada, 2000) outlining significant mitigation measures underway and planned in a range of sectors.
- The Voluntary Challenge Registry, Canada's independent GHG registry for major source categories, has identified significant actions planned and underway among a number of important Canadian industries (Rawson, 2001).
- Based on discussions with governments and other stakeholders, Natural Resources Canada's Emissions Analysis and Modelling Team has developed forecasts of GHG emissions from source categories for a Business-as-Usual (NRCan, 1999) and a Kyoto (NRCan, 2000) scenario.
- The Greenhouse Gas Division of Environment Canada has carried out research on uncertainties in the CGHGI (McCann, 1994).

The overall purpose of identifying key sources is the institution of best practices in GHG inventory development. Source category definition, therefore, is crucial to grouping emission sources in meaningful categories that reflect not only sources of emissions but also methods of deriving emission estimates. Thus, while the UNFCCC CRF categories provide a basis for identifying sources, some aggregation of these sources can occur when using the same emission factors based on common emission estimate assumptions. In this analysis, major categories such as Fuel Combustion, Fugitive Emissions, Industrial Processes, Agriculture, and Waste are in keeping with the CRF.[40] Within these major categories, grouping can occur if emission estimates are made based on common assumptions about emission factors and on common methods of accumulating activity data. For example, within the Fuel Combustion category, emissions from Residential, Commercial, and Agriculture subsectors are combined under the Other sector category.

40 Minor categories include Solvent and Other Product Use, as well as International Bunkers. CO2 emissions from Land-Use Change and Forestry are excluded.

In developing source categories, it is necessary to consider each GHG separately, since estimating methods, emission factors, and related uncertainties differ for each gas. Accordingly, source categories are given for each major greenhouse gas – CO_2, methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6) – where that gas is a contributor to the national inventory.

A complete listing of all source categories is shown in Table A1-1.

TABLE A1-1: Source Category Analysis Summary

Source Table	IPCC Source Categories	Direct Greenhouse Gas	Key Source Category (Yes or No)	If Yes, Criteria for Identification
1-A-1-a	Fuel Combustion – Public Electricity and Heat Production	CO_2	Yes	Level, Trend, 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, 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, Quality
1-A-1-c	Fuel Combustion – Manufacture of Solid Fuels and Other Energy Industries	CH_4		
1-A-1-c	Fuel Combustion – Manufacture of Solid Fuels and Other Energy Industries	N_2O		
1-A-2	Fuel Combustion – Manufacturing Industries and Construction	CO_2	Yes	Level, 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
1-A-3-a	Fuel Combustion – Civil Aviation	CH_4		
1-A-3-a	Fuel Combustion – Civil Aviation	N_2O		
1-A-3-b	Fuel Combustion – Road Transportation	CO_2	Yes	Level, Trend, Quality
1-A-3-b	Fuel Combustion – Road Transportation	CH_4		
1-A-3-b	Fuel Combustion – Road Transportation	N_2O	Yes	Level, Trend, Quality
1-A-3-c	Fuel Combustion – Railways	CO_2	Yes	Level, Trend
1-A-3-c	Fuel Combustion – Railways	CH_4		
1-A-3-c	Fuel Combustion – Railways	N_2O		
1-A-3-d	Fuel Combustion – Navigation	CO_2		
1-A-3-d	Fuel Combustion – Navigation	CH_4		
1-A-3-d	Fuel Combustion – Navigation	N_2O		
1-A-3-e	Fuel Combustion – Other Transport	CO_2	Yes	Level
1-A-3-e	Fuel Combustion – Other Transport	CH_4		
1-A-3-e	Fuel Combustion – Other Transport	N_2O		
1-A-3-f	Fuel Combustion – Pipeline Transport	CO_2	Yes	Level, Trend, Quality
1-A-3-f	Fuel Combustion – Pipeline Transport	CH_4		
1-A-3-f	Fuel Combustion – Pipeline Transport	N_2O		
1-A-4	Fuel Combustion – Other Sectors	CO_2	Yes	Level, Trend
1-A-4	Fuel Combustion – Other Sectors	CH_4		
1-A-4	Fuel Combustion – Other Sectors	N_2O		
1-B-1-a	Fugitive Emissions – Coal Mining	CH_4	Yes	Level
1-B-2-(a+b)	Fugitive Emissions – Oil and Natural Gas	CO_2		
1-B-2-(a+b)	Fugitive Emissions – Oil and Natural Gas	CH_4	Yes	Level, Trend, Quality
1-B-2-c	Fugitive Emissions – Oil and Natural Gas – Venting and Flaring	CO_2	Yes	Level, Trend, Quality
1-B-2-c	Fugitive Emissions – Oil and Natural Gas – Venting and Flaring	CH_4	Yes	Quality
2-A-1	Industrial Processes – Cement Production	CO_2	Yes	Level, Quality
2-A-2	Industrial Processes – Lime Production	CO_2		
2-A-3	Industrial Processes – Limestone and Dolomite Use	CO_2		
2-A-4	Industrial Processes – Soda Ash Production and Use	CO_2		
2-B-1	Industrial Processes – Ammonia Production	CO_2	Yes	Level
2-B-2	Industrial Processes – Nitric Acid Production	N_2O		
2-B-3	Industrial Processes – Adipic Acid Production	N_2O	Yes	Level, Trend, Quality
2-C-1	Industrial Processes – Iron and Steel Production	CO_2	Yes	Level
2-C-3	Industrial Processes – Aluminium Production	CO_2		
2-C-3	Industrial Processes – Aluminium Production	PFCs	Yes	Level, Quality
2-C-4	Industrial Processes – Aluminium and Magnesium Production	SF_6	Yes	Level, Quality
2-F	Industrial Processes – Other (Undifferentiated Processes)	CO_2	Yes	Level
2-F	Industrial Processes – Other (Undifferentiated Processes)	PFCs		
2-F	Industrial Processes – Other (Undifferentiated Processes)	HFCs		
3-D	Solvent and Other Product Use	N_2O		
4-A	Agriculture – Enteric Fermentation	CH_4	Yes	Level
4-B	Agriculture – Manure Management	CH_4	Yes	Level
4-B	Agriculture – Manure Management	N_2O		
4-D	Agriculture – Agricultural Soils	CO_2		
4-D	Agriculture – Agricultural Soils	N_2O	Yes	Level
5-E	Fires caused by human activities	CH_4		
5-E	Fires caused by human activities	N_2O		
6-A	Waste – Solid Waste Disposal on Land	CH_4	Yes	Level, Quality
6-B	Waste – Wastewater Handling	CH_4		
6-B	Waste – Wastewater Handling	N_2O		
6-C	Waste – Waste Incineration	CO_2		
6-C	Waste – Waste Incineration	CH_4		
6-C	Waste – Waste Incineration	N_2O		

KEY SOURCE TABLES

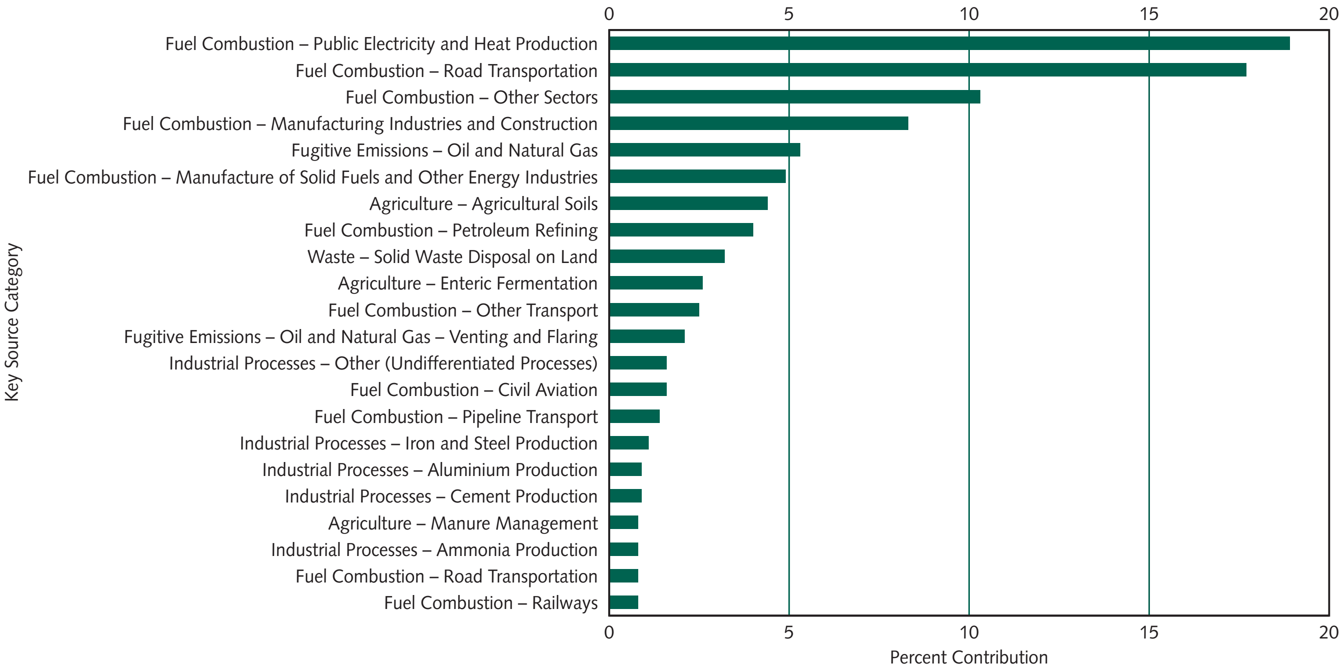
LEVEL ASSESSMENT

Table A1-2 shows key sources indicated from level assessment. Figure A1-1 shows the contribution of key sources to level assessments.

TABLE A1-2: Key Source Categories Level Assessment

Source Table	IPCC Categories	Direct Greenhouse Gas	Base Year Estimates (kt CO_2 eq)	Current Year Estimate (kt CO_2 eq)	Level Assessment
1-A-1-a	Fuel Combustion – Public Electricity and Heat Production	CO_2	94 745	136 296	18.9%
1-A-3-b	Fuel Combustion – Road Transportation	CO_2	102 868	127 487	17.7%
1-A-4	Fuel Combustion – Other Sectors	CO_2	69 415	74 266	10.3%
1-A-2	Fuel Combustion – Manufacturing Industries and Construction	CO_2	62 090	59 657	8.3%
1-B-2-(a+b)	Fugitive Emissions – Oil and Natural Gas	CH_4	25 685	37 814	5.3%
1-A-1-c	Fuel Combustion – Manufacture of Solid Fuels and Other Energy Industries	CO_2	23 555	35 508	4.9%
4-D	Agriculture – Agricultural Soils	N_2O	27 364	31 409	4.4%
1-A-1-b	Fuel Combustion – Petroleum Refining	CO_2	25 977	28 962	4.0%
6-A	Waste – Solid Waste Disposal on Land	CH_4	18 530	23 057	3.2%
4-A	Agriculture – Enteric Fermentation	CH_4	15 994	18 800	2.6%
1-A-3-e	Fuel Combustion – Other Transport	CO_2	15 095	17 681	2.5%
1-B-2-c	Fugitive Emissions – Oil and Natural Gas – Venting and Flaring	CO_2	9 787	15 200	2.1%
1-A-3-a	Fuel Combustion – Civil Aviation	CO_2	10 407	11 751	1.6%
2-F	Industrial Processes – Other (Undifferentiated Processes)	CO_2	9 218	11 664	1.6%
1-A-3-f	Fuel Combustion – Pipeline Transport	CO_2	6 705	9 965	1.4%
2-C-1	Industrial Processes – Iron and Steel Production	CO_2	7 585	7 920	1.1%
2-A-1	Industrial Processes – Cement Production	CO_2	5 873	6 493	0.9%
2-C-3	Industrial Processes – Aluminium Production	PFCs	5 975	6 153	0.9%
2-B-1	Industrial Processes – Ammonia Production	CO_2	5 008	5 923	0.8%
1-A-3-c	Fuel Combustion – Railways	CO_2	6 315	5 820	0.8%
1-A-3-b	Fuel Combustion – Road Transportation	N_2O	3 646	5 744	0.8%
4-B	Agriculture – Manure Management	CH_4	4 595	5 473	0.8%

FIGURE A1-1: Contributions of Key Source Categories to Level Assessment



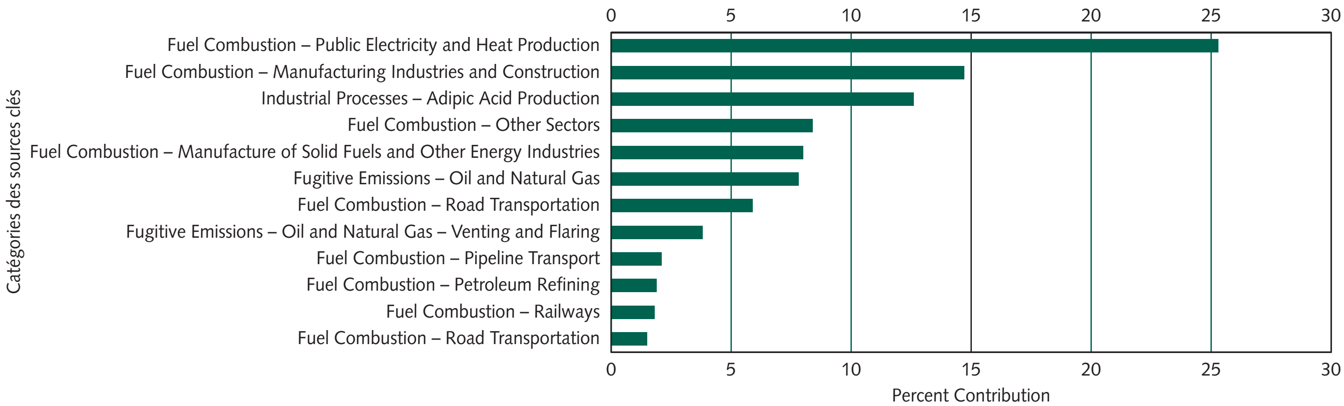
TREND ASSESSMENT

Table A1-3 shows key sources indicated from trend assessment. Figure A1-2 shows the contribution of key sources to trend assessments.

TABLE A1-3: Key Source Categories by Trend Assessment

Table	Greenhouse IPCC Categories	Direct Year Gas	Base Year Estimates	Current Trend Estimate	Source Assessment
1-A-1-a	Fuel Combustion – Public Electricity and Heat Production	CO_2	94 745	136 296	0.028
1-A-2	Fuel Combustion – Manufacturing Industries and Construction	CO_2	62 090	59 657	0.016
2-B-3	Industrial Processes – Adipic Acid Production	N_2O	10 718	802	0.014
1-A-4	Fuel Combustion – Other Sectors	CO_2	69 415	74 266	0.009
1-A-1-c	Fuel Combustion – Manufacture of Solid Fuels and Other Energy Industries	CO_2	23 555	35 508	0.009
1-B-2-(a+b)	Fugitive Emissions – Oil and Natural Gas	CH_4	25 685	37 814	0.009
1-A-3-b	Fuel Combustion – Road Transportation	CO_2	102 868	127 487	0.007
1-B-2-c	Fugitive Emissions – Oil and Natural Gas – Venting and Flaring	CO_2	9 787	15 200	0.004
1-A-3-f	Fuel Combustion – Pipeline Transport	CO_2	6 705	9 965	0.002
1-A-1-b	Fuel Combustion – Petroleum Refining	CO_2	25 977	28 962	0.002
1-A-3-c	Fuel Combustion – Railways	CO_2	6 315	5 820	0.002
1-A-3-b	Fuel Combustion – Road Transportation	N_2O	3 646	5 744	0.002

FIGURE A1-2: Contributions of Key Source Categories to Trend Assessment



QUALITATIVE ASSESSMENT

Mitigation Techniques and Technologies

Mitigation techniques are important for good practices, in particular if they are inclined to produce departures from the norm under which activity data and emission factors are estimated. Table A1-4 shows key sources identified as a result of having significant mitigation techniques and technologies introduced that have had (since 1990), or will have, an impact on emission estimates.

TABLE A1-4: Key Sources by Significant Mitigation Techniques and Technologies

Key Source	GHG	Reference	Comments
Fugitive Emissions – Oil and Natural Gas – Venting and Flaring	CO_2	NRCan, 2000	Upstream oil and gas industry is planning to reduce flaring by 50% by 2006 with use of micro-turbines: Voluntary measure
Fuel Combustion – Road Transportation	CO_2	CCCS, 2000; Government of Canada, 2000	Voluntary efficiency standards, increased ethanol use: Voluntary measure
Fuel Combustion – Public Electricity and Heat Production	CO_2	NRCan, 1999; CCCS, 2000; Government of Canada, 2000	Utility deregulation opens market to distributed power and reduced barriers to interprovincial trade. Natural gas replaces coal and oil generation: Voluntary measure
Fuel Combustion – Manufacture of Solid Fuels and Other Energy Industries	CO_2	CCCS, 2000; Government of Canada, 2000	Demonstrate CO_2 capture and storage: Voluntary measure
Industrial Processes – Cement Production	CO_2	Rawson, 2001	Move to dry kiln technique and use of fly ash: Voluntary measure
Waste – Solid Waste on Land	CH_4	Olsen, 2001; Rawson, 2001	Landfills are collecting CH_4 emissions for combustion or power generation: Policy measure
Fugitive Emissions – Oil and Natural Gas – Venting and Flaring	CH_4	NRCan, 2000; Rawson, 2001	Upstream oil and gas industry is reducing pipeline and exploration venting: Voluntary measure
Industrial Processes – Adipic Acid Production	N_2O	NRCan, 2000; Olsen, 2001	Canada's one plant introduced technology to reduce emissions in the mid-1990s. Reduction is expected to be over 98% in the next few years: Voluntary measure
Industrial Processes – Aluminium Production	PFCs	Rawson, 2001	Reduction through computer controls: Voluntary measure
Industrial Processes – Aluminium and Magnesium Production	SF_6	NRCan, 1999	Elimination by 2005 of SF_6 in magnesium casting and smelting: Voluntary measure

References:

CCCS (2000), *Canada's First National Climate Change Business Plan,* Canadian Climate Change Secretariat, October.

Government of Canada (2000), *Government of Canada Action Plan 2000 on Climate Change.*

NRCan (1999), *Canada's Emissions Outlook: An Update,* Analysis and Modelling Team, National Climate Change Process, Natural Resources Canada, December.

NRCan (2000), *An Assessment of the Economic and Environmental Implications for Canada of the Kyoto Protocol,* Analysis and Modelling Team, National Climate Change Process, Natural Resources Canada, November.

Olsen, K. (2001), Personal communication, Greenhouse Gas Division, Environment Canada, February.

Rawson, B. (2001), Personal communication, Voluntary Challenge Registry, March.

High Emissions Growth

Table A1-5 shows key sources 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 A1-5: Key Sources Identified from Anticipated High Emissions Growth

Key Source	GHG	Reference	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; CCCS, 2000	Increased heavy oil use
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 – 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
Industrial Processes – Aluminium and Magnesium Production	SF_6	Rawson, 2001	An increase expected due to plant openings, then drop in emissions due to process changes

References:

CCCS (2000), *Canada's First National Climate Change Business Plan,* Canadian Climate Change Secretariat, October.

NRCan (1999), *Canada's Emissions Outlook: An Update,* Analysis and Modelling Team, National Climate Change Process, Natural Resources Canada, December.

Rawson, B. (2001), Personal communication, Voluntary Challenge Registry, March.

High Uncertainty

The McCann (1994) study of uncertainty associated with 1990 inventory estimates is the most current source of information for key sources. In this study, uncertainties are reported in categories similar to the UNFCCC CRF so that reconciliation of key source determination with the McCann report proceeded (as with the determination of all source categories). If uncertainty was only attributed to a subcomponent of a source category, that category was nevertheless identified as key. For example, a 25% uncertainty was given to the combustion of still gas (McCann, 1994). Fuel Combustion – Petroleum Refining (where still gas is used in its entirety) was, therefore, identified as a key source, even though emission estimates for other aspects of petroleum refining may not have had this high a level of uncertainty. Table A1-6 shows key sources identified as having a relatively high composite uncertainty (meaning both activity and emission factor uncertainties) compared with the expected norm. Sources were identified as key when uncertainty limits were >±15% for CO_2 and >±30% for CH_4 and N_2O.

TABLE A1-6: Key Sources with a High Composite Uncertainty

Key Source	GHG	Reference
Agriculture – Agricultural Soils	CO_2	Olsen, 2001
Fuel Combustion – Manufacturing of Solid Fuels and Other Energy Industries	CO_2	McCann, 1994
Fuel Combustion – Petroleum Refining	CO_2	McCann, 1994; NRCan, 2000
Waste – Waste Incineration	CO_2	McCann, 1994
Agriculture – Enteric Fermentation	CH_4	McCann, 1994
Agriculture – Manure Management	CH_4	McCann, 1994
Anthropogenic Fires – LUCF	CH_4	McCann, 1994
Waste – Wastewater Handling	CH_4	McCann, 1994
Fuel Combustion – Road Transportation	N_2O	McCann, 1994
Agriculture – Agricultural Soils	N_2O	McCann, 1994; Olsen, 2001
Anthropogenic Fires – LUCF	N_2O	McCann, 1994

References:

McCann, T.J. (1994), *Uncertainties in Canada's 1990 Greenhouse Gas Emission Estimates: A Quantitative Assessment,* prepared for Environment Canada by T.J. McCann and Associates, March.

NRCan (2000), *An Assessment of the Economic and Environmental Implications for Canada of the Kyoto Protocol,* Analysis and Modelling Team, National Climate Change Process, Natural Resources Canada, November.

SUMMARY ASSESSMENT

The results of key source assessment in accordance with *IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC/OECD/IEA, 2000) are given in Table A1-1.

REFERENCES

CCCS (2000), *Canada's First National Climate Change Business Plan,* Canadian Climate Change Secretariat, October.

Coombs, A. (1999), *Major Changes in the Historical Data for the Quarterly Report on Energy Supply and Demand (QRESD) (1990–1997),* Allen Coombs & Associates Inc., December.

Government of Canada (2000), *Government of Canada Action Plan 2000 on Climate Change.*

IPCC/OECD/IEA (2000), *IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories,* Intergovernmental Panel on Climate Change, Organisation for Economic Co-operation and Development, and International Energy Agency, Tokyo.

McCann, T.J. (1994), *Uncertainties in Canada's 1990 Greenhouse Gas Emission Estimates: A Quantitative Assessment,* prepared for Environment Canada by T.J. McCann and Associates, March.

NRCan (1999), *Canada's Emissions Outlook: An Update,* Analysis and Modelling Team, National Climate Change Process, Natural Resources Canada, December.

NRCan (2000), *An Assessment of the Economic and Environmental Implications for Canada of the Kyoto Protocol,* Analysis and Modelling Team, National Climate Change Process, Natural Resources Canada, November.

Rawson, B. (2001), Personal communication, Voluntary Challenge Registry, March.

ANNEX 2: METHODOLOGY AND DATA FOR ESTIMATING EMISSIONS FROM FUEL COMBUSTION

METHODOLOGY

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 7:

- *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 Greenhouse Gas Inventory Reference Manual (IPCC, 1997).

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 (Jaques, 1992). The factors have been obtained and developed from a number of studies conducted by Environment Canada, the U.S. Environmental Protection Agency (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 emission).

Emission factors are based upon the physical quantity of fuel combusted, rather than on the energy content of the fuel, and provide a more accurate estimate of emissions, since the number of conversions required to derive the estimates are minimized because fuels are – initially – commonly reported in physical units. 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.

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. Emission factors are listed in Annex 7.

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. Emission factors are listed in Annex 7.

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 section totals. They are accounted for in the Land-Use Change and Forestry (LUCF) section 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 section in the appropriate subsectors and included in inventory totals.

DATA

STATISTICS CANADA ENERGY-USE DATA – THE QRESD

The fossil fuel energy-use data used to estimate combustion emissions are from the *Quarterly Report on Energy Supply-Demand in Canada* (QRESD) compiled by Statistics Canada, Canada's national statistics agency. It is the principal source of energy-use data (Statistics Canada, #57-003).

The QRESD uses a top-down approach to estimate the supply and demand of energy in Canada. The production of fuels in Canada is balanced with the use of fuels in broad categories such as import/export, producer consumption, industry, residential, etc. Industrial energy-use data are divided into broad sectors based on Standard Industrial Classification (SIC) or North American Industrial Classification System (NAICS) codes.

While the QRESD 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 QRESD 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 QRESD) may provide more accurate information at the sector level for future inventories.

ANNEX 3: METHODOLOGY AND DATA FOR ESTIMATING AGRICULTURAL SOURCES AND SINKS

The Agriculture sector has two different types of sources, animal production and agricultural soils. Depending upon how they are managed, agricultural soils can act as a source or sink of CO_2. This annex describes the detailed accounting methodologies (i.e. specific equations, models, activity data and emission factors) that are used to derive the GHG estimates for the following sources:

1. Animal production:
   - CH_4 emissions from enteric fermentation; and
   - CH_4 and N_2O emissions from manure management.
2. Agricultural soils:
   - CO_2 emissions and removals associated with the cultivation of mineral soils, organic soils and lime application;
   - Direct N_2O emissions associated with synthetic fertilizer and manure application; crop residue decomposition; nitrogen-fixing plants; cultivation of organic soils; manure on pasture and paddock; and
   - Indirect N_2O emissions that occur offsite from volatilization, leaching and runoff of nitrogen contained in synthetic fertilizer and manure.

ANIMAL PRODUCTION

METHANE EMISSIONS FROM ENTERIC FERMENTATION

Methodology

The IPCC Tier 1 methodology is used to estimate CH_4 emissions from enteric fermentation. Equation A3-1 is used to calculate the release of CH_4 from enteric fermentation from different types of livestock in Canada.

Equation A3-1:

$$CH_{4_{EF}} = N_T \times EF_{(EF)T}$$

where:

$CH_{4_{EF}}$ = Enteric fermentation emissions for each specific animal category

N_T = Animal population for each specific animal category (by province)

$EF_{(EF)T}$ = Emission factor for each specific animal category (Refer to Table A3-1 for IPCC Default Emission Factors for Cool Climate for all categories except bulls, beef heifers, dairy heifers and beef cows.)

TABLE A3-1: Enteric Fermentation Emission Factors

Animal Category (N_T)	Emission Factors $EF_{(EF)T}$ kg CH_4/head/year
Cattle	
Bulls	75 [1]
Dairy Cows*	118
Beef Cows	72 [1]
Dairy Heifers	56 [1]
Beef Heifers	56 [1]
Heifers for Slaughter	47
Steers	47
Calves	47
Pigs	
Swine	1.5
Poultry	
Chickens	Not Estimated
Hens	Not Estimated
Turkeys	Not Estimated
Other Livestock	
Sheep	8
Goats	8
Horses	13

1 Emission factors deviate from the IPCC defaults. Reference: Ray Desjardins (1998).

* Note that dairy heifers are treated as dairy cattle in the Manure Management, but they are considered as non-dairy cattle in the Enteric Fermentation.

Data Sources

Annual livestock population data at a provincial level are used to develop emission estimates. The following is a list of livestock and their corresponding data sources:

TABLE A3-2: Data Sources for Animal Populations

Animal Category	Source
Cattle (Types): Bull, Dairy Cow, Beef Cow, Dairy Heifer, Beef Heifer for slaughter, Steer, and Calves	Statistics Canada, Cat. No. 23-603-UPE, Table 1, Cattle and Calves on Farms
Pigs (Types): Boar, Sow, Pig (<20 kg), Pig (20 to 60 kg), and Pig (>60 kg)	Statistics Canada, Cat. No. 23-603-UPE, Table 1, Pigs on Farms
Goats:	Statistics Canada, 2001 Census of Agriculture, Cat. No. 95F0301XIE, Table 22.1. Other Livestock and colonies of Bees, by Province, Census Agricultural Region and Census Division, May 15, 2001
Poultry (Types):	
Chickens, Hens, and Turkeys	Statistics Canada, Cat. No. 23-202-XIB, Table 1, Production, Chicken and Stewing Hen Meat
	Statistics Canada, Cat. No. 23-202-XIB, Table 3, Disposition, Turkey Meat
	Statistics Canada, Cat. No. 23-202-XIB, Table 5, Production of Eggs Yearly Average
Other Livestock:	
Sheep, Lambs, Goats and Horses	Sheep and Lamb: Statistics Canada, Cat. No. 23-603-UPE, Table 1. Sheep and Lambs on Farms
	Statistics Canada, 2001 Census of Agriculture, Cat. No. 95F0301XIE, Table 22.1. Other Livestock and colonies of Bees, by Province, Census Agricultural Region and Census Division, May 15, 2001
	Statistics Canada, Cat. No. 95F0301XIE, 2001 Census of Agriculture, Table 22.1. Other Livestock and Colonies of Bees, by Province, Census Agricultural Region and Census Division, May 15, 2001.

Livestock Population Adjustments

The following adjustments are made to convert livestock population data to an annual basis. These adjustments are necessary for cattle, pig and sheep/lamb data since they are collected on a quarterly or a semi-annual basis. Horses, goat and poultry population data are recorded as an annual total, therefore population data adjustments are not necessary.

Cattle data are reported semi-annually by Statistics Canada, therefore livestock population adjustments are necessary. Cattle populations are collected for January and July for each inventory year. Average cattle population distribution is calculated using the equation shown below for each cattle type.

Equation A3-2:

$$\overline{\text{Cattle Population}} = \left(\frac{\text{Cattle Population (January + July)}}{2}\right)$$

Pig population data are collected on a quarterly basis, therefore population data adjustments are necessary. The annual pig population is calculated using Equation A3-3.

Equation A3-3:

$$\overline{\text{Pig Population}} = \left(\frac{\text{Pig Population (January + April + July + October)}}{4}\right)$$

Statistics Canada collects population data on sheep and lambs on a semi-annual basis, therefore population data adjustments are necessary. Annual sheep/lamb population is calculated using Equation A3-4.

Equation A3-4:

$$\overline{\text{Sheep \& Lamb Population}} = \left(\frac{\text{Sheep \& Lamb Population (January + July)}}{2}\right)$$

METHANE EMISSIONS FROM MANURE MANAGEMENT

Methodology

The IPCC Tier 1 methodology is used to estimate CH_4 emissions from manure management. Equation A3-5 is used to calculate CH_4 emissions from manure management for different types of livestock in Canada.

Equation A3-5:

$$CH_{4MM} = N_T \times EF_{(MM)T}$$

where:

CH_{4MM} = Emissions for each specific animal category

N_T = Animal population for each specific animal category (by province)

$EF_{(MM)T}$ = Emission factor for each specific animal category. (For IPCC Default Emission Factors for Cool Climate, Refer to Table A3-3.)

Data Sources

Sources of animal population data are the same as those used in the enteric fermentation estimations with one exception. Dairy heifers are treated as dairy cattle in manure management estimations, but they are considered as non-dairy cattle in the enteric fermentation estimations.

TABLE A3-3: Manure Management Emission Factors

Animal Category (N_T)	Emission Factors $EF_{(MM)T}$ kg CH_4/head/year
Cattle	
Bulls	1
Dairy Cows	36
Beef Cows	1
Dairy Heifers	36
Beef Heifers	1
Heifers for Slaughter	1
Steers	1
Calves	1
Pigs	
Swine	10
Poultry	
Chickens	0.078
Hens	0.078
Turkeys	0.078
Other Livestock	
Sheep	0.19
Goats	0.12
Horses	1.4

NITROUS OXIDE EMISSIONS FROM MANURE MANAGEMENT

Methodology

The IPCC Tier 1 methodology is used to estimate N_2O emissions from animal waste management systems (AWMS). The IPCC methodology is based on the quantity of manure nitrogen produced by domestic animals and the methods of AWMS. Emission estimates of N_2O from AWMS, excluding those from manure in pasture, range and paddock systems, are calculated using Equation A3-6. (Note that N_2O emissions from the manure on pasture and paddock are covered under Agricultural Soils.)

Nitrous oxide emissions from animal production systems from different types of livestock in Canada are estimated using Equation A3-6. Three factors are required for estimating emissions of N_2O resulting from manure management, i.e. (1) nitrogen excretion rates for various animal types and categories, (2) types of AWMS, and (3) emissions factors associated with each manure management system.

Equation A3-6:

$$N_2O_{AWMS} = \left(N_T \times NE \times N_A\right) \times \frac{44}{28}$$

where:

N_2O_{AWMS} = N_2O emissions for each specific animal category.

N_T = Population for each specific animal category (by province). (Refer to "Methane Emissions from Enteric Fermentation" for livestock population data sources and calculations.)

NE = Nitrogen excretion rate for each animal category. (Refer to Table A3-4.)

N_A = Fraction of nitrogen available for N_2O emissions from Manure Management for specific AWMS. (Refer to Equation A3-7.)

Animal waste management systems in Canada are comprised of liquid systems, solid storage and drylot, pasture range and paddock, and other systems.

Equation A3-7:

$$N_A = N_P \times N_L$$

where:

N_P = Percentage of nitrogen produced by AWMS (%). (Refer to Table A3-5.)

N_L = Percentage of manure nitrogen excreted that is lost as N_2O (Emission factors for specific AWMS, EF3). (Refer to Table A3-6.)

Data Sources

The N_2O emissions are estimated on a provincial basis. The estimates are updated on an annual basis. However, the estimates for horses and goats animal categories depend on the Census of Agriculture data, and are, therefore, revised only every five years (last year of revision: 2001).

Nitrogen Excretion Rates for Various Domestic Animals

The Revised 1996 IPCC Guidelines 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. However, the US-based American Society of Agricultural Engineering (ASAE, 1999) has published average rates of nitrogen excretion. These values, listed in Table A3-4, are considered to be more representative of Canadian conditions than IPCC default values, and have therefore been adopted.

TABLE A3-4: Nitrogen Excretion Rate for Each Specific Animal Category

Animal Category (N_T)	Nitrogen Excretion (NE) kg N/head-yr	Source
Non-Dairy Cattle	44.7	ASAE (1999)
Dairy Cattle	105.2	ASAE (1999)
Poultry	0.36	ASAE (1999)
Sheep and Lambs	4.1	ASAE (1999)
Swine	11.6	ASAE (1999)
Other (goats and horses)	49.3	ASAE (1999)

ASAE (1999) ASAE Standards 1999, 46th Edition, American Society of Agricultural Engineering, St. Joseph, MI.

The quantity of nitrogen excretion is estimated using the average rate of nitrogen excretion for a specific animal category multiplied by the respective animal population.

Animal Waste Management Systems

In Canada, the major types of animal waste management systems include liquid, drylot, pasture and paddock, and others. However, there is no formal tracking of AWMS by animal category in place at this time. Therefore, the percentages of manure handled in specific animal waste management systems, as presented in Table A3-5, are based on expert opinion.

TABLE A3-5: Percentage of Manure Nitrogen Handled by AWMS (N_P), %

Animal Category (N_T)	Liquid Systems	Solid Storage & Drylot	Other Systems	Pasture Range & Paddock
Non-Dairy Cattle	1	56	1	42
Dairy Cattle	53	27	0	20
Poultry	4	0	95	1
Sheep and Lambs	0	46	10	44
Swine	90	10	0	0
Other (goats and horses)	0	46	8	46

Emission Factors Associated with Animal Waste Management Systems

It is known that the type of animal waste management system 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 A3-6, are used for emission estimates.

TABLE A3-6: Percentage of Manure Nitrogen Lost as N_2O-N for Specific AWMS (N_L), %

Animal Category (N_T)	Liquid Systems	Solid Storage & Drylot	Other Systems	Pasture Range & Paddock
Non-Dairy Cattle	0.1	2.0	0.5	2.0
Dairy Cattle	0.1	2.0	0.5	2.0
Poultry	0.1	2.0	0.5	2.0
Sheep and Lambs	0.1	2.0	0.5	2.0
Swine	0.1	2.0	0.5	2.0
Other (goats and horses)	0.1	2.0	0.5	2.0

AGRICULTURAL SOILS

EMISSIONS OR REMOVALS OF CARBON DIOXIDE FROM AGRICULTURAL SOILS

Canada's agricultural soils CO_2 inventory currently applies to cropland, i.e., agricultural land that is managed for crop production.

Cultivation of Mineral Soils (CENTURY model)

The following section briefly describes the method that Smith et al. (1997) developed for estimating fluxes or removals of CO_2 from mineral agricultural soils in Canada using the CENTURY model. A more detailed description of the methodology was published in the Canadian Journal of Soil Science (77:219-229).

The CENTURY model was used to estimate the rate of soil organic carbon (SOC) change in agricultural soils in Canada. The analysis was carried out on 180 soil landscapes of Canada polygons, representing 15% of the soil landscape of Canada (SLC) polygons within agricultural regions. The analysis was stratified into soil zones and into soil textural classes. For each sampled polygon, the CENTURY model was run for 1 to 5 types of crop rotations under conventional tillage as well as no-tillage, providing that no-till was used on at least 5% of the land. From the Century simulations, it was estimated that the overall rate of SOC loss from agricultural soils in Canada for 1990 was 39.1 kg $ha^{-1}yr^{-1}$. This implies that 1.93 Mt of SOC (7.08 Mt of CO_2) was lost from agricultural soils in Canada. Compared to 1990, the SOC loss was estimated to have been greater by 11.9 kg $ha^{-1}yr^{-1}$ in 1980 and 9.1 kg $ha^{-1}yr^{-1}$ in 1985. The lower loss in 1990 was primarily due to the incorporation of no-till practices and reduction of summer fallow in the mid 1980s. In 1990, at the provincial level, Alberta had the highest rate of SOC loss at 74.5 kg $ha^{-1}yr^{-1}$, followed by Manitoba with 66.1 kg $ha^{-1}yr^{-1}$. In Ontario, Quebec, and the Atlantic Provinces, the average provincial rate of SOC loss was less than 35 kg $ha^{-1}yr^{-1}$. Higher SOC loss rates were typically found in soils with coarser texture and greater native SOC content.

Methodology

Stratification of Canadian agricultural soils for analysis using the CENTURY model: Soil data for 1992 agriculturally designated polygons were obtained from the Soil Landscapes of Canada (1:1,000,000) dominant characteristics files (Shields et al., 1991), which are part of the Canadian Soil Information System (CanSIS). This is the most extensive database for agro-ecosystems in Canada. Within a polygon, the dominant soil represents at least 40% of the polygon area. Furthermore, the polygon is the smallest and most detailed landscape area with uniform coverage for all of Canada.

A sample of 15% of the total number of agriculturally designated polygons in Canada was used to estimate SOC dynamics. Sampling of SLC polygons was stratified by major soil zones and textural classes so that an equal percentage of the total area of each soil zone and textural class was sampled. Weighted sampling ensured representation of all significant soil groups and soil textures within Canada. The number of polygons sampled within a soil group was proportional to its fraction of the total Canadian agriculturally designated area. A minimum of one polygon was sampled from each soil group, except for the Solonetzic group, which represents 4% of the agricultural land in Canada.

The Century does not describe well SOC dynamics in Solonetzic soils. The polygons within each soil group were further sorted by soil texture. The number of polygons to be sampled within a textural class was calculated as the fraction of the total area the texture represented within a soil group times the number of polygons sampled in the soil group. For example, for the Brown Chernozemic group, 11 polygons with a loam texture were chosen randomly from a population of 57.

Current SOC content to the 30-cm depth for each SLC polygon was estimated from the Soil Carbon Layer Database (Tarnocai, 1994). The Soil Carbon Layer Database is the most comprehensive database on SOC for all of Canada.

Tillage practices used in Century simulations for the Prairie Provinces.

The dynamics of SOC under conventional tillage practices were simulated for all polygons. Simulations were also carried out for no-tillage practices, providing the area of no-tillage in a polygon was greater than 5% of the polygon's total agricultural area. Depending on the crop rotation, no-till usually started in 1986, following conventional tillage from 1910 to 1985. For all polygons, Century runs were carried out from 1910 to 1996. In order to better represent changing tillage and cropping practices, the runs were broken into four or five time blocks. No-tillage was introduced in the 5th block (1985 to 1995). Reductions in summer fallow were reflected in Century analysis by exchanging some of the fallow rotations with more intensive rotations in later blocks.

In 1980 and 1985 the rate of SOC change in agricultural soils in Canada was higher than in 1990. The estimated reduction in the rate of carbon loss was small between 1980 and 1985 (1.8 kg ha^{-1}), but larger between 1985 and 1990 (9.1 kg ha^{-1}). This is partly due to the influence of no-till practices, which were introduced to some areas of Canada in the mid 1980s. The reduction in summer-fallow in the later time blocks used in the Century simulation also resulted in less carbon loss in later years.

The change in soil carbon stocks was compared to the control run 10 years after the introduction of the management changes. The carbon coefficients, averaged over the 10-year period, were determined by weighting the fraction of crop rotation, soil texture, and soil group.

Equation A3-8:

$$C = \Sigma^g F_g (\Sigma^t F_t(\Sigma^r F_r R_r))$$

where:

C = carbon coefficient
g = number of soil groups
F_g = proportion of area covered by soil group
t = number of soil textures
F_t = proportion of area covered by soil texture
r = number of crop rotations
F_r = proportion of areas covered by crop rotation
R_r = carbon coefficient for a crop within a soil texture and soil group.

The land management activities for which the CENTURY-derived CO_2 coefficients were negative indicated a sink of CO_2, while a positive coefficient indicated a source of CO_2.

Agricultural Soils – 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 soil nutrient availability, in particular phosphorus, reduce heavy metal toxicity such as Al^{+++}, and improve crop growth environment. During this neutralization process, CO_2 is released in the following bicarbonate equilibrium reactions that take place in the soil:

$$CaCO_3 + 2H^+ = CO_2 + Ca^{++} + H_2O$$

$$CaMg(CO_3)_2 + 4\,H^+ = 2\,CO_2 + Ca^{++} + Mg^{++} + 2\,H_2O$$

The rate of release will vary with soil conditions and the types of compounds applied. In most cases where liming is practised, repeated applications are made every few years. Thus, for the purposes of the inventory, it is assumed that the addition rate of lime is in near equilibrium to the consumption of lime applied in previous years. Emissions associated with use of lime can be calculated from the amount and composition of the lime applied annually.

Methodology

The calculation of the amount of CO_2 released as a result of limestone application is shown in Equation A3-9:

Equation A3-9:

CO_2 = x • 44/100

where:

x = Annual limestone consumption (tonnes/yr)

44 = Molecular weight of CO_2, and 100 is the molecular weight of limestone.

Similarly, the calculation for the amount of CO_2 released as a result of dolomite application is shown in Equation A3-10:

Equation A3-10:

CO_2 = 2 • x • 44/184.3

where:

x = Annual consumption of dolomitic lime

44 = Molecular weight of CO_2, and 184.3 is the molecular weight of dolomite.

If the type of lime was not known, it was assumed to be comprised of 50% calcitic lime and 50% dolomitic lime.

Data Sources

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. Estimates of CO_2 emissions from liming were done in 1996, and have not been updated since. It is expected this update could be completed for the next inventory year.

Currently, CO_2 emissions resulting from liming are combined and reported together with mineral soil emissions and removals under agricultural soils. Even though emissions from this source are small, this is a source under the IPCC Guidelines, and should be reported separately in NIR.

Cultivation of Organic Soils

Methodology

The IPCC Tier 1 methodology is based on the rate of CO_2 released per unit land area.

Equation A3-11:

CO_2 = x • EF

where:

x = Area of organic soils that are cultivated for agricultural production, and EF is emission factor (tonnes of carbon dioxide loss per hectare per year). An IPCC default emission factor of 10 tonnes of CO_2 per ha per year for a cold climate is adopted.

EF = Emission factor

Data Sources

Areas of cultivated histosols at a provincial level are not covered in the Census of Agriculture, which is collected regularly at five-year intervals by Statistics Canada. In the absence of this data, consultations with numerous soil and crop specialists across Canada have been undertaken. Based on these consultations, the total area of cultivated organic soils in Canada is 29,800 ha.

EMISSIONS OF NITROUS OXIDE FROM AGRICULTURAL SOILS

Direct Nitrous Oxide Emissions from Synthetic Nitrogen Fertilizers

Methodology

The IPCC Tier 1 methodology is used to estimate N_2O emissions from synthetic fertilizer application on agricultural soils. Equation A3-12 is used to estimate N_2O emissions by province and for the country as a whole.

Equation A3-12:

$$N_2O_{FSN} = \left(SF_T \times F_{ASN} \times EF_T\right) \times \frac{44}{28}$$

where:

N_2O_{FSN} = Emissions from synthetic nitrogen
Note: N_2O emissions are calculated for each province

SF_T = Total synthetic fertilizer consumption (kg N/yr) (Data Source: Korol, Canadian Fertilizer Consumption, Shipments and Trade, Farm Input Markets Unit, Farm Income Policy and Programs Directorate, Agriculture and Agri-Food Canada, http://www.agr.ca/policy/cdnfert/text.html)

F_{ASN} = Fraction of synthetic nitrogen fertilizer available for nitrification/denitrification processes.

Equation A3-13:

$$F_{ASN} = 1 - Frac_{gasf}$$

where:

$Frac_{gasf}$ = Fraction of synthetic nitrogen fertilizers applied to soil that volatilizes as NH_3 and NO_x
0.1 kg (NH_3-N + NO_x-N) / kg N (IPCC, 1997)
Assuming that 10% of nitrogen is lost through volatilization.

EF_T = Emission Factor (IPCC default, 1997)
0.0125 kg N_2O-N/kg N

Data Source

The Farm Input Markets Unit of the Farm Income and Adaptation Policy Directorate of Agriculture and Agri-Food Canada produces an annual publication titled "Canadian Fertilizer Consumption, Shipments and Trade" (Maurice Korol, 2002 – this material is also available on the web at http://www.agr.ca/policy/cdnfert/text.html). According to this information, the most reliable sources for fertilizer consumption are the regional fertilizer associations that conduct surveys of all the principal companies engaged in fertilizer retailing at the provincial level.

Direct Emissions of Nitrous Oxide from Manure Applied as Fertilizer

Methodology

Emissions of N_2O in this section represent the N_2O produced from the application of manure from dry lot, liquid and other waste management systems as fertilizer on agricultural soils. The IPCC Tier 1 methodology is used to estimate N_2O emissions from manure applied as fertilizer. The IPCC methodology is based on the quantity of manure nitrogen produced by domestic animals and the methods of animal waste management systems. Nitrous oxide emission estimates from this source, including all manure nitrogen produced from AWMS (except manure contained in Pasture Range & Paddock Systems), are calculated using Equation A3-10.

Equation A3-14:

$$N_2O_{MAF} = \left(N_{EX} \times F_A \times EF1\right) \times \frac{44}{28}$$

where:

N_2O_{MAF} = N_2O emissions from animal manure applied as fertilizers

Equation A3-15:

$$N_{EX} = \Sigma N_{AWMS} - \Sigma N_{PR\&P}$$

where:

Assuming that all nitrogen produced from all AWMS (excluding Pasture Range & Paddock) is applied as fertilizer.

N_{EX} = Total nitrogen from AWMS (excluding Pasture Range & Paddock)

ΣN_{AWMS} = Sum of nitrogen content from the following AWMS:
a. Liquid Systems
b. Solid Storage & Drylot
c. Other Systems
d. Pasture & Paddock

$\Sigma N_{PR\&P}$ = Sum of nitrogen from Pasture Range & Paddock System

Note: Refers to *Nitrous Oxide from Animal Waste Systems* for nitrogen from AWMS and Pasture Range & Paddock system for data sources and calculation of ΣN_{AWMS} and $\Sigma N_{PR\&P}$.

Equation A3-16:

$$F_A = 1 - Frac_{GASM}$$

where:

F_A = Fraction of nitrogen available for nitrification/denitrification processes due to animal waste applied as fertilizers.

$Frac_{GASM}$ = Fraction of livestock nitrogen excreted that is volatilized as NH_3 and NO_x
0.2 kg ($NH_3 \cong N$ + $NO_x \cong N$) / kg N (IPCC, 1997)

EF1 = Emission factors for fraction of nitrogen input
0.0125 kg ($N_2O \cong N$) / kg N (IPCC, 1997).

Direct Emissions of Nitrous Oxide from Biological Nitrogen Fixation

Methodology

The IPCC Tier 1 methodology is used to estimate N_2O emissions from nitrogen fixing crops. Equation A3-17 is used to estimate provincial N_2O emissions from nitrogen fixing crops.

Equation A3-17:

$$N_2O_{FBN} = \left(N_{FC} \times F_N \times EF_T\right) \times \frac{44}{28}$$

where:

N_2O_{FBN} = N_2O emissions from nitrogen fixing crops

Equation A3-18:

$$N_{FC} = 2 \times (C_T \times DMF_T)$$

where:

Assuming the mass of nitrogen fixing crops is twice (2:1) the mass of edible portions (except for the mass of alfalfa, 1:1). The mass of nitrogen fixing crops (alfalfa) is estimated to be 60% of tame hay produced.

N_{FC} = Amount of nitrogen from nitrogen fixing crops produced

C_T = Specific type of nitrogen fixing crop produced (Data Source: Statistics Canada, Catalogue No. 22-002-XIB.)
Nitrogen fixing crops include dry peas, soybean, dry white beans, coloured beans, chick peas, lentils, and tame hay.

DMF_T = Specific dry matter fraction. (Refer to Table A3-7.)

TABLE A3-7: Dry Matter Fraction (DMF_T)

Specific Crop Types	Dry Matter Fraction DMF_T
Peas	0.86
Beans	0.86
Soya	0.86
Lentils	0.86
All Others	0.86

F_N = Fraction of nitrogen content from dry mass of crops produced 0.03 kg N / kg dry mass (IPCC, 1997)

Assuming dry mass nitrogen content is constant for all nitrogen fixing crops.

EF_T = Emission Factor
0.0125 kg N_2O-N / kg N (IPCC, 1997)

Data Source

Statistics Canada collects annual field crop data and publishes "Table 1, November estimate of the 2001 production of principal field crops, Canada" (Cat. No. 22-002-XIB). Non-nitrogen fixing crops include wheat, barley, corn/maize, oats, rye, mixed grains, flax seed, canola, buckwheat, mustard seed, sunflower seed, canary seeds, fodder corn, and sugar beets. Nitrogen fixing crops include dry peas, soybean, dry white beans, coloured beans, chick peas, and lentils. Figures for tame hay are also presented, but are not used in this report.

Direct Emissions of Nitrous Oxide from Crop Residues

Methodology

The decomposition of crop residues left on fields results in N_2O emissions into the atmosphere. The IPCC Tier 1 methodology is used to estimate N_2O emissions from crop residues. Equation A3-19 below is used to estimate provincial releases of N_2O from crop residues.

Equation A3-19:

$$N_2O_{CR} = 2 \times \left(\begin{matrix}[(\Sigma C_{TCR} \times F_N) + (\Sigma C_{TNF} \times F_{NFC})] \\ \times (1-F_B) \times (1-F_R) \times EF1\end{matrix}\right) \times \frac{44}{28}$$

where:

N_2O_{CR} = N_2O from crop residues

Equation A3-20:

$$\Sigma C_{TCR} = (C_{TCR} \times DMF_T)$$

where:

ΣC_{TCR} = Sum of all non-nitrogen fixing crops

C_{TCR} = Non-nitrogen fixing crop produced
Data Source: Statistics Canada, Catalogue Number 22-002-XIB, Table 1, November estimate of the 2001 production of principal field crops, Canada. Non-nitrogen fixing crops include wheat, barley, corn/maize, oats, rye, mixed grains, flax seed, canola, buckwheat, mustard seed, sunflower seed, canary seeds, fodder corn, and sugar beets.

DMF_T = Specific dry matter fraction. (Refer to Table A3-8.)

Equation A3-21:

$$\Sigma C_{TNF} = (C_{TNF} \times DMF_T)$$

where:

ΣC_{TNF} = Sum of all nitrogen fixing crops

C_{TNF} = Nitrogen fixing crop produced
Data Source: Statistics Canada, Catalogue Number 22-002-XIB, Nitrogen fixing crops include dry peas, soybean, dry white beans, coloured beans, chick peas, and lentils. Tame hay is also reported, but not used here.

DMF_T = Specific dry matter fraction. (Refer to Table A3-8.)

TABLE A3-8: Dry Matter Fraction (DMF_T)

Specific Crop Types	Dry Matter Fraction DMF_T
Wheat	0.86
Barley	0.86
Maize	0.86
Oats	0.86
Rye	0.86
Peas	0.86
Beans	0.86
Soya	0.86
Fodder Corn	0.30
Lentils	0.86
Sugar Beets	0.20
All Others	0.86

F_N = 0.03 kg N / kg dry mass (IPCC, 1997)
Assuming constant fraction of nitrogen in nitrogen fixing crops

F_{NFC} = 0.015 kg N / kg dry mass (IPCC, 1997)
Assuming constant fraction of nitrogen in non-nitrogen fixing crops

F_B = Fraction of crop residues that are burned
0 kg N / kg dry mass
Assuming to be negligible in Canada

F_R = Fraction of crop mass removed from fields 45%
Assuming 55% of crop mass remains in fields as crop residues

EF1 = Emission Factor
0.0125 kg N_2O-N / kg N (IPCC Default, 1997)

Data Source

Statistics Canada collects annual field crop data and publishes "Table 1, November estimate of the 2001 production of principal field crops, Canada" (Cat. No. 22-002-XIB). Non-nitrogen fixing crops include wheat, barley, corn/maize, oats, rye, mixed grains, flax seed, canola, buckwheat, mustard seed, sunflower seed, canary seeds, fodder corn, and sugar beets. Nitrogen fixing crops include dry peas, soybean, dry white beans, coloured beans, chick peas, and lentils. Figures for tame hay are also presented, but are not used in this report.

Direct Emissions of Nitrous Oxide from 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. Nitrous oxide emissions from cultivation of histosols are calculated as shown in Equation A3-22.

Equation A3-22:

$$N_2O_H = A_C \times EF \times \frac{44}{28}$$

where:

N_2O_H = N_2O emissions from histosols

A_C = Total area of cultivated histosols

EF = IPCC Default emission factor
5.0 kg N_2O-N / ha.yr

Source of Activity Data

Areas of cultivated histosols at a provincial level are not covered in the Census of Agriculture, which is collected regularly at five-year intervals by Statistics Canada. In the absence of this data, consultations with numerous soil and crop specialists across Canada have been made. Based on these consultations, the total area of cultivated organic soils in Canada is 29,800 ha, and is assumed to be constant from 1990 to 2001. This data is believed to represent a close approximation of the actual area.

Direct Emissions of Nitrous Oxide from Manure on Pasture 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. Nitrous oxide emission estimates from Manure on Pasture, Range and Paddock are calculated using Equation A3-23. Note that N_2O emissions from manure on pasture and paddock are reported under Agricultural Soils, and not under Manure Management.

Equation A3-23:

$$N_2O_{MPP} = \left(N_T \times NE \times N_A\right) \times EF_3 \times \frac{44}{28}$$

where:

N_2O_{MPP} = N_2O emissions from Manure on Pasture and Paddock from Grazing Animals

N_T = Animal population (by province) (Refer to "*Methane Emissions from Enteric Fermentation*" for livestock population data sources and calculations.)

NE = Nitrogen excretion rate for each animal category. (Refer to Table A3-4.)

N_A = Fraction of nitrogen available for N_2O emissions from Manure on Pasture and Paddock. (Refer to Equation A3-24.)

EF_3 = Emissions factor, 0.02 kg N_2O-N/kg N (IPCC, 1997)

Equation A3-24:

$$N_A = N_P \times N_L$$

where:

N_P = Percentage of nitrogen produced on Pasture and Paddock by AWMS (%). (Refer to Table A3-5.)

N_L = Fraction of manure nitrogen excreted is lost as NH_3^- and NO_x – N, 0.2 kg N_2O-N/kg N (IPCC, 1997)

Indirect Emissions of Nitrous Oxide from Volatilization and Re-deposition of Nitrogen

Methodology

The IPCC Tier 1 methodology is used to estimate indirect N_2O emissions due to volatilization and re-deposition of fertilizer and manure nitrogen applied to agricultural soils. The emission calculation is shown in Equation A3-25.

Equation A3-25:

$$N_2O_{VD} = \left[\left(SF_P \times EF_{SF}\right) + \left(N_{LS} \times EF_{LS}\right)\right] EF_{VD} \times \frac{44}{28}$$

where:

N_2O_{VD} = Indirect N_2O emissions due to volatilization and re-deposition

SF_p = Provincial synthetic fertilizer consumption (all fertilizer types). (Refer to Equation A3-26.)

Equation A3-26:

$$SF_P = \sum_{Type} SF_T$$

where:

SF_T = Specific synthetic fertilizer consumption (kg N /yr) (Refer to "*Nitrous Oxide Direct Emissions from Synthetic Fertilizer*" methodology for calculation and data source.)

Equation A3-27:

$$N_{LS} = \sum_{\text{All Animal Types}} (N_T \times NE)$$

where:

N_{LS} = Total nitrogen from livestock excretion. (Refer to Equation A3-27.)

N_T = Animal population (Refer to "*Nitrous Oxide from Animal Waste Systems*" methodology for calculation and data source.)

NE = Nitrogen excretion from each specific animal types (Refer to "*Nitrous Oxide from Animal Waste Systems*" methodology for calculation and data source.)

EF_{SF} = Fraction of synthetic fertilizer nitrogen applied to soils that volatilized as NH_3 and NO_x 0.1 kg (NH_3-N + NO_x-N) / kg N (IPCC, 1997) *Assuming 10% of applied synthetic fertilizer nitrogen will be volatilized or deposited back on soil.*

EF_{LS} = Fraction of excreted livestock nitrogen that is available for volatilisation as NH_3 and NO_x 0.2 kg (NH_3-N + NO_x-N) / kg N (IPCC, 1997) *Assuming 20% of applied manure nitrogen volatilizes and re-deposits on soil.*

EF_{VD} = Emission Factor due to Volatilization 0.01 kg N_2O-N / kg N (IPCC, 1997).

Indirect Emissions of Nitrous Oxide from Leaching, Runoff and Erosion

Methodology

The IPCC Tier 1 methodology is used to estimate indirect N_2O emissions from leaching, runoff and erosion of fertilizers or manure nitrogen applied to agricultural soils.

Equation A3-28:

$$N_2O_L = F_L \times EF_L\left(SF_P + N_{LS}\right) \times \frac{44}{28}$$

N_2O_L = Indirect N_2O emissions due to leaching and runoff

F_L = Fraction nitrogen input to soils lost through leaching and runoffs
0.15 kg N / kg of fertilizer or manure nitrogen
Assuming 15% of nitrogen from synthetic fertilizer and manure are available for runoff and leaching

EF_L = Leaching/runoff emission factor
0.025 kg N_2O-N / kg N (IPCC, 1997)

SF_p = Specific provincial synthetic fertilizer consumption (all fertilizer types). (Refer to Equation A3-29.)

Equation A3-29:

$$SF_P = \sum_{Type} SF_T$$

where:

SF_T = Specific synthetic fertilizer consumption
(Refer to *"Nitrous Oxide Direct Emissions from Synthetic Fertilizer"* methodology for calculation and data source.)

N_{LS} = Total nitrogen from livestock excretion.
(Refer to Equation A3-26.)

Equation A3-30:

$$N_{LS} = \sum_{\text{All Animal Types}}(N_T \times NE)$$

where:

N_T = Animal population (all animal types)
(Refer to *"Methane Emissions from Enteric Fermentation"* methodology for calculation and data source.)

NE = Nitrogen excretion from each specific animal type
(Refer to *"Nitrous Oxide from Animal Waste Management Systems"* methodology for calculation and data source.)

Fraction of Synthetic Fertilizer and Manure Nitrogen Leached

The current IPCC Tier 1 methodology estimates assume that 30% of the nitrogen applied as synthetic fertilizer or manure is lost by leaching or runoff. This amount is then multiplied by 0.025 kg N_2O-N / kg N leaching/runoff to obtain an emission estimate (IPCC, 1997).

In Canada, leaching losses of nitrogen vary widely among regions. High nitrogen inputs in humid conditions may lead to greater than 100 kg N $ha^{-1}yr^{-1}$ 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 agro-ecosystems. In Ontario, Goss and Goorahoo (1995) predicted leaching losses of 0 to 37 kg N ha^{-1}, accounting for 0 to 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 nitrogen inputs. 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 N leaching in non-irrigated, heavily-manured plots despite large accumulations of soil nitrate in the soil profile. In the prairie provinces of western Canada, which account for more than 80% of fertilizer inputs and agricultural land in Canada, potential evaporation exceeds precipitation by a large margin (Reynolds et al., 1995). Leaching losses in Canada are probably lower than in many other countries with intensive agriculture. Thus, IPCC default leaching losses of 30% were reduced to 15% to reflect Canadian climatic conditions.

ANNEX 4: COMPARISON OF SECTORAL AND REFERENCE APPROACHES

This annex provides a description of the quality assurance/quality control (QA/QC) and verification procedures used in the preparation of the greenhouse gas (GHG) inventory. Reference approaches and expert reviews were used as the primary means to ensure the quality of the inventory.

REFERENCE APPROACH METHODOLOGY

GENERAL

For the most part, the IPCC-designated methods are followed for this evaluation. Fuel quantities are recorded from the *Quarterly Report on Energy Supply-Demand* (QRESD) and entered in their natural units (typically megalitres, thousands of cubic metres, kilotonnes, and gigalitres). Apparent consumption is determined and, when necessary, the conversion factor (TJ/unit) is derived using the IPCC default (IPCC, 1997), NHV values (TJ/kt), and the fuel-specific density (specific gravity). Since the IPCC values are presented in NHV units, this conversion circumvents the national protocol of reporting energy in GHV.

CRUDE OIL

The value listed as "crude oil production" has been adjusted to include the inter-product transfer that would account for crude oil consumed to supply still gas in the oil sand and bitumen upgraders. Producer-consumed upgrader petroleum is not accounted for in marketable production statistics because synthetic crude oil production statistics are based on marketable volumes of crude produced, not on volumes of bitumen extracted.

NATURAL GAS LIQUIDS (NGLS)

NGLs are accommodated by representing them as a virtual composite mixture of ethane, propane, and butane. Dependent upon the annual proportions, a specific gravity and carbon emission factor (tC/TJ) for that year is generated using IPCC default values and, hence, maintains the requested NHV dimensions.

GASOLINE

This category is a combination of *motor gasoline* and *aviation gasoline,* with the former dominating the total.

LIQUEFIED PETROLEUM GAS (LPG)

LPG includes *stored carbon due to butane* to account for the lack of consistency between LPG segregation in the stored carbon worksheet – Table 1-A(d) of the CRF – and that in the sectoral reference approach – Table 1-A(b) of the CRF.

REFINERY FEEDSTOCK

The TJ/unit conversion factor is derived using IPCC factors, Canada-specific NHV for Organisation for Economic Co-operation and Development (OECD) countries, and the specific gravity of the feedstocks.

OTHER OILS

This category includes stored carbon due to other products from Table 1-A(d) of the CRF.

NATURAL GAS

The value listed as "natural gas production" in the QRESD 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). The energy conversion factor is dependent upon the GHV value from the QRESD for natural gas for that specific year and is discounted, according to IPCC/OECD/IEA (2000), to accommodate the difference between GHV and NHV.

BIOMASS

Solid biomass includes Canadian industrial and residential sources, whereas liquid biomass addresses spent pulping liquor. All calculations are made using default IPCC values for the conversion factors.

ANNEX 5: ASSESSMENT OF COMPLETENESS

Although this inventory report serves as a comprehensive assessment of anthropogenic GHG emissions and removals in Canada, some sources have not been included. It is important to note that these missing sources are minor, and the overall inventory is complete and unbiased. As discussed in Section 1.6, ozone precursors and SO_2 have not been reported for all categories.

ENERGY

Overall, the Energy section of the national inventory provides a full estimate of all significant sources. The following section lists sources which are not currently estimated and which may represent a source in their particular sector, but which do not affect the overall completeness of the inventory due to their relatively small contribution.

FUEL COMBUSTION

Emissions from the combustion of waste fuels (such as tires, solvents, etc.) for the production of energy at industrial facilities (such as 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 there is no double counting of GHG emissions from the non-energy use of fossil fuels (reported under the industrial process category). Where IPCC default factors are currently applied, it is assumed that these account for GHG emissions from the non-energy use of fossil fuels and disposal of its products (such as tires used as waste fuels by the cement production industry).

FUGITIVE EMISSIONS

Flaring and fugitive emissions from industrial facilities such as petroleum refineries, chemical plants and metallurgical coke production are not accounted for (fugitive emissions from oil and gas production facilities are inventoried). An appropriate data collection mechanism and emission estimation methodology has not yet been identified for this source of emissions.

INDUSTRIAL PROCESSES

Overall, the Industrial Processes portion of the national inventory provides a full estimate of all significant sources. The following section lists sources which are not currently estimated and which may represent a source in their particular sector, but which do not affect the overall completeness of the inventory.

MINERAL PRODUCTS

CO_2 emissions attributed to limestone use in the pulp and paper industry are not currently inventoried. New data sources are being evaluated for this emission source. Furthermore, emissions from asphalt roofing, road paving with asphalt, and glass production (other than limestone-use emissions) are not estimated and are thought to be negligible.

CHEMICAL PRODUCTION

N_2O emissions associated with the production of chemicals other than nitric and adipic acid are not estimated. Production of chemicals other than nitric acid and adipic acid may be sources of N_2O, however more research is required to determine their significance.

Similarly, there is insufficient data available to estimate CH_4 emissions from chemical manufacturing processes in Canada, though they are thought to be insignificant.

METAL PRODUCTION

SF_6 emissions attributed to its use as a cover gas in magnesium casting operations are currently not inventoried. An appropriate data collection method for this source has not been established.

CH_4 emissions associated with the production of metals are not estimated and are thought to be significant.

PRODUCTION AND CONSUMPTION OF SF_6

SF_6 emissions attributed to its use as an insulating gas in electrical equipment are not currently inventoried. As discussed in Section 4.9.1, future improvements will concentrate on developing an effective methodology for estimating SF_6 emissions from the use of SF_6 in electrical equipment.

SOLVENT AND OTHER PRODUCT USE

This category is complete.

AGRICULTURE

Overall, the Agriculture section of the national inventory provides a complete estimate of the significant sources. The following list includes the sources that are not currently estimated. Most of these are considered to be minor sources, with the exception of grassland management, which is a potentially significant sink.

ENTERIC FERMENTATION AND MANURE MANAGEMENT

Some smaller animal categories, such as domestic bison, deer, and elk have not yet been included. Due to their relatively low populations, these are considered to be minor sources.

RESIDUE BURNING

Residue burning is practised to a small extent in Canada. Flax residue, for example, is generally burned. This is considered to be a minor source of emissions. An appropriate data collection method for this source has not been established.

RICE PRODUCTION

Methane emissions from rice production are not currently inventoried as rice production is quite small in Canada. An appropriate data collection method for this source has not been established.

CULTIVATION OF MINERAL SOILS

Methane emissions or removals from mineral soils are not currently inventoried as the processes related to CH_4 fluxes in soils are not fully understood.

Sewage and industrial sludge application on agricultural soils is also not included. The appropriate data collection methods for these sludges have not been established.

CULTIVATION OF ORGANIC SOILS

For the same reason cited for mineral soils, methane emissions or removals from organic soils are not currently inventoried as the processes related to CH_4 fluxes in soils are not fully understood.

GRASSLAND MANAGEMENT

Canada's current CO_2 inventory focuses on cropland management. With the exception of manure application on pasture and paddock, GHG emissions and removals associated with practices on pasture or grassland have not been inventoried. The appropriate data collection and accounting methods have not yet been established.

SHELTERBELTS

Forest growth in the form of shelterbelts is not currently inventoried, although farm woodlots are included in the Land Use Change and Forestry section. An appropriate data collection method for this sink has not been established.

GREENHOUSE PRODUCTION

Non-energy GHG emissions from greenhouse operations are not currently inventoried. An appropriate data collection method for this source has not been established.

LAND-USE CHANGE AND FORESTRY

FORESTS

Currently, only CO_2 removals associated with above-ground biomass of managed forests are included in the inventory; harvesting residues (slash) are assumed to be immediately released as a CO_2 emission in the year of harvest (i.e. no carbon is transferred to the dead organic matter soil pools). For completeness, the CO_2 exchanges with the other forest pools should be estimated. Practicable data collection and accounting methods for these source/sinks have not been established.

With the exception of emissions from fire, CH_4 and N_2O emissions associated with the managed forest are not currently inventoried. Practicable data collection and accounting methods for these source/sinks have not been established.

LAND-USE CHANGE

Non-CO_2 Estimates for Forest and Grassland Conversion

The CH_4 and N_2O emissions associated with forest and grassland conversion are not currently inventoried because there is insufficient information on how much biomass is lost by burning, decay, etc. Practicable data collection methods for these source/sinks have not been established.

Comprehensive Coverage of Land-Use Changes

Not all types of land-use changes are currently inventoried. Practicable data collection and accounting methods for these sources/sinks have not been established. The IPCC Good Practice Guidance for LULUCF is expected to provide new guidance for inventorying these sources/sinks.

WASTE

This category, is for the most part, complete with the exception of the following:

INDUSTRIAL WASTE WATER TREATMENT SYSTEMS

An appropriate data collection mechanism has not been identified for this source of emissions.

WASTE INCINERATION

Emissions of methane from MSW incineration and emissions of nitrous oxide from sewage sludge are not estimated due to lack of underlying emission research.

ANNEX 6: METHODOLOGIES FOR ADDITIONAL ASSESSMENTS

ESTIMATION OF CARBON STORED IN HARVEST WOOD PRODUCTS

In addition to the current IPCC default approach, Section 7.1.2 outlined three alternative methods for carbon accounting in harvested wood products: stock-change, production, and atmospheric flow. Although these approaches yield the same net carbon exchange to the atmosphere on a global level, they differ on a national level in the way they account for the time and place of emissions releases.

CURRENT APPROACH: REVISED 1996 IPCC GUIDELINES FOR NATIONAL GREENHOUSE GAS INVENTORIES

In the *Revised 1996 Guidelines for National Greenhouse Gas Inventories* (IPCC, 1997), henceforth denoted as the IPCC default approach, only the net changes in forest carbon stocks are 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. The net change in carbon stocks retained in wood products is not considered.

Change in C stocks = stock change in the forest = forest growth – slash – firewood and charcoal – industrial roundwood production

ALTERNATE APPROACH: STOCK-CHANGE

The stock-change approach accounts for the changes in carbon stocks in two pools: the forest reservoir and the long-lived wood products[41] reservoir. Changes in forest carbon stocks are accounted for in the country in which the wood is grown, referred to as the producing country. Changes in the long-lived wood products pool are accounted for in the country where the products are used and disposed of, referred to as the consuming country.

Change in C stocks = (stock change in the forest) + (stock change in long-lived wood products consumed domestically) = (forest growth – slash – firewood and charcoal – industrial roundwood harvest) + (long-lived commodity consumption – inherited emissions of commodities consumed domestically)

Note that in the above equation, commodity consumption equals production plus imports minus exports.

ALTERNATE APPROACH: PRODUCTION

The production approach accounts for the changes in C stocks in the forest and long-lived wood products pool. It differs from the stock-change approach in that it attributes changes in both pools to the producing country. This approach uses inventories of domestically produced stocks only.

Change in C stocks = (stock change in the forest) + (stock change in long-lived commodities produced domestically) = (forest growth – slash – firewood and charcoal – industrial roundwood harvest) + (long-lived wood commodity production – inherited emissions from commodities produced domestically)

ALTERNATE APPROACH: ATMOSPHERIC FLOW

The atmospheric flow approach estimates the *flows* of carbon to and from the atmosphere within national boundaries. Removals of C from the atmosphere due to forest growth are accounted for in the producing country, while emissions of C to the atmosphere from the oxidation of wood products consumed domestically are accounted for in the consuming country.

Atmospheric carbon flow = forest growth – slash – consumption of (firewood and charcoal + short-lived commodities + bioenergy + other waste) + inherited emissions from the consumption of long-lived wood commodities

For Canada, gross harvest emissions (i.e. not including forest regrowth) in 2000 vary from 160 Mt CO_2 (atmospheric flow) to 250 Mt CO_2 (IPCC default), depending on the approach selected. It should be noted that these estimates would differ if other forest carbon pools, besides the above ground forest biomass carbon pool, were included.

As indicated in Section 7.1.2 of this report, once the IPCC report on Good Practice Guidance for the LUCF sector is complete, it will further elaborate the details of each approach and formalise the respective methodologies.

41 Long-lived wood commodities are defined here as products that have a lifespan of five years or more. Conversely, short-lived wood commodities are defined here as products that have a lifespan of less than five years.

ANNEX 7: EMISSION FACTORS

This section summarises the development and selection of emission factors used to prepare the national greenhouse gas (GHG) inventory.

FUEL COMBUSTION

NATURAL GAS AND NATURAL GAS LIQUIDS (STATIONARY SOURCES)

Carbon Dioxide

Carbon dioxide (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 fuels combusted in Canada: marketable fuel (processed), and non-marketable fuel (unprocessed). Emission factors have been developed for these two categories (Table A7-1) based on data from the chemical analysis of representative natural gas samples (McCann, 2000) and an assumed fuel combustion efficiency of 99.5% (IPCC, 1997). The emission factor for marketable fuel matches closely with previous factors based on energy contents reported in the *Quarterly Report on Energy Supply-Demand* (QRESD) (Jaques, 1992). The factor for non-marketable natural gas is higher than that for marketable fuels due to its raw nature, which results in higher levels of natural gas liquids (NGLs) in the fuel.

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, 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.

Methane

Emissions of methane (CH_4) from fuel combustion are technology dependent. Sectoral emission factors (Table A7-1) have been developed based on technologies typically used in Canada. The factors were developed based on a review of emission factors for combustion technologies and an analysis of combustion technologies (SGA, 2000). The emission factor for the producer consumption of natural gas was developed based on a technology split for the upstream oil and gas industry (Picard and Ross, 1999) and technology-specific emission factors from the AP 42 (EPA, 1996).

Nitrous Oxide

Emissions of nitrous oxide (N_2O) from fuel combustion are technology dependent. Emission factors for sectors (Table A7-1) have been developed based on technologies typically used in Canada. The factors were developed from a review of emission factors for combustion technologies and an analysis of combustion technologies (SGA, 2000).

TABLE A7-1: Natural Gas and Natural Gas Liquids (Energy Stationary Combustion Sources)

	CO_2	CH_4	N_2O
Natural Gas	**g/m^3**	**g/m^3**	**g/m^3**
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]	0.033 [2]
Pipelines	1891 [1]	1.9 [2]	0.05 [2]
Residential, Commercial, Agriculture	1891 [1]	0.037 [2]	0.035 [2]
Natural Gas Liquids	**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]

1 Adapted from McCann, T.J. (2000), *1998 Fossil Fuel and Derivative Factors,* prepared for Environment Canada, March.

2 SGA (2000), *Emission Factors and Uncertainties for CH_4 & N_2O from Fuel Combustion,* SGA Energy Limited, August.

3 EPA (1996), *Compilation of Air Pollutant Emission Factors, Vol. 1, Stationary Point and Area Sources,* 5th Edition, U.S. Environmental Protection Agency, AP-42.

4 CAPP (1999), *CH_4 and VOC Emissions from Upstream Oil and Gas Operations in Canada, Vol. 2,* Canadian Association of Petroleum Producers, CAPP Publication No. 1999–0010.

REFINED PETROLEUM PRODUCTS (STATIONARY COMBUSTION SOURCES)

Carbon Dioxide

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 A7-2) based on standard fuel properties and an assumed fuel combustion efficiency of 99.0% (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 from industry on a mass basis and were converted to a volumetric basis for comparability with the national energy data using the density of coke used by Statistics Canada (QRESD).

Methane

Emissions of CH_4 from fuel combustion are technology dependent. Emission factors for sectors have been developed (Table A7-2) based on technologies typically used in Canada. The factors were developed from a review of emission factors for combustion technologies 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) could not be found, so it was assumed to be similar to that of natural gas combustion in industry.

Nitrous Oxide

Emissions of N_2O from fuel combustion are technology dependent. Emission factors for sectors have been developed (Table A7-2) based on technologies typically used in Canada. The factors were developed from a review of emission factors for combustion technologies 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 use in industry.

TABLE A7-2: Refined Petroleum Products (Energy Stationary Combustion Sources)

	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]	0.037 [2]	0.002 [2]

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

2 SGA (2000), *Emission Factors and Uncertainties for CH_4 & N_2O from Fuel Combustion,* SGA Energy Limited, August.

3 Nyboer, J. (1996), Personal communication with P. Boileau, Greenhouse Gas Division, Environment Canada, January.

COAL AND COAL PRODUCTS (STATIONARY COMBUSTION SOURCES)

Carbon Dioxide

CO_2 emission factors for coal combustion are dependent on the properties of the fuel and, to a lesser extent, the combustion technology.

TABLE A7-3: Coal and Coal Products (Energy Stationary Combustion Sources): Carbon Dioxide

Coals	1990–1994	1995–2000
Nova Scotia	**g/kg**	**g/kg**
Canadian Bituminous	2300 [1]	2249 [2]
U.S. Bituminous	2330 [1]	2288 [2]
New Brunswick	**g/kg**	**g/kg**
Canadian Bituminous	2230 [1]	1996 [2]
U.S. Bituminous	2500 [1]	2311 [2]
Quebec	**g/kg**	**g/kg**
U.S. Bituminous	2500 [1]	2343 [2]
Anthracite	2390 [1]	2390 [1]
Ontario	**g/kg**	**g/kg**
Canadian Bituminous	2520 [1]	2254 [2]
U.S. Bituminous	2500 [1]	2432 [2]
Sub-Bituminous[3]	2520 [1]	1733 [2]
Lignite	1490 [1]	1476 [2]
Anthracite	2390 [1]	2390 [1]
Manitoba	**g/kg**	**g/kg**
Canadian Bituminous	2520 [1]	2252 [2]
Sub-Bituminous	2520 [1]	1733 [2]
Lignite	1520 [1]	1424 [2]
Saskatchewan	**g/kg**	**g/kg**
Lignite	1340 [1]	1427 [2]
Alberta	**g/kg**	**g/kg**
Canadian Bituminous	1700 [1]	1852 [2]
Sub-Bituminous[3]	1740 [1]	1765 [2]
Anthracite	2390 [1]	2390 [1]
British Columbia	**g/kg**	**g/kg**
Canadian Bituminous	1700 [1]	2072 [2]
All Provinces	**g/kg**	**g/kg**
Metallurgical Coke	2480 [1]	2480 [1]
	g/m^3	**g/m^3**
Coke Oven Gas	1600 [1]	1600 [1]

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

2 Adapted from McCann, T.J. (2000), *1998 Fossil Fuel and Derivative Factors,* prepared for Environment Canada by T.J. McCann and Associates, March.

3 Represents both domestic and imported sub-bituminous.

Coal emission factors (Table A7-3) 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 period 1990–1994 are based on supply and quality data from 1988 (Jaques, 1992). For 1995 to the present, factors are based on 1998 coal quality and supply (McCann, 2000).

Coke and coke oven gas emission factors were developed based on industry data (Jaques, 1992).

Methane

Emissions of CH_4 from fuel combustion are technology dependent. Emission factors for sectors (Table A7-4) have been developed based on technologies typically used in Canada. The factors were developed from a review of emission factors for combustion technologies and an analysis of combustion technologies (SGA, 2000).

Nitrous Oxide

Emissions of N_2O from fuel combustion are technology dependent. Emission factors for sectors (Table A7-4) have been developed based on technologies typically used in Canada. The factors were developed from a review of emission factors for combustion technologies and an analysis of technologies (SGA, 2000).

TABLE A7-4: Methane and Nitrous Oxide Emission Factors for Coals

All Coals	CH_4 g/kg	N_2O g/kg
Electric Utilities	0.022 [2]	0.032 [2]
Industry	0.003 [2]	0.02 [2]
Residential	4 [2]	0.02 [2]
Metallurgical Coke	0.03 [2]	0.02 [2]
	g/m^3	**g/m^3**
Coke Oven Gas	0.037 [2]	0.035 [2]

2 SGA Energy Limited, Emission Factors and Uncertainties for CH_4 and N_2O from fuel combustion, August 2000.

TABLE A7-5: Energy Mobile Combustion Sources

Use	CO_2 g/L fuel	CH_4 g/L fuel	N_2O g/L fuel
On-Road Transport			
Gasoline			
Light-Duty Gasoline Automobiles (LDGA)			
- 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 (LDGT)			
- 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 (HDGV)			
- 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			
Light-Duty Diesel Automobiles (LDDA)			
- 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 (LDDT)			
- 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 (HDDV)			
- 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]	6.0E-05 [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]

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

2 SGA (2000), *Emission Factors and Uncertainties for CH_4 & N_2O from Fuel Combustion,* SGA Energy Limited, August.

3 Adapted from McCann, T.J. (2000), *1998 Fossil Fuel and Derivative Factors,* prepared for Environment Canada, March.

MOBILE COMBUSTION

Carbon Dioxide

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 A7-5).

Methane

Emissions of CH_4 from fuel combustion are technology dependent. Emission factors for sectors have been developed (Table A7-5) based on technologies typically used in Canada. The factors were developed from a review of emission factors for combustion technologies and an analysis of combustion technologies (SGA, 2000).

Nitrous Oxide

Emissions of N_2O from fuel combustion are technology dependent. Emission factors for sectors have been developed (Table A7-5) based on technologies typically used in Canada. The factors were developed from a review of emission factors for combustion technologies and an analysis of technologies (SGA, 2000).

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 the coal formation during mining. The emission factors have been developed (Table A7-6) based on mine-specific and basin-specific data (King, 1994). The development of the factors is described in the Fugitive Emissions section of the inventory report.

TABLE A7-6: Fugitive Sources – Coal Mining

Province	Method	Coal Type	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, B. (1994), *Management of Methane Emissions from Coal Mines: Environmental, Engineering, Economic and Institutional Implication of Options*, Neil and Gunter Ltd., Halifax, March 1994.

INDUSTRIAL PROCESSES

Emissions from industrial processes are process and technology specific. The development of the factors for each source (Table A7-7) is described in detail in the Industrial Processes section of the inventory report.

TABLE A7-7: Industrial Process Sources

Source	Description	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	440	–	–	–
Soda Ash Use	In Glass Manufacture	415	–	–	–
Mineral Products			**g/kg product**		
Cement Production	Limestone Calcination	500	–	–	–
Lime Production	Limestone Calcination	790	–	–	–
Chemical Industry			**kg/t product**		
Ammonia Production	From Natural Gas	1600	–		–
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/kg product**		
Primary Aluminium	Electrolysis Process	(1.54–1.83)	–	(0.3–1.1)	(0.02–0.1)
			g/kg feed (coke)		
Iron and Steel Production		2480	–	–	–

Sources:

CO_2 Emission Factors:

Limestone Use – ORTECH Corporation (1994), *Inventory Methods Manual for Estimating Canadian Emissions of Greenhouse Gases,* report to Environment Canada, April.

Soda Ash Use – DOE/EIA (1993), *Emission of Greenhouse Gases in the United States, 1985–1990,* Department of Energy/Energy Information Administration, Washington, D.C., Report No. 0573.

Lime Production – ORTECH Corporation (1991), *Compilation of an Ontario Gridded Carbon Dioxide and Nitrous Oxide Emissions Inventory,* prepared for the Ontario Ministry of the Environment, P-91-50-6436/OG.

Cement Production – Orchard, D.F. (1973), *Concrete Technology, Vol. 1,* Applied Science Publisher Ltd., London, U.K.; Jaques, A. (1992), *Canada's Greenhouse Gas Emissions: Estimates for 1990,* Environmental Protection, Conservation and Protection, Environment Canada, EPS 5/AP/4, December.

Ammonia Production – Faith, W.L., D.B. Keyes, and R.L. Clark (eds.) (1975), *Industrial Chemicals,* 4th Edition, Wiley and Sons, New York, NY; Jaques, A. (1992), *Canada's Greenhouse Gas Emissions: Estimates for 1990,* Environmental Protection, Conservation and Protection, Environment Canada, EPS 5/AP/4, December.

Primary Aluminium – ORTECH Corporation (1994), *Inventory Methods Manual for Estimating Canadian Emissions of Greenhouse Gases,* report to Environment Canada, April. (emission factors vary with technology used).

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

N_2O Emission Factors:

Adipic Acid Production – Thiemens, M.C. and U.C. Trogler (1991), Nylon production: An unknown source of nitrous oxide, Science, 251: 932–934.

CF_4, C_2F_6 Emission Factors:

Primary Aluminium Production – Unisearch Associates (1994), *Measurements of CF_4 and C_2F_6 in the Emissions from Canadian Aluminium Smelters by Tunable Diode Absorption Laser Spectroscopy,* report to the Canadian Aluminium Association, April, adapted by Environment Canada.

NON-ENERGY USE OF FOSSIL FUELS

Carbon Dioxide

The use of fossil fuels as feedstocks or for other non-energy uses may result in emissions during the life of manufactured products. These emissions are process and technology specific. General emission rates have been developed based on life-cycle analysis of the processes and products where these fuels are used as feedstocks. Industry-average factors have been developed based on IPCC default emission rates (IPCC, 1997) and the carbon content of Canadian fuels (McCann, 2000). The factors are presented on a gram CO_2 per unit of fossil fuel used as feedstock or non-energy product basis (Table A7-8).

TABLE A7-8: Hydrocarbon Non-Energy Products

Description	CO_2
	g/L feedstock
Ethane Use	197
Ethane Use	197
Butane Use	349
Propane Use	303
Petrochemical Distillate Use for Feedstocks	500
Naptha Used for Various Products	625
Petroleums Used for Lubricants	1410
Petroleums Used for Other Products	1450
	g/m^3
Natural Gas Use for Chemical Products	1267

Sources:

IPCC (1997), *Greenhouse Gas Inventory Reporting Instructions, Vol. 1;* and *Greenhouse Gas Inventory Reference Manual, Vol. 3,* Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Intergovernmental Panel on Climate Change, Bracknell, U.K.

McCann, T.J. (2000), *1998 Fossil Fuel and Derivative Factors,* prepared for Environment Canada by T.J. McCann and Associates, March.

SOLVENT AND OTHER PRODUCT USE

The emissions resulting from the use of solvents or products are process and technology specific. The emission factor development (Table A7-9) is described in the Solvent and Other Product Use section of Chapter 5.

TABLE A7-9: Solvent and Other Product Emission Factors

Product	Application	N_2O g/capita	HFCs kg loss/kg consumed
NO_2 Use	Anaesthetic Usage	46.2	
	Propellant Usage	2.38	
HFC Use	Aerosols		1
	Foams		0.04
	AC OEM		1
	AC Service		0.1
	Refrigeration		0.35
	Total Flooding Systems		0.35

Sources:

N_2O Emission Factors: Anaesthetic Usage – Fettes, W. (1994), Communication between Senes Consultants and Puitan Bennet, February.

HFC Emission Factors: IPCC (1997), *Greenhouse Gas Inventory Reporting Instructions, Vol. 1;* and Greenhouse Gas Inventory Reference Manual, Vol. 3, Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Intergovernmental Panel on Climate Change, Bracknell, U.K.

AGRICULTURE

Emissions from agriculture result from enteric fermentation, land management, and manure management. Methodologies for generating these emission estimates (Table A7-10 to Table A7-15) are detailed in the Agriculture section of Annex 7.

TABLE A7-10: Methane Emission Factors for Livestock and Manure[1]

Animal Types	Enteric Fermentation kg CH_4/head/year	Manure Management kg CH_4/head/year
Cattle		
Bulls	75 [2]	1
Dairy Cows	118	36
Beef Cows	72 [2]	1
Dairy Heifers	56 [2]	36
Beef Heifers	56 [2]	1
Heifers for Slaughter	47	1
Steers	47	1
Calves	47	1
Pigs		
Swine	1.5	10
Other Livestock		
Sheep	8	0.19
Goats	8	0.12
Horses	13	1.4
Poultry		
Chickens	Not Estimated	0.078
Hens	Not Estimated	0.078
Turkeys	Not Estimated	0.078

1 Unless specified, sources of emission factors are from IPCC (1997), *Greenhouse Gas Inventory Reporting Instructions, Vol. 1;* and *Greenhouse Gas Inventory Reference Manual, Vol. 3,* Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Intergovernmental Panel on Climate Change, Bracknell, U.K.

2 Sources of emission factors are country specific.

TABLE A7-11: Nitrogen Excretion for Each Specific Animal Type[1]

Animal Type	Nitrogen Excretion kg N/head per year
Non-Dairy Cattle	44.7
Dairy Cattle	105.2
Poultry	0.36
Sheep and Lambs	4.1
Swine	11.6
Other (Goats and Horses)	49.3

1 ASAE (1999), *Manure Production and Characteristics in ASAE Standards 1999,* 46th Edition, Standards Engineering Practices Data, The Society for Engineering in Agricultural, Food, and Biological Systems, American Society of Agricultural Engineers, pp. 663–665.

TABLE A7-12: Percentage of Manure Nitrogen Produced by Animal Waste Management Systems in North America[1]

Animal Type	Liquid Systems	Solid Storage and Drylot	Other Systems	Pasture Range and Paddock
Non-Dairy Cattle	1	56	1	42
Dairy Cattle	53	27	0	20
Poultry	4	0	95	1
Sheep and Lambs	0	46	10	44
Swine	90	10	0	0
Other (Goats and Horses)	0	46	8	46

1 Expert opinion (Ray Desjardins, 1997, Agriculture and Agri-Food Canada).

TABLE A7-13: Percentage of Manure Nitrogen Lost as N_2O for Specific Animal Waste Manure Management Systems[1]

Animal Type	Liquid Systems	Solid Storage and Drylot	Other Systems	Pasture Range and Paddock
Non-Dairy Cattle	0.1	2.0	0.5	2.0
Dairy Cattle	0.1	2.0	0.5	2.0
Poultry	0.1	2.0	0.5	2.0
Sheep and Lambs	0.1	2.0	0.5	2.0
Swine	0.1	2.0	0.5	2.0
Other (Goats and Horses)	0.1	2.0	0.5	2.0

1 IPCC (1997), *Greenhouse Gas Inventory Reporting Instructions, Vol. 1;* and *Greenhouse Gas Inventory Reference Manual, Vol. 3,* Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Intergovernmental Panel on Climate Change, Bracknell, U.K.

TABLE A7-14: Dry Matter Fraction of Various Crops[1]

Specific Crop Type	Dry Matter Fraction
Wheat	0.86
Barley	0.86
Corn	0.86
Oats	0.86
Rye	0.86
Mixed Grains	0.86
Flaxseed	0.86
Canola	0.86
Buckwheat	0.86
Mustard Seed	0.86
Sunflower Seed	0.86
Canary Seed	0.86
Tame Hay	0.86
Fodder Corn	0.30[2]
Sugar Beets	0.20[2]
Dry Peas	0.86
Soya Beans	0.86
Lentils	0.86
Field Beans	0.86
Potatoes	0.25[2]

1 Unless specified, data are from IPCC (1997), *Greenhouse Gas Inventory Reporting Instructions, Vol. 1;* and *Greenhouse Gas Inventory Reference Manual, Vol. 3,* Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Intergovernmental Panel on Climate Change, Bracknell, U.K.

2 Sources of data are expert opinion.

TABLE A7-15: IPCC Default Emission Factors and Parameters[1]

Emission Process	Emission Factors
Synthetic Fertilizer Nitrogen	0.0125 kg N_2O-N/kg N
Biological Nitrogen Fixation	0.0125 kg N_2O-N/kg N
Animal Waste Applied as Fertilizers	0.0125 kg N_2O-N/kg N
Crop Residue Decomposition	0.0125 kg N_2O-N/kg N
Cultivation of Histosols	5 kg N_2O-N/ha per year
Volatilization and Redeposition of Nitrogen	0.01 kg N_2O-N/kg N
Leaching and Runoff of Nitrogen	0.025 kg N_2O-N/kg N
	Parameters
Fraction of Fertilizer Nitrogen Available to Volatilization as NH_3 and NO_x	0.1 kg N/kg N
Fraction of Manure Nitrogen Available to Volatilization as NH_3 and NO_x	0.2 kg N/kg N
Fraction of Manure and Fertilizer Nitrogen Available to Leaching and Runoff	0.15 kg N/kg N[2]
Fraction of Nitrogen Contained in Legume Crops	0.03 kg N/kg dry mass
Fraction of Nitrogen Contained in Non-Legume Crops	0.015 kg N/kg dry mass
Fraction of Tame Hay Assumed to Be Alfalfa	0.60[2]

1 Unless specified, emission factors or parameters are from IPCC (1997), *Greenhouse Gas Inventory Reporting Instructions, Vol. 1;* and *Greenhouse Gas Inventory Reference Manual, Vol. 3,* Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Intergovernmental Panel on Climate Change, Bracknell, U.K.

2 Sources of parameters are country specific.

BIOMASS COMBUSTION

Carbon Dioxide

Emissions of CO_2 from the combustion of biomass (whether for energy use, from prescribed burning, or from wildfires of human origin) are not included in national inventory totals. These emissions are estimated and recorded as a loss of biomass stock in the Land-Use Change and Forestry section.

The emissions related to energy use are reported as memo items in the Common Reporting Format (CRF) as required by the United Nations Framework Convention on Climate Change (UNFCCC). Emissions from this source are primarily dependent on the characteristics of the fuel being combusted. The methodology for deriving the emission factors (Table A7-16) is described in the Biomass Combustion section of the inventory report.

CO_2 emissions from prescribed burning are included in the emissions from the on-site, natural decay of post-harvest residues (slash). The carbon emitted as CO_2 during forest fires is considered as a reduction in the carbon sequestration rate.

Methane

Emissions of CH_4 from fuel combustion are technology dependent. The emission factors (Table A7-16) 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).

CH_4 emissions from prescribed burns and wildfires are obtained from the estimated average fuel consumptions (kt biomass/ha) and the emission factors (g/kg biomass consumed). Emission factors for both prescribed burns and wildfires were taken from Taylor and Sherman (1996).

Nitrous Oxide

Emissions of N_2O from fuel combustion are technology dependent. The emission factors (Table A7-16) 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 prescribed burns and wildfires are obtained from the estimated average fuel consumptions (kt biomass/ha) and the emission factors (g/kg biomass consumed). Emission factors for both prescribed burns and wildfires were taken from Taylor and Sherman (1996).

TABLE A7-16: Biomass Emission Factors

Source	Description	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
Accidental Forest Fires	Open Combustion	1630	3	1.75
Prescribed Burns	Open Combustion	1620	6.2	1.3
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

Note: CO_2 emission from biomass sources are not included in inventory totals. CH_4 and N_2O emissions are inventoried under Energy, except for accidental forest fires and prescribed burns, which are reported under Land-Use Change and Forestry.

Sources:

CO_2 Emission Factors:

Wood Fuel/Wood Waste – EPA (1996), *Compilation of Air Pollutant Emission Factors, Vol. 1, Stationary Point and Area Sources,* 5th Edition, U.S. Environmental Protection Agency, AP-42.

Accidental Forest Fires and Prescribed Burns – Taylor, S.W. and K.L. Sherman (1996), *Biomass Consumption and Smoke Emissions from Contemporary and Prehistoric Wildland Fires in British Columbia,* prepared by the Pacific Forestry Centre, Canadian Forest Service, Natural Resources Canada, FRDA Report 249, March.

CH_4 Emission Factors:

Wood Fuel/Wood Waste – EPA (1985), *Compilation of Air Pollutant Emission Factors, Vol. 1, Stationary Point and Area Sources,* 4th Edition, U.S. Environmental Protection Agency, AP-42.

Accidental Forest Fires and Prescribed Burns – Taylor, S.W. and K.L. Sherman (1996), *Biomass Consumption and Smoke Emissions from Contemporary and Prehistoric Wildland Fires in British Columbia,* prepared by the Pacific Forestry Centre, Canadian Forest Service, Natural Resources Canada, FRDA Report 249, March.

N_2O Emission Factors:

Wood Fuel/Wood Waste – Rosland, A. and M. Steen (1990), *Klimgass-Regnshap For Norge,* Statens Forurensningstilsyn, Oslo, Norway.

Radke, L.F., D.A. Hegg, P.V. Hobbs, J.D. Nance, J.H. Lyons, K.K. Laursen, R.E. Weiss, P.J. Riggan, and D.E. Ward (1991), Particulate and trace gas emissions from large biomass fires in North America, in *Global Biomass Burning: Atmospheric Climatic and Biospheric Implications,* J.S. Levine (ed.), Massachusetts Institute of Technology, Cambridge, Massachusetts.

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Nyboer, J. (1996), Personal communication with P. Boileau, Greenhouse Gas Division, Environment Canada, January.

Orchard, D.F. (1973), *Concrete Technology, Vol. 1,* Applied Science Publisher Ltd., London, U.K.

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Rosland, A. and M. Steen (1990), *Klimgass-Regnshap For Norge,* Statens Forurensningstilsyn, Oslo, Norway.

SGA (2000), *Emission Factors and Uncertainties for CH_4 & N_2O from Fuel Combustion,* SGA Energy Limited, August.

Statistics Canada, *Quarterly Report on Energy Supply-Demand in Canada* (QRESD), Catalogue No. 57-003.

Taylor, S.W. and K.L. Sherman (1996), *Biomass Consumption and Smoke Emissions from Contemporary and Prehistoric Wildland Fires in British Columbia,* prepared by the Pacific Forestry Centre, Canadian Forest Service, Natural Resources Canada, FRDA Report 249, March.

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Unisearch Associates (1994), *Measurements of CF_4 and C_2F_6 in the Emissions from Canadian Aluminium Smelters by Tunable Diode Absorption Laser Spectroscopy,* report to the Canadian Aluminium Association, April.

ANNEX 8: ANALYSIS OF EMISSION TRENDS FOR CANADIAN INDUSTRIAL SECTORS

INTRODUCTION

This annex discusses and identifies, where available, short-term (2000–2001) and long-term (1990–2001) greenhouse gas emission and GDP trends identified for a series of Canadian industrial sectors. This analysis is unique from any presented previously in this document in that it presents information by industrial sector rather than the standard IPCC format.

Generally, in this report information and discussions are separated into the six conventional IPCC source categories: Energy; Industrial Processes; Solvent and Other Product Use; Agriculture; Land-Use Change and Forestry; and Waste. This examination of greenhouse gas emission trends, however, groups emission data, that may otherwise appear in separate IPCC categories, into groupings based on the Canadian industrial sector in which they occur. That is, for a given industry, fuel combustion emissions, process-related emissions, and fugitive emissions are combined and total emission values are provided for each sector (see Table A8-1).

Table A8-1 at the end of this section shows emissions from various Canadian industrial sectors for 1990, 2000, and 2001. The Canadian industrial sectors are separated into categories based on the North American Industry Classification System or NAICS. Energy data is consistent with the NAICS code breakdown used in Statistics Canada's *Quarterly Report On Energy Supply – Demand in Canada* (Statistics Canada, #57-003) and, as such, the QRESD should be used as a reference to interpret the NAICS groupings.

PETROLEUM INDUSTRY

In 2001, the Petroleum Industry as a whole contributed 136 Mt CO_2 eq (19%) of Canada's total greenhouse gas emissions, of which the Upstream and Downstream Petroleum sector contributed 113 Mt CO_2 eq and 23 Mt CO_2 eq, respectively. Emission details for the industry are presented in Table A8-1. As a result of increased foreign demand, the Petroleum Industry has experienced a 38.8 Mt CO_2 eq (40%) increase in greenhouse gas emissions since 1990. Increased demand for crude oil and natural gas resulted in 139% growth in energy export and 43% growth in GDP (Informetrica Limited and Statistics Canada).

In 2001, oil and gas production contributed 97.5 Mt CO_2 eq and the transmission of natural gas contributed 15.8 Mt CO_2 eq of the emissions attributable to the Upstream Petroleum sector. The refining of petroleum products contributed 19.7 Mt CO_2 eq and the distribution of natural gas contributed 3.3 Mt CO_2 eq of emissions from the Downstream Petroleum sector.

Since 1990, the Upstream Petroleum Industry experienced 47% growth in GDP and a 53% (34.6 Mt CO_2 eq) increase in greenhouse gas emissions due to increasing foreign energy demands (Informetrica Limited and Statistics Canada). Emissions from the transmission of natural gas increased by 4.6 Mt CO_2 eq (41%) while GDP grew by 77%, since 1990 (Informetrica Limited and Statistics Canada). Between 2000 and 2001, combustion emissions from natural gas pipelines decreased by 9% (3.4 Mt CO_2 eq) due to a 9.1% drop in domestic demand, although a 2% increase in natural gas production was observed due largely to a 7% increase in foreign demand for natural gas (Statistics Canada, #57-003).

Since 1990, the Downstream Petroleum Industry experienced 22% growth in GDP with a 1.7% decline in greenhouse gas emissions (Informetrica Limited and Statistics Canada). As refining efficiency has improved, fuel combustion emissions from petroleum refining have decreased by 5.6% (about 1 Mt CO_2 eq) with a 14% increase in production (CIEEDAC, 2003).

MINING

In 2001, the mining industry contributed 9.6 Mt CO_2 eq (or 1.3%) to Canada's greenhouse gas emissions, as shown in Table A8-1.

Between 1990 and 2001, the mining industry observed a 28% increase in GDP and emitted 2.7 Mt CO_2 eq (or 40%) more greenhouse gas emissions, of which 90%

of emissions were due to stationary combustion of fossil fuels (Informetrica Limited and Statistics Canada). Emissions from stationary combustion activities have increased by 74% (3.7 Mt CO_2 eq) due largely to increased demand for natural gas (by 120% or 59 PJ) and natural gas liquids (by 330% or 18 PJ) (Statistics Canada, #57-003).

Fugitive emissions of methane from underground coal mines have decreased by 49% between 1990 and 2001, due largely to mine closures in the Maritime Provinces.

Note that greenhouse gas emissions from the mining industry, as discussed and as shown in Table A8-1, exclude emissions from the use of natural gas by oil sands operations.

SMELTING AND REFINING INDUSTRIES

In 2001, greenhouse gas emissions from non-ferrous smelting and refining activities are estimated at 17.4 Mt CO_2 eq, or 2.4% of Canada's national greenhouse gas emission total, as shown in Table A8-1.

Between 1990 and 2001, the non-ferrous smelting and refining industry has experienced growth in GDP of almost 55% (Infometrica Limited and Statistics Canada) while GHG emissions have increased about 8%. Greenhouse gas emission intensity has decreased quite substantially since 1990 due primarily to improvements resulting in lower process emissions which accounted for almost 80% of the industry's greenhouse gas emissions in 2001. Magnesium producers have improved process controls, which has resulted in a 30% reduction in SF_6 emissions since 1990, despite a 370% increase in production. In the same timeframe, primary aluminium production increased 65% while process emissions increased by only 20%. Reduced emission intensity in the aluminium industry can be attributed to better control of smelting through electronic monitoring and the selection of less greenhouse gas-intensive technologies for new capacity additions.

PULP, PAPER AND SAW MILLS

In 2001, stationary fuel combustion from the pulp, paper and saw mill industry contributed 9.6 Mt CO_2 eq (or 1.3%) to Canada's total greenhouse gas emissions, as shown in Table A8-1.

Between 1990 and 2001, the industry saw a 3.9 Mt CO_2 eq reduction of greenhouse gas emissions and a 12.5% growth in GDP (Informetrica Limited and Statistics Canada). An increased use of natural gas and spent pulping liquors[42] combined with a lower demand of greenhouse gas-intensive fossil fuels such as coal (decreased by 60%) and refined petroleum products (decreased by 37%) has contributed to an overall emission reduction of 29% (Statistics Canada, #57-003). Also, from 2000 to 2001, the pulp, paper and saw mills industry observed a 5.2% decline in GDP and a 12% drop in greenhouse gas emissions.

In addition to using less greenhouse gas intensive fossil fuels, impacts such as the slow down in the U.S. economy, anti-dumping duties, mill closures and a surplus of wood products in 2001 also contributed to the largest year-to-year decrease in emissions since 1990 (FPAC, 2001).

PRIMARY AND OTHER STEEL INDUSTRIES

In 2001, the primary and other steel industries contributed 13.8 Mt CO_2 eq (or 1.9%) to Canada's total greenhouse gas emissions, refer to Table A8-1. Stationary fuel combustion and process-related sources accounted for 43% (or 5.9 Mt CO_2 eq) and 57% (or 7.9 Mt CO_2 eq) of the greenhouse gas emission for the industry, respectively.

Between 1990 and 2001, the industry experienced a 104% growth in GDP (Informetrica Limited and Statistics Canada) and a 2% decline in greenhouse gas emissions. Process emissions from the use of coke in reducing iron increased by 4% (0.3 Mt CO_2 eq) while emissions from stationary combustion for all ferrous metal production decreased by 9% (0.6 Mt CO_2 eq) during this timeframe.

Fuel switching to less greenhouse gas-intensive fossil fuels combined with process and technology

42 CO_2 resulting from the use of biomass is not included in the inventory totals (IPCC, 1997).

improvements such as a shift to continuous flow processes with a further refinement to integrated mill and electric arc furnace technologies are contributing to the industry's emission reductions (CSPA, 2003[1]). A 24% increase in the use of electricity coupled with a 12% and a 37% decrease in the use of coke oven gas and refined petroleum products, respectively, resulted in the observed 1.9% decrease in greenhouse gas emissions since 1990 (Statistics Canada, #57-003).

Between 2000 and 2001, in addition to energy efficiency, process and technology improvements, an 8% drop in raw steel production also contributed to the decrease in greenhouse gas emissions for the primary and other steel industries (CSPA, 2003[2], [3]). During this timeframe, an overall 12% decrease in greenhouse gas emissions was observed for the industry, which reflected an 18% and a 7% drop in stationary fuel combustion and processes emissions, respectively.

CEMENT

In 2001, greenhouse gas emissions from cement production contributed an estimated 9.8 Mt CO_2 eq (or 1.3%) to Canada's national greenhouse gas emission total, as presented in Table A8-1.

Over the 1990 to 2001 period, the cement industry experienced a 5% increase in greenhouse gas emissions and a 9.7% decrease in GDP (Infometrica Limited and Statistics Canada). It should be noted, however, that cement production has increased over 10% in the same timeframe (NRCan). Conversely, GDP for the cement industry has shown a modest increase from 2000 to 2001 attributable primarily to continued growth in the housing sector, relatively low interest rates, and growth in exports to the United States (NRCan).

CO_2 emissions occurring as a result of the clinker production process account for approximately two-thirds of the total emissions from the cement industry while the balance is attributable to fuel combustion.

INDUSTRIAL CHEMICAL INDUSTRIES

In 2001, greenhouse gas emissions from industrial chemical production are estimated at 17.6 Mt CO_2 eq, or 2.4% of Canada's national greenhouse gas emission total, as shown in Table A8-1.

In 2001, the downward trend in greenhouse gas emissions from this sector continued. Almost 64% of the greenhouse gas emissions from this industry are process emissions, which have decreased about 46% since 1990.

The Canadian chemical industries have exhibited decreases in greenhouse gas emissions of 36% and 12% since 1990 and 2000, respectively. From an economic standpoint, since 1990 the Canadian chemical manufacturing industry has continued to expand, with GDP growing over 28%. However, chemical demand was forced down by the economic downturn of 2001 resulting in a 6.8% decline in GDP from 2000 (Infometrica Limited and Statistics Canada).

While production has increased at the sole adipic acid production plant in Canada since 1990, the installation of an emission abatement system at this facility in 1997 has resulted in a 10 Mt reduction of process-related nitrous oxide emissions over the 1990 to 2001 period. Conversely, process emissions associated with the production of ammonia and nitric acid have increased 18% and 2%, respectively, since 1990. Process-related emissions trends have closely imitated ammonia and nitric acid production trends since 1990. A 45% decrease in overall greenhouse gas intensity[43] for the chemical industry over the 1990 to 2001 period is due in large part to the reductions in adipic acid process emissions.

OTHER INDUSTRIES

The category of Other Industries accounts for greenhouse gas emissions from the combustion of fossil fuels for the following three industries:

- *Construction:* Construction of buildings, highways and those servicing the industry such as plumbing, carpentry, painting etc.

43 The term greenhouse gas intensity, as used here, represents GHG emission data normalized using production data (Statistics Canada, #46-006).

- *Agriculture:* Agriculture, hunting and trapping industry (excluding food processing, farm machinery manufacturing and repairs).
- *Forestry:* Includes the forestry and logging service industry.

In 2001, the construction industry's greenhouse gas emissions totalled 1 Mt CO_2 equivalent, contributing to less than 1% of the national emissions. Emissions associated with off-road vehicle usage within the construction industry are discussed in the Transportation sector (section 2.3.1.2 Transport).

Between 1990 and 2001, the construction industry's greenhouse gas emissions decreased by 46% while the industry experienced a 4.2% growth in GDP (Infometrica Limited and Statistics Canada). A decrease in the use of both refined petroleum products (such as light fuel oil and heavy fuel oil) and propane also contributed to the decrease in greenhouse gas emissions (Statistics Canada, #57-003).

In 2001, natural gas consumption accounted for 71% to the overall fuel mix relative to 59% in 1990. Also in 2001, refined petroleum products and natural gas liquids contributed 16% and 13% to the overall fuel mix relative to a 19% and 22% contribution in 1990, respectively.

A discussion of the emission trends for the stationary fuel combustion-related emissions in the agriculture and forestry industries is available in section 2.3.1.3 of this report.

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TABLE A8-1: Industrial GHG Emissions by Fuel Combustion, Process and Fugitive Sources for 1990, 2000 and 2001, Mt CO_2 equivalent

Sector	Fuel Combustion			Industrial Process			Fugitive			Total			GDP[1]			Emission Intensity		
	1990	2000	2001	1990	2000	2001	1990	2000	2001	1990	2000	2001	1990	2000	2001	1990	2000	2001
Petroleum Industry	**59.6**	**79.8**	**79.2**	**1.9**	**3.4**	**3.3**	**36.0**	**53.1**	**53.8**	**97.5**	**136**	**136**	**22,068**	**31,414**	**31,472**	**1.00**	**0.98**	**0.98**
Upstream Petroleum Industry	39.7	62.0	60.4	1.1	2.3	2.4	33.3	49.8	50.5	74.1	114	113	18,123	26,467	26,668	1.0	1.05	1.04
Upstream Oil and Gas[2]	32.8	50.8	50.2	1.1	2.3	2.4	29.0	44.2	44.9	62.9	97.3	97.5	15,795	22,312	22,511	1.0	1.10	1.09
Natural Gas Transmission	6.9	11.3	10.3				4.3	5.6	5.6	11.2	16.8	15.8	2,328	4,155	4,157	1.0	0.84	0.79
Downstream Petroleum Industry	19.9	17.7	18.8	0.8	1.0	1.0	2.8	3.3	3.3	23.4	22.1	23.0	3,945	4,947	4,804	1.0	0.75	0.81
Petroleum Refining[3]	19.9	17.7	18.8	0.8	1.0	1.0				20.7	18.8	19.7	1,516	1,720	1,782	1.0	0.80	0.81
Natural Gas Distribution							2.8	3.3	3.3	2.8	3.3	3.3	2,429	3,227	3,022	1.0	0.90	0.96
Mining and Manufacturing Industries	**63.7**	**65.4**	**60.7**	**51.1**	**47.5**	**45.7**	**1.9**	**0.9**	**1.0**	**117**	**114**	**107**	**217,239**	**273,283**	**264,250**	**1.0**	**0.78**	**0.76**
Mining[4]	5.0	8.8	8.6				1.9	0.9	1.0	6.9	9.7	9.6	11,396	14,150	14,549	1.0	1.14	1.10
Smelting and Refining Industries	3.2	3.2	3.5	12.9	14.2	13.9				16.1	17.4	17.4	3,648	5,499	5,638	1.0	0.72	0.70
Pulp and Paper and Sawmills	13.5	10.8	9.6							13.5	10.8	9.6	9,789	11,616	11,017	1.0	0.67	0.63
Primary & Other Steel Industries	6.5	7.2	5.9	7.6	8.5	7.9				14.1	15.7	13.8	4,258	5,503	5,180	1.0	0.86	0.81
Cement	3.4	3.4	3.3	5.9	6.3	6.5				9.3	9.7	9.8	703	630	635	1.0	1.17	1.17
Industrial Chemical Industries	7.1	7.9	6.5	20.6	12.1	11.2				27.7	20.0	17.6	5,589	7,690	7,166	1.0	0.52	0.50
Other Manufacturing (all others not included elsewhere)	20.8	20.5	20.1	4.1	6.4	6.3				24.9	26.9	26.4	94,478	136,166	129,512	1.0	0.75	0.77
Other Industries (Construction, Agriculture & Forestry)	4.3	3.6	3.2							4.3	3.6	3.2	87,378	92,029	90,553	1.0	0.80	0.72

Notes:

1 GDP in Million Dollars, Constant 1997 Dollars (Infometrica Limited and Statistics Canada).

2 Includes combustion, process and fugitive emissions associated with conventional and unconventional production of oil and gas.

3 Includes combustion and process emissions associated with the refining of crude oil.

4 A small proportion of emissions from the Upstream Petroleum Industry (NAICS 211) is accounted for in the Mining sector due to data limitations.

Emissions data is normalized using GDP data to produce the Emission Intensity column (Indexed to 1990 = 1).

ANNEX 9: PROVINCIAL EMISSION TRENDS ANALYSIS

The following discussion describes GHG emission trends from a provincial perspective for both the long term (LT, 1990–2001) and the short term (ST, 2000–2001). Due to data limitations, specifically confidentiality, the evaluation is done according to IPCC sector allocations presented throughout the main body of this submission and does not emulate the cross-sector consolidations of the previous Canadian industrial trends discussion at the national level.

All emission references are from the 2001 Canadian GHG Inventory and are given in units of CO_2 equivalent unless otherwise stated. All energy quantities, gross domestic product and heating degree-day values originate from Statistics Canada (2001) although the GDP is further manipulated by Informetrica (2001) to provide a consistent time series, which is otherwise unavailable through traditional government sources.

Heating degree-days (HDD) are a measure (indicator) of the severity of winter in a region. The number of HDD is calculated for each day by subtracting the day's mean temperature from a base temperature (usually, 20 °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 heating degree-days. Only one value is given per province per year and, although real, is a weighted-average of many weather stations in a province and, therefore, may not be completely indicative of local conditions, but 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.

NEWFOUNDLAND

In 2001, Newfoundland and Labrador represented 1.7% of Canada's population, generated 1.3% of the GHGs and 1.2% of Canada's total GDP. Combined, these parameters registered 17.9 tonnes CO_2 eq per person and 758kt per million GDP. Since 1990, socio-economic indicators show a 22.9% increase in total GDP, while population and HDD show decreases of 7.7% and 4.7%, respectively.

Emissions from the IPCC Energy and Waste sectors account for 94.4% and 4.6%, respectively, towards their total regional contribution and, subsequently, changes in the remaining sectors have limited influence on total performance. Of the Energy sector, stationary sources comprise 58%, while transportation is responsible for 40%.

Over the long term (1990–2001) Newfoundland and Labrador's GHG emissions have increased 1.2% from 9.4 to 9.6 Mt CO_2 eq. Sources belonging to the IPCC Energy sector were responsible for both the greatest growth and decline. Increases due to fossil fuel industries (0.4 Mt); off-road fuel use (0.2 Mt); electricity and heat generation (0.2 Mt); heavy-duty diesel vehicles (0.2 Mt); light-duty gasoline trucks (0.1 Mt); and fugitive emissions resulting from oil and natural gas production (0.1 Mt) have been offset by reductions in domestic marine (0.1 Mt); aviation (0.1 Mt); gas automobiles (0.1 Mt); combustion emissions from the manufacturing industries (0.2 Mt); mining (0.3 Mt); and residential heating (0.2 Mt).

The 276% increase in energy production (primary) since 1990 has been a strong influence, with a 171% growth spike occurring in the 1997–1998 years following the first full year of production from Hibernia. This is in sharp contrast to the 1.9% increase in energy net supply (primary and secondary) since 1990.

The 8.1% (802 kt) increase over the short term (2000–2001), dwarfed the 1.2% increase over the long term (116 kt). A 90% increase over 2000 in emissions from electricity and heat generation (976 to 1,831 kt) drove the long-term change from a 6.4% decrease in 2000 to a 1.2% increase by 2001.

Emissions generated from the Agriculture sector account for less than 0.5% of the provincial total. Due to confidentiality requirements, some of the 2001 data for Newfoundland had to be suppressed. Consequently, the 2001 values for Newfoundland are underestimated.

Agriculture emissions from enteric fermentation decreased between 1990 and 2000, whereas emissions from manure management, direct N_2O from cropland soils and indirect N_2O occuring offsite increased until 2000. Declining cattle populations reduced the emissions from enteric fermentation, while higher poultry populations increased emissions from manure management and direct and indirect N_2O from soil.

FIGURE A9-1: Newfoundland Long-term Emission Trends, 1990–2001

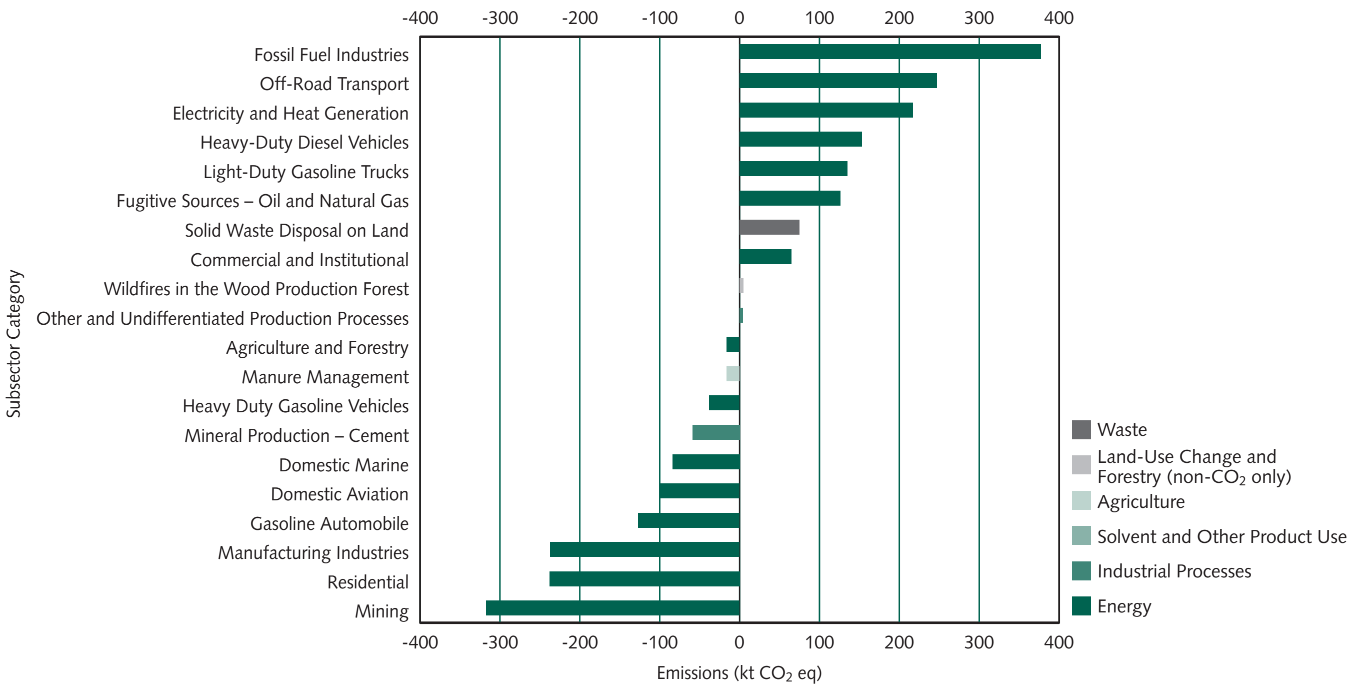
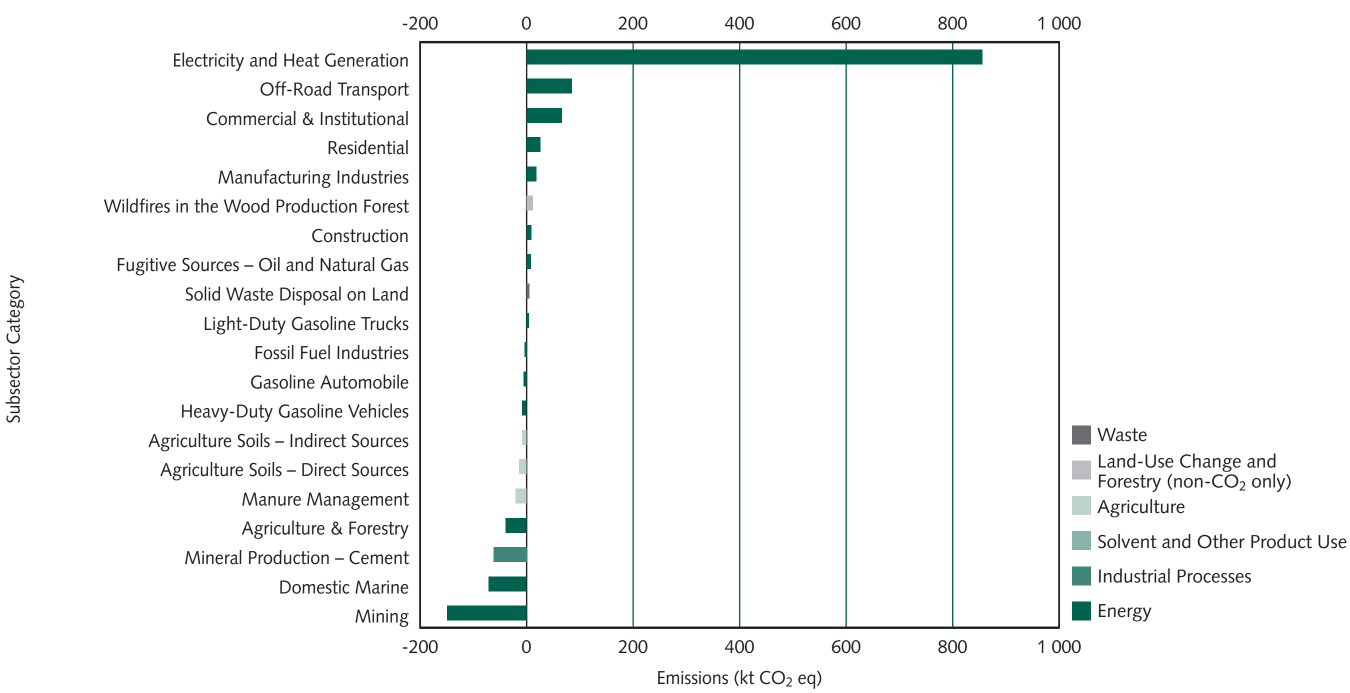


FIGURE A9-2: Newfoundland Short-term Emission Trends, 2000–2001



PRINCE EDWARD ISLAND

PEI, with 0.4% of Canada's population (942K), contributed 2.1 Mt (0.3%) and 3.2 B$ (0.3%) towards Canada's GHG and GDP totals in 2001. These values are up 6.4%, 5.4% and 35.4%, respectively, since 1990 with their GHG down 5.2% and GDP unchanged since 2000.

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 with respect to the other Atlantic provinces (19.2% and 76% respectively).

Agriculture emissions from direct N_2O from cropland soils and indirect N_2O that occurs offsite fluctuated but generally increased between 1990 and 2001, while emissions from enteric fermentation and manure management declined over this period. Higher synthetic fertilizer consumption increased emissions, while reductions in cattle population lowered emissions.

The short-term trend (between 2000 and 2001) showed all agriculture emission sources to be declining. The reduction in direct and indirect N_2O emissions is attributed to less synthetic fertilizer use in 2001.

The Energy sector has shown an overall long term increase of 6.9% (0.1 Mt) resulting from a 3.4% decline in stationary sources being offset by a 22.7% increase from road transport-related emissions, specifically a 68.6% and 68.8% increase in the emissions from light-duty gasoline and heavy-duty diesel trucks. Both the stationary and transport sources have decreased in the short term by 7.1% and 1.3%, respectively.

FIGURE A9-3: PEI Long-term Emission Trends, 1990–2001

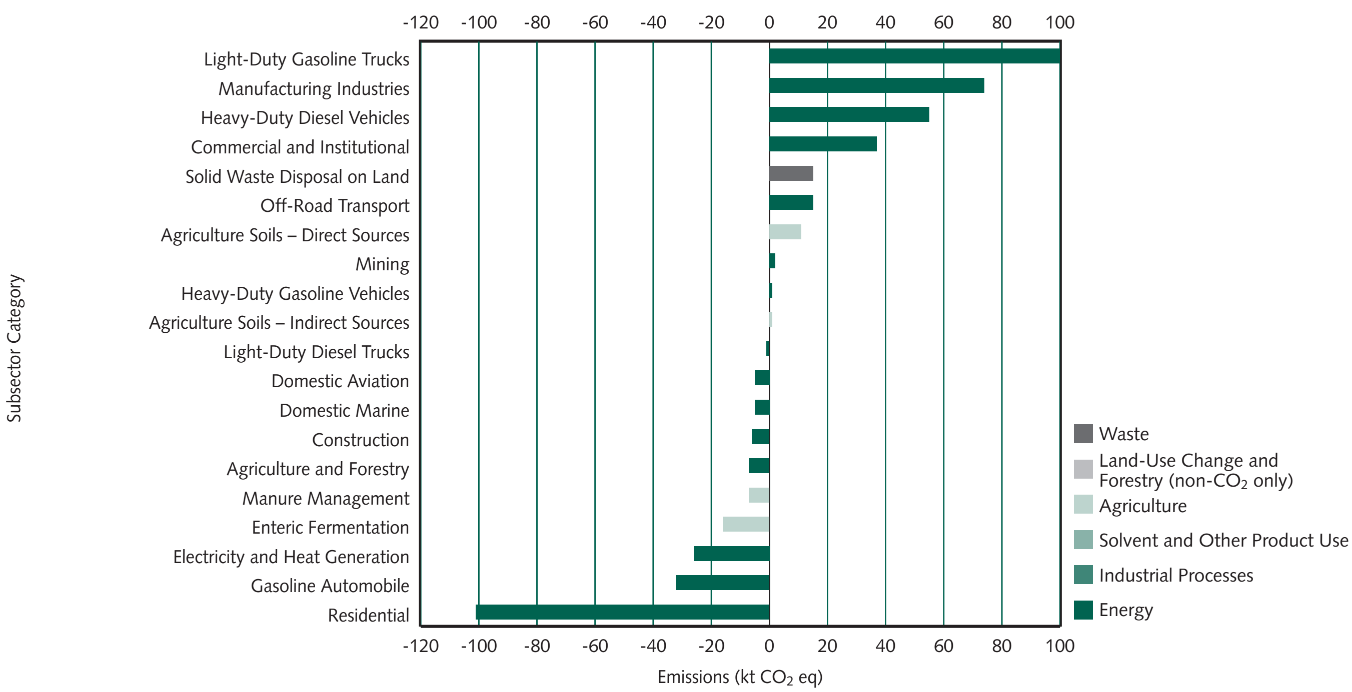
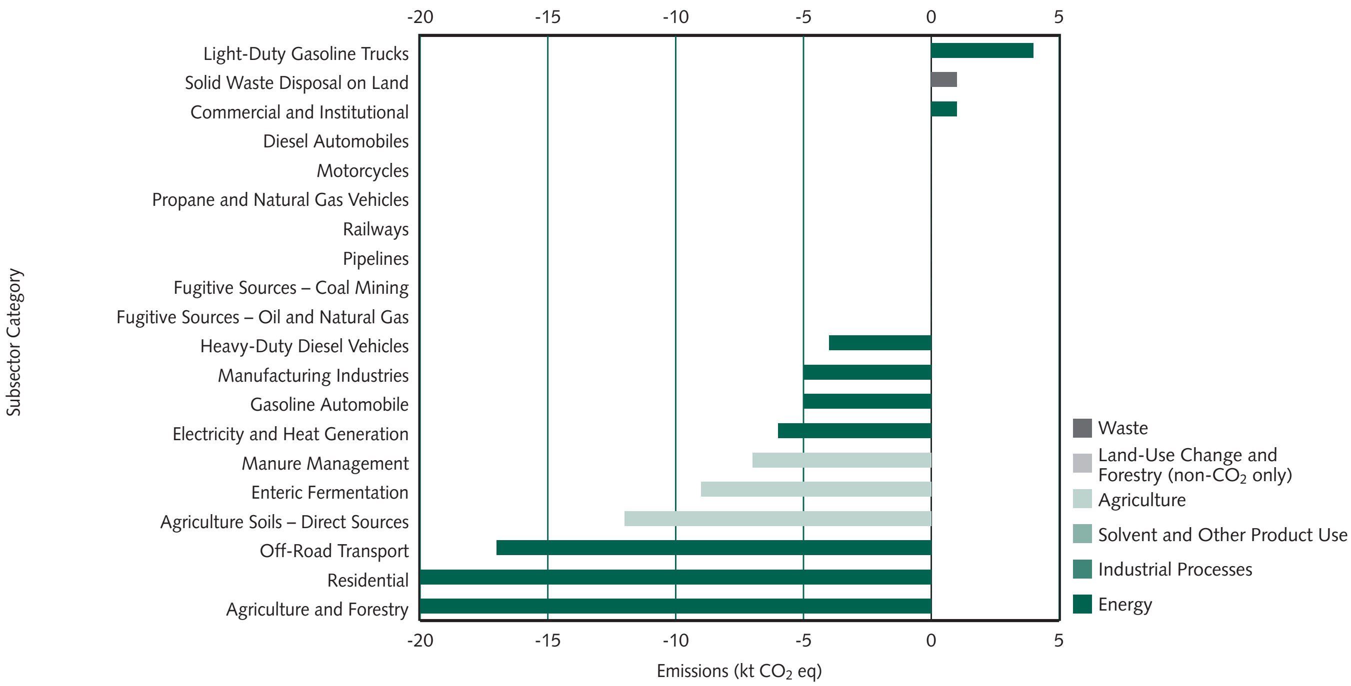


FIGURE A9-4: PEI Short-term Emission Trends, 2000–2001



NOVA SCOTIA

In 2001, Nova Scotia generated 20.9 Mt, 2.9% of Canada's total GHGs. Nova Scotians represent 3.0% of the population and contribute 2.3% to the total GDP. Since 1990, GHGs, population and GDP output have increased 8.1%, 3.6% and 24% respectively, while a review of the heating degree-days show that 2001 accumulated 2.1% less then the 1990 "base" year and just over 1% more over 2000.

Energy, Waste and Agriculture account for almost 99% of this province's total GHG emissions in 2001 (92.4%, 3.4% and 2.8%).

Energy-related emissions in 2001 have increased 8.4% since 1990 but have decreased 3.4% over the previous year. In Nova Scotia, the dominant Energy subsectors are electricity and heat generation and road transport. Both subsectors experienced growth since 1990, the former exhibits 27.5% growth while the latter shows 11.8%. These subsectors have also both shown short-term decreases of 3.9% and 1.6%, respectively. Light-duty gasoline cars and trucks and heavy-duty diesel trucks dominate transport. The annual contribution from gasoline cars has been fairly stable since 1990, while that from light-duty gas trucks and heavy-duty diesel trucks has shown constant growth over the same period.

Fugitive emissions from coal mining have drastically declined since 1990 (77% less) 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 (up 44% since 2000).

Total agriculture emissions have been relatively stable in the long and short term (-3.0% and –3.5% respectively). Emissions from manure management, direct N_2O from cropland soils, and indirect N_2O that occurs offsite fluctuated but generally increased between 1990 and 2001, while emissions from enteric fermentation declined over this period. Direct CO_2 emissions from soils declined as a result of increased adoption of no-till, from 3.8% in 1991 to 8.3% in 2001 (2001 Census of Agriculture). Higher poultry populations resulted in higher emissions from manure management. Reductions in cattle population reduced emissions from enteric fermentation.

The short-term trend (between 2000 and 2001) shows the same pattern for agriculture emissions from enteric fermentation. However, emissions from manure management and direct and indirect N_2O declined mainly because of a smaller swine population and lower use of synthetic fertilizer.

FIGURE A9-5: Nova Scotia Long-term Emission Trends, 1990–2001

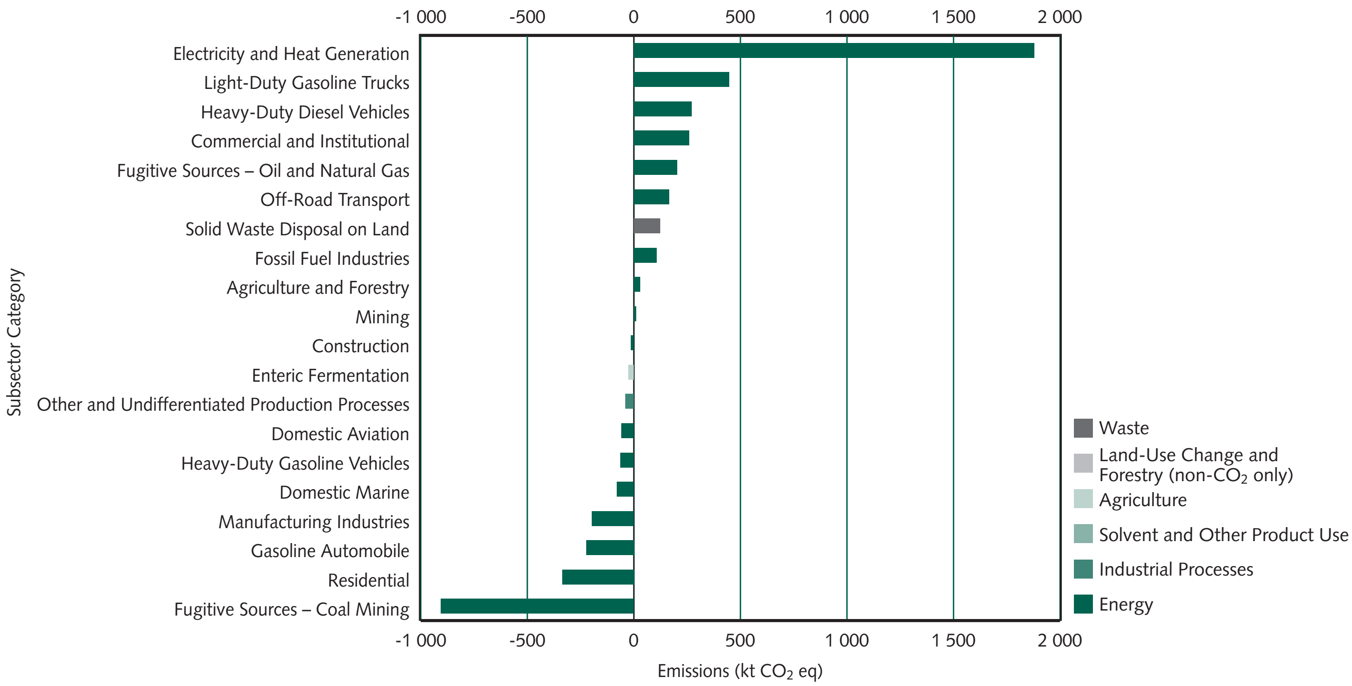
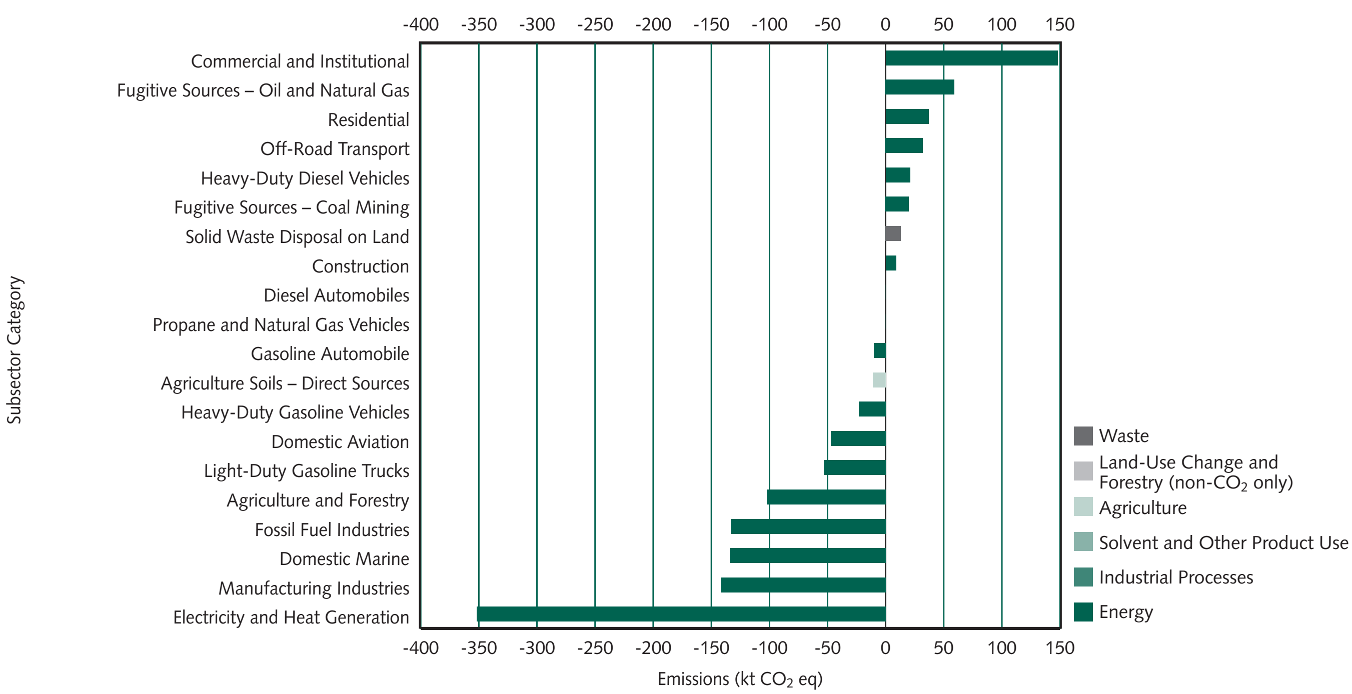


FIGURE A9-6: Nova Scotia Short-term Emission Trends, 2000–2001



NEW BRUNSWICK

In 2001, New Brunswick contributed 22.7 Mt or 3.2% of Canada's total GHGs. This is up 42.9% since 1990 and 11.5% over 2000.

With 2.4% of Canada's population, their GDP contribution has increased 26.5% since 1990 to represent 1.9% of the national total in 2001. Total heating degree-days were similar for 2000 and 2001, up only 3% when compared to the 1990 year. In 2001, GHGs per capita were 30 tonnes per person, up 40% over 1990.

The Energy sector represents 93.7% of the provincial GHG total, with Waste, Agriculture and Industrial Processes contributing 2.7%, 2.4%, and 1.4% respectively. Emissions from Land-use change and forestry and Solvents combined contribute less than 1%.

Emissions growth over the long term (6.8 Mt) was driven by Energy sector contributions and has shown steady growth from electricity and heat generation (68.5%), fossil fuel industries (150%) and transportation (35.8%). The latter of which is a result of increases from light-duty gas trucks (53.1%), heavy-duty diesel trucks (50%) and off-road use (142%).

Similarly, the short run growth in emissions (2.3 Mt) is primarily attributed to further increases from electricity and heat generation (16.6%) and the fossil fuel industries (51.5%) while reductions were observed in the residential (10.4%), heavy-duty diesel vehicle (8.8%) and manufacturing industries (11.9%) Energy subsectors.

Agriculture emissions from manure management, direct N_2O from cropland soils, and indirect N_2O that occurs offsite fluctuated but, generally, increased between 1990 and 2001, while emissions from enteric fermentation declined over this period. Higher swine and poultry populations resulted in higher emissions from manure management. Reductions in cattle population reduced emissions from enteric fermentation.

FIGURE A9-7: New Brunswick Long-term Emission Trends, 1990–2001

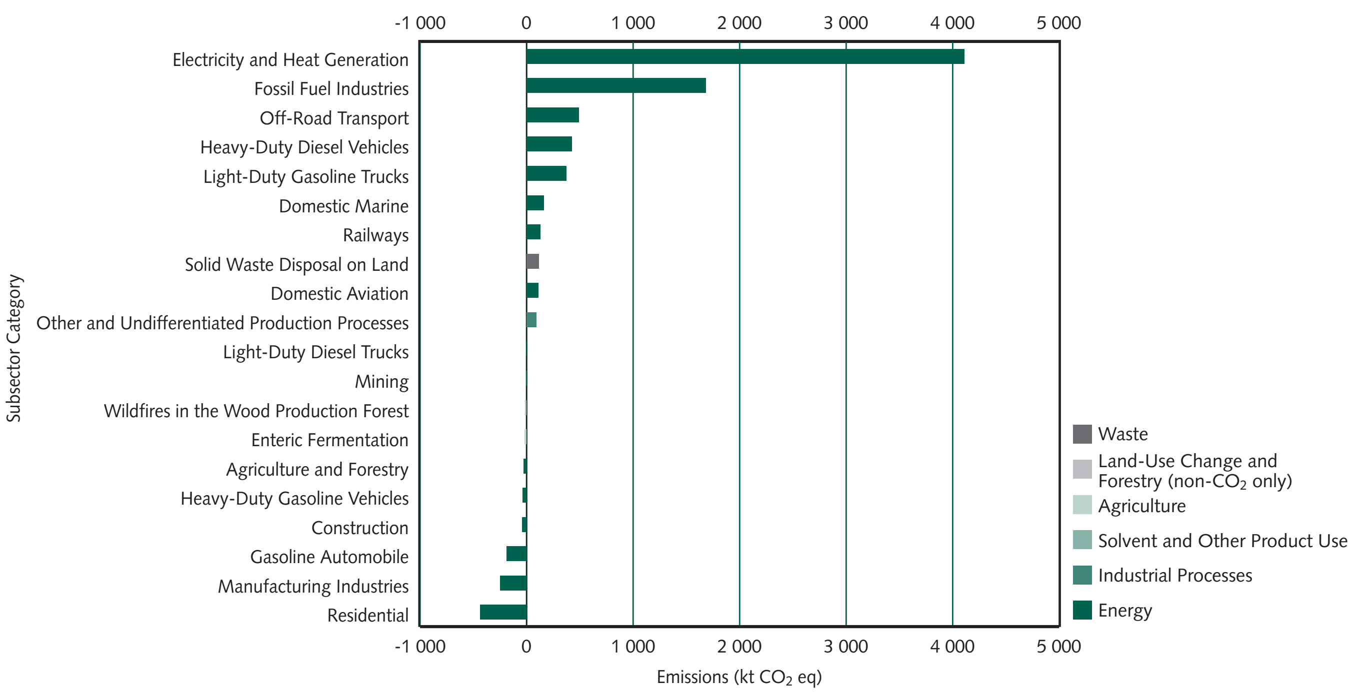
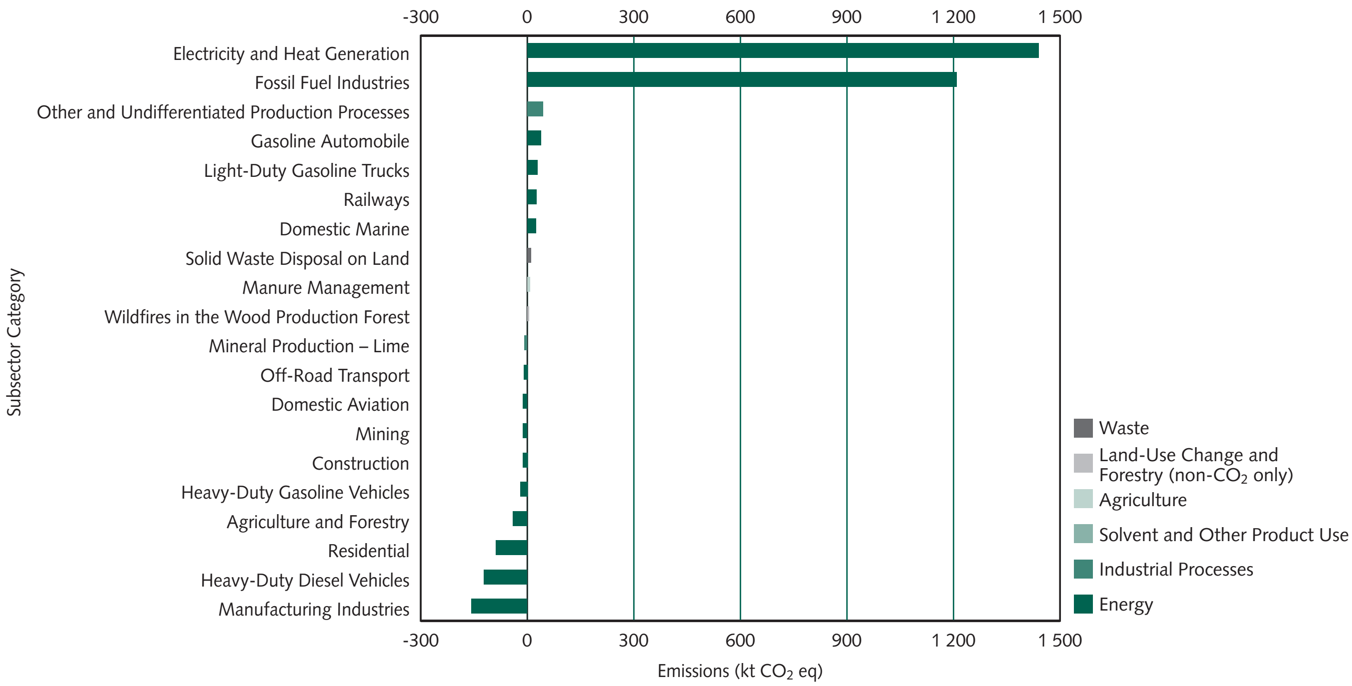


FIGURE A9-8: New Brunswick Short-term Emission Trends, 2000–2001



QUEBEC

In 2001, the province of Quebec represented 23.8% (7.4 million) of the country's population and accounted for 21.3% (217.9 Billion$) and 12.5% (90.0 Mt CO_2 eq) of Canada's GDP and GHG totals respectively. Per capita, this equates to 12.1 tonnes GHG per person while only generating 0.41 Mt CO_2 eq per Billion$ GDP. Since 1990, the population has increased almost 6% and the province's economic output has jumped 27.6%. Climatically, 2001 registered a 3.1% decrease in HDD with respect to 1990.

Since 1990, Quebec's GHG emissions have increased 4.6%. In the short term (2000–2001), a 0.7% reduction in their total represents the fourth non-consecutive period of year-over-year decline ('91, '95, '97 and '01). All years showing a decline were accompanied by positive GDP growth, except 1991.

Because of Quebec's abundant hydro-generated electricity and small petroleum industry, the contribution to total emissions from the Energy sector is favorable. The Energy, Industrial Processes, Agriculture and Waste sectors comprise 68%, 15%, 9% and 8% of the regional total. Transportation and stationary sources contribute 53% and 46%, respectively, to the Energy sector while 80% of industrial process emissions are released during aluminium production and magnesium smelting.

The province of Quebec is by far Canada's primary producer of aluminium and magnesium, with limited activity in Ontario and British Columbia (NRCan, 2003). In 2001, Quebec accounted for almost 90% of Canada's GHG emissions associated with primary aluminium production. Steady growth in the primary aluminium industry in Quebec has resulted in a 26% increase in emissions since 1990 and a 4.5% increase since 2000. In January 2002, the Aluminium Association of Canada and the Government of Quebec signed a framework agreement on the voluntary reduction of an additional 200 kt of GHG emissions from Quebec smelters by the end of 2007 while allowing for continued growth in the province's aluminium industry (www.aia.aluminium.qc.ca).

Since 1990, Quebec's magnesium industry emissions have declined by 46% while production from the province's two primary magnesium facilities continues to increase. In 2002, Magnolia Metallurgy Inc. is expected to significantly increase production of its new Danville, QC commercial magnesium plant to over three times that reported in 2001 (www.norandamagnesium.com).

The Norsk Hydro Canada Inc. plant located in Bécancour, QC, has focused on reducing the bottleneck in the existing operations thus improving process efficiency. This work is expected to increase production capacity by 11% in 2002.

Agriculture emissions from manure management, direct N_2O from cropland soils, and indirect N_2O that occurs offsite increased between 1990 and 2001, while emissions from enteric fermentation fluctuated but generally declined over this period. The direct CO_2 emissions from soils declined by a small amount as a result of increased no-till, from 2.5% in 1991 to 5% in 2001 (2001 Census of Agriculture). Higher swine and poultry populations resulted in higher emissions from manure management. Reductions in cattle population reduced emissions from enteric fermentation.

The short-term trend (between 2000 and 2001) in agriculture emissions follows a similar pattern to that described above. Emissions from enteric fermentation rose by a small amount in 2001 because of increases in swine and beef cattle populations.

FIGURE A9-9: Quebec Long-term Emission Trends, 1990–2001

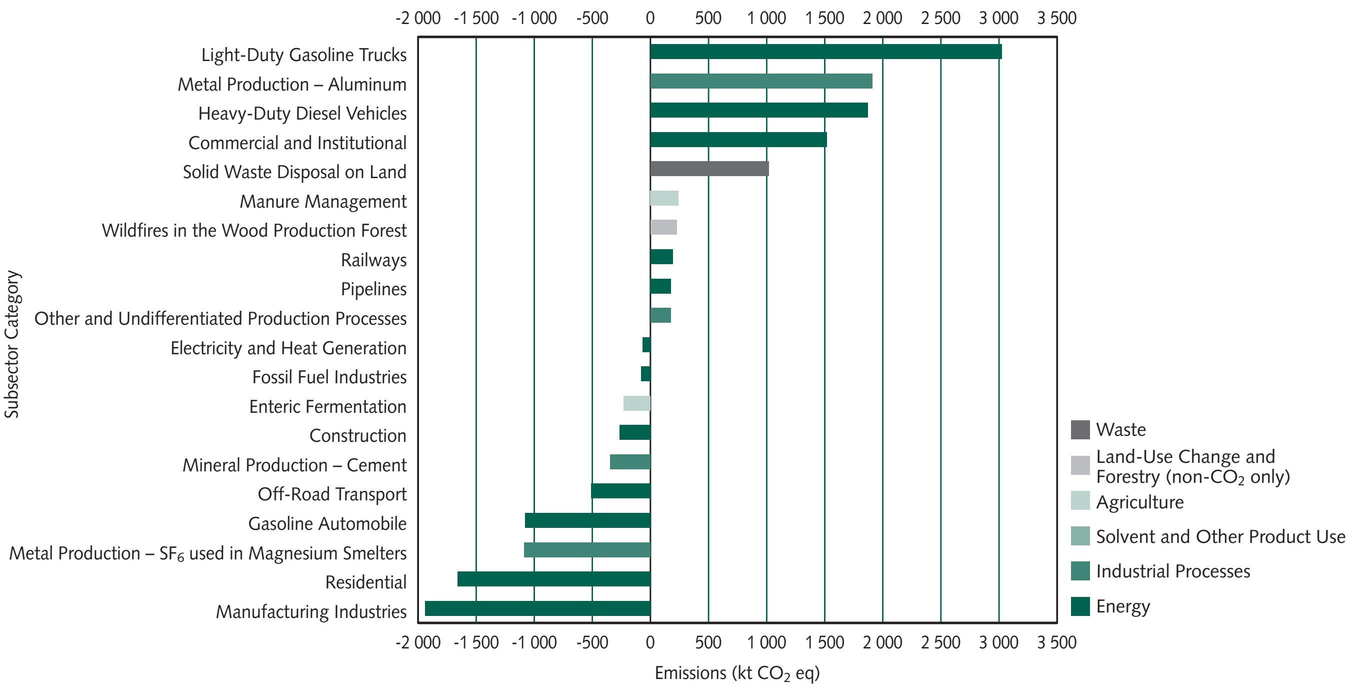
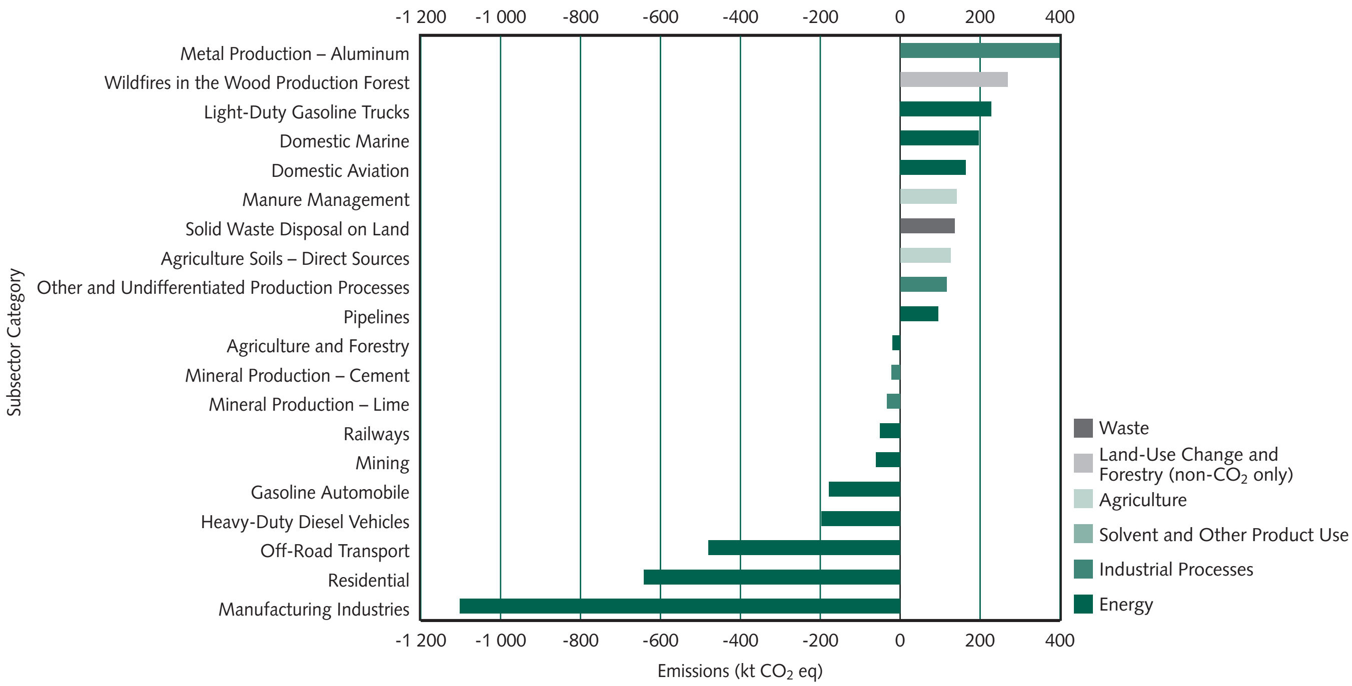


FIGURE A9-10: Quebec Short-term Emission Trends, 2000–2001



ONTARIO

In 2001, Canada's most populated province at 11.9 million (38.2% of total) generated 27.9% (200.5 Mt CO_2 eq) of total GHGs and 42.1% of the country's GDP (430.5 B$). Since 1990, its emissions increased 19.2 Mt (10.6%) while GDP and population increased 35.8% and 15.5%, respectively. In the short term (2000–2001), total emission output declined 4.1% or 8.6 Mt CO_2 eq with a commensurate 10.7% reduction in HDD and a 3.4% reduction in net supply of primary and secondary energy.

Ninety percent of Ontario's GHG emissions are attributable to the Energy (81.4%) and Industrial Processes (8.7%) sectors, with Agriculture (5.5%) and Waste (4.2%) making up the majority of the remainder.

Since 1990, increases in emissions from electricity and heat generation (14.2 Mt CO_2 eq), light-duty gasoline truck use (7.5 Mt CO_2 eq), heavy-duty diesel vehicles (5.0 Mt CO_2 eq) and commercial and institutional sources (4.4 Mt CO_2 eq) were offset by 97% reduction 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 remained stable since the early '90s, with coal and natural gas-fired sources steadily increasing to account for the decline from nuclear sources beginning in the mid 1990s. In Ontario, hydro-generated electricity is still second only to nuclear and the analysis here ignores import and export magnitudes.

The short-term emissions growth echoes the long-term trend with respect to growth from light-duty gasoline trucks (1.2 Mt CO_2 eq) and the commercial and institutional sectors (1.0 Mt CO_2 eq). In sharp contrast to the long-term trend in emission from light-duty gasoline automobiles ("cars")(4.5% decrease since 1990), this source actually increased more in the short term (5.1%, 978 kt CO_2 eq) over the previous year. It is speculated that the desire for secure personal ground transportation after the events of September 11th explains this sharp increase.

The majority of the short-term reductions are realized in the Energy sector where the combustion emissions from manufacturing, residential heating, pipeline transport, domestic aviation, off-road and the electricity and heat generation subsectors contributed 9.2 Mt CO_2 eq fewer emissions than in 2000.

With respect to agriculture, emissions from manure management increased between 1990 and 2001, while emissions from enteric fermentation, direct N_2O from cropland soils, and indirect N_2O that occurs offsite declined over this period. Direct CO_2 emissions from soils declined as a result of increased no-till, from 4%

in 1991 to 27% in 2001 (2001 Census of Agriculture). Higher swine and poultry populations resulted in higher emissions from manure management. Reductions in cattle population, less crop production (crop residue and nitrogen-fixing crops were down) and lower use of synthetic fertilizer reduced the sector's emissions.

The short-term trend in agriculture follows a similar pattern to that described above, with the following exceptions. Between 2000 and 2001, direct N_2O emissions declined because there was less crop production. Emissions from enteric fermentation rose by a small amount because of increased animal populations in almost all categories.

FIGURE A9-11: Ontario Long-term Emission Trends, 1990–2001

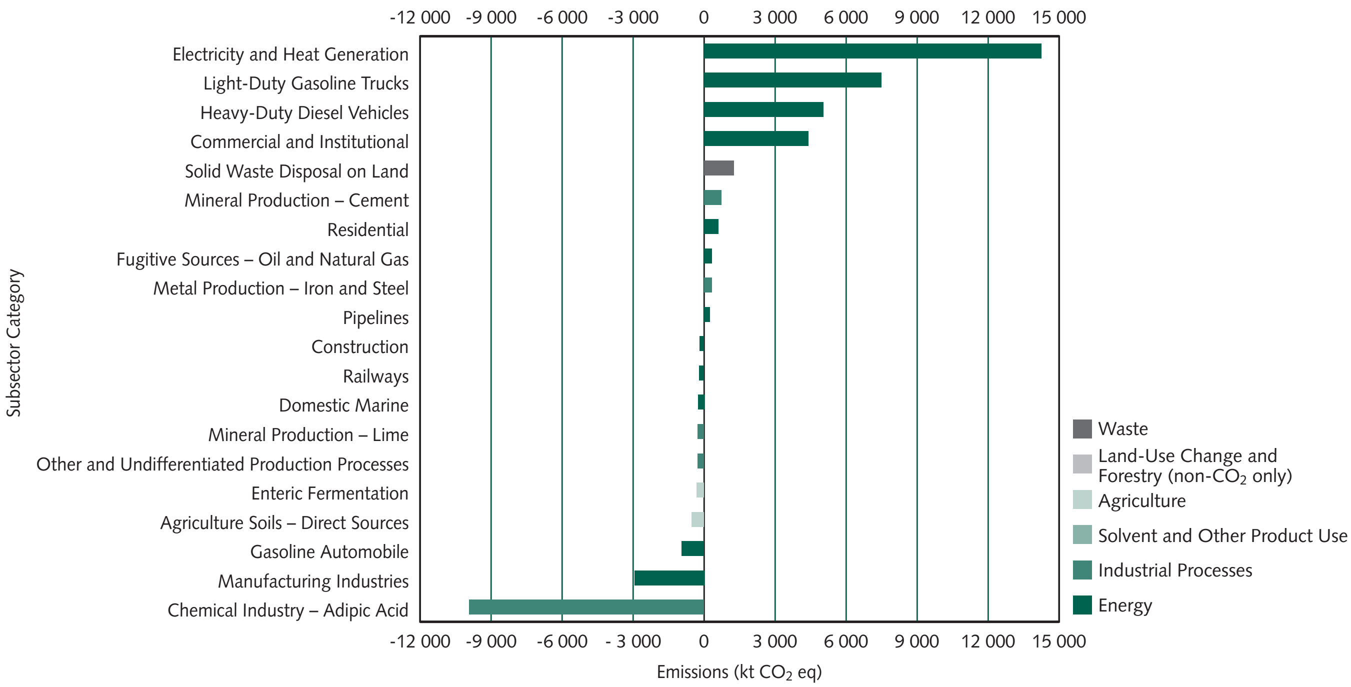
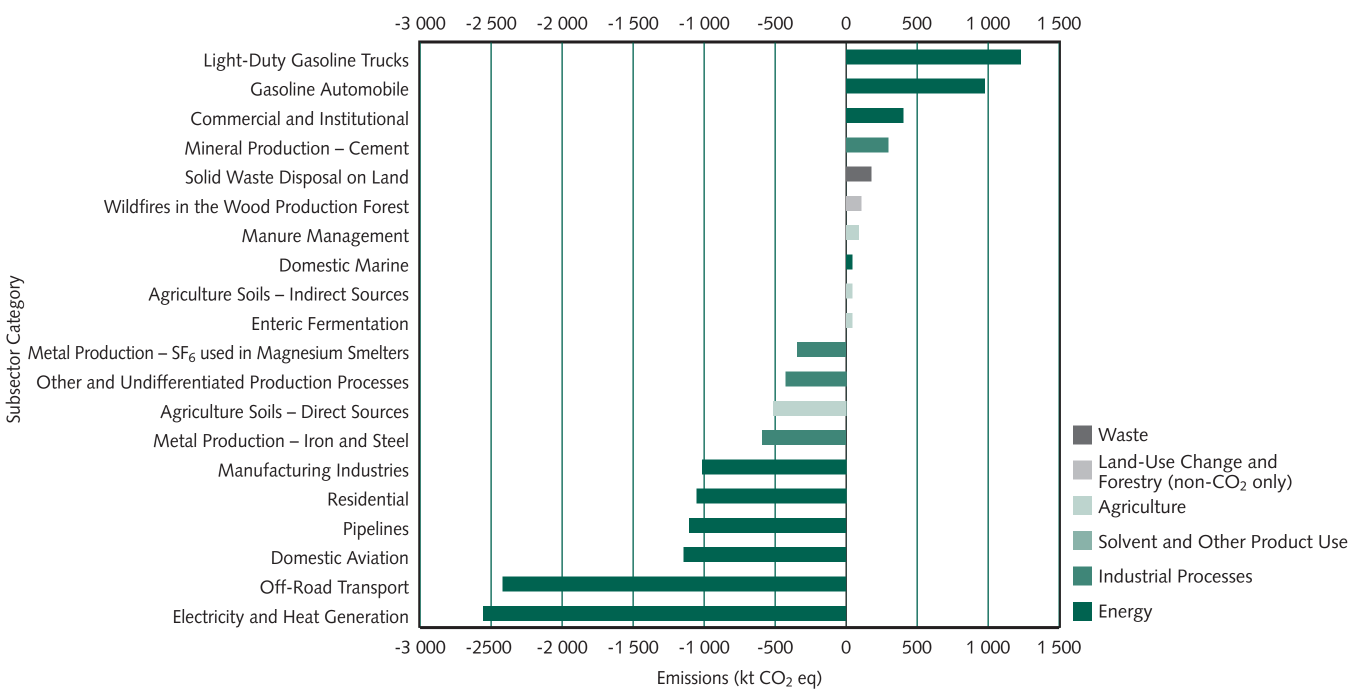


FIGURE A9-12: Ontario Short-term Emission Trends, 2000–2001



MANITOBA

In 2001, Manitoba's GHG emissions were up 0.9% (0.2 Mt) with respect to 1990's total of 20.3 Mt and down 4.0% (.9 Mt) since 2000. Over the long-term, the province's annual GDP and population have increased 20.5% and 3.9%, respectively, and contribute to declines in both GHG per capita (18 in 2001) and GHG per unit GDP (622 kt/B$ in 2001).

Manitoba's economic structure gives its GHG inventory the lowest percentage of emissions from the Energy sector (60%) and the highest percentage from the Agricultural sector (33%). The overall contributions from the Energy sector have been fairly stable over the long term with increases from light-duty gasoline trucks (0.6 Mt) and heavy-duty diesel vehicles (0.4 Mt) being offset with reductions from light-duty gasoline vehicle (0.6 Mt), residential (0.4 Mt), railway (0.4 Mt) and pipeline (0.3 Mt) subsectors.

The greatest single reduction since 1990 is 1.0 Mt from agricultural soils – direct sources. Direct CO_2 emissions from soils have declined over the decade and Manitoba's cropland soils are believed to be currently acting as a net sink, removing more CO_2 than they are emitting. These lower emissions and higher removals of soil CO_2 are attributed to increased adoption of no-till (5% in 1991 to 13% in 2001).

Agriculture emissions from all other sources (i.e. enteric fermentation, manure management, direct N_2O from cropland soils, indirect N_2O that occurs offsite) grew substantially between 1990 and 2001. The main factors contributing to the increased emissions were higher swine and beef cattle populations and greater use of synthetic fertilizer. The short-term trend between 2000 and 2001 follows the same pattern as described above, with the exception of direct N_2O from cropland soils where emissions decreased because there was less crop production and lower use of synthetic fertilizer

Emissions from wildfires in the wood production forest are found near the top of the growth sectors in the long run (0.4 Mt) and are the top growth sector in the short run (0.4 Mt). Emissions from this LUCF sub-sector were very small in 1990 (0.2 Mt) and rose to 1.6 Mt by 1995. Zero emissions from this sector were reported from 1996 until 2001 where a 425 kt total skewed the long and short term trends. This subsector registers emissions that are essentially random or accidental in a managed forest and, subsequently, a trend is not indicative of fiscal performance.

FIGURE A9-13: Manitoba Long-term Emission Trends, 1990–2001

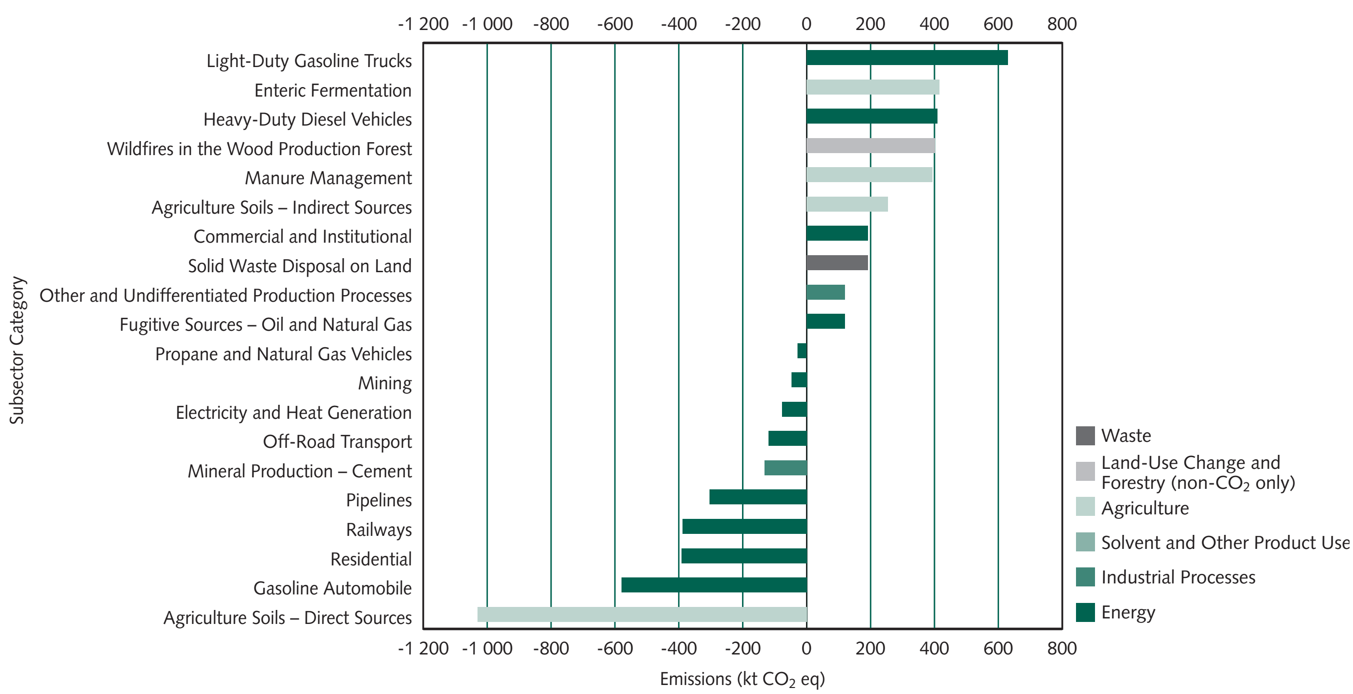
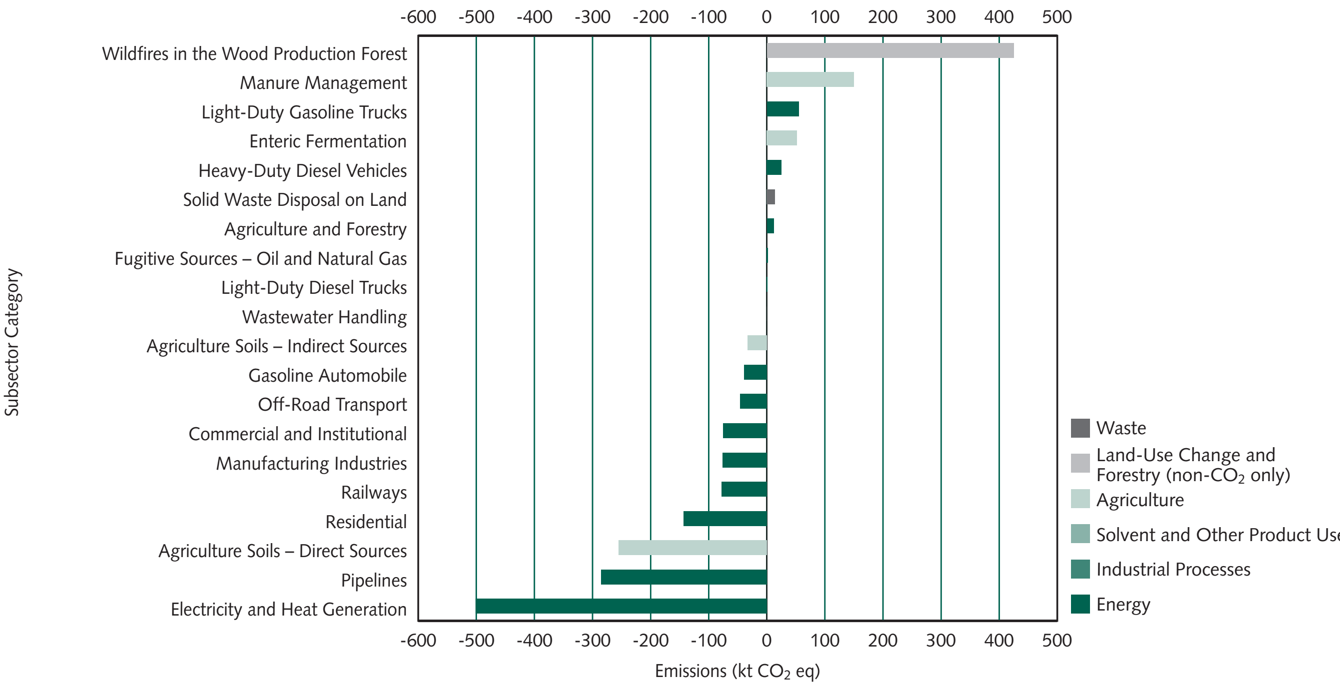


FIGURE A9-14: Manitoba Short-term Emission Trends, 2000–2001



SASKATCHEWAN

This province generated 60.7 Mt GHGs in 2001 (8.4% of Canada's total), a 29% increase over the 1990 base year and a 1.8% decrease compared to 2000. GDP output has increased 24% since 1990, while population has increased 1%. In 2001 these measures translate to 60 tonnes per person and 2.0 Mt/M$ 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 and decreasing portion of agricultural emissions. With Energy accounting for 78.2%, Agriculture 16.5% and Industrial Processes at 3.4%, these key sectors combine to account for over 98% of the regional total.

Both long- and short-term growth trends show energy sub-sectors as strong contributors, specifically emissions from electricity and heat generation (5 Mt LT, 0.5 Mt ST) and the petroleum industries, including combustion emissions from the fossil fuel industries and fugitive emissions from oil and natural gas. Total electricity produced shows steady growth since 1990, with the contribution from hydro sources at their lowest since 1992. Coal-generated capacity has remained the predominant source of electricity and appears to have peaked with natural gas and biomass taking on increasing capacity.

Primary energy production has increased 55% since 1990, while net supply and energy use – final demand – have increased 26% and 17%, respectively. Conversely, the annual heating degree-days (HDD) measured in 2001 declined 3.4% compared to 1990 and 8% compared to 2000.

Agriculture emissions from enteric fermentation, direct N_2O from cropland soils, indirect N_2O that occurs offsite, and manure management grew substantially between 1990 and 2001. Direct CO_2 emissions from soils have declined over the decade and Saskatchewan's cropland soils are believed to be currently acting as a net sink, removing more CO_2 than they are emitting. The lower emissions and higher removals are attributed to increased adoption of no-till (10% in 1991 to 39% in 2001) and a reduction in the frequency of summer fallow. The main factors contributing to the increased emissions were higher beef cattle and swine populations, greater use of synthetic fertilizer and more production of N-fixing crops. The short-term trend between 2000 and 2001 follows the same pattern as described above with the exception of direct N_2O from cropland soils. Here emissions decreased in 2001 because there was less crop production and lower use of synthetic fertilizer.

FIGURE A9-15: Saskatchewan Long-term Emission Trends, 1990–2001

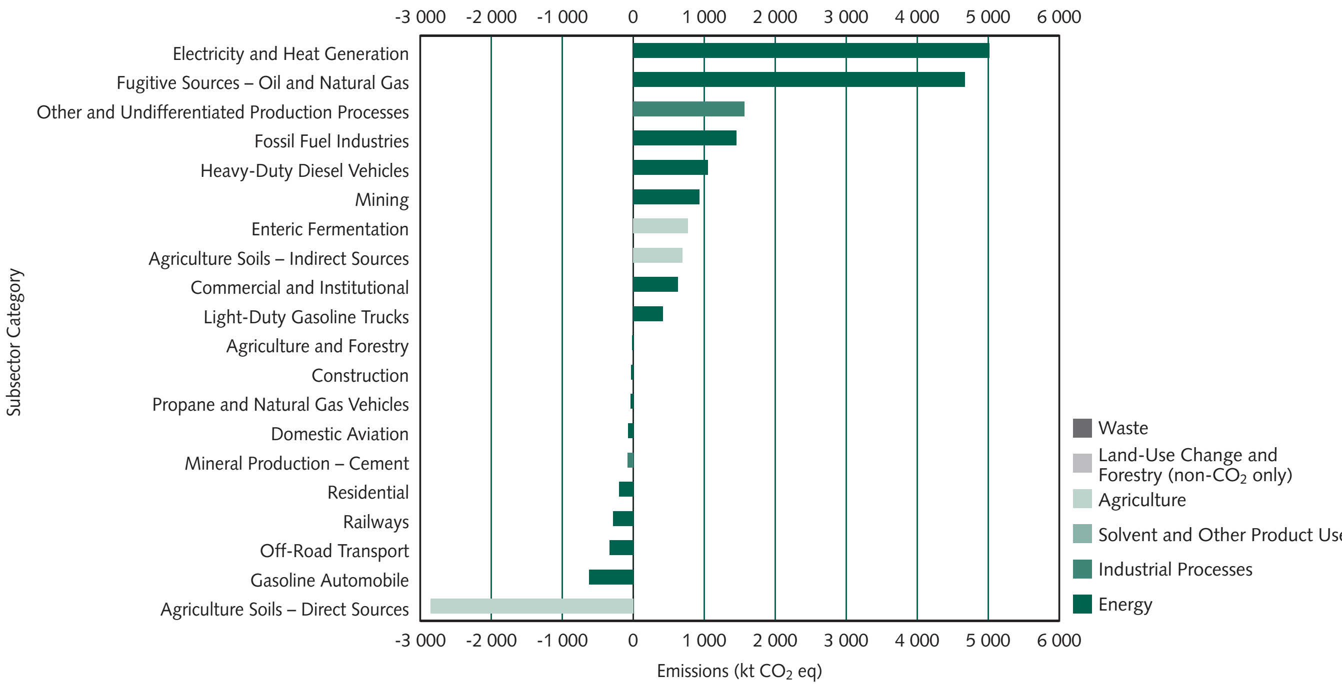
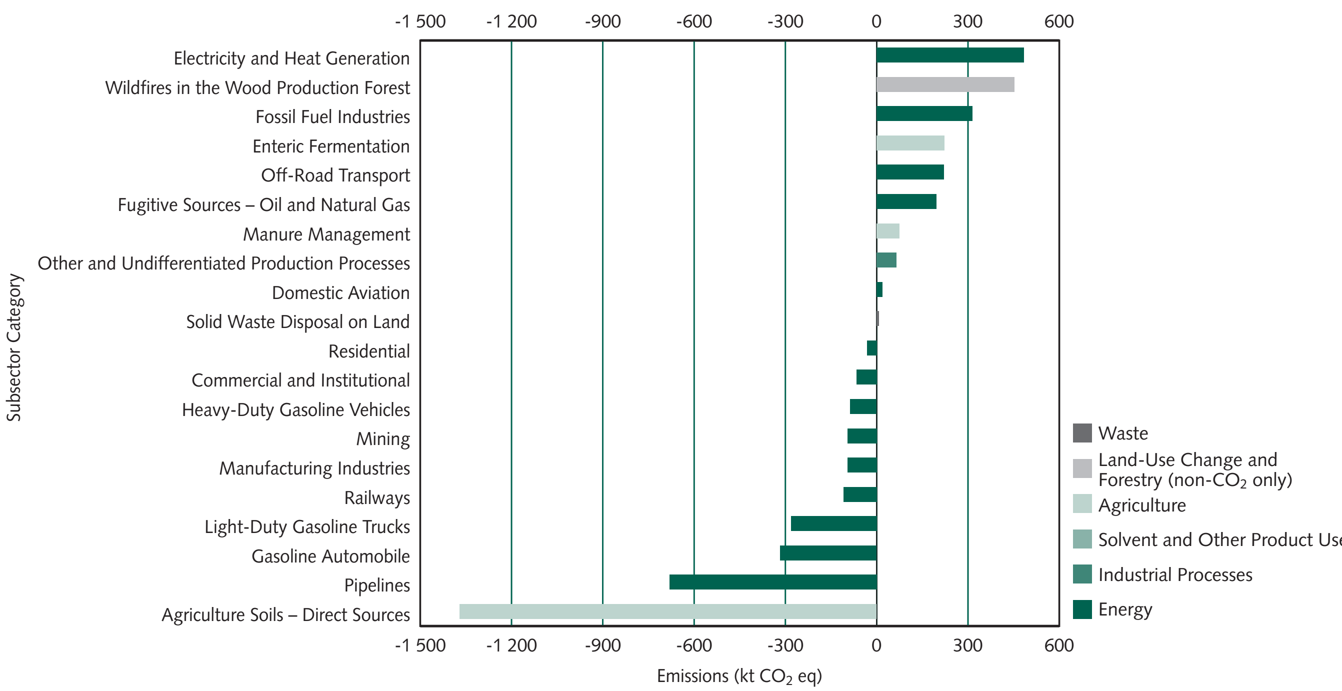


FIGURE A9-16: Saskatchewan Short-term Emission Trends, 2000–2001



ALBERTA

The Province of Alberta generated 12% of Canada's GDP in 2001 with 9.8% of the total population. Since 1990, its GDP and GHG output have increased 48.9% and 31.3% to 224 Mt and 122.9 B$, respectively. The short-term trends show no growth in total GHGs, while observing a 2.3% increase in economic output and a 10% reduction in HDD over the previous year.

Alberta, known for its abundant fossil-based natural resources, provided over 65% of Canada's primary energy production in 2001. Not surprisingly, its total GHG emissions are dominated by combustion emissions related to the IPCC Energy sector. With 85.6% of the provincial total from the Energy sector, the remaining sources are a combination of Agriculture (8.8%) and Industrial Processes (4.9%).

Long-term emissions growth has contributed an additional 53.4 Mt to the provincial total. Predominantly driven by increases from electricity and heat generation (14.5 Mt), fossil fuel industries (13.4 Mt), fugitive sources from the oil and gas industry (8.6 Mt), heavy-duty diesel vehicles (3.5 Mt), mining (3.4 Mt), light-duty gas trucks (2.5 Mt) and pipelines (2.1 Mt), all of which are constituents of the Energy sector. Decline over the long term has been limited to combustion emission from manufacturing industries (1.2 Mt) and direct sources from agricultural soils (0.9 Mt).

As mentioned earlier, the total short-term change was insignificant with marginal increases in electricity and heat generation (1.2 Mt) and pipelines (0.7 Mt) being offset by reductions in sectors which had, historically, been responsible for high growth such as fossil fuel industries, fugitive sources from oil and natural gas and off-road transportation.

Agriculture emissions from enteric fermentation direct N_2O from cropland soils, indirect N_2O that occurs offsite, and manure management grew substantially between 1990 and 2001. Direct CO_2 emissions from soils declined as a result of increased no-till and reduction of summer fallow. The adoption of no-till increased from 3% in 1991 to 27% in 2001 (2001 Census of Agriculture). The main factors contributing to the increased emissions were higher beef cattle and swine populations, and greater use of synthetic fertilizer. The short-term trend follows a similar pattern, noting that Alberta's swine population increased significantly between 2000 and 2001.

FIGURE A9-17: Alberta Long-term Emission Trends, 1990–2001

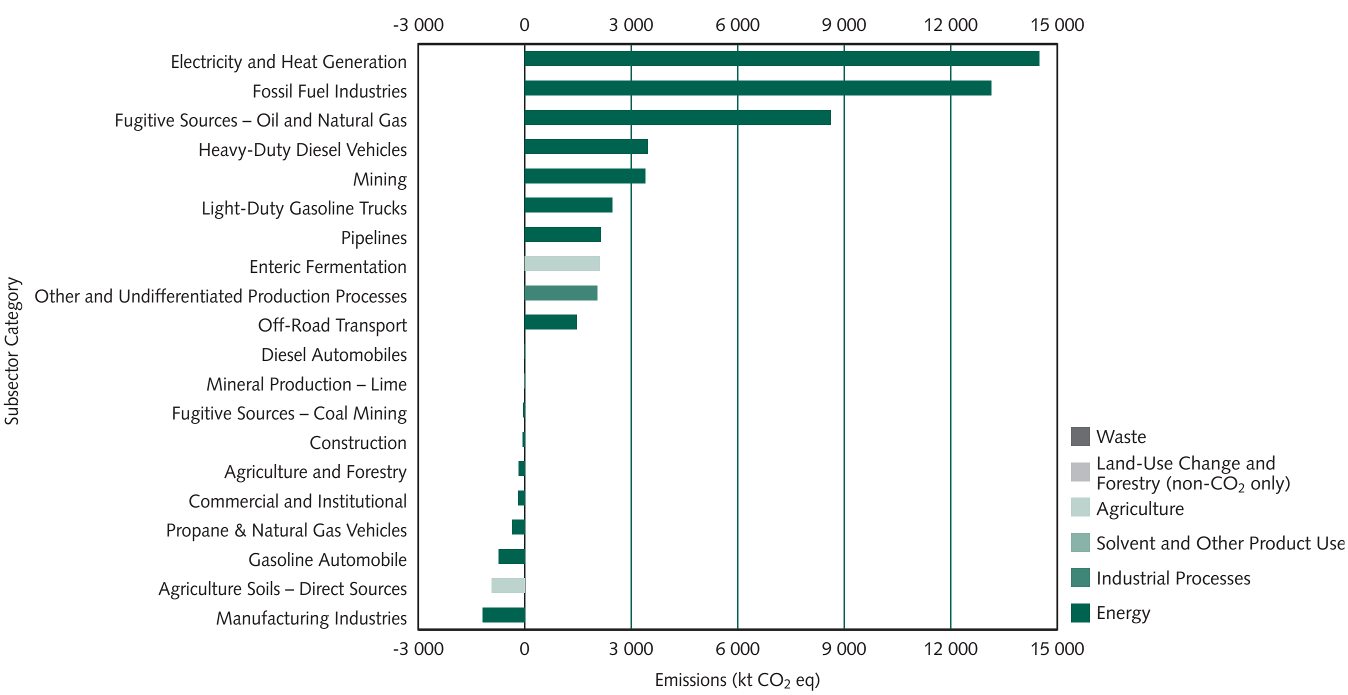
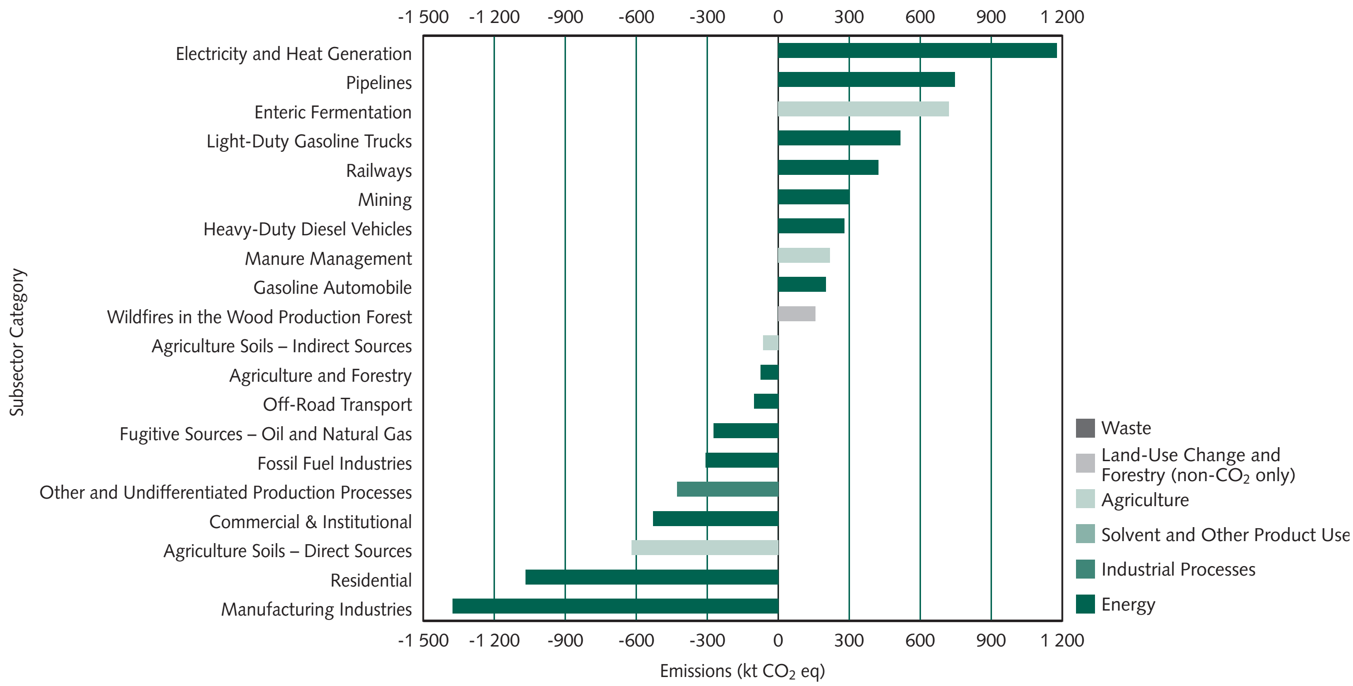


FIGURE A9-18: Alberta Short-term Emission Trends, 2000–2001



BRITISH COLUMBIA

In 2001, British Columbia's 4.1 million residents generated 65.0 Mt CO_2 eq of total GHGs and contributed 123.9 B$ to the country's GDP. This represents 9.0% of Canada's total GHGs and 12.1% of the total GDP. Since 1990, the province's total emissions have increased 12.1 Mt or 22.9%, while GDP and population increased 29.4% and 24.6% respectively. B.C.'s annual generation rate has declined to 15.9 tonnes per person since 1990 and its GHG per GDP works out to 525 kt per $M in 2001. In the short term, (2000–2001), total emission output declined 1.2 Mt CO_2 eq or 1.7%. Although the province's annual HDD fluctuated by as much as 13% between 1990 and 2001, the long- and short-term comparisons yield a difference of less then 2%.

A review of B.C.'s sectors shows 82.9% of emissions arising from the Energy sources. Waste, Agriculture and Industrial Processes add 7.9%, 4.3% and 4.1%, respectively. Combined, the emission attributed to the solvent and LUCF sectors make up less than 1% of the provinces total in 2001. Of the Energy sector, stationary sources represent 40% and mobile sources (transport) represent 48%, with fugitive emissions making up the remaining 12%, predominantly from oil and natural gas operations.

This province's Energy sector is resident to those subsectors contributing the greatest changes in annual GHGs in both the long and short term. Nine of the top 10 growth sectors reside here over the long term, six of those represented by transportation, a subsector that has achieved almost 50% growth since 1990. Increases from light-duty gasoline trucks and heavy-duty diesel vehicles have been offset by reductions from gasoline cars and alternatively fueled vehicles. Fugitive emissions from oil and natural gas have increased 3.4 Mt or 27.7% while combustion emissions from the fossil fuel industries are down in both the long and short term (-21.2% and -19.4% respectively). B.C.'s production of primary energy has increased 36.9% since 1990, while its net supply has only increased 15%. In the short run, changes are observed again with 8 of the top 10 growth line items belonging to the Energy sector with the subsector's representation almost the same. However, polar shifts in growth occurred with respect to the manufacturing and domestic aviation subsectors. These both have exhibited long term growth, only to register short-term contraction, sometimes dramatic as in the case of domestic aviation, which has shown steady increase throughout the '90s only to have a 66% drop in emissions between 2000 and 2001.

The Waste sector sources have increased by a total of 40% since 1990 but only 1.6% since 2000. 94% of this sector's total is due to solid waste disposal on land.

Agriculture emissions from direct N_2O from cropland soils, indirect N_2O that occurs offsite, enteric fermentation and manure management increased between 1990 and 2001. The main factors contributing to this growth are higher cattle and poultry populations. This has been partially offset by declining use of synthetic fertilizer, especially between 1998 and 2000.

FIGURE A9-19: British Columbia Long-term Emission Trends, 1990–2001

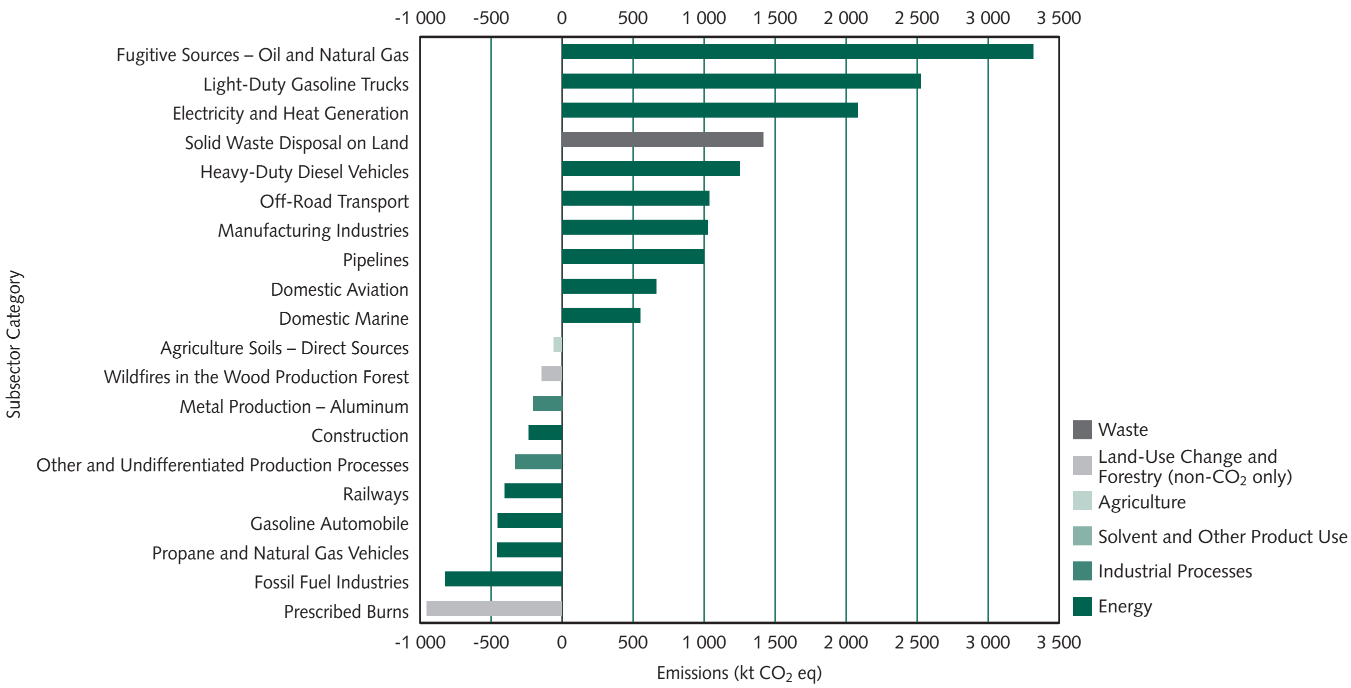
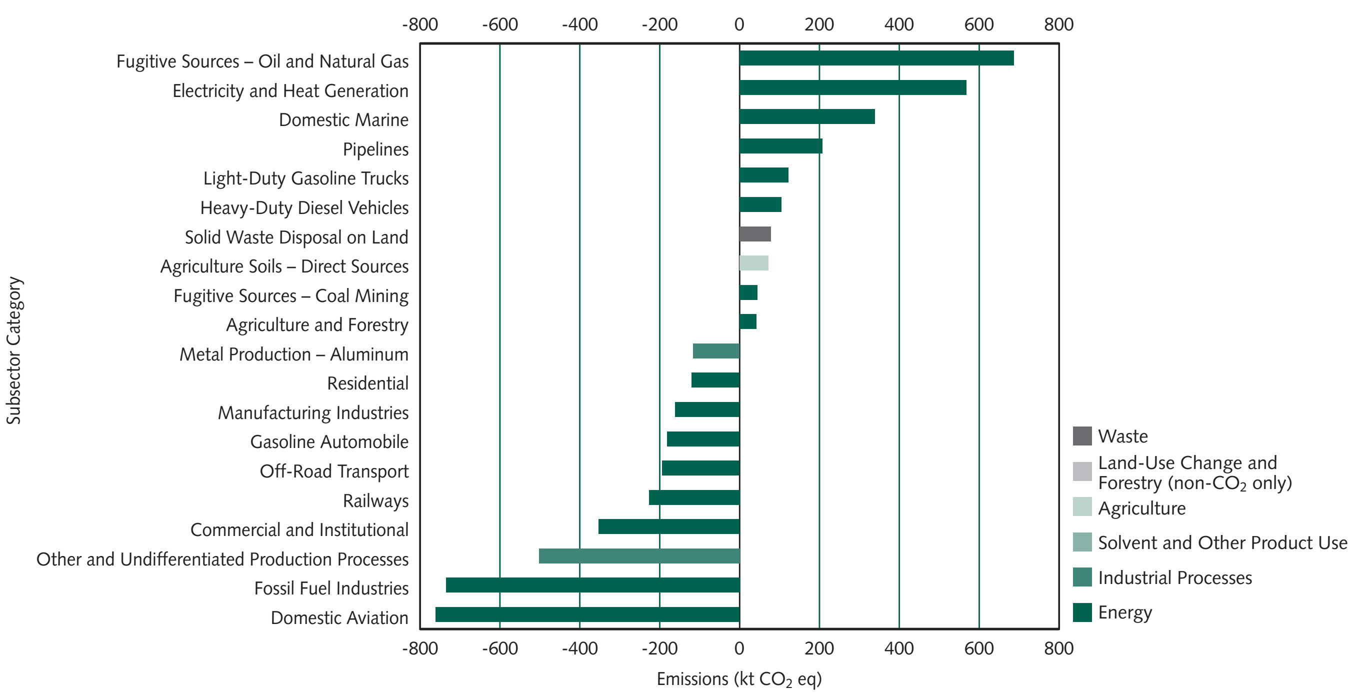


FIGURE A9-20: British Columbia Short-term Emission Trends, 2000–2001



YUKON, NORTHWEST AND NUNAVUT TERRITORIES

Together, Canada's territories contribute 2.8 Mt or 0.4% to the national GHG total and 5.0 M$ or 0.5% to the national GDP in 2001. 98.6% of the territories' total emissions are from the Energy sector with 1.0% from the Waste sector.

Yukon, with a total for 2001 less than 0.5 Mt, has shown a 14.4% reduction since 1990, most of which is due to reductions in the combustion emission from the off-road and electricity and heat generation subsectors. However, some of the reduction is attributed to wildfires, which had a relatively substantial contribution in the 1990 base year but were otherwise minimal since. Within this net reduction is an absolute increase from the petroleum industry, including both the combustion emissions from the fossil fuel industries and the fugitive emissions from oil and natural gas operations. These two subsectors have shown steady growth since the early '90s and the modest long-term trend has only recently been mitigated by an abrupt, substantial short-term decrease. Since 1990, Yukon's population has increased almost 9% while its GDP has increased over 10%. Per capita, Yukon residents generate 16.3 tonnes annually, down 20% since 1990.

The Northwest and Nunavut Territories generated around 2.4 Mt total GHGs in 2001. This is a 50% increase since 1990 that has been driven entirely from increases within the Energy sector. Annual growth in emissions, predominantly in the off-road sector but including fossil fuel industry, fugitive oil and gas, domestic aviation, mining, electricity and heat generation sectors, has occurred throughout the long and short terms. Since 1990, these regions' combined population has increased 18% to almost 70,000, during which time the annual GDP has grown almost 60%. GHGs per capita registered almost 34 tonnes in 2001, a 27% increase over 1990.

As a whole, heating degree-days for the three territories for 2001 show an overall decrease of around 10% when compared to 1990 and 2% less than 2000. Energy production (primary only) expanded 45% from 1990 while net supply and energy use-final demand rose 27% and 22%, respectively.

FIGURE A9-21: Yukon Long-term Emission Trends, 1990–2001

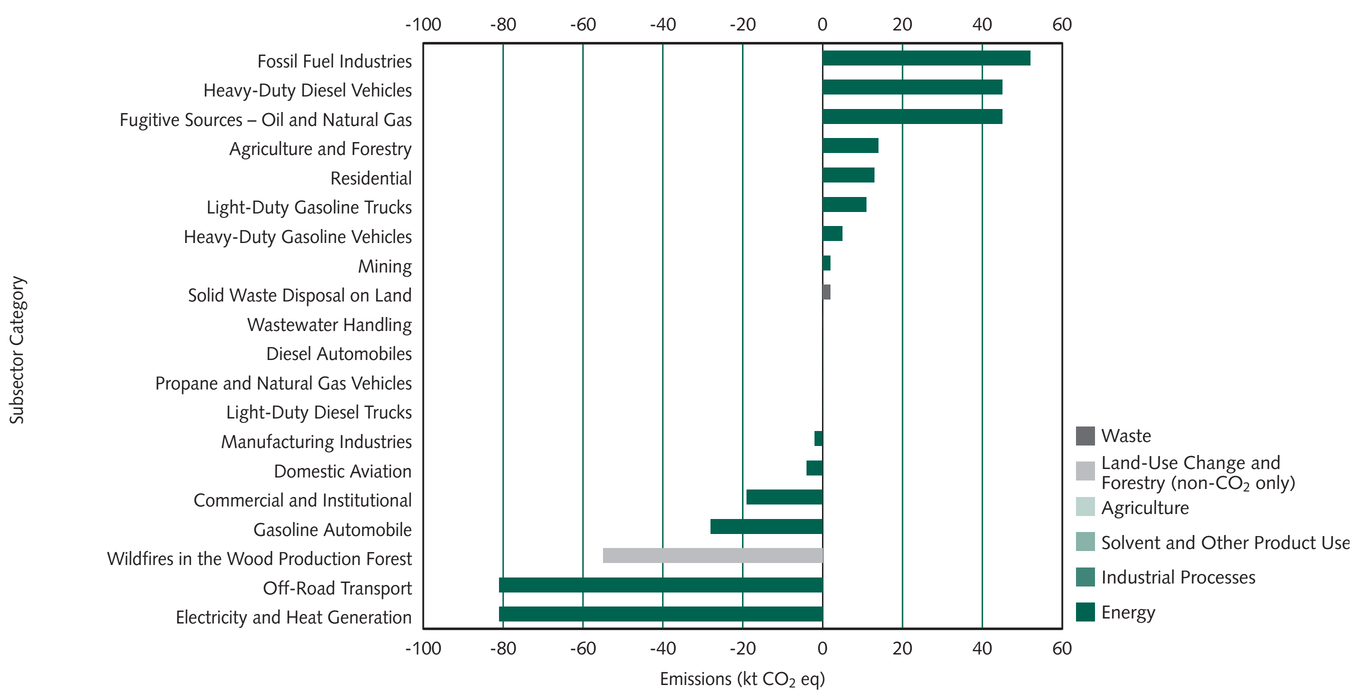


FIGURE A9-22: NWT and Nunavut Long-term Emission Trends, 1990–2001

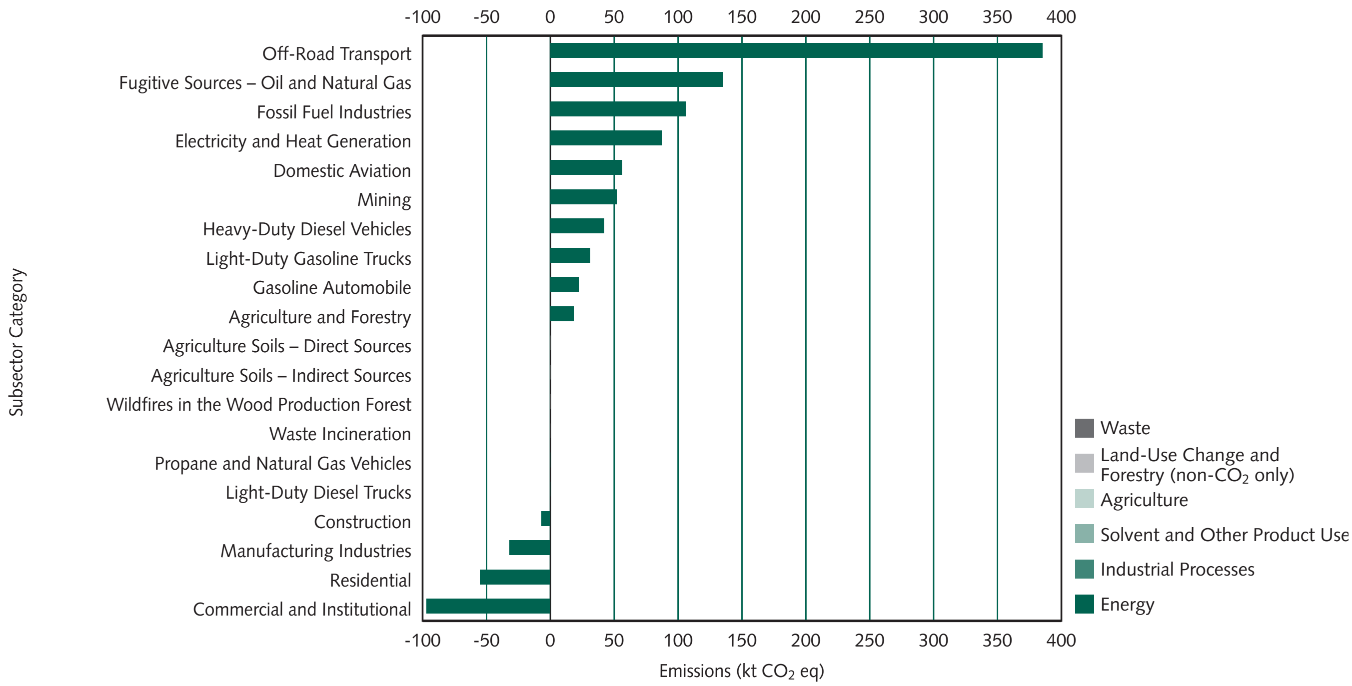


FIGURE A9-23: Yukon Short-term Emission Trends, 2000–2001

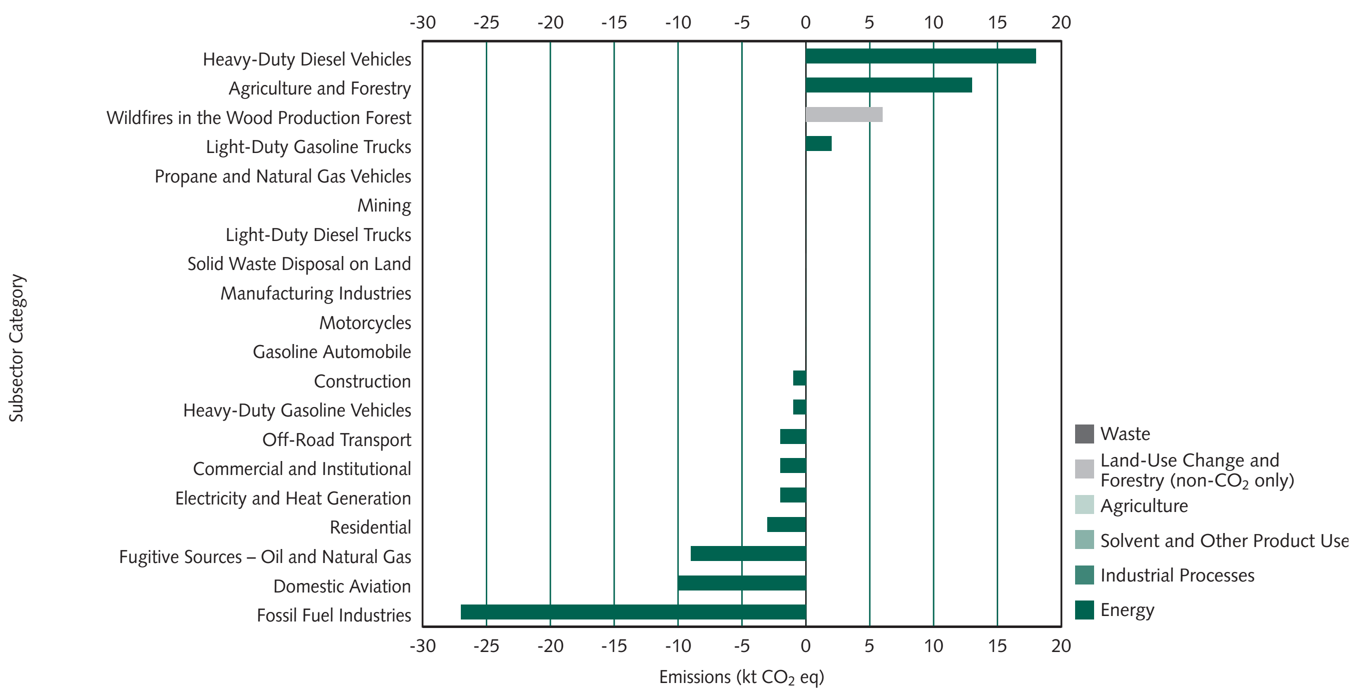
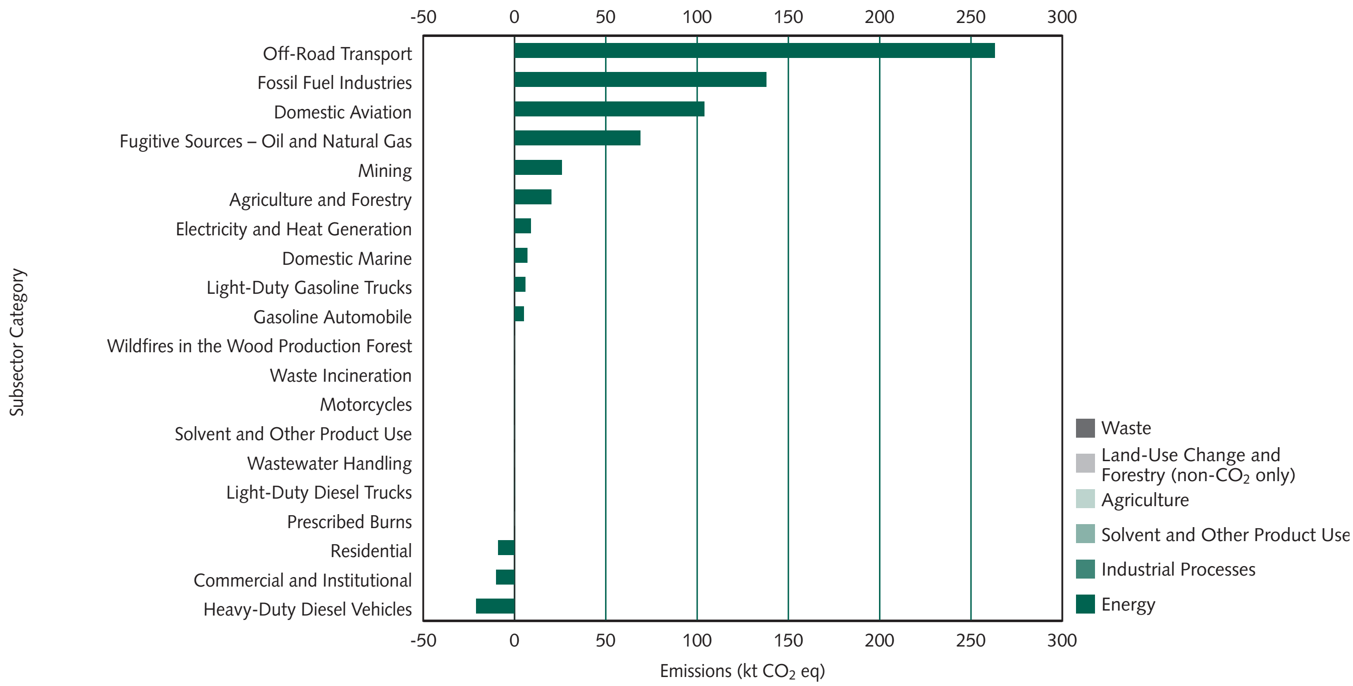


FIGURE A9-24: NWT and Nunavut Short-term Emission Trends, 2000–2001



ANNEX 10: NATIONAL AND PROVINCIAL GREENHOUSE GAS EMISSION TRENDS, 1990–2001

Summary tables illustrating GHG emissions by province and territory are included in Annexes 10 and 11. Although the UNFCCC reporting guidelines require that only national-level detail be reported, provincial- and territorial-level detail is important due to the regional differences in emission levels and trends. Note that provincial and territorial emission estimates may not necessarily sum to the national totals due to rounding and suppression of confidential data. Provincial and territorial emission totals do not include:

- hydrofluorocarbons (e.g. fugitive releases from air conditioning and refrigeration systems);
- perfluorocarbons (used during the fabrication of semi-conductors);
- CO_2 from limestone and soda ash use; and,
- Emissions associated with ammonia production.

1990 to 2001 Greenhouse Gas Emission Estimates for Canada, by Sector

GHG Source and Sink Category	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
						All Gases / kt CO_2 eq						
TOTAL	**608,000**	**601,000**	**616,000**	**619,000**	**640,000**	**658,000**	**673,000**	**682,000**	**690,000**	**706,000**	**730,000**	**720,000**
ENERGY	**473,000**	**464,000**	**482,000**	**482,000**	**498,000**	**513,000**	**528,000**	**539,000**	**549,000**	**568,000**	**593,000**	**584,000**
a. Stationary Combustion Sources	**282,000**	**276,000**	**287,000**	**281,000**	**287,000**	**294,000**	**302,000**	**307,000**	**313,000**	**326,000**	**348,000**	**342,000**
Electricity and Heat Generation	95,300	96,700	103,000	93,800	96,000	101,000	100,000	111,000	124,000	125,000	136,000	137,000
Fossil Fuel Industries	51,500	49,500	52,100	52,600	53,400	54,700	55,300	51,000	56,500	65,400	66,900	67,300
Petroleum Refining	26,100	25,800	27,000	28,000	27,200	28,400	28,700	26,900	27,000	27,400	27,800	29,100
Fossil Fuel Production	25,400	23,700	25,000	24,600	26,200	26,300	26,600	24,100	29,600	38,100	39,100	38,200
Mining	6,190	5,030	4,790	7,370	7,490	7,860	8,740	8,970	8,020	7,450	10,390	10,250
Manufacturing Industries	54,500	52,100	51,500	49,100	52,200	52,900	54,700	54,600	52,400	52,800	53,000	48,900
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
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	3,500
Chemical	7,100	7,480	7,450	7,310	8,530	8,460	8,800	8,890	8,570	8,460	7,860	6,470
Pulp and Paper	13,500	12,800	12,100	12,000	11,800	11,500	12,000	11,800	11,000	11,000	10,800	9,600
Cement	3,390	2,900	2,840	2,860	3,270	3,420	3,270	3,250	3,290	3,550	3,430	3,290
Other Manufacturing	20,800	19,800	19,600	17,500	17,800	19,400	19,700	20,100	19,200	19,300	20,500	20,100
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
Commercial & Institutional	25,800	26,500	27,000	28,100	27,400	29,000	29,600	30,000	27,200	28,900	33,200	32,900
Residential	44,000	42,300	43,500	45,500	46,300	44,900	49,700	46,400	41,000	43,000	45,000	41,900
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
b. Transportation Combustion Sources	**153,000**	**148,000**	**152,000**	**156,000**	**164,000**	**169,000**	**173,000**	**180,000**	**184,000**	**189,000**	**190,000**	**187,000**
Domestic Aviation	10,700	9,600	9,700	9,400	10,100	10,900	11,900	12,400	13,000	13,600	13,700	12,100
Road Transportation	107,000	104,000	108,000	110,000	116,000	119,000	120,000	126,000	127,000	131,000	131,000	134,000
Gasoline Automobiles	53,700	51,200	51,600	51,800	52,300	51,300	49,900	50,000	49,700	49,800	48,300	48,700
Light-Duty Gasoline Trucks	21,800	22,300	24,000	25,600	27,400	28,500	29,900	32,000	32,800	36,600	37,600	39,400
Heavy-Duty Gasoline Vehicles	3,140	3,330	3,730	4,070	4,480	4,760	4,980	5,050	5,490	4,210	4,370	4,130
Motorcycles	230	220	218	219	221	214	210	221	232	233	239	242
Diesel Automobiles	672	634	631	624	617	594	602	600	597	605	605	596
Light-Duty Diesel Trucks	591	507	456	429	432	416	402	505	455	500	645	643
Heavy-Duty Diesel Vehicles	24,500	23,800	24,300	25,700	28,500	30,800	32,500	35,500	35,600	37,300	38,700	38,600
Propane & Natural Gas Vehicles	2,210	2,320	2,680	2,030	1,920	2,100	1,980	1,840	1,780	1,500	1,100	1,140
Railways	7,110	6,590	6,890	6,860	7,100	6,430	6,290	6,380	6,140	6,510	6,670	6,550
Domestic Marine	5,050	5,250	5,100	4,480	4,660	4,380	4,470	4,530	5,150	4,970	5,110	5,510
Others	23,400	22,400	23,000	25,100	26,700	28,600	30,400	31,000	33,100	33,000	33,400	29,700
Off-Road	16,500	14,700	13,100	14,700	15,900	16,600	17,900	18,400	20,600	20,500	22,100	19,500
Pipelines	6,900	7,640	9,900	10,400	10,800	12,000	12,500	12,500	12,500	12,600	11,300	10,300
c. Fugitive Sources	**37,900**	**39,600**	**42,400**	**44,400**	**46,600**	**49,800**	**52,700**	**52,800**	**52,400**	**52,800**	**54,000**	**54,800**
Coal Mining	1,910	2,090	1,830	1,830	1,770	1,710	1,770	1,640	1,360	1,080	950	990
Oil and Natural Gas	36,000	38,000	41,000	43,000	45,000	48,000	51,000	51,000	51,000	52,000	53,000	54,000
Oil	8,600	9,200	10,000	11,000	11,000	13,000	14,000	14,000	14,000	13,000	14,000	14,000
Natural Gas	17,000	18,000	19,000	20,000	21,000	22,000	23,000	23,000	23,000	23,000	24,000	24,000
Venting	4,500	4,800	5,300	5,800	6,200	6,700	6,900	6,900	7,200	7,400	7,500	7,800
Flaring	5,800	5,700	5,800	6,000	6,100	6,800	7,200	7,300	7,200	7,600	7,800	8,000
INDUSTRIAL PROCESSES	**52,900**	**53,700**	**52,500**	**54,000**	**56,400**	**56,200**	**58,400**	**57,200**	**53,300**	**51,500**	**50,900**	**49,000**
a. Mineral Production	**8,160**	**6,980**	**6,640**	**6,880**	**7,510**	**7,690**	**8,030**	**8,180**	**8,680**	**9,100**	**8,700**	**8,650**
Cement	5,870	4,690	4,300	4,700	5,290	5,360	5,790	5,870	6,060	6,310	6,310	6,490
Lime	1,850	1,880	1,880	1,880	1,930	1,990	1,900	1,960	1,940	2,030	2,000	1,750
Limestone and Soda Use	-	-	-	-	-	-	-	-	1,000	1,000	-	-
b. Chemical Industry	**16,500**	**15,700**	**15,800**	**15,500**	**17,500**	**18,000**	**18,800**	**17,300**	**12,400**	**9,000**	**9,000**	**8,000**
Ammonia Production	5,010	4,940	5,110	5,690	5,810	6,480	6,520	6,680	6,610	6,850	6,850	5,920
Nitric Acid Production	780	770	780	780	770	780	790	790	770	790	800	800
Adipic Acid Production	10,700	10,000	10,000	9,080	11,000	10,700	11,500	9,890	5,070	1,750	900	800
c. Metal Production	**19,100**	**21,500**	**21,100**	**21,900**	**20,700**	**19,900**	**19,300**	**19,200**	**19,700**	**20,300**	**20,900**	**20,300**
Iron and Steel Production	7,590	8,900	9,080	8,760	8,090	8,440	8,290	8,100	8,320	8,500	8,510	7,920
Aluminium Production	8,610	9,330	9,810	11,200	10,600	9,560	8	9,760	9,840	10,100	10,000	10,300
SF_6 used in Magnesium Smelters	2,870	3,260	2,170	2,010	2,040	1,880	1,360	1,390	1,540	1,670	2,310	2,020
d. Consumption of Halocarbons	-	-	-	-	-	**510**	**910**	**880**	**940**	**940**	**940**	**940**
e. Other & Undifferentiated Production	**9,220**	**9,560**	**8,960**	**9,680**	**10,580**	**10,180**	**11,370**	**11,530**	**11,500**	**11,840**	**11,850**	**11,660**
SOLVENT & OTHER PRODUCT USE	**417**	**422**	**428**	**432**	**437**	**442**	**447**	**452**	**456**	**459**	**463**	**468**
AGRICULTURE	**59,200**	**58,100**	**58,200**	**58,400**	**60,700**	**61,100**	**61,700**	**61,300**	**60,900**	**61,100**	**60,800**	**60,000**
a. Enteric Fermentation	16,000	16,100	16,600	16,700	17,500	18,100	18,200	18,400	18,000	17,800	17,700	18,800
b. Manure Management	8,270	8,310	8,470	8,500	8,930	9,220	9,350	9,300	9,370	9,410	9,380	10,100
c. Agriculture Soils	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000
Direct Sources	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	20,000
Indirect Sources	5,000	5,000	6,000	6,000	6,000	6,000	7,000	7,000	7,000	7,000	7,000	7,000
LAND-USE CHANGE AND FORESTRY (non-CO_2 only)[1]	**2,260**	**3,840**	**2,430**	**2,720**	**3,040**	**4,670**	**1,840**	**750**	**2,910**	**1,410**	**660**	**2,080**
a. Prescribed Burns	1,560	2,010	1,560	1,410	540	-	-	-	-	560	580	570
b. Wildfires in the Wood Production Forest	700	1,820	880	1,310	2,500	4,260	1,400	0	2,470	850	-	1,510
WASTE	**20,100**	**20,700**	**21,200**	**21,700**	**21,900**	**22,000**	**22,100**	**22,600**	**23,100**	**23,800**	**24,300**	**24,800**
a. Solid Waste Disposal on Land	18,500	19,200	19,600	20,100	20,300	20,400	20,400	20,900	21,400	22,100	22,600	23,100
b. Wastewater Handling	1,220	1,240	1,250	1,270	1,280	1,300	1,310	1,330	1,340	1,350	1,360	1,370
c. Waste Incineration	-	-	-	-	-	-	-	-	-	-	-	-
LAND USE CHANGE AND FORESTRY[1]	**-100,000**	**-90,000**	**-90,000**	**-70,000**	**-40,000**	**-10,000**	**-40,000**	**-50,000**	**-30,000**	**-30,000**	**-50,000**	**-40,000**
a. Changes in Forest and Woody Biomass Stocks	-100,000	-100,000	-90,000	-70,000	-40,000	-10,000	-40,000	-50,000	-40,000	-30,000	-60,000	-40,000
b. Forest and Grassland Conversion	1,000	1,000	1,000	2,000	2,000	2,000	3,000	3,000	3,000	3,000	3,000	4,000
c. Abandonment of Managed Lands	-3,000	-3,000	-3,000	-3,000	-3,000	-3,000	-3,000	-3,000	-3,000	-3,000	-3,000	-3,000
d. CO_2 Emissions and Removals from Soil	4,000	4,000	3,000	3,000	3,000	2,000	3,000	3,000	2,000	2,000	2,000	2,000

Notes:

1 CO_2 emissions and removals in the LUCF sector are not included in the national totals. Non-CO_2 emissions from fires located in the National Parks are not included in the provincial/territorial totals but are reported in the national totals.

Totals may not add due to rounding.

1990 to 2001 Greenhouse Gas Emission Estimates for Newfoundland, by Sector

GHG Source and Sink Category	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
						All Gases kt CO_2 eq						
TOTAL	**9,440**	**8,220**	**8,110**	**8,230**	**7,300**	**8,220**	**8,330**	**8,820**	**10,230**	**9,070**	**8,840**	**9,550**
ENERGY	**8,890**	**7,670**	**7,570**	**7,670**	**6,720**	**7,630**	**7,730**	**8,230**	**9,630**	**8,380**	**8,230**	**9,030**
a. Stationary Combustion Sources	**5,410**	**4,500**	**4,430**	**4,500**	**3,650**	**4,500**	**4,490**	**4,940**	**6,310**	**4,890**	**4,470**	**5,250**
Electricity and Heat Generation	1,610	1,280	1,480	1,340	720	1,250	1,160	1,210	1,020	990	980	1,830
Fossil Fuel Industries	1,050	1,020	865	1,050	574	944	1,080	1,250	3,180	2,030	1,430	1,420
Mining	1,050	672	581	565	907	900	927	1,050	895	641	885	737
Manufacturing Industries	497	386	310	330	299	315	269	282	211	252	241	259
Construction	33	24	27	22	18	18	15	15	13	12	10	19
Commercial & Institutional	326	317	307	329	341	321	312	364	306	316	325	391
Residential	818	759	800	804	741	692	673	691	614	584	553	579
Agriculture & Forestry	25	42	61	56	54	57	59	76	76	69	48	9
b. Transportation Combustion Sources	**3,480**	**3,170**	**3,140**	**3,160**	**3,070**	**3,140**	**3,240**	**3,300**	**3,300**	**3,420**	**3,640**	**3,650**
Domestic Aviation	518	393	449	383	368	396	408	394	361	340	418	417
Road Transportation	1,900	1,900	1,850	1,900	1,950	1,890	1,870	1,870	1,870	1,960	2,010	2,010
Gasoline Automobiles	770	743	743	749	748	718	700	682	655	667	648	643
Light Duty Gasoline Trucks	566	569	590	615	638	631	634	639	645	695	697	701
Heavy Duty Gasoline Vehicles	75	75	78	81	84	83	75	57	68	47	45	36
Motorcycles	7	6	5	5	5	5	5	4	4	4	4	4
Diesel Automobiles	4	3	3	3	3	2	2	2	2	2	2	2
Light Duty Diesel Trucks	14	13	9	8	7	5	4	6	4	7	7	8
Heavy Duty Diesel Vehicles	459	484	422	435	464	442	452	482	488	535	608	612
Propane & Natural Gas Vehicles	1	2	1	6	2	2	2	3	1	4	1	1
Railways	-	-	-	-	-	-	-	-	-	-	-	-
Domestic Marine	706	659	613	540	466	562	610	623	647	688	692	622
Others	361	223	229	339	290	290	346	406	427	427	523	608
Off Road	361	223	229	339	290	290	346	406	427	427	523	608
Pipelines	-	-	-	-	-	-	-	-	-	-	-	-
c. Fugitive Sources	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**18**	**74**	**118**	**126**
Coal Mining	-	-	-	-	-	-	-	-	-	-	-	-
Oil and Natural Gas	-	-	-	-	-	-	-	-	18	74	120	130
INDUSTRIAL PROCESSES	**77**	**69**	**63**	**79**	**77**	**77**	**74**	**78**	**81**	**92**	**85**	**23**
a. Mineral Production[1]	**59**	**54**	**49**	**65**	**63**	**63**	**59**	**62**	**68**	**71**	**62**	**-**
Cement	59	54	49	65	63	63	59	62	68	71	62	-
Lime	-	-	-	-	-	-	-	-	-	-	-	-
b. Chemical Industry[2]	-	-	-	-	-	-	-	-	-	-	-	-
Nitric Acid Production	-	-	-	-	-	-	-	-	-	-	-	-
Adipic Acid Production	-	-	-	-	-	-	-	-	-	-	-	-
c. Metal Production	-	-	-	-	-	-	-	-	-	-	-	-
Iron and Steel Production	-	-	-	-	-	-	-	-	-	-	-	-
Aluminum Production	-	-	-	-	-	-	-	-	-	-	-	-
SF6 used in Magnesium Smelters	-	-	-	-	-	-	-	-	-	-	-	-
d. Consumption of Halocarbons[1]	-	-	-	-	-	-	-	-	-	-	-	-
e. Other & Undifferentiated Production[2]	**19**	**15**	**14**	**14**	**14**	**15**	**15**	**16**	**14**	**21**	**23**	**23**
SOLVENT & OTHER PRODUCT USE	**9**	**9**	**9**	**9**	**9**	**9**	**8**	**8**	**8**	**8**	**8**	**8**
AGRICULTURE	**77**	**76**	**79**	**80**	**82**	**87**	**85**	**81**	**82**	**83**	**83**	**43**
a. Enteric Fermentation	18	18	18	18	17	17	17	17	16	16	16	18
b. Manure Management	25	25	25	26	27	28	29	27	28	29	29	9
c. Agriculture Soils	30	30	40	40	40	40	40	40	40	40	40	20
Direct Sources	30	20	30	30	30	30	30	30	30	30	30	10
Indirect Sources	9	9	9	9	10	10	10	10	10	10	10	3
LAND-USE CHANGE AND FORESTRY (non-CO_2 only)[3]	**18**	**26**	**4**	**6**	**7**	**4**	**19**	**1**	**9**	**75**	**-**	**14**
a. Prescribed Burns	11	3	1	6	5	3	-	-	-	-	-	1
b. Wildfires in the Wood Production Forest	8	23	3	-	3	-	19	1	9	75	-	13
WASTE	**364**	**374**	**383**	**392**	**398**	**405**	**8**	**418**	**423**	**428**	**433**	**437**
a. Solid Waste Disposal on Land	337	347	356	364	371	378	385	391	397	402	407	412
b. Wastewater Handling	19	19	19	19	19	19	19	18	18	18	18	18
c. Waste Incineration	8	8	8	8	8	8	8	8	8	8	8	8

Notes:

1 Emissions associated with the use of HFCs, PFCs, limestone and soda ash are reported in the national industrial processes total.

2 Ammonia production emissions are included under undifferentiated production at the provincial level.

3 CO_2 emissions and removals in the LUCF sector are not included in the national totals. Non-CO_2 emissions from fires located in the National Parks are not included in the provincial/territorial totals but are reported in the national totals.

Totals may not add due to rounding.

1990 to 2001 Greenhouse Gas Emission Estimates for Prince Edward Island, by Sector

GHG Source and Sink Category	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
						All Gases kt CO_2 eq						
TOTAL	**1,960**	**1,920**	**1,940**	**1,920**	**1,920**	**1,880**	**2,000**	**2,040**	**1,990**	**2,020**	**2,170**	**2,060**
ENERGY	**1,470**	**1,440**	**1,420**	**1,420**	**1,410**	**1,370**	**1,480**	**1,520**	**1,470**	**1,490**	**1,650**	**1,570**
a. Stationary Combustion Sources	**749**	**713**	**708**	**709**	**676**	**649**	**693**	**747**	**668**	**639**	**778**	**723**
Electricity and Heat Generation	102	92	52	75	59	39	27	37	11	39	83	77
Fossil Fuel Industries	-	-	1	2	1	2	2	2	3	1	2	-
Mining	1	1	1	-	-	1	1	1	2	2	5	3
Manufacturing Industries	55	70	77	79	80	72	91	110	91	56	133	129
Construction	11	10	10	9	9	7	6	5	7	6	7	5
Commercial & Institutional	161	157	160	158	161	180	184	192	177	171	198	199
Residential	399	363	379	358	339	310	334	349	329	321	318	299
Agriculture & Forestry	19	20	28	28	27	41	47	51	49	44	32	12
b. Transportation Combustion Sources	**717**	**723**	**715**	**709**	**733**	**717**	**785**	**770**	**801**	**856**	**871**	**844**
Domestic Aviation	15	12	9	9	9	8	11	12	11	11	10	10
Road Transportation	541	537	537	546	567	579	594	611	646	684	672	663
Gasoline Automobiles	286	273	264	258	256	253	247	252	249	276	259	254
Light-Duty Gasoline Trucks	146	149	154	161	170	180	192	201	215	240	242	246
Heavy-Duty Gasoline Vehicles	21	24	28	32	36	40	42	39	49	28	25	22
Motorcycles	1	1	1	1	1	1	1	1	1	1	1	1
Diesel Automobiles	3	3	3	3	3	3	3	3	3	3	3	3
Light-Duty Diesel Trucks	2	2	2	1	1	1	1	1	1	2	2	2
Heavy-Duty Diesel Vehicles	80	85	85	90	101	100	106	113	128	133	140	136
Propane & Natural Gas Vehicles	1	1	1	1	-	1	1	1	1	2	1	1
Railways	-	-	-	-	-	-	-	-	-	-	-	-
Domestic Marine	90	114	128	111	91	63	113	72	66	74	85	85
Others	72	61	40	42	66	67	67	76	78	87	104	86
Off-Road	72	61	40	42	66	67	67	76	78	87	104	86
Pipelines	-	-	-	-	-	-	-	-	-	-	-	-
c. Fugitive Sources	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Coal Mining	-	-	-	-	-	-	-	-	-	-	-	-
Oil and Natural Gas	-	-	-	-	-	-	-	-	-	-	-	-
INDUSTRIAL PROCESSES	**3**	**3**	**3**	**3**	**4**	**3**	**3**	**3**	**3**	**3**	**3**	**3**
a. Mineral Production[1]	-	-	-	-	-	-	-	-	-	-	-	-
Cement	-	-	-	-	-	-	-	-	-	-	-	-
Lime	-	-	-	-	-	-	-	-	-	-	-	-
b. Chemical Industry[2]	-	-	-	-	-	-	-	-	-	-	-	-
Nitric Acid Production	-	-	-	-	-	-	-	-	-	-	-	-
Adipic Acid Production	-	-	-	-	-	-	-	-	-	-	-	-
c. Metal Production	-	-	-	-	-	-	-	-	-	-	-	-
Iron and Steel Production	-	-	-	-	-	-	-	-	-	-	-	-
Aluminium Production	-	-	-	-	-	-	-	-	-	-	-	-
SF_6 used in Magnesium Smelters	-	-	-	-	-	-	-	-	-	-	-	-
d. Consumption of Halocarbons[1]	-	-	-	-	-	-	-	-	-	-	-	-
e. Other & Undifferentiated Production[2]	**3**	**3**	**3**	**3**	**4**	**3**	**3**	**3**	**3**	**3**	**3**	**3**
SOLVENT & OTHER PRODUCT USE	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**
AGRICULTURE	**408**	**405**	**437**	**411**	**424**	**422**	**433**	**426**	**430**	**430**	**429**	**397**
a. Enteric Fermentation	135	131	130	129	130	130	129	129	130	131	127	118
b. Manure Management	77	76	74	73	76	78	78	75	75	78	77	70
c. Agriculture Soils	200	200	200	200	200	200	200	200	200	200	200	200
Direct Sources	200	200	200	200	200	200	200	200	200	200	200	200
Indirect Sources	40	40	40	40	40	40	40	40	40	40	40	40
LAND-USE CHANGE AND FORESTRY (non-CO_2 only)[3]	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
a. Prescribed Burns	-	-	-	-	-	-	-	-	-	-	-	-
b. Wildfires in the Wood Production Forest	-	-	-	-	-	-	-	-	-	-	-	-
WASTE	**77**	**78**	**79**	**81**	**83**	**84**	**8**	**87**	**88**	**90**	**91**	**93**
a. Solid Waste Disposal on Land	61	62	64	65	67	68	69	71	72	73	75	76
b. Wastewater Handling	7	7	7	7	7	7	7	7	7	7	8	8
c. Waste Incineration	8	8	9	9	9	9	9	9	9	9	9	9

Notes:

1 Emissions associated with the use of HFCs, PFCs, limestone and soda ash are reported in the national industrial processes total.

2 Ammonia production emissions are included under undifferentiated production at the provincial level.

3 CO_2 emissions and removals in the LUCF sector are not included in the national totals. Non-CO_2 emissions from fires located in the National Parks are not included in the provincial/territorial totals but are reported in the national totals.

Totals may not add due to rounding.

1990 to 2001 Greenhouse Gas Emission Estimates for Nova Scotia, by Sector

GHG Source and Sink Category	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
						All Gases kt CO_2 eq						
TOTAL	**19,400**	**19,300**	**19,800**	**19,800**	**19,300**	**19,000**	**19,100**	**19,700**	**19,800**	**20,500**	**21,600**	**20,900**
ENERGY	**799**	**17,800**	**18,400**	**18,300**	**17,700**	**17,400**	**17,500**	**18,200**	**18,100**	**18,800**	**20,000**	**19,300**
a. Stationary Combustion Sources	**11,500**	**11,400**	**12,100**	**12,000**	**11,400**	**11,200**	**11,500**	**12,200**	**12,100**	**12,600**	**13,800**	**13,200**
Electricity and Heat Generation	6,830	7,010	7,410	7,350	7,190	6,850	7,070	7,520	7,800	8,220	9,060	8,710
Fossil Fuel Industries	714	799	790	914	598	699	730	709	701	570	952	819
Mining	35	33	32	22	30	33	39	41	47	48	54	45
Manufacturing Industries	712	621	633	638	763	870	800	757	779	799	658	516
Construction	50	37	32	26	30	35	29	30	36	32	28	37
Commercial & Institutional	810	794	948	789	735	817	809	946	756	865	922	1,070
Residential	2,210	1,950	2,060	2,090	1,950	1,680	1,790	1,910	1,790	1,810	1,830	1,870
Agriculture & Forestry	107	191	237	154	148	203	227	250	222	209	237	135
b. Transportation Combustion Sources	**5,200**	**5,010**	**5,010**	**5,190**	**5,320**	**5,380**	**5,220**	**5,340**	**5,490**	**5,940**	**5,880**	**5,660**
Domestic Aviation	496	492	455	498	483	491	472	454	464	498	485	438
Road Transportation	3,610	3,410	3,520	3,620	3,550	3,820	3,820	3,780	3,740	4,160	4,100	4,030
Gasoline Automobiles	1,680	1,550	1,570	1,610	1,540	1,640	1,580	1,550	1,370	1,610	1,460	1,450
Light-Duty Gasoline Trucks	939	908	956	1,020	1,010	1,120	1,150	1,160	1,230	1,380	1,440	1,390
Heavy-Duty Gasoline Vehicles	136	129	133	137	133	144	141	121	137	88	97	74
Motorcycles	12	12	11	11	10	10	12	9	10	10	9	9
Diesel Automobiles	26	25	26	27	26	28	28	28	25	29	28	29
Light-Duty Diesel Trucks	21	17	15	13	11	10	8	10	8	12	16	15
Heavy-Duty Diesel Vehicles	790	757	797	800	826	854	896	894	951	1,010	1,040	1,060
Propane & Natural Gas Vehicles	7	7	7	8	3	5	6	9	5	14	4	4
Railways	67	50	58	57	60	46	34	36	42	60	76	72
Domestic Marine	615	698	614	599	631	571	571	597	661	718	670	536
Others	417	361	370	414	592	452	324	473	584	506	551	583
Off-Road	417	361	370	414	592	452	324	473	584	506	551	583
Pipelines	-	-	-	-	-	-	-	-	-	-	-	-
c. Fugitive Sources	**1,170**	**1,340**	**1,200**	**1,080**	**972**	**835**	**835**	**690**	**511**	**335**	**394**	**473**
Coal Mining	1,200	1,300	1,200	1,100	970	830	830	690	510	330	24	270
Oil and Natural Gas	-	-	3	5	6	6	5	4	4	2	140	200
INDUSTRIAL PROCESSES	**300**	**259**	**234**	**287**	**275**	**293**	**280**	**263**	**316**	**300**	**275**	**263**
a. Mineral Production[1]	**199**	**182**	**166**	**228**	**219**	**217**	**210**	**192**	**204**	**213**	**206**	**201**
Cement	199	182	166	228	219	217	210	192	204	213	206	201
Lime	-	-	-	-	-	-	-	-	-	-	-	-
b. Chemical Industry[2]	-	-	-	-	-	-	-	-	-	-	-	-
Nitric Acid Production	-	-	-	-	-	-	-	-	-	-	-	-
Adipic Acid Production	-	-	-	-	-	-	-	-	-	-	-	-
c. Metal Production	-	-	-	-	-	-	-	-	-	-	-	-
Iron and Steel Production	-	-	-	-	-	-	-	-	-	-	-	-
Aluminium Production	-	-	-	-	-	-	-	-	-	-	-	-
SF_6 used in Magnesium Smelters	-	-	-	-	-	-	-	-	-	-	-	-
d. Consumption of Halocarbons[1]	-	-	-	-	-	-	-	-	-	-	-	-
e. Other & Undifferentiated Production[2]	**101**	**77**	**68**	**59**	**56**	**77**	**70**	**71**	**112**	**88**	**69**	**62**
SOLVENT & OTHER PRODUCT USE	**14**	**14**	**14**	**14**	**14**	**14**	**14**	**14**	**14**	**14**	**14**	**14**
AGRICULTURE	**609**	**605**	**605**	**593**	**620**	**619**	**633**	**620**	**613**	**616**	**612**	**591**
a. Enteric Fermentation	189	188	186	185	185	185	184	186	178	175	170	164
b. Manure Management	139	137	134	134	138	142	144	144	144	149	146	143
c. Agriculture Soils	300	300	300	300	300	300	300	300	300	300	300	300
Direct Sources	200	200	200	200	200	200	200	200	200	200	200	200
Indirect Sources	60	60	60	60	60	70	70	70	70	70	70	70
LAND-USE CHANGE AND FORESTRY (non-CO_2 only)[3]	**2**	**4**	**3**	**-**	**-**	**1**	**1**	**1**	**1**	**4**	**4**	**2**
a. Prescribed Burns	-	-	-	-	-	-	-	-	-	-	-	-
b. Wildfires in the Wood Production Forest	2	4	3	-	-	1	1	1	1	4	4	2
WASTE	**593**	**605**	**617**	**631**	**614**	**629**	**8**	**664**	**677**	**691**	**705**	**718**
a. Solid Waste Disposal on Land	538	550	562	575	558	573	593	608	621	635	648	662
b. Wastewater Handling	39	39	39	39	39	40	40	40	40	40	40	40
c. Waste Incineration	16	16	16	16	16	16	16	16	16	16	16	16

Notes:

1 Emissions associated with the use of HFCs, PFCs, limestone and soda ash are reported in the national industrial processes total.

2 Ammonia production emissions are included under undifferentiated production at the provincial level.

3 CO_2 emissions and removals in the LUCF sector are not included in the national totals. Non-CO_2 emissions from fires located in the National Parks are not included in the provincial/territorial totals but are reported in the national totals.

Totals may not add due to rounding.

1990 to 2001 Greenhouse Gas Emission Estimates for New Brunswick, by Sector

GHG Source and Sink Category	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
						All Gases kt CO_2 eq						
TOTAL	**15,900**	**15,300**	**16,000**	**15,200**	**16,600**	**16,800**	**16,600**	**19,000**	**19,900**	**19,100**	**20,300**	**22,700**
ENERGY	**14,700**	**14,100**	**14,700**	**14,000**	**15,400**	**15,500**	**15,300**	**17,700**	**18,500**	**17,700**	**19,000**	**21,300**
a. Stationary Combustion Sources	**10,600**	**10,000**	**10,500**	**9,700**	**10,800**	**11,000**	**10,600**	**12,800**	**13,500**	**12,300**	**13,300**	**15,600**
Electricity and Heat Generation	6,000	5,460	6,130	5,170	6,340	6,760	5,990	8,300	9,460	8,280	8,670	10,110
Fossil Fuel Industries	1,130	1,090	1,110	1,250	1,280	997	1,430	1,340	1,210	1,280	1,610	2,810
Mining	127	82	96	103	115	117	153	121	98	97	134	122
Manufacturing Industries	1,410	1,400	1,360	1,400	1,380	1,450	1,410	1,340	1,200	1,240	1,320	1,170
Construction	68	53	53	35	41	41	40	49	39	37	40	27
Commercial & Institutional	587	655	507	461	505	555	495	593	504	491	614	607
Residential	1,200	1,190	1,190	1,160	1,050	917	933	957	844	817	853	765
Agriculture & Forestry	54	65	81	87	87	131	110	119	104	101	66	26
b. Transportation Combustion Sources	**4,120**	**4,080**	**4,210**	**4,300**	**4,560**	**4,520**	**4,700**	**4,860**	**5,060**	**5,360**	**5,630**	**5,590**
Domestic Aviation	94	92	97	92	108	117	121	190	189	202	216	204
Road Transportation	3,280	3,200	3,250	3,360	3,530	3,540	3,650	3,710	3,750	4,040	3,920	3,860
Gasoline Automobiles	1,570	1,500	1,490	1,490	1,500	1,430	1,450	1,450	1,470	1,480	1,350	1,390
Light-Duty Gasoline Trucks	705	712	756	797	848	853	914	946	943	1,040	1,050	1,080
Heavy-Duty Gasoline Vehicles	101	104	111	118	125	126	137	110	126	69	86	66
Motorcycles	7	6	6	6	7	6	7	7	8	7	8	8
Diesel Automobiles	19	18	18	19	19	18	19	19	19	18	18	18
Light-Duty Diesel Trucks	21	17	14	12	12	10	9	16	14	19	16	19
Heavy-Duty Diesel Vehicles	847	837	850	910	1,010	1,090	1,100	1,150	1,160	1,390	1,390	1,270
Propane & Natural Gas Vehicles	5.0	5.0	5.0	9.0	4.0	8.0	8.0	10.0	9.0	16.0	7.0	10.0
Railways	132	134	142	131	121	115	113	148	184	203	236	262
Domestic Marine	268	264	294	279	304	301	307	307	327	355	403	428
Others	347	395	419	439	499	455	508	502	612	561	848	839
Off-Road	347	395	419	439	499	455	508	502	612	561	848	839
Pipelines	-	-	-	-	-	-	-	-	-	-	-	-
c. Fugitive Sources	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**-**	**1**	**1**	**30**	**30**
Coal Mining	1	1	1	1	1	1	1	-	1	1	1	-
Oil and Natural Gas	-	-	-	-	-	-	-	-	-	-	29	29
INDUSTRIAL PROCESSES	**154**	**169**	**181**	**193**	**137**	**260**	**255**	**254**	**248**	**244**	**229**	**266**
a. Mineral Production[1]	**78**	**76**	**81**	**88**	**93**	**97**	**96**	**100**	**100**	**105**	**106**	**98**
Cement	-	-	-	-	-	-	-	-	-	-	-	-
Lime	78	76	81	88	93	97	96	100	100	105	106	98
b. Chemical Industry[2]	-	-	-	-	-	-	-	-	-	-	-	-
Nitric Acid Production	-	-	-	-	-	-	-	-	-	-	-	-
Adipic Acid Production	-	-	-	-	-	-	-	-	-	-	-	-
c. Metal Production	-	-	-	-	-	-	-	-	-	-	-	-
Iron and Steel Production	-	-	-	-	-	-	-	-	-	-	-	-
Aluminium Production	-	-	-	-	-	-	-	-	-	-	-	-
SF_6 used in Magnesium Smelters	-	-	-	-	-	-	-	-	-	-	-	-
d. Consumption of Halocarbons[1]	-	-	-	-	-	-	-	-	-	-	-	-
e. Other & Undifferentiated Production[2]	**75**	**92**	**100**	**105**	**44**	**163**	**160**	**154**	**148**	**139**	**123**	**168**
SOLVENT & OTHER PRODUCT USE	**11**	**11**	**11**	**11**	**11**	**11**	**11**	**11**	**11**	**11**	**11**	**11**
AGRICULTURE	**495**	**486**	**504**	**496**	**496**	**509**	**515**	**508**	**521**	**524**	**533**	**536**
a. Enteric Fermentation	152	151	150	149	149	148	148	143	144	143	140	136
b. Manure Management	102	101	102	101	106	106	109	106	111	113	116	124
c. Agriculture Soils	200	200	300	200	200	300	300	300	300	300	300	300
Direct Sources	200	200	200	200	200	200	200	200	200	200	200	200
Indirect Sources	50	50	50	50	50	50	60	60	60	60	60	60
LAND-USE CHANGE AND FORESTRY (non-CO_2 only)[3]	**19**	**10**	**17**	**2**	**1**	**1**	**6**	**1**	**1**	**4**	**1**	**6**
a. Prescribed Burns	-	-	-	-	-	-	-	-	-	-	-	-
b. Wildfires in the Wood Production Forest	19	10	17	2	1	1	6	1	1	4	1	6
WASTE	**499**	**510**	**521**	**532**	**543**	**554**	**8**	**575**	**585**	**595**	**605**	**614**
a. Solid Waste Disposal on Land	448	460	470	481	492	503	513	524	534	543	553	563
b. Wastewater Handling	50	51	51	51	51	51	51	51	51	51	52	52
c. Waste Incineration	-	-	-	-	-	-	-	-	-	-	-	-

Notes:

1 Emissions associated with the use of HFCs, PFCs, limestone and soda ash are reported in the national industrial processes total.

2 Ammonia production emissions are included under undifferentiated production at the provincial level.

3 CO_2 emissions and removals in the LUCF sector are not included in the national totals. Non-CO_2 emissions from fires located in the National Parks are not included in the provincial/territorial totals but are reported in the national totals.

Totals may not add due to rounding.

1990 to 2001 Greenhouse Gas Emission Estimates for Quebec, by Sector

GHG Source and Sink Category	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
						All Gases kt CO_2 eq						
TOTAL	**86,000**	**81,400**	**81,900**	**83,300**	**86,300**	**85,500**	**86,600**	**86,400**	**87,800**	**89,200**	**90,600**	**90,000**
ENERGY	**59,400**	**54,300**	**56,400**	**56,500**	**59,300**	**58,400**	**59,700**	**59,900**	**61,300**	**62,000**	**63,100**	**61,200**
a. Stationary Combustion Sources	**29,800**	**26,500**	**27,600**	**27,000**	**28,000**	**27,200**	**28,300**	**28,000**	**27,700**	**27,900**	**29,100**	**27,400**
Electricity and Heat Generation	1,510	526	946	295	502	396	425	459	1,560	1,930	1,410	1,440
Fossil Fuel Industries	3,690	3,040	3,140	3,320	3,560	3,330	3,520	3,380	3,450	3,250	3,600	3,610
Mining	734	805	730	798	736	824	825	870	760	759	921	860
Manufacturing Industries	11,900	10,800	10,800	10,600	11,200	10,800	11,400	11,500	11,300	10,900	11,000	9,900
Construction	458	399	371	289	275	188	191	225	188	191	190	192
Commercial & Institutional	4,270	4,180	4,500	4,650	4,730	5,070	5,000	5,000	4,670	4,710	5,720	5,790
Residential	6,990	6,370	6,640	6,700	6,680	6,250	6,680	6,320	5,600	5,860	5,980	5,340
Agriculture & Forestry	293	380	449	348	330	302	277	289	258	264	261	243
b. Transportation Combustion Sources	**29,300**	**27,500**	**28,500**	**29,200**	**30,900**	**30,800**	**31,000**	**31,500**	**33,100**	**33,600**	**33,600**	**33,400**
Domestic Aviation	1,880	1,420	1,720	1,550	1,740	1,670	1,800	1,470	1,640	1,710	1,880	2,040
Road Transportation	24,000	23,200	24,000	24,600	25,700	26,400	26,900	27,400	28,100	28,600	28,000	27,900
Gasoline Automobiles	13,800	12,800	13,100	13,400	13,600	13,600	13,400	13,100	13,300	13,200	12,900	12,700
Light-Duty Gasoline Trucks	3,320	3,380	3,750	4,110	4,490	4,730	5,000	5,160	5,450	6,050	6,120	6,340
Heavy-Duty Gasoline Vehicles	520	508	541	572	604	620	850	796	843	625	626	621
Motorcycles	45	41	41	43	45	47	49	50	55	59	64	68
Diesel Automobiles	247	232	237	241	245	243	238	231	229	223	228	225
Light-Duty Diesel Trucks	95	86	79	74	74	76	75	84	94	96	112	102
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	7,770
Propane & Natural Gas Vehicles	111	112	119	86	55	46	36	45	51	35	36	59
Railways	583	618	628	612	611	556	445	501	740	887	827	775
Domestic Marine	1,400	1,440	1,410	1,110	1,280	910	928	1,050	1,590	1,320	1,370	1,570
Others	1,400	910	784	1,240	1,570	1,260	907	1,050	990	1,060	1,450	1,060
Off-Road	1,370	882	753	1,210	1,540	1,230	889	1,020	974	1,040	1,340	860
Pipelines	26	28	30	26	27	24	18	26	16	25	107	203
c. Fugitive Sources	**281**	**315**	**320**	**326**	**385**	**396**	**404**	**406**	**439**	**441**	**444**	**444**
Coal Mining	-	-	-	-	-	-	-	-	-	-	-	-
Oil and Natural Gas	280	320	320	330	380	400	400	410	440	440	440	440
INDUSTRIAL PROCESSES	**12,600**	**12,900**	**12,300**	**13,300**	**13,300**	**12,500**	**11,800**	**11,900**	**12,000**	**12,400**	**12,900**	**13,400**
a. Mineral Production[1]	**1,710**	**1,410**	**1,220**	**1,410**	**1,670**	**1,720**	**1,690**	**1,720**	**1,770**	**1,600**	**1,550**	**1,500**
Cement	1,430	1,130	955	1,170	1,420	1,400	1,420	1,310	1,350	1,170	1,110	1,090
Lime	278	271	269	242	255	322	262	417	417	436	443	410
b. Chemical Industry[2]	**15**	**14**	**15**	**15**	**14**	**15**	**14**	**14**	**13**	**14**	**15**	**14**
Nitric Acid Production	15	14	15	15	14	15	14	14	13	14	15	14
Adipic Acid Production	-	-	-	-	-	-	-	-	-	-	-	-
c. Metal Production	**9,690**	**10,800**	**10,200**	**11,400**	**10,900**	**9,770**	**9,300**	**9,340**	**9,550**	**9,740**	**10,100**	**10,500**
Iron and Steel Production	-	1	8	9	7	7	9	6	9	7	13	13
Aluminium Production	7,330	8,050	8,510	9,850	9,320	8,420	8,460	8,610	8,670	8,900	8,840	9,230
SF_6 used in Magnesium Smelters	2,370	2,760	1,670	1,510	1,530	1,340	837	731	875	838	1,230	1,280
d. Consumption of Halocarbons[1]	-	-	-	-	-	-	-	-	-	-	-	-
e. Other & Undifferentiated Production[2]	**1,200**	**727**	**866**	**490**	**718**	**962**	**836**	**814**	**668**	**1,030**	**1,260**	**1,380**
SOLVENT & OTHER PRODUCT USE	**106**	**106**	**107**	**108**	**109**	**109**	**110**	**110**	**110**	**111**	**111**	**112**
AGRICULTURE	**8,060**	**7,610**	**7,570**	**7,810**	**7,980**	**8,100**	**8,220**	**8,170**	**8,150**	**8,120**	**7,820**	**8,160**
a. Enteric Fermentation	2,440	2,360	2,350	2,360	2,400	2,420	2,470	2,410	2,310	2,230	2,170	2,210
b. Manure Management	1,980	1,950	1,950	1,960	2,030	2,080	2,130	2,120	2,120	2,120	2,080	2,230
c. Agriculture Soils	4,000	3,000	3,000	3,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
Direct Sources	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000
Indirect Sources	800	700	700	700	700	800	800	800	800	800	800	800
LAND-USE CHANGE AND FORESTRY (non-CO_2 only)[3]	**44**	**1,095**	**25**	**4**	**6**	**581**	**840**	**254**	**32**	**96**	**2**	**271**
a. Prescribed Burns	0	0	0	1	-	-	-	-	-	-	-	-
b. Wildfires in the Wood Production Forest	44	1,095	25	3	6	581	840	254	32	96	2	271
WASTE	**5,770**	**5,300**	**5,500**	**5,670**	**5,620**	**5,780**	**8**	**6,030**	**6,180**	**6,530**	**6,670**	**6,810**
a. Solid Waste Disposal on Land	5,380	4,910	5,100	5,280	5,220	5,380	5,480	5,630	5,770	6,120	6,260	6,390
b. Wastewater Handling	251	253	254	256	258	259	260	261	262	263	264	265
c. Waste Incineration	138	139	141	141	143	144	144	145	145	146	146	147

Notes:

1 Emissions associated with the use of HFCs, PFCs, limestone and soda ash are reported in the national industrial processes total.

2 Ammonia production emissions are included under undifferentiated production at the provincial level.

3 CO_2 emissions and removals in the LUCF sector are not included in the national totals. Non-CO_2 emissions from fires located in the National Parks are not included in the provincial/territorial totals but are reported in the national totals.

Totals may not add due to rounding.

1990 to 2001 Greenhouse Gas Emission Estimates for Ontario, by Sector

GHG Source and Sink Category	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
							All Gases kt CO_2 eq					
TOTAL	**181,000**	**180,000**	**184,000**	**175,000**	**178,000**	**181,000**	**189,000**	**194,000**	**194,000**	**200,000**	**209,000**	**201,000**
ENERGY	**136,000**	**134,000**	**138,000**	**130,000**	**131,000**	**133,000**	**141,000**	**148,000**	**152,000**	**160,000**	**170,000**	**163,000**
a. Stationary Combustion Sources	**84,500**	**84,300**	**86,300**	**77,700**	**76,700**	**77,400**	**83,100**	**87,800**	**90,100**	**95,200**	**104,900**	**100,400**
Electricity and Heat Generation	26,600	28,000	27,900	18,800	16,500	18,900	20,600	25,800	33,700	36,200	43,400	40,900
Fossil Fuel Industries	6,660	5,970	6,530	6,720	6,170	5,950	6,410	6,290	6,470	6,230	6,570	6,550
Mining	501	675	811	553	651	678	680	658	528	459	469	402
Manufacturing Industries	22,800	21,500	21,100	20,700	21,900	21,100	21,500	21,900	21,100	21,300	20,800	19,800
Construction	573	527	559	337	421	373	444	492	451	477	439	384
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
Residential	17,400	17,000	18,100	19,400	20,200	19,400	21,400	20,200	16,600	18,000	19,100	18,000
Agriculture & Forestry	781	894	1,106	997	940	1,153	1,130	1,055	936	959	902	752
b. Transportation Combustion Sources	**49,700**	**48,300**	**49,900**	**51,200**	**52,600**	**54,400**	**56,000**	**58,700**	**60,100**	**62,900**	**63,800**	**61,200**
Domestic Aviation	3,210	2,890	2,670	2,720	2,780	3,070	3,440	3,950	4,310	4,460	4,360	3,220
Road Transportation	37,900	36,700	38,000	39,500	40,600	41,800	42,400	44,400	44,000	46,400	47,300	49,400
Gasoline Automobiles	21,000	20,200	20,100	20,300	20,500	20,000	19,500	19,800	19,200	19,500	19,000	20,000
Light-Duty Gasoline Trucks	7,710	7,960	8,490	9,130	9,740	10,100	10,800	11,600	11,700	13,300	14,000	15,200
Heavy-Duty Gasoline Vehicles	888	922	981	1,050	1,120	1,160	1,200	1,220	1,270	1,010	1,030	1,010
Motorcycles	85	82	80	81	78	73	69	71	71	68	70	70
Diesel Automobiles	211	200	195	191	186	176	183	185	183	190	197	201
Light-Duty Diesel Trucks	163	124	110	101	92	86	72	90	67	108	118	128
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
Propane & Natural Gas Vehicles	544	662	1,111	1,012	585	798	834	711	630	612	389	409
Railways	1,830	1,970	1,940	1,930	1,910	1,690	1,820	1,830	1,580	1,700	1,720	1,630
Domestic Marine	939	942	895	689	712	659	712	822	815	684	635	680
Others	5,870	5,780	6,350	6,420	6,580	7,240	7,650	7,700	9,400	9,730	9,800	6,280
Off-Road	3,590	3,380	3,100	3,010	3,130	3,200	3,290	3,460	5,340	5,620	6,180	3,760
Pipelines	2,270	2,400	3,250	3,410	3,460	4,040	4,360	4,240	4,060	4,110	3,630	2,520
c. Fugitive Sources	**1,360**	**1,400**	**1,440**	**1,450**	**1,480**	**1,500**	**1,510**	**1,530**	**1,560**	**1,630**	**1,720**	**1,690**
Coal Mining	-	-	-	-	-	-	-	-	-	-	-	-
Oil and Natural Gas	1,400	1,400	1,400	1,500	1,500	1,500	1,500	1,500	1,600	1,600	1,700	1,700
INDUSTRIAL PROCESSES	**26,700**	**26,600**	**26,800**	**25,200**	**26,800**	**27,300**	**28,500**	**26,700**	**22,200**	**19,700**	**18,800**	**17,500**
a. Mineral Production[1]	**3,690**	**3,020**	**3,040**	**2,850**	**3,190**	**3,230**	**3,650**	**3,690**	**3,650**	**4,190**	**4,030**	**4,140**
Cement	2,610	1,880	1,890	1,720	2,040	2,110	2,610	2,620	2,600	3,140	3,030	3,330
Lime	1,080	1,140	1,150	1,130	1,150	1,120	1,040	1,060	1,050	1,050	1,000	807
b. Chemical Industry[2]	**10,800**	**10,100**	**10,000**	**9,200**	**11,000**	**10,800**	**11,500**	**9,964**	**5,137**	**1,826**	**982**	**883**
Nitric Acid Production	83	78	82	83	78	85	79	77	71	77	82	81
Adipic Acid Production	10,700	10,000	9,950	9,080	11,000	10,700	11,500	9,890	5,070	1,750	900	802
c. Metal Production	**8,090**	**9,400**	**9,570**	**9,240**	**8,580**	**8,950**	**8,800**	**8,750**	**8,960**	**9,320**	**9,580**	**8,650**
Iron and Steel Production	7,590	8,900	9,070	8,740	8,070	8,420	8,280	8,090	8,300	8,490	8,500	7,910
Aluminium Production	-	-	-	-	-	-	-	-	-	-	-	-
SF_6 used in Magnesium Smelters	504	504	504	504	504	539	526	659	661	836	1,087	742
d. Consumption of Halocarbons[1]	-	-	-	-	-	-	-	-	-	-	-	-
e. Other & Undifferentiated Production[2]	**4,080**	**4,100**	**4,200**	**3,940**	**3,930**	**4,340**	**4,480**	**4,340**	**4,500**	**4,360**	**4,230**	**3,800**
SOLVENT & OTHER PRODUCT USE	**155**	**157**	**159**	**161**	**163**	**165**	**167**	**169**	**172**	**174**	**176**	**179**
AGRICULTURE	**11,600**	**11,400**	**11,200**	**11,200**	**11,700**	**11,800**	**11,200**	**11,500**	**11,600**	**11,700**	**11,300**	**10,900**
a. Enteric Fermentation	3,280	3,250	3,180	3,050	3,070	3,140	3,050	3,190	3,100	2,990	2,940	2,980
b. Manure Management	2,230	2,220	2,210	2,140	2,230	2,260	2,260	2,250	2,270	2,300	2,270	2,360
c. Agriculture Soils	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000
Direct Sources	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	4,000
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
LAND-USE CHANGE AND FORESTRY (non-CO_2 only)[3]	**129**	**142**	**152**	**29**	**13**	**205**	**508**	**39**	**176**	**240**	**23**	**122**
a. Prescribed Burns	117	126	115	28	12	44	-	-	-	4	22	14
b. Wildfires in the Wood Production Forest	12	16	37	-	1	161	508	39	176	236	1	108
WASTE	**7,170**	**7,840**	**8,050**	**8,240**	**8,360**	**8,080**	**8**	**7,860**	**8,040**	**8,120**	**8,310**	**8,490**
a. Solid Waste Disposal on Land	6,710	7,370	7,570	7,760	7,880	7,590	7,220	7,360	7,540	7,610	7,790	7,970
b. Wastewater Handling	382	386	392	396	401	406	411	417	422	427	432	440
c. Waste Incineration	80	81	82	79	79	81	82	83	84	85	86	87

Notes:

1 Emissions associated with the use of HFCs, PFCs, limestone and soda ash are reported in the national industrial processes total.

2 Ammonia production emissions are included under undifferentiated production at the provincial level.

3 CO_2 emissions and removals in the LUCF sector are not included in the national totals. Non-CO_2 emissions from fires located in the National Parks are not included in the provincial/territorial totals but are reported in the national totals.

Totals may not add due to rounding.

1990 to 2001 Greenhouse Gas Emission Estimates for Manitoba, by Sector

GHG Source and Sink Category	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
	All Gases kt CO_2 eq											
TOTAL	**20,300**	**20,000**	**20,500**	**19,800**	**22,000**	**22,300**	**21,400**	**20,600**	**20,900**	**20,700**	**21,300**	**20,400**
ENERGY	**12,600**	**12,100**	**12,100**	**12,100**	**12,200**	**12,900**	**13,300**	**12,700**	**12,800**	**12,800**	**13,300**	**12,100**
a. Stationary Combustion Sources	4,850	4,520	4,290	4,180	4,030	4,180	4,600	4,280	4,840	4,600	5,350	4,570
Electricity and Heat Generation	570	421	423	290	262	199	326	233	962	549	994	493
Fossil Fuel Industries	3	-	1	-	-	1	1	1	1	1	1	1
Mining	73	76	58	28	8	13	11	12	34	27	29	25
Manufacturing Industries	1,040	953	768	707	781	811	832	802	910	1,080	1,140	1,060
Construction	63	45	51	38	41	34	32	45	85	76	62	62
Commercial & Institutional	1,410	1,430	1,480	1,530	1,430	1,590	1,670	1,650	1,490	1,470	1,680	1,600
Residential	1,640	1,550	1,460	1,480	1,420	1,460	1,620	1,440	1,280	1,310	1,390	1,250
Agriculture & Forestry	43	47	52	101	77	77	110	98	72	86	63	75
b. Transportation Combustion Sources	7,320	7,160	7,360	7,430	7,720	8,220	8,190	7,940	7,490	7,680	7,420	7,020
Domestic Aviation	477	444	410	410	510	543	581	597	516	571	554	531
Road Transportation	4,160	4,220	4,260	4,220	4,410	4,550	4,560	4,540	4,570	4,680	4,590	4,620
Gasoline Automobiles	1,980	1,970	1,910	1,810	1,790	1,750	1,650	1,540	1,540	1,510	1,440	1,400
Light-Duty Gasoline Trucks	868	931	984	1,010	1,080	1,130	1,230	1,260	1,300	1,420	1,440	1,500
Heavy-Duty Gasoline Vehicles	193	211	224	230	246	258	204	255	250	228	239	234
Motorcycles	7	8	7	7	7	6	4	5	5	4	4	3
Diesel Automobiles	20.0	20.0	19.0	18.0	17.0	17.0	17.0	16.0	16.0	15.0	15.0	14.0
Light-Duty Diesel Trucks	31	30	31	32	33	35	37	30	28	32	34	36
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
Propane & Natural Gas Vehicles	61	64	60	27	71	97	83	120	107	113	36	33
Railways	622	537	545	535	572	565	524	449	351	322	311	233
Domestic Marine	-	-	-	-	-	-	-	-	-	-	-	-
Others	2,060	1,960	2,140	2,270	2,230	2,570	2,530	2,360	2,060	2,110	1,970	1,640
Off-Road	1,210	980	920	1,020	1,030	1,270	1,230	1,160	1,100	1,050	1,140	1,090
Pipelines	847	976	1,220	1,260	1,200	1,300	1,300	1,200	959	1,060	828	543
c. Fugitive Sources	415	420	433	440	443	458	487	502	510	509	532	534
Coal Mining	-	-	-	-	-	-	-	-	-	-	-	-
Oil and Natural Gas	420	420	430	440	440	460	490	500	510	510	530	530
INDUSTRIAL PROCESSES	**455**	**415**	**295**	**301**	**300**	**299**	**305**	**312**	**318**	**446**	**472**	**459**
a. Mineral Production[1]	191	179	61	67	71	74	73	76	76	70	71	66
Cement	132	121	-	-	-	-	-	-	-	-	-	-
Lime	59	58	61	67	71	74	73	76	76	70	71	66
b. Chemical Industry[2]	21	20	21	21	24	27	30	30	30	29	31	30
Nitric Acid Production	21	20	21	21	24	27	30	30	30	29	31	30
Adipic Acid Production	-	-	-	-	-	-	-	-	-	-	-	-
c. Metal Production	-	-	-	-	-	-	-	-	-	-	-	-
Iron and Steel Production	-	-	-	-	-	-	-	-	-	-	-	-
Aluminium Production	-	-	-	-	-	-	-	-	-	-	-	-
SF_6 used in Magnesium Smelters	-	-	-	-	-	-	-	-	-	-	-	-
d. Consumption of Halocarbons[1]	-	-	-	-	-	-	-	-	-	-	-	-
e. Other & Undifferentiated Production[2]	243	217	213	214	205	199	202	207	213	347	370	363
SOLVENT & OTHER PRODUCT USE	**17**	**17**	**17**	**17**	**17**	**17**	**17**	**17**	**17**	**17**	**17**	**17**
AGRICULTURE	**6,760**	**6,790**	**6,900**	**6,760**	**7,010**	**6,960**	**7,270**	**6,940**	**7,180**	**6,880**	**6,880**	**6,800**
a. Enteric Fermentation	1,300	1,320	1,410	1,470	1,580	1,680	1,770	1,730	1,710	1,670	1,660	1,710
b. Manure Management	672	694	740	757	816	892	942	910	951	922	917	1,070
c. Agriculture Soils	5,000	5,000	5,000	5,000	5,000	4,000	5,000	4,000	5,000	4,000	4,000	4,000
Direct Sources	4,000	4,000	4,000	4,000	4,000	3,000	4,000	3,000	3,000	3,000	3,000	3,000
Indirect Sources	700	800	800	900	900	1,000	1,000	1,000	1,000	1,000	1,000	1,000
LAND-USE CHANGE AND FORESTRY (non-CO_2 only)[3]	**24**	**200**	**672**	**157**	**2,010**	**1,620**	**-**	**-**	**-**	**-**	**-**	**425**
a. Prescribed Burns	-	-	-	-	1	-	-	-	-	-	-	-
b. Wildfires in the Wood Production Forest	24	200	672	157	2,004	1,616	-	-	-	-	-	425
WASTE	**424**	**473**	**488**	**503**	**518**	**533**	**8**	**562**	**576**	**590**	**604**	**618**
a. Solid Waste Disposal on Land	367	416	431	446	460	475	489	504	517	531	545	559
b. Wastewater Handling	57	57	57	57	58	58	58	58	58	59	59	59
c. Waste Incineration	-	-	-	-	-	-	-	-	-	-	-	-

Notes:

1 Emissions associated with the use of HFCs, PFCs, limestone and soda ash are reported in the national industrial processes total.

2 Ammonia production emissions are included under undifferentiated production at the provincial level.

3 CO_2 emissions and removals in the LUCF sector are not included in the national totals. Non-CO_2 emissions from fires located in the National Parks are not included in the provincial/territorial totals but are reported in the national totals.

Totals may not add due to rounding.

1990 to 2001 Greenhouse Gas Emission Estimates for Saskatchewan, by Sector

GHG Source and Sink Category	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
						All Gases kt CO_2 eq						
TOTAL	**47,000**	**46,300**	**50,100**	**53,500**	**56,400**	**59,700**	**60,100**	**60,900**	**62,500**	**61,300**	**61,800**	**60,700**
ENERGY	**34,500**	**33,900**	**37,900**	**40,200**	**43,500**	**46,200**	**46,200**	**46,900**	**47,400**	**47,900**	**48,000**	**47,500**
a. Stationary Combustion Sources	**18,900**	**18,000**	**20,900**	**22,300**	**24,500**	**25,900**	**24,900**	**25,400**	**26,200**	**26,300**	**26,200**	**26,700**
Electricity and Heat Generation	10,400	10,500	12,000	12,100	12,800	14,100	14,200	15,000	15,100	15,000	14,900	15,400
Fossil Fuel Industries	3,230	1,630	2,400	3,350	4,630	5,150	3,420	3,760	4,680	4,720	4,360	4,680
Mining	965	978	969	1,700	1,810	1,690	1,320	1,900	1,810	1,660	2,000	1,900
Manufacturing Industries	774	1,340	2,180	1,120	1,530	1,290	1,570	1,060	1,120	964	930	834
Construction	70	57	80	71	65	73	87	56	65	87	50	39
Commercial & Institutional	1,010	1,010	926	1,480	1,310	1,210	1,420	1,200	1,250	1,590	1,710	1,650
Residential	2,150	2,150	2,050	2,130	2,080	2,140	2,450	2,090	1,910	1,950	1,980	1,950
Agriculture & Forestry	302	274	303	333	327	328	387	349	292	339	281	282
b. Transportation Combustion Sources	**9,520**	**9,620**	**10,295**	**10,553**	**11,105**	**11,478**	**11,786**	**11,754**	**11,349**	**11,542**	**11,230**	**9,950**
Domestic Aviation	260	224	222	184	179	221	235	202	214	182	165	183
Road Transportation	4,370	4,750	5,430	5,410	5,610	5,490	5,810	6,580	5,960	6,190	6,150	5,420
Gasoline Automobiles	1,590	1,600	1,900	1,770	1,640	1,480	1,440	1,490	1,370	1,370	1,280	968
Light-Duty Gasoline Trucks	1,030	1,100	1,400	1,400	1,420	1,400	1,560	1,680	1,500	1,750	1,730	1,450
Heavy-Duty Gasoline Vehicles	193	242	355	406	459	507	516	595	591	480	480	393
Motorcycles	2	2	3	3	3	3	3	6	6	6	7	7
Diesel Automobiles	14	14	17	15	13	11	13	13	12	13	13	9
Light-Duty Diesel Trucks	75	87	84	86	99	99	108	122	110	102	120	110
Heavy-Duty Diesel Vehicles	1,400	1,640	1,600	1,660	1,930	1,940	2,120	2,610	2,310	2,420	2,480	2,460
Propane & Natural Gas Vehicles	65	64	80	62	52	50	44	59	59	48	27	26
Railways	600	304	372	369	524	527	579	592	471	441	423	314
Domestic Marine	-	-	-	-	-	-	-	-	-	-	-	-
Others	4,280	4,340	4,270	4,590	4,790	5,240	5,170	4,380	4,710	4,730	4,500	4,040
Off-Road	2,640	2,560	1,840	2,130	2,520	2,630	2,600	1,880	2,050	1,940	2,090	2,310
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
c. Fugitive Sources	**6,140**	**6,350**	**6,750**	**7,390**	**7,880**	**8,770**	**9,570**	**9,800**	**9,810**	**10,000**	**10,600**	**10,800**
Coal Mining	12	11	13	13	13	14	14	15	15	15	14	14
Oil and Natural Gas	6,100	6,300	6,700	7,400	7,900	8,800	9,600	9,800	9,800	10,000	11,000	11,000
INDUSTRIAL PROCESSES	**587**	**679**	**690**	**1,180**	**987**	**797**	**1,670**	**1,790**	**2,030**	**2,020**	**2,010**	**2,070**
a. Mineral Production[1]	**82**	**75**	-	-	-	-	-	-	-	-	-	-
Cement	82	75	-	-	-	-	-	-	-	-	-	-
Lime	-	-	-	-	-	-	-	-	-	-	-	-
b. Chemical Industry[2]	-	-	-	-	-	-	-	-	-	-	-	-
Nitric Acid Production	-	-	-	-	-	-	-	-	-	-	-	-
Adipic Acid Production	-	-	-	-	-	-	-	-	-	-	-	-
c. Metal Production	-	-	-	-	-	-	-	-	-	-	-	-
Iron and Steel Production	-	-	-	-	-	-	-	-	-	-	-	-
Aluminium Production	-	-	-	-	-	-	-	-	-	-	-	-
SF_6 used in Magnesium Smelters	-	-	-	-	-	-	-	-	-	-	-	-
d. Consumption of Halocarbons[1]	-	-	-	-	-	-	-	-	-	-	-	-
e. Other & Undifferentiated Production[2]	**506**	**604**	**690**	**1,180**	**987**	**797**	**1,670**	**1,790**	**2,030**	**2,020**	**2,010**	**2,070**
SOLVENT & OTHER PRODUCT USE	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**
AGRICULTURE	**11,200**	**10,800**	**10,900**	**10,500**	**11,000**	**10,900**	**11,600**	**11,600**	**11,000**	**10,700**	**11,100**	**10,000**
a. Enteric Fermentation	2,460	2,530	2,700	2,780	2,930	3,090	3,180	3,280	3,150	3,070	3,000	3,230
b. Manure Management	802	830	881	904	950	972	1,000	1,010	989	976	982	1,060
c. Agriculture Soils	8,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	6,000
Direct Sources	7,000	7,000	6,000	6,000	6,000	5,000	6,000	6,000	5,000	5,000	5,000	4,000
Indirect Sources	900	900	1,000	1,000	1,000	1,000	2,000	2,000	2,000	2,000	2,000	2,000
LAND-USE CHANGE AND FORESTRY (non-CO_2 only)[3]	**258**	**431**	**55**	**1,090**	**380**	**1,210**	**16**	**4**	**1,400**	**1**	**13**	**468**
a. Prescribed Burns	-	-	-	-	-	-	-	-	-	1	1	4
b. Wildfires in the Wood Production Forest	258	431	55	1,094	380	1,211	16	4	1,402	-	11	464
WASTE	**504**	**519**	**534**	**547**	**558**	**568**	**8**	**590**	**598**	**607**	**615**	**623**
a. Solid Waste Disposal on Land	417	432	447	460	470	481	491	501	510	518	526	535
b. Wastewater Handling	87	87	87	87	87	88	88	88	89	89	89	88
c. Waste Incineration	-	-	-	-	-	-	-	-	-	-	-	-

Notes:

1 Emissions associated with the use of HFCs, PFCs, limestone and soda ash are reported in the national industrial processes total.

2 Ammonia production emissions are included under undifferentiated production at the provincial level.

3 CO_2 emissions and removals in the LUCF sector are not included in the national totals. Non-CO_2 emissions from fires located in the National Parks are not included in the provincial/territorial totals but are reported in the national totals.

Totals may not add due to rounding.

1990 to 2001 Greenhouse Gas Emission Estimates for Alberta, by Sector

GHG Source and Sink Category	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
						All Gases kt CO_2 eq						
TOTAL	**171,000**	**173,000**	**180,000**	**185,000**	**194,000**	**200,000**	**203,000**	**205,000**	**207,000**	**216,000**	**224,000**	**224,000**
ENERGY	**143,000**	**145,000**	**153,000**	**156,000**	**164,000**	**169,000**	**172,000**	**173,000**	**175,000**	**183,000**	**192,000**	**192,000**
a. Stationary Combustion Sources	**95,100**	**97,700**	**102,000**	**104,000**	**108,000**	**111,000**	**111,000**	**110,000**	**111,000**	**119,000**	**127,000**	**125,000**
Electricity and Heat Generation	40,200	42,000	45,100	45,800	49,200	49,500	48,600	51,300	51,800	51,500	53,500	54,700
Fossil Fuel Industries	30,900	32,700	35,100	34,800	34,600	34,600	33,900	31,300	33,000	42,100	44,300	44,000
Mining	2,400	1,430	1,200	3,200	2,880	3,340	4,280	3,920	3,450	3,450	5,500	5,800
Manufacturing Industries	9,400	9,590	9,360	8,260	8,900	9,940	9,920	10,461	10,010	9,650	9,590	8,210
Construction	236	202	244	212	206	189	216	211	136	166	172	168
Commercial & Institutional	4,950	4,760	4,410	4,540	4,570	5,520	4,970	5,020	4,640	4,580	5,290	4,760
Residential	6,630	6,570	6,440	6,610	7,260	7,570	8,670	7,710	7,350	7,450	8,280	7,210
Agriculture & Forestry	468	458	560	574	358	335	410	380	341	348	361	286
b. Transportation Combustion Sources	**23,100**	**21,300**	**21,900**	**22,600**	**25,100**	**25,400**	**26,900**	**29,400**	**30,300**	**30,400**	**30,900**	**33,100**
Domestic Aviation	1,660	1,390	1,450	1,530	1,580	1,660	1,850	1,910	2,040	2,090	2,110	2,220
Road Transportation	14,400	13,600	13,900	13,900	15,800	16,000	16,100	17,500	17,900	18,100	18,700	19,700
Gasoline Automobiles	5,630	5,150	5,070	4,940	5,200	5,040	4,620	4,770	4,960	4,820	4,680	4,880
Light-Duty Gasoline Trucks	3,650	3,520	3,670	3,770	4,180	4,270	4,260	4,700	4,840	5,480	5,610	6,120
Heavy-Duty Gasoline Vehicles	649	692	788	869	1,030	1,100	1,100	1,180	1,320	990	1,130	1,120
Motorcycles	25	24	23	24	26	23	22	24	27	25	25	27
Diesel Automobiles	52	46	44	41	40	36	34	36	38	38	37	35
Light-Duty Diesel Trucks	87	70	61	58	60	54	52	104	85	95	158	158
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	7,120
Propane & Natural Gas Vehicles	628.0	628.0	703.0	323.0	514.0	514.0	551.0	478.0	433.0	336.0	271.0	270.0
Railways	1,800	1,540	1,560	1,560	1,620	1,240	1,150	1,340	1,360	1,460	1,770	2,200
Domestic Marine	-	-	1	1	-	1	-	-	-	-	-	-
Others	5,320	4,780	4,920	5,570	6,090	6,510	7,800	8,610	9,000	8,810	8,290	8,930
Off-Road	4,050	3,420	3,000	3,460	3,490	3,850	5,030	5,440	5,750	5,600	5,620	5,520
Pipelines	1,270	1,360	1,920	2,100	2,600	2,670	2,770	3,160	3,250	3,210	2,670	3,410
c. Fugitive Sources	**25,000**	**26,100**	**28,300**	**29,500**	**30,600**	**32,300**	**34,100**	**33,600**	**33,500**	**33,800**	**33,900**	**33,600**
Coal Mining	239	247	265	272	273	301	292	281	287	242	206	184
Oil and Natural Gas	25,000	26,000	28,000	29,000	30,000	32,000	34,000	33,000	33,000	34,000	34,000	33,000
INDUSTRIAL PROCESSES	**8,800**	**9,330**	**9,170**	**10,100**	**10,500**	**10,400**	**11,200**	**11,800**	**11,500**	**11,700**	**11,500**	**11,100**
a. Mineral Production[1]	**869**	**793**	**718**	**914**	**889**	**894**	**795**	**809**	**944**	**1,040**	**1,070**	**1,060**
Cement	679	621	566	748	719	722	715	726	860	896	924	893
Lime	190	172	151	166	170	172	80	83	83	147	149	166
b. Chemical Industry[2]	659	655	659	659	649	655	669	666	660	666	672	670
Nitric Acid Production	659	655	659	659	649	655	669	666	660	666	672	670
Adipic Acid Production	-	-	-	-	-	-	-	-	-	-	-	-
c. Metal Production	-	-	-	-	-	-	-	-	-	-	-	-
Iron and Steel Production	-	-	-	-	-	-	-	-	-	-	-	-
Aluminium Production	-	-	-	-	-	-	-	-	-	-	-	-
SF_6 used in Magnesium Smelters	-	-	-	-	-	-	-	-	-	-	-	-
d. Consumption of Halocarbons[1]	-	-	-	-	-	-	-	-	-	-	-	-
e. Other & Undifferentiated Production[2]	**7,270**	**7,880**	**7,800**	**8,520**	**8,940**	**8,810**	**9,720**	**10,370**	**9,870**	**9,980**	**9,750**	**9,320**
SOLVENT & OTHER PRODUCT USE	**38**	**39**	**40**	**40**	**41**	**41**	**42**	**43**	**44**	**45**	**45**	**46**
AGRICULTURE	**17,400**	**17,500**	**17,400**	**17,900**	**18,700**	**18,900**	**18,900**	**18,600**	**18,700**	**19,400**	**19,400**	**19,700**
a. Enteric Fermentation	5,120	5,280	5,500	5,620	6,040	6,220	6,210	6,270	6,240	6,410	6,520	7,240
b. Manure Management	1,770	1,810	1,890	1,910	2,030	2,110	2,110	2,100	2,110	2,160	2,180	2,400
c. Agriculture Soils	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Direct Sources	10,000	9,000	9,000	9,000	9,000	9,000	9,000	8,000	8,000	9,000	9,000	8,000
Indirect Sources	1,000	1,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000
LAND-USE CHANGE AND FORESTRY (non-CO_2 only)[3]	**114**	**62**	**28**	**68**	**106**	**829**	**2**	**11**	**849**	**223**	**41**	**225**
a. Prescribed Burns	34	57	26	21	75	236	-	-	-	31	34	60
b. Wildfires in the Wood Production Forest	80	5	3	47	31	593	2	11	849	192	7	165
WASTE	**1,010**	**1,070**	**923**	**962**	**1,000**	**1,040**	**8**	**1,030**	**1,060**	**1,170**	**1,200**	**1,230**
a. Solid Waste Disposal on Land	875	933	782	819	855	891	845	881	909	1,010	1,040	1,070
b. Wastewater Handling	136	138	141	143	144	146	149	152	155	158	160	164
c. Waste Incineration	-	-	-	-	-	-	-	-	-	-	-	-

Notes:

1 Emissions associated with the use of HFCs, PFCs, limestone and soda ash are reported in the national industrial processes total.

2 Ammonia production emissions are included under undifferentiated production at the provincial level.

3 CO_2 emissions and removals in the LUCF sector are not included in the national totals. Non-CO_2 emissions from fires located in the National Parks are not included in the provincial/territorial totals but are reported in the national totals.

Totals may not add due to rounding.

1990 to 2001 Greenhouse Gas Emission Estimates for British Columbia, by Sector

GHG Source and Sink Category	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
						All Gases kt CO_2 eq						
TOTAL	**52,900**	**52,700**	**51,500**	**54,200**	**56,000**	**60,000**	**62,700**	**61,400**	**62,000**	**64,600**	**66,100**	**65,000**
ENERGY	**42,200**	**41,600**	**40,900**	**43,000**	**45,100**	**49,300**	**51,800**	**50,400**	**51,300**	**53,500**	**54,700**	**53,900**
a. Stationary Combustion Sources	**19,000**	**17,700**	**16,400**	**17,900**	**17,900**	**20,000**	**21,500**	**19,100**	**19,500**	**21,500**	**22,300**	**21,500**
Electricity and Heat Generation	1,170	1,040	1,270	2,340	2,180	2,700	770	1,190	1,870	1,520	2,690	3,260
Fossil Fuel Industries	3,890	3,130	1,950	1,060	1,970	2,770	4,790	3,010	3,670	5,200	3,800	3,060
Mining	253	225	271	336	202	163	449	344	324	228	316	250
Manufacturing Industries	5,930	5,390	4,910	5,250	5,390	6,210	6,810	6,360	5,960	6,500	7,120	6,950
Construction	304	268	317	340	283	198	207	126	100	86	76	70
Commercial & Institutional	2,820	3,070	3,180	3,560	3,290	3,360	3,400	3,290	2,880	2,960	3,390	3,040
Residential	4,310	4,180	4,100	4,590	4,370	4,400	4,920	4,530	4,450	4,730	4,600	4,480
Agriculture & Forestry	323	375	374	374	205	155	191	270	253	263	315	357
b. Transportation Combustion Sources	**19,800**	**20,300**	**20,700**	**21,000**	**22,400**	**23,900**	**24,500**	**25,400**	**25,800**	**26,100**	**26,300**	**25,600**
Domestic Aviation	1,910	1,970	2,010	1,780	2,030	2,430	2,700	2,950	2,970	3,340	3,340	2,580
Road Transportation	12,400	12,500	12,600	13,100	13,900	14,300	14,400	15,000	15,500	15,500	15,400	15,400
Gasoline Automobiles	5,370	5,320	5,300	5,360	5,410	5,320	5,250	5,380	5,450	5,330	5,100	4,920
Light-Duty Gasoline Trucks	2,770	2,980	3,220	3,490	3,780	3,990	4,140	4,560	4,860	5,140	5,180	5,300
Heavy-Duty Gasoline Vehicles	355	412	481	558	640	706	708	667	827	623	596	532
Motorcycles	39	38	39	39	40	39	38	43	45	47	46	45
Diesel Automobiles	75	71	68	66	63	59	65	66	69	72	65	60
Light-Duty Diesel Trucks	78	60	49	43	40	37	34	41	39	26	60	64
Heavy-Duty Diesel Vehicles	2,920	2,840	2,890	3,020	3,300	3,530	3,710	3,850	3,750	3,950	4,060	4,170
Propane & Natural Gas Vehicles	782	769	582	491	622	571	407	403	482	313	331	325
Railways	1,470	1,430	1,640	1,670	1,680	1,690	1,620	1,470	1,400	1,430	1,300	1,070
Domestic Marine	1,030	1,130	1,150	1,140	1,180	1,240	1,140	1,040	1,010	1,130	1,240	1,580
Others	2,950	3,290	3,230	3,400	3,660	4,280	4,680	4,950	4,950	4,690	4,970	4,980
Off-Road	2,100	2,200	2,200	2,280	2,420	2,910	3,190	3,520	3,390	3,300	3,340	3,140
Pipelines	845	1,090	1,040	1,110	1,240	1,370	1,490	1,430	1,560	1,390	1,630	1,840
c. Fugitive Sources	**3,460**	**3,600**	**3,840**	**4,100**	**4,820**	**5,430**	**5,770**	**5,840**	**5,930**	**5,880**	**6,080**	**6,810**
Coal Mining	487	482	355	470	512	569	630	657	553	490	478	522
Oil and Natural Gas	3,000	3,100	3,500	3,600	4,300	4,900	5,100	5,200	5,400	5,400	5,600	6,300
INDUSTRIAL PROCESSES	**2,840**	**2,830**	**2,550**	**3,210**	**3,390**	**3,350**	**2,880**	**2,990**	**2,780**	**2,940**	**3,280**	**2,650**
a. Mineral Production[1]	**843**	**781**	**668**	**947**	**1,020**	**1,060**	**1,070**	**1,120**	**1,080**	**1,050**	**1,200**	**1,190**
Cement	678	620	668	761	827	853	872	911	864	826	971	979
Lime	165	161	171	186	196	205	202	211	211	221	224	208
b. Chemical Industry[2]	-	-	-	-	-	-	-	-	-	-	-	-
c. Nitric Acid Production	-	-	-	-	-	-	-	-	-	-	-	-
Adipic Acid Production	-	-	-	-	-	-	-	-	-	-	-	-
c. Metal Production	**1,290**	**1,290**	**1,310**	**1,320**	**1,270**	**1,140**	**1,150**	**1,150**	**1,170**	**1,210**	**1,200**	**1,080**
Iron and Steel Production	-	-	-	-	-	-	-	-	-	-	-	-
Aluminium Production	1,290	1,290	1,310	1,320	1,270	1,140	1,150	1,150	1,170	1,210	1,200	1,080
SF_6 used in Magnesium Smelters	-	-	-	-	-	-	-	-	-	-	-	-
d. Consumption of Halocarbons[1]	-	-	-	-	-	-	-	-	-	-	-	-
e. Other & Undifferentiated Production[2]	**711**	**758**	**574**	**944**	**1,098**	**1,153**	**662**	**714**	**534**	**685**	**883**	**381**
SOLVENT & OTHER PRODUCT USE	**50**	**51**	**52**	**54**	**55**	**57**	**58**	**60**	**60**	**61**	**61**	**62**
AGRICULTURE	**2,580**	**2,490**	**2,560**	**2,610**	**2,730**	**2,770**	**2,830**	**2,840**	**2,580**	**2,680**	**2,620**	**2,790**
a. Enteric Fermentation	909	926	949	942	1,010	1,050	1,050	1,020	979	976	960	1,000
b. Manure Management	467	472	476	487	527	546	554	554	556	563	571	591
c. Agriculture Soils	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Direct Sources	1,000	900	900	900	900	900	1,000	1,000	800	900	800	900
Indirect Sources	200	200	300	300	300	300	300	300	200	300	300	300
LAND-USE CHANGE AND FORESTRY (non-CO_2 only)[3]	**1,590**	**1,850**	**1,420**	**1,250**	**518**	**205**	**453**	**444**	**443**	**443**	**495**	**492**
a. Prescribed Burns	1,400	1,810	1,360	1,240	443	107	443	443	443	443	443	443
b. Wildfires in the Wood Production Forest	191	41	62	5	75	98	10	1	-	-	52	49
WASTE	**3,640**	**3,920**	**4,050**	**4,070**	**4,170**	**4,300**	**8**	**4,720**	**4,810**	**4,960**	**5,040**	**5,120**
a. Solid Waste Disposal on Land	3,390	3,660	3,780	3,800	3,890	4,010	4,330	4,420	4,500	4,650	4,730	4,810
b. Wastewater Handling	185	189	195	200	207	212	218	222	224	226	228	230
c. Waste Incineration	67	68	70	72	75	77	79	80	81	82	82	83

Notes:

1 Emissions associated with the use of HFCs, PFCs, limestone and soda ash are reported in the national industrial processes total.

2 Ammonia production emissions are included under undifferentiated production at the provincial level.

3 CO_2 emissions and removals in the LUCF sector are not included in the national totals. Non-CO_2 emissions from fires located in the National Parks are not included in the provincial/territorial totals but are reported in the national totals.

Totals may not add due to rounding.

1990 to 2001 Greenhouse Gas Emission Estimates for Yukon, by Sector

GHG Source and Sink Category	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
						All Gases kt CO_2 eq						
TOTAL	**575**	**491**	**623**	**507**	**495**	**581**	**628**	**599**	**527**	**558**	**509**	**492**
ENERGY	**507**	**483**	**615**	**499**	**487**	**570**	**618**	**589**	**518**	**549**	**500**	**477**
a. Stationary Combustion Sources	**196**	**154**	**229**	**175**	**164**	**237**	**260**	**244**	**203**	**216**	**197**	**175**
Electricity and Heat Generation	96	59	54	31	28	55	104	89	33	27	17	15
Fossil Fuel Industries	3	3	92	60	50	92	75	81	92	90	82	55
Mining	3	3	-	1	2	9	12	4	3	6	4	5
Manufacturing Industries	2	1	1	2	1	1	-	1	-	-	-	-
Construction	1	1	1	-	2	4	4	3	2	2	2	1
Commercial & Institutional	71	68	61	56	49	51	37	36	33	40	54	52
Residential	20	15	12	22	27	17	22	25	32	41	36	33
Agriculture & Forestry	1	4	8	5	6	8	6	6	8	11	1	14
b. Transportation Combustion Sources	**311**	**309**	**338**	**275**	**277**	**291**	**318**	**307**	**272**	**274**	**249**	**257**
Domestic Aviation	24	20	18	19	22	25	30	19	27	26	30	20
Road Transportation	183	183	196	196	239	248	244	190	226	254	195	215
Gasoline Automobiles	80	80	84	85	76	74	67	64	74	70	52	52
Light-Duty Gasoline Trucks	34	37	41	44	42	43	43	44	52	55	44	45
Heavy-Duty Gasoline Vehicles	6	6	7	8	8	8	8	8	10	14	11	10
Motorcycles	-	-	-	-	-	-	-	-	-	-	-	-
Diesel Automobiles	1	1	1	1	1	1	1	1	1	1	1	1
Light-Duty Diesel Trucks	1	1	1	1	1	1	1	1	1	1	1	1
Heavy-Duty Diesel Vehicles	59	56	59	55	105	115	120	70	85	112	85	104
Propane & Natural Gas Vehicles	2	2	3	2	6	4	2	2	2	2	1	1
Railways	-	-	-	-	-	-	-	-	-	-	-	-
Domestic Marine	-	-	-	-	-	-	-	-	-	-	-	-
Others	103	106	124	60	17	18	43	98	19	-6	24	22
Off-Road	103	106	124	60	17	18	43	98	19	-6	24	22
Pipelines	-	-	-	-	-	-	-	-	-	-	-	-
c. Fugitive Sources	-	**20**	**47**	**48**	**45**	**42**	**40**	**38**	**43**	**59**	**53**	**45**
Coal Mining	-	-	-	-	-	-	-	-	-	-	-	-
Oil and Natural Gas	-	20	47	48	45	42	40	38	43	59	53	45
INDUSTRIAL PROCESSES	**1**	**1**	**1**	-	-	**2**	**2**	**1**	-	**1**	**1**	**1**
a. Mineral Production[1]	-	-	-	-	-	-	-	-	-	-	-	-
Cement	-	-	-	-	-	-	-	-	-	-	-	-
Lime	-	-	-	-	-	-	-	-	-	-	-	-
b. Chemical Industry[2]	-	-	-	-	-	-	-	-	-	-	-	-
Nitric Acid Production	-	-	-	-	-	-	-	-	-	-	-	-
Adipic Acid Production	-	-	-	-	-	-	-	-	-	-	-	-
c. Metal Production	-	-	-	-	-	-	-	-	-	-	-	-
Iron and Steel Production	-	-	-	-	-	-	-	-	-	-	-	-
Aluminium Production	-	-	-	-	-	-	-	-	-	-	-	-
SF_6 used in Magnesium Smelters	-	-	-	-	-	-	-	-	-	-	-	-
d. Consumption of Halocarbons[1]	-	-	-	-	-	-	-	-	-	-	-	-
e. Other & Undifferentiated Production[2]	**1**	**1**	**1**	-	-	**2**	**2**	**1**	-	**1**	**1**	**1**
SOLVENT & OTHER PRODUCT USE	-	-	-	-	-	-	-	-	-	-	-	-
AGRICULTURE	-	-	-	-	-	-	-	-	-	-	-	-
a. Enteric Fermentation	-	-	-	-	-	-	-	-	-	-	-	-
b. Manure Management	-	-	-	-	-	-	-	-	-	-	-	-
c. Agriculture Soils	-	-	-	-	-	-	-	-	-	-	-	-
Direct Sources	-	-	-	-	-	-	-	-	-	-	-	-
Indirect Sources	-	-	-	-	-	-	-	-	-	-	-	-
LAND-USE CHANGE AND FORESTRY (non-CO_2 only)[3]	**61**	-	-	-	-	-	-	-	-	-	-	**6**
a. Prescribed Burns	-	-	-	-	-	-	-	-	-	-	-	-
b. Wildfires in the Wood Production Forest	61	-	-	-	-	-	-	-	-	-	-	6
WASTE	**7**	**7**	**7**	**7**	**8**	**8**	**8**	**8**	**8**	**8**	**8**	**8**
a. Solid Waste Disposal on Land	4	4	4	4	4	4	4	5	5	5	5	5
b. Wastewater Handling	3	3	3	3	3	4	4	4	4	4	4	3
c. Waste Incineration	-	-	-	-	-	-	-	-	-	-	-	-

Notes:

1 Emissions associated with the use of HFCs, PFCs, limestone and soda ash are reported in the national industrial processes total.

2 Ammonia production emissions are included under undifferentiated production at the provincial level.

3 CO_2 emissions and removals in the LUCF sector are not included in the national totals. Non-CO_2 emissions from fires located in the National Parks are not included in the provincial/territorial totals but are reported in the national totals.

Totals may not add due to rounding.

1990 to 2001 Greenhouse Gas Emission Estimates for Northwest Territories and Nunavut, by Sector

GHG Source and Sink Category	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
						All Gases kt CO_2 eq						
TOTAL	**1,570**	**1,540**	**1,400**	**1,740**	**1,860**	**1,940**	**1,810**	**1,800**	**1,640**	**1,410**	**1,740**	**2,350**
ENERGY	**1,550**	**1,500**	**1,320**	**1,600**	**1,740**	**1,840**	**1,730**	**1,780**	**1,620**	**1,390**	**1,720**	**2,320**
a. Stationary Combustion Sources	**911**	**950**	**807**	**908**	**988**	**1,120**	**817**	**922**	**746**	**636**	**808**	**983**
Electricity and Heat Generation	215	215	186	197	198	371	351	348	326	302	293	302
Fossil Fuel Industries	188	107	11	25	31	31	15	-	-	-	156	293
Mining	51	56	41	66	152	103	44	49	64	69	77	103
Manufacturing Industries	32	21	23	9	14	20	18	10	-	-	-	-
Construction	8	7	8	7	4	20	1	1	-	1	1	1
Commercial & Institutional	250	341	332	371	392	454	197	339	214	172	163	153
Residential	166	192	193	230	195	116	191	176	141	92	120	111
Agriculture & Forestry	2	10	12	2	2	-	-	-	-	-	-	20
b. Transportation Combustion Sources	**583**	**485**	**457**	**627**	**697**	**669**	**863**	**813**	**828**	**711**	**784**	**1,150**
Domestic Aviation	201	206	222	245	268	232	272	280	235	152	152	257
Road Transportation	121	100	100	77	105	149	144	138	282	206	232	222
Gasoline Automobiles	28	24	24	25	28	27	22	26	26	39	45	50
Light-Duty Gasoline Trucks	12	11	12	13	15	16	14	18	18	31	38	43
Heavy-Duty Gasoline Vehicles	2	2	2	2	3	3	3	3	3	6	8	8
Motorcycles	-	-	-	-	-	-	-	-	-	-	-	-
Diesel Automobiles	-	-	-	-	-	-	-	-	-	-	1.0	1.0
Light-Duty Diesel Trucks	2	1	1	-	1	1	1	1	3	1	1	1
Heavy-Duty Diesel Vehicles	75	59	59	33	52	97	102	87	230	125	138	117
Propane & Natural Gas Vehicles	2	2	3	2	6	4	2	2	2	2	1	1
Railways	3	2	2	2	2	2	1	3	2	3	3	4
Domestic Marine	-	-	1	1	-	71	90	12	31	8	10	17
Others	259	177	132	302	323	215	355	380	278	343	387	649
Off-Road	259	177	132	302	320	215	355	380	273	338	381	644
Pipelines	-	-	-	-	2	-	-	-	5	5	6	6
c. Fugitive Sources	**58**	**61**	**59**	**61**	**53**	**53**	**50**	**48**	**45**	**44**	**123**	**193**
Coal Mining	-	-	-	-	-	-	-	-	-	-	-	-
Oil and Natural Gas	58	61	59	61	53	53	50	48	45	44	120	190
INDUSTRIAL PROCESSES	**3**	**11**	**2**	**24**	**102**	**84**	**64**	**3**	**1**	**2**	**4**	**5**
a. Mineral Production[1]	-	-	-	-	-	-	-	-	-	-	-	-
Cement	-	-	-	-	-	-	-	-	-	-	-	-
Lime	-	-	-	-	-	-	-	-	-	-	-	-
b. Chemical Industry[2]	-	-	-	-	-	-	-	-	-	-	-	-
Nitric Acid Production	-	-	-	-	-	-	-	-	-	-	-	-
Adipic Acid Production	-	-	-	-	-	-	-	-	-	-	-	-
c. Metal Production	-	-	-	-	-	-	-	-	-	-	-	-
Iron and Steel Production	-	-	-	-	-	-	-	-	-	-	-	-
Aluminium Production	-	-	-	-	-	-	-	-	-	-	-	-
SF_6 used in Magnesium Smelters	-	-	-	-	-	-	-	-	-	-	-	-
d. Consumption of Halocarbons[1]	-	-	-	-	-	-	-	-	-	-	-	-
e. Other & Undifferentiated Production[2]	**3**	**11**	**2**	**24**	**102**	**84**	**64**	**3**	**1**	**2**	**4**	**5**
SOLVENT & OTHER PRODUCT USE	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
AGRICULTURE	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
a. Enteric Fermentation	-	-	-	-	-	-	-	-	-	-	-	-
b. Manure Management	-	-	-	-	-	-	-	-	-	-	-	-
c. Agriculture Soils	-	-	-	-	-	-	-	-	-	-	-	-
Direct Sources	-	-	-	-	-	-	-	-	-	-	-	-
Indirect Sources	-	-	-	-	-	-	-	-	-	-	-	-
LAND-USE CHANGE AND FORESTRY (non-CO_2 only)[3]	**-**	**15**	**59**	**109**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
a. Prescribed Burns	-	15	59	109	-	-	-	-	-	-	-	-
b. Wildfires in the Wood Production Forest	-	-	-	-	-	-	-	-	-	-	-	-
WASTE	**14**	**14**	**15**	**15**	**16**	**16**	**8**	**17**	**18**	**18**	**19**	**19**
a. Solid Waste Disposal on Land	7	7	8	8	8	9	9	9	10	10	10	11
b. Wastewater Handling	7	7	7	7	8	8	8	8	8	8	8	8
c. Waste Incineration	-	-	-	-	-	-	-	-	-	-	-	-

Notes:

1 Emissions associated with the use of HFCs, PFCs, limestone and soda ash are reported in the national industrial processes total.

2 Ammonia production emissions are included under undifferentiated production at the provincial level.

3 CO_2 emissions and removals in the LUCF sector are not included in the national totals. Non-CO_2 emissions from fires located in the National Parks are not included in the provincial/territorial totals but are reported in the national totals.

Totals may not add due to rounding.

ANNEX 11: CANADA'S GREENHOUSE GAS EMISSIONS BY GAS AND SECTOR, 1990–2001

1990 Greenhouse Gas Emission Summary for Canada

GHG Source and Sink Category	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	Total
Global Warming Potential	1		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	**472,000**	**3,500**	**73,000**	**170**	**53,000**	**-**	**6,000**	**3,000**	**608,000**
ENERGY	**432,000**	**1,600**	**33,000**	**27**	**8,400**	**-**	**-**	**-**	**473,000**
a. Stationary Combustion Sources	**276,000**	**180**	**3,800**	**6**	**2,000**	**-**	**-**	**-**	**282,000**
Electricity and Heat Generation	94,700	2	38	2	550	-	-	-	95,300
Fossil Fuel Industries	49,500	78	1,600	1	310	-	-	-	51,500
Petroleum Refining	26,000	-	8	-	86	-	-	-	26,100
Fossil Fuel Production	23,600	78	1,600	1	220	-	-	-	25,400
Mining	6,150	-	3	-	37	-	-	-	6,190
Manufacturing Industries	54,100	2	36	1	370	-	-	-	54,500
Iron and Steel	6,420	-	5	-	58	-	-	-	6,490
Non Ferrous Metals	3,210	-	1	-	15	-	-	-	3,230
Chemical	7,060	-	3	-	38	-	-	-	7,100
Pulp and Paper	13,400	1	16	-	120	-	-	-	13,500
Cement	3,370	-	1	-	14	-	-	-	3,390
Other Manufacturing	20,600	-	9	-	120	-	-	-	20,800
Construction	1,860	-	1	-	17	-	-	-	1,880
Commercial & Institutional	25,700	-	10	-	150	-	-	-	25,800
Residential	41,300	100	2,100	2	530	-	-	-	44,000
Agriculture & Forestry	2,403	-	1	-	17	-	-	-	2,420
b. Transportation Combustion Sources	**146,000**	**31**	**640**	**21**	**6,400**	**-**	**-**	**-**	**153,000**
Domestic Aviation	10,407	1	14	1	320	-	-	-	10,700
Road Transportation	103,000	16	350	12	3,600	-	-	-	107,000
Gasoline Automobiles	51,600	9	190	6	2,000	-	-	-	53,700
Light-Duty Gasoline Trucks	20,400	4	83	4	1,300	-	-	-	21,800
Heavy-Duty Gasoline Vehicles	2,990	-	9	-	140	-	-	-	3,140
Motorcycles	225	-	4	-	1	-	-	-	230
Diesel Automobiles	657	-	-	-	15	-	-	-	672
Light-Duty Diesel Trucks	577	-	-	-	13	-	-	-	591
Heavy-Duty Diesel Vehicles	24,300	1	25	1	221	-	-	-	24,500
Propane & Natural Gas Vehicles	2,160	2	36	-	13	-	-	-	2,210
Railways	6,320	-	7	3	790	-	-	-	7,110
Domestic Marine	4,730	-	7	1	310	-	-	-	5,050
Others	21,800	13	270	4	1,400	-	-	-	23,400
Off-Road	15,100	6	130	4	1,300	-	-	-	16,500
Pipelines	6,700	7	140	-	55	-	-	-	6,900
c. Fugitive Sources	**9,830**	**1,300**	**28,000**	**-**	**-**	**-**	**-**	**-**	**37,900**
Coal Mining	-	91	1,900	-	-	-	-	-	1,910
Oil and Natural Gas	9,800	1,200	26,000	-	-	-	-	-	36,000
Oil	27	410	8,500	-	-	-	-	-	8,570
Natural Gas	19	820	17,000	-	-	-	-	-	17,200
Venting	4,500	-	-	-	-	-	-	-	4,500
Flaring	5,300	24	500	-	-	-	-	-	5,780
INDUSTRIAL PROCESSES	**32,600**	**-**	**-**	**37**	**11,000**	**-**	**6,000**	**3,000**	**52,900**
a. Mineral Production	**8,160**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**8,160**
Cement	5,870	-	-	-	-	-	-	-	5,870
Lime	1,850	-	-	-	-	-	-	-	1,850
Limestone and Soda Use	439	-	-	-	-	-	-	-	439
b. Chemical Industry	**5,010**	**-**	**-**	**37**	**11,000**	**-**	**-**	**-**	**16,500**
Ammonia Production	5,010	-	-	-	-	-	-	-	5,010
Nitric Acid Production	-	-	-	3	780	-	-	-	777
Adipic Acid Production	-	-	-	35	10,718	-	-	-	10,700
c. Metal Production	**10,200**	**-**	**-**	**-**	**-**	**-**	**6,000**	**3,000**	**19,100**
Iron and Steel Production	7,590	-	-	-	-	-	-	-	7,590
Aluminium Production	2,640	-	-	-	-	-	6,000	-	8,610
SF_6 used in Magnesium Smelters	-	-	-	-	-	-	-	3,000	2,870
d. Consumption of Halocarbons	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
e. Other & Undifferentiated Production	**9,220**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**9,220**
SOLVENT & OTHER PRODUCT USE	**-**	**-**	**-**	**1**	**420**	**-**	**-**	**-**	**417**
AGRICULTURE	**7,550**	**980**	**21,000**	**100**	**31,000**	**-**	**-**	**-**	**59,200**
a. Enteric Fermentation	-	760	16,000	-	-	-	-	-	16,000
b. Manure Management	-	220	4,600	12	3,700	-	-	-	8,270
c. Agriculture Soils	8,000	-	-	90	30,000	-	-	-	30,000
Direct Sources	8,000	-	-	70	20,000	-	-	-	30,000
Indirect Sources	-	-	-	20	5,000	-	-	-	5,000
LAND-USE CHANGE AND FORESTRY (non-CO2 only)[1]	**-**	**62**	**1,300**	**3**	**960**	**-**	**-**	**-**	**2,256**
a. Prescribed Burns	-	47	980	2	580	-	-	-	1,560
b. Wildfires in the Wood Production Forest	-	15	320	1	380	-	-	-	698
WASTE	**254**	**900**	**19,000**	**3**	**920**	**-**	**-**	**-**	**20,100**
a. Solid Waste Disposal on Land	-	880	19,000	-	-	-	-	-	18,500
b. Wastewater Handling	-	17	360	3	870	-	-	-	1,220
c. Waste Incineration	254	-	9	-	54	-	-	-	317
LAND-USE CHANGE AND FORESTRY[1]	**-100,000**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-100,000**
a. Changes in Forest and Woody Biomass Stocks	-100,000	-	-	-	-	-	-	-	-100,000
b. Forest and Grassland Conversion	1,000	-	-	-	-	-	-	-	1,000
c. Abandonment of Managed Lands	-3,000	-	-	-	-	-	-	-	-3,000
d. CO_2 Emissions and Removals from Soil	4,000	-	-	-	-	-	-	-	4,000

Notes:

1 CO_2 emissions and removals in the LUCF sector are not included in the national totals. Non-CO_2 emissions from fires located in the National Parks are not included in the provincial/territorial totals but are reported in the national totals.

Totals may not add due to rounding.

1991 Greenhouse Gas Emission Summary for Canada

GHG Source and Sink Category	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	Total
Global Warming Potential	1		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	**462,000**	**3,625**	**76,000**	**170**	**53,000**	**-**	**6,000**	**3,000**	**601,000**
ENERGY	**422,000**	**1,607**	**34,000**	**27**	**8,500**	**-**	**-**	**-**	**464,000**
a. Stationary Combustion Sources	**271,000**	**170**	**3,600**	**6**	**1,900**	**-**	**-**	**-**	**276,000**
Electricity and Heat Generation	96,100	2	36	2	550	-	-	-	96,700
Fossil Fuel Industries	47,600	74	1,500	1	300	-	-	-	49,500
Petroleum Refining	25,700	-	8	-	90	-	-	-	25,800
Fossil Fuel Production	21,900	73	1,500	1	210	-	-	-	23,700
Mining	5,000	-	2	-	32	-	-	-	5,030
Manufacturing Industries	51,700	2	34	1	360	-	-	-	52,100
Iron and Steel	6,390	-	5	-	61	-	-	-	6,450
Non Ferrous Metals	2,600	-	1	-	12	-	-	-	2,610
Chemical	7,440	-	3	-	41	-	-	-	7,480
Pulp and Paper	12,700	1	15	-	120	-	-	-	12,800
Cement	2,890	-	1	-	12	-	-	-	2,900
Other Manufacturing	19,700	-	8	-	120	-	-	-	19,800
Construction	1,610	-	1	-	16	-	-	-	1,630
Commercial & Institutional	26,300	-	10	1	160	-	-	-	26,500
Residential	39,800	95	2,000	2	510	-	-	-	42,300
Agriculture & Forestry	2,740	-	1	-	18	-	-	-	2,760
b. Transportation Combustion Sources	**141,000**	**30**	**630**	**21**	**6,500**	**-**	**-**	**-**	**148,000**
Domestic Aviation	9,260	1	12	1	280	-	-	-	9,550
Road Transportation	100,000	16	340	13	4,000	-	-	-	104,310
Gasoline Automobiles	49,000	8	170	7	2,100	-	-	-	51,200
Light-Duty Gasoline Trucks	20,600	4	83	5	1,500	-	-	-	22,300
Heavy-Duty Gasoline Vehicles	3,170	-	9	-	150	-	-	-	3,330
Motorcycles	215	-	4	-	1	-	-	-	220
Diesel Automobiles	619	-	-	-	14	-	-	-	634
Light-Duty Diesel Trucks	495	-	-	-	11	-	-	-	507
Heavy-Duty Diesel Vehicles	23,600	1	24	1	210	-	-	-	23,800
Propane & Natural Gas Vehicles	2,260	2	41	-	14	-	-	-	2,320
Railways	5,850	-	7	2	730	-	-	-	6,590
Domestic Marine	4,940	-	8	1	300	-	-	-	5,250
Others	20,900	13	270	4	1,200	-	-	-	22,400
Off-Road	13,500	6	120	4	1,200	-	-	-	14,700
Pipelines	7,430	7	160	-	61	-	-	-	7,640
c. Fugitive Sources	**10,100**	**1,400**	**30,000**	**-**	**-**	**-**	**-**	**-**	**39,600**
Coal Mining	-	99	2,100	-	-	-	-	-	2,090
Oil and Natural Gas	10,000	1,300	27,000	-	-	-	-	-	37,500
Oil	25	440	9,200	-	-	-	-	-	9,200
Natural Gas	20	840	18,000	-	-	-	-	-	18,000
Venting	4,800	-	-	-	-	-	-	-	4,800
Flaring	5,200	23	490	-	-	-	-	-	5,700
INDUSTRIAL PROCESSES	**33,400**	**-**	**-**	**35**	**11,000**	**-**	**6,000**	**3,000**	**53,700**
a. Mineral Production	**6,980**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**6,980**
Cement	4,690	-	-	-	-	-	-	-	4,690
Lime	1,880	-	-	-	-	-	-	-	1,880
Limestone and Soda Use	418	-	-	-	-	-	-	-	418
b. Chemical Industry	**4,940**	**-**	**-**	**35**	**11,000**	**-**	**-**	**-**	**15,700**
Ammonia Production	4,940	-	-	-	-	-	-	-	4,940
Nitric Acid Production	-	-	-	2	770	-	-	-	766
Adipic Acid Production	-	-	-	32	10,000	-	-	-	10,000
c. Metal Production	**11,900**	**-**	**-**	**-**	**-**	**-**	**6,000**	**3,000**	**21,500**
Iron and Steel Production	8,900	-	-	-	-	-	-	-	8,900
Aluminium Production	3,010	-	-	-	-	-	6,000	-	9,330
SF_6 used in Magnesium Smelters	-	-	-	-	-	-	-	3,000	3,260
d. Consumption of Halocarbons	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
e. Other & Undifferentiated Production	**9,560**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**9,560**
SOLVENT & OTHER PRODUCT USE	**-**	**-**	**-**	**1**	**420**	**-**	**-**	**-**	**422**
AGRICULTURE	**6,950**	**990**	**21,000**	**98**	**30,000**	**-**	**-**	**-**	**58,100**
a. Enteric Fermentation	-	770	16,000	-	-	-	-	-	16,100
b. Manure Management	-	220	4,600	12	3,700	-	-	-	8,310
c. Agriculture Soils	7,000	-	-	90	30,000	-	-	-	30,000
Direct Sources	7,000	-	-	70	20,000	-	-	-	30,000
Indirect Sources	-	-	-	20	5,000	-	-	-	5,000
LAND-USE CHANGE AND FORESTRY (non-CO_2 only)[1]	**-**	**100**	**2,100**	**6**	**1,700**	**-**	**-**	**-**	**3,840**
a. Prescribed Burns	-	60	1,300	2	750	-	-	-	2,010
b. Wildfires in the Wood Production Forest	-	40	840	3	990	-	-	-	1,820
WASTE	**257**	**930**	**20,000**	**3**	**930**	**-**	**-**	**-**	**20,700**
a. Solid Waste Disposal on Land	-	910	19,000	-	-	-	-	-	19,200
b. Wastewater Handling	-	17	360	3	880	-	-	-	1,240
c. Waste Incineration	257	-	10	-	54	-	-	-	321
LAND-USE CHANGE AND FORESTRY[1]	**-90,000**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-90,000**
a. Changes in Forest and Woody Biomass Stocks	-100,000	-	-	-	-	-	-	-	-100,000
b. Forest and Grassland Conversion	1,000	-	-	-	-	-	-	-	1,000
c. Abandonment of Managed Lands	-3,000	-	-	-	-	-	-	-	-3,000
d. CO_2 Emissions and Removals from Soil	4,000	-	-	-	-	-	-	-	4,000

Notes:

1 CO_2 emissions and removals in the LUCF sector are not included in the national totals. Non-CO_2 emissions from fires located in the National Parks are not included in the provincial/territorial totals but are reported in the national totals.

Totals may not add due to rounding.

1992 Greenhouse Gas Emission Summary for Canada

GHG Source and Sink Category	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	Total
Global Warming Potential	1		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	**476,000**	**3,700**	**79,000**	**172**	**53,000**	**-**	**7,000**	**2,000**	**616,000**
ENERGY	**436,000**	**1,700**	**36,000**	**29**	**9,100**	**-**	**-**	**-**	**482,000**
a. Stationary Combustion Sources	**281,000**	**180**	**3,700**	**6**	**2,000**	**-**	**-**	**-**	**287,000**
Electricity and Heat Generation	102,200	2	49	2	180	-	-	-	103,000
Fossil Fuel Industries	50,100	77	1,600	1	180	-	-	-	52,100
Petroleum Refining	26,900	-	8	-	88	-	-	-	27,000
Fossil Fuel Production	23,200	77	1,600	1	180	-	-	-	25,000
Mining	4,760	-	2	-	33	-	-	-	4,790
Manufacturing Industries	51,100	2	34	1	180	-	-	-	51,500
Iron and Steel	6,650	-	5	-	63	-	-	-	6,720
Non Ferrous Metals	2,820	-	1	-	13	-	-	-	2,830
Chemical	7,410	-	3	-	40	-	-	-	7,450
Pulp and Paper	12,000	1	14	-	180	-	-	-	12,100
Cement	2,820	-	1	-	12	-	-	-	2,840
Other Manufacturing	19,400	-	8	-	180	-	-	-	19,600
Construction	1,730	-	1	-	17	-	-	-	1,750
Commercial & Institutional	26,900	-	10	1	180	-	-	-	27,000
Residential	41,000	94	2,000	2	180	-	-	-	43,500
Agriculture & Forestry	3,250	-	1	-	24	-	-	-	3,270
b. Transportation Combustion Sources	**145,000**	**32**	**180**	**23**	**7,100**	**-**	**-**	**-**	**152,000**
Domestic Aviation	9,430	1	11	1	180	-	-	-	9,720
Road Transportation	103,000	16	180	15	4,600	-	-	-	108,000
Gasoline Automobiles	49,100	8	180	8	2,300	-	-	-	51,600
Light-Duty Gasoline Trucks	22,100	4	88	6	1,800	-	-	-	24,000
Heavy-Duty Gasoline Vehicles	3,560	-	10	1	180	-	-	-	3,730
Motorcycles	213	-	4	-	1	-	-	-	218
Diesel Automobiles	617	-	-	-	14	-	-	-	631
Light-Duty Diesel Trucks	445	-	-	-	10	-	-	-	456
Heavy-Duty Diesel Vehicles	24,100	1	25	1	180	-	-	-	24,300
Propane & Natural Gas Vehicles	2,610	2	47	-	16	-	-	-	2,680
Railways	6,120	-	7	2	180	-	-	-	6,890
Domestic Marine	4,790	-	8	1	180	-	-	-	5,100
Others	21,600	14	180	4	1,200	-	-	-	23,000
Off-Road	12,000	4	94	3	1,100	-	-	-	13,100
Pipelines	9,610	10	180	-	78	-	-	-	9,890
c. Fugitive Sources	**10,600**	**1,511**	**32,000**	**-**	**-**	**-**	**-**	**-**	**42,400**
Coal Mining	-	87	1,800	-	-	-	-	-	1,830
Oil and Natural Gas	11,000	1,400	30,000	-	-	-	-	-	41,000
Oil	26	180	10,000	-	-	-	-	-	11,000
Natural Gas	21	180	19,000	-	-	-	-	-	19,000
Venting	5,300	-	-	-	-	-	-	-	5,300
Flaring	5,300	24	180	-	-	-	-	-	5,300
INDUSTRIAL PROCESSES	**33,000**	**-**	**-**	**35**	**11,000**	**-**	**7,000**	**2,000**	**52,500**
a. Mineral Production	**6,640**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**6,640**
Cement	4,300	-	-	-	-	-	-	-	4,300
Lime	1,880	-	-	-	-	-	-	-	1,880
Limestone and Soda Use	453	-	-	-	-	-	-	-	453
b. Chemical Industry	**5,110**	**-**	**-**	**35**	**11,000**	**-**	**-**	**-**	**15,800**
Ammonia Production	5,110	-	-	-	-	-	-	-	5,110
Nitric Acid Production	-	-	-	3	180	-	-	-	776
Adipic Acid Production	-	-	-	32	10,000	-	-	-	9,950
c. Metal Production	**12,300**	**-**	**-**	**-**	**-**	**-**	**7,000**	**2,000**	**21,100**
Iron and Steel Production	9,080	-	-	-	-	-	-	-	9,080
Aluminium Production	3,210	-	-	-	-	-	7,000	-	9,810
SF^6 used in Magnesium Smelters	-	-	-	-	-	-	-	2,000	2,170
d. Consumption of Halocarbons	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
e. Other & Undifferentiated Production	**8,960**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**8,960**
SOLVENT & OTHER PRODUCT USE	**-**	**-**	**-**	**1**	**180**	**-**	**-**	**-**	**428**
AGRICULTURE	**6,080**	**1,000**	**21,000**	**180**	**31,000**	**-**	**-**	**-**	**58,200**
a. Enteric Fermentation	-	180	17,000	-	-	-	-	-	16,600
b. Manure Management	-	180	4,700	12	3,800	-	-	-	8,470
c. Agriculture Soils	10,000	-	-	90	30,000	-	-	-	30,000
Direct Sources	10,000	-	-	70	20,000	-	-	-	30,000
Indirect Sources	-	-	-	20	6,000	-	-	-	10,000
LAND-USE CHANGE AND FORESTRY (non-CO^2 only)[1]	**-**	**66**	**1,400**	**3**	**1,100**	**-**	**-**	**-**	**2,430**
a. Prescribed Burns	-	46	180	2	180	-	-	-	1,560
b. Wildfires in the Wood Production Forest	-	19	180	2	180	-	-	-	877
WASTE	**261**	**180**	**20,000**	**3**	**180**	**-**	**-**	**-**	**21,200**
a. Solid Waste Disposal on Land	-	180	20,000	-	-	-	-	-	19,600
b. Wastewater Handling	-	17	180	3	180	-	-	-	1,250
c. Waste Incineration	261	-	10	-	55	-	-	-	326
LAND-USE CHANGE AND FORESTRY[1]	**-90,000**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-90,000**
a. Changes in Forest and Woody Biomass Stocks	-90,000	-	-	-	-	-	-	-	-90,000
b. Forest and Grassland Conversion	0	-	-	-	-	-	-	-	0
c. Abandonment of Managed Lands	0	-	-	-	-	-	-	-	0
d. CO^2 Emissions and Removals from Soil	0	-	-	-	-	-	-	-	0

Notes:

1 CO_2 emissions and removals in the LUCF sector are not included in the national totals. Non-CO_2 emissions from fires located in the National Parks are not included in the provincial/territorial totals but are reported in the national totals.

Totals may not add due to rounding.

1993 Greenhouse Gas Emission Summary for Canada

GHG Source and Sink Category	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	Total
Global Warming Potential	1		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	**474,000**	**3,800**	**81,000**	**180**	**54,000**	**-**	**7,000**	**2,000**	**619,000**
ENERGY	**434,000**	**1,800**	**37,000**	**31**	**9,700**	**-**	**-**	**-**	**482,000**
a. Stationary Combustion Sources	**275,000**	**180**	**3,800**	**6**	**2,000**	**-**	**-**	**-**	**281,000**
Electricity and Heat Generation	93,200	3	53	2	550	-	-	-	93,800
Fossil Fuel Industries	50,600	77	1,600	1	310	-	-	-	52,600
Petroleum Refining	27,900	-	9	-	90	-	-	-	28,000
Fossil Fuel Production	22,800	76	1,600	1	220	-	-	-	24,600
Mining	7,320	-	3	-	48	-	-	-	7,370
Manufacturing Industries	48,700	2	32	1	340	-	-	-	49,100
Iron and Steel	6,600	-	5	-	61	-	-	-	6,660
Non Ferrous Metals	2,710	-	1	-	12	-	-	-	2,730
Chemical	7,270	-	3	-	40	-	-	-	7,310
Pulp and Paper	11,900	1	13	-	110	-	-	-	12,000
Cement	2,840	-	1	-	12	-	-	-	2,860
Other Manufacturing	17,400	-	8	-	110	-	-	-	17,500
Construction	1,370	-	-	-	10	-	-	-	1,390
Commercial & Institutional	27,900	-	10	1	170	-	-	-	28,100
Residential	42,900	99	2,100	2	530	-	-	-	45,500
Agriculture & Forestry	3,040	-	1	-	22	-	-	-	3,060
b. Transportation Combustion Sources	**148,000**	**32**	**680**	**25**	**7,800**	**-**	**-**	**-**	**156,000**
Domestic Aviation	9,120	1	11	1	280	-	-	-	9,410
Road Transportation	105,000	16	340	17	5,100	-	-	-	110,000
Gasoline Automobiles	49,100	8	160	8	2,500	-	-	-	51,800
Light-Duty Gasoline Trucks	23,300	4	91	7	2,100	-	-	-	25,600
Heavy-Duty Gasoline Vehicles	3,880	1	11	1	180	-	-	-	4,070
Motorcycles	214	-	4	-	1	-	-	-	219
Diesel Automobiles	610	-	-	-	14	-	-	-	624
Light-Duty Diesel Trucks	420	-	-	-	10	-	-	-	429
Heavy-Duty Diesel Vehicles	25,400	1	26	1	230	-	-	-	25,700
Propane & Natural Gas Vehicles	1,970	2	43	-	12	-	-	-	2,030
Railways	6,090	-	7	2	760	-	-	-	6,860
Domestic Marine	4,190	-	6	1	280	-	-	-	4,480
Others	23,500	15	310	4	1,300	-	-	-	25,100
Off-Road	13,400	5	100	4	1,200	-	-	-	14,700
Pipelines	10,100	10	210	-	82	-	-	-	10,400
c. Fugitive Sources	11,300	1,600	33,000	-	-	-	-	-	44,400
Coal Mining	-	87	1,800	-	-	-	-	-	1,830
Oil and Natural Gas	11,000	1,500	31,000	-	-	-	-	-	43,000
Oil	27	510	11,000	-	-	-	-	-	11,000
Natural Gas	23	950	20,000	-	-	-	-	-	20,000
Venting	5,800	-	-	-	-	-	-	-	5,800
Flaring	5,600	25	520	-	-	-	-	-	6,000
INDUSTRIAL PROCESSES	**34,800**	**-**	**-**	**32**	**9,900**	**-**	**7,000**	**2,000**	**54,000**
a. Mineral Production	**6,880**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**6,875**
Cement	4,700	-	-	-	-	-	-	-	4,700
Lime	1,880	-	-	-	-	-	-	-	1,880
Limestone and Soda Use	299	-	-	-	-	-	-	-	299
b. Chemical Industry	**5,690**	**-**	**-**	**32**	**9,900**	**-**	**-**	**-**	**15,500**
Ammonia Production	5,690	-	-	-	-	-	-	-	5,690
Nitric Acid Production	-	-	-	3	780	-	-	-	777
Adipic Acid Production	-	-	-	29	9,100	-	-	-	9,080
c. Metal Production	**12,500**	**-**	**-**	**-**	**-**	**-**	**7,000**	**2,000**	**21,900**
Iron and Steel Production	8,760	-	-	-	-	-	-	-	8,760
Aluminium Production	3,770	-	-	-	-	-	7,000	-	11,168
SF_6 used in Magnesium Smelters	-	-	-	-	-	-	-	2,000	2,010
d. Consumption of Halocarbons	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
e. Other & Undifferentiated Production	**9,680**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**9,680**
SOLVENT & OTHER PRODUCT USE	**-**	**-**	**-**	**1**	**430**	**-**	**-**	**-**	**432**
AGRICULTURE	**4,960**	**1,000**	**21,000**	**103**	**32,000**	**-**	**-**	**-**	**58,400**
a. Enteric Fermentation	-	800	17,000	-	-	-	-	-	16,700
b. Manure Management	-	220	4,600	12	3,900	-	-	-	8,500
c. Agriculture Soils	5,000	-	-	90	30,000	-	-	-	30,000
Direct Sources	5,000	-	-	70	20,000	-	-	-	30,000
Indirect Sources	-	-	-	20	6,000	-	-	-	6,000
LAND-USE CHANGE AND FORESTRY (non-CO_2 only)[1]	**-**	**71**	**1,500**	**4**	**1,200**	**-**	**-**	**-**	**2,720**
a. Prescribed Burns	-	42	880	2	530	-	-	-	1,410
b. Wildfires in the Wood Production Forest	-	29	600	2	710	-	-	-	1,310
WASTE	**264**	**970**	**20,000**	**3**	**950**	**-**	**-**	**-**	**21,700**
a. Solid Waste Disposal on Land	-	960	20,000	-	-	-	-	-	20,100
b. Wastewater Handling	-	18	370	3	900	-	-	-	1,270
c. Waste Incineration	264	-	7	-	56	-	-	-	326
LAND-USE CHANGE AND FORESTRY[1]	**-70,000**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-70,000**
a. Changes in Forest and Woody Biomass Stocks	-70,000	-	-	-	-	-	-	-	-70,000
b. Forest and Grassland Conversion	2,000	-	-	-	-	-	-	-	2,000
c. Abandonment of Managed Lands	-3,000	-	-	-	-	-	-	-	-3,000
d. CO_2 Emissions and Removals from Soil	3,000	-	-	-	-	-	-	-	3,000

Notes:

1 CO_2 emissions and removals in the LUCF sector are not included in the national totals. Non-CO_2 emissions from fires located in the National Parks are not included in the provincial/territorial totals but are reported in the national totals.

Totals may not add due to rounding.

1994 Greenhouse Gas Emission Summary for Canada

GHG Source and Sink Category	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	Total
Global Warming Potential	1		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	**488,000**	**4,000**	**84,000**	**190**	**59,000**	**-**	**7,000**	**2,000**	**640,000**
ENERGY	**448,000**	**1,900**	**39,000**	**34**	**11,000**	**-**	**-**	**-**	**498,000**
a. Stationary Combustion Sources	**281,000**	**185**	**3,900**	**7**	**2,000**	**-**	**-**	**-**	**287,000**
Electricity and Heat Generation	95,400	3	54	2	570	-	-	-	96,000
Fossil Fuel Industries	51,300	81	1,700	1	310	-	-	-	53,400
Petroleum Refining	27,100	-	8	-	81	-	-	-	27,200
Fossil Fuel Production	24,300	81	1,700	1	230	-	-	-	26,200
Mining	7,440	-	3	-	53	-	-	-	7,490
Manufacturing Industries	51,800	2	34	1	350	-	-	-	52,200
Iron and Steel	7,400	-	6	-	64	-	-	-	7,470
Non Ferrous Metals	3,290	-	2	-	15	-	-	-	3,310
Chemical	8,480	-	4	-	46	-	-	-	8,530
Pulp and Paper	11,700	1	14	-	110	-	-	-	11,800
Cement	3,250	-	1	-	14	-	-	-	3,270
Other Manufacturing	17,700	-	7	-	97	-	-	-	17,800
Construction	1,390	-	-	-	10	-	-	-	1,400
Commercial & Institutional	27,300	1	11	1	180	-	-	-	27,400
Residential	43,700	99	2,100	2	540	-	-	-	46,300
Agriculture & Forestry	2,540	-	1	-	19	-	-	-	2,560
b. Transportation Combustion Sources	**155,000**	**33**	**691**	**27**	**8,500**	**-**	**-**	**-**	**164,000**
Domestic Aviation	9,770	1	11	1	300	-	-	-	10,100
Road Transportation	110,000	16	340	18	5,700	-	-	-	116,000
Gasoline Automobiles	49,400	8	160	9	2,800	-	-	-	52,300
Light-Duty Gasoline Trucks	24,900	5	95	8	2,500	-	-	-	27,400
Heavy-Duty Gasoline Vehicles	4,270	1	13	1	200	-	-	-	4,480
Motorcycles	216	-	4	-	1	-	-	-	221
Diesel Automobiles	603	-	-	-	14	-	-	-	617
Light-Duty Diesel Trucks	423	-	-	-	10	-	-	-	432
Heavy-Duty Diesel Vehicles	28,200	1	29	1	260	-	-	-	28,500
Propane & Natural Gas Vehicles	1,870	2	42	-	11	-	-	-	1,920
Railways	6,310	-	7	3	790	-	-	-	7,100
Domestic Marine	4,350	-	7	1	300	-	-	-	4,660
Others	24,900	15	320	5	1,400	-	-	-	26,700
Off-Road	14,500	5	100	4	1,400	-	-	-	15,900
Pipelines	10,500	10	220	-	85	-	-	-	10,800
c. Fugitive Sources	11,900	1,700	35,000	-	-	-	-	-	46,600
Coal Mining	-	84	1,800	-	-	-	-	-	1,770
Oil and Natural Gas	12,000	1,600	33,000	-	-	-	-	-	45,000
Oil	28	540	11,000	-	-	-	-	-	11,000
Natural Gas	25	1,000	21,000	-	-	-	-	-	21,000
Venting	6,200	-	-	-	-	-	-	-	6,000
Flaring	5,600	25	520	-	-	-	-	-	6,000
INDUSTRIAL PROCESSES	**35,700**	**-**	**-**	**38**	**12,000**	**-**	**7,000**	**2,000**	**56,400**
a. Mineral Production	**7,510**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**7,510**
Cement	5,290	-	-	-	-	-	-	-	5,290
Lime	1,930	-	-	-	-	-	-	-	1,930
Limestone and Soda Use	280	-	-	-	-	-	-	-	280
b. Chemical Industry	**5,810**	**-**	**-**	**38**	**12,000**	**-**	**-**	**-**	**17,500**
Ammonia Production	5,810	-	-	-	-	-	-	-	5,810
Nitric Acid Production	-	-	-	2	770	-	-	-	766
Adipic Acid Production	-	-	-	35	11,000	-	-	-	11,000
c. Metal Production	**11,800**	**-**	**-**	**-**	**-**	**-**	**7,000**	**2,000**	**20,700**
Iron and Steel Production	8,090	-	-	-	-	-	-	-	8,090
Aluminium Production	3,680	-	-	-	-	-	7,000	-	10,600
SF_6 used in Magnesium Smelters	-	-	-	-	-	-	-	2,000	2,040
d. Consumption of Halocarbons	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
e. Other & Undifferentiated Production	**10,600**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**10,600**
SOLVENT & OTHER PRODUCT USE	**-**	**-**	**-**	**1**	**440**	**-**	**-**	**-**	**437**
AGRICULTURE	**4,520**	**1,100**	**22,000**	**109**	**34,000**	**-**	**-**	**-**	**60,700**
a. Enteric Fermentation	-	830	18,000	-	-	-	-	-	17,500
b. Manure Management	-	230	4,800	13	4,100	-	-	-	8,930
c. Agriculture Soils	5,000	-	-	100	30,000	-	-	-	30,000
Direct Sources	5,000	-	-	80	20,000	-	-	-	30,000
Indirect Sources	-	-	-	20	6,000	-	-	-	6,000
LAND-USE CHANGE AND FORESTRY (non-CO_2 only)[1]	**-**	**71**	**1,500**	**5**	**1,600**	**-**	**-**	**-**	**3,040**
a. Prescribed Burns	-	16	340	1	200	-	-	-	536
b. Wildfires in the Wood Production Forest	-	55	1,100	4	1,400	-	-	-	2,500
WASTE	**267**	**980**	**21,000**	**3**	**960**	**-**	**-**	**-**	**21,900**
a. Solid Waste Disposal on Land	-	970	20,000	-	-	-	-	-	20,300
b. Wastewater Handling	-	18	370	3	910	-	-	-	1,280
c. Waste Incineration	267	-	6	-	56	-	-	-	330
LAND-USE CHANGE AND FORESTRY[1]	**-40,000**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-40,000**
a. Changes in Forest and Woody Biomass Stocks	-40,000	-	-	-	-	-	-	-	-40,000
b. Forest and Grassland Conversion	2,000	-	-	-	-	-	-	-	2,000
c. Abandonment of Managed Lands	-3,000	-	-	-	-	-	-	-	-3,000
d. CO_2 Emissions and Removals from Soil	3,000	-	-	-	-	-	-	-	3,000

Notes:

1 CO_2 emissions and removals in the LUCF sector are not included in the national totals. Non-CO_2 emissions from fires located in the National Parks are not included in the provincial/territorial totals but are reported in the national totals.

Totals may not add due to rounding.

1995 Greenhouse Gas Emission Summary for Canada

GHG Source and Sink Category	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	Total
Global Warming Potential	1		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	**501,000**	**4,200**	**87,000**	**200**	**61,000**	**500**	**6,000**	**2,000**	**658,000**
ENERGY	**461,000**	**2,000**	**41,000**	**35**	**11,000**	**-**	**-**	**-**	**513,000**
a. Stationary Combustion Sources	**288,000**	**183**	**3,800**	**7**	**2,100**	**-**	**-**	**-**	**294,000**
Electricity and Heat Generation	100,400	3	63	2	600	-	-	-	101,000
Fossil Fuel Industries	52,600	83	1,700	1	320	-	-	-	54,700
Petroleum Refining	28,300	-	9	-	86	-	-	-	28,400
Fossil Fuel Production	24,300	82	1,700	1	240	-	-	-	26,300
Mining	7,800	-	3	-	59	-	-	-	7,860
Manufacturing Industries	52,500	2	36	1	370	-	-	-	52,918
Iron and Steel	6,980	-	5	-	62	-	-	-	7,040
Non Ferrous Metals	3,090	-	1	-	14	-	-	-	3,110
Chemical	8,410	-	4	-	46	-	-	-	8,460
Pulp and Paper	11,400	1	16	-	120	-	-	-	11,500
Cement	3,400	-	1	-	14	-	-	-	3,420
Other Manufacturing	19,300	-	8	-	110	-	-	-	19,400
Construction	1,170	-	-	-	10	-	-	-	1,180
Commercial & Institutional	28,800	1	11	1	200	-	-	-	29,000
Residential	42,400	95	2,000	2	530	-	-	-	44,900
Agriculture & Forestry	2,770	-	1	-	21	-	-	-	2,790
b. Transportation Combustion Sources	**159,000**	**34**	**710**	**28**	**8,800**	**-**	**-**	**-**	**169,000**
Domestic Aviation	10,500	1	12	1	320	-	-	-	10,900
Road Transportation	112,000	16	340	19	5,900	-	-	-	119,000
Gasoline Automobiles	48,400	7	150	9	2,800	-	-	-	51,300
Light-Duty Gasoline Trucks	25,800	5	95	8	2,600	-	-	-	28,500
Heavy-Duty Gasoline Vehicles	4,530	1	13	1	210	-	-	-	4,760
Motorcycles	209	-	4	-	1	-	-	-	214
Diesel Automobiles	581	-	-	-	13	-	-	-	594
Light-Duty Diesel Trucks	407	-	-	-	9	-	-	-	416
Heavy-Duty Diesel Vehicles	30,500	1	31	1	280	-	-	-	30,800
Propane & Natural Gas Vehicles	2,050	2	43	-	12	-	-	-	2,100
Railways	5,710	-	7	2	710	-	-	-	6,430
Domestic Marine	4,060	-	6	1	310	-	-	-	4,380
Others	26,700	17	350	5	1,500	-	-	-	28,600
Off-Road	15,100	5	100	5	1,400	-	-	-	16,600
Pipelines	11,700	12	240	-	95	-	-	-	12,000
c. Fugitive Sources	**13,000**	**1,800**	**37,000**	**-**	**-**	**-**	**-**	**-**	**49,800**
Coal Mining	-	82	1,700	-	-	-	-	-	1,710
Oil and Natural Gas	13,000	1,700	35,000	-	-	-	-	-	48,000
Oil	29	600	13,000	-	-	-	-	-	13,000
Natural Gas	26	1,000	22,000	-	-	-	-	-	22,000
Venting	6,700	-	-	-	-	-	-	-	6,700
Flaring	6,300	28	580	-	-	-	-	-	6,800
INDUSTRIAL PROCESSES	**36,300**	**-**	**-**	**37**	**12,000**	**500**	**6,000**	**2,000**	**56,200**
a. Mineral Production	**7,690**	-	-	-	-	-	-	-	**7,691**
Cement	5,360	-	-	-	-	-	-	-	5,360
Lime	1,990	-	-	-	-	-	-	-	1,990
Limestone and Soda Use	343	-	-	-	-	-	-	-	343
b. Chemical Industry	**6,480**	**-**	**-**	**37**	**12,000**	**-**	**-**	**-**	**18,000**
Ammonia Production	6,480	-	-	-	-	-	-	-	6,480
Nitric Acid Production	-	-	-	3	780	-	-	-	782
Adipic Acid Production	-	-	-	35	11,000	-	-	-	10,700
c. Metal Production	**12,000**	-	-	-	-	-	**6,000**	**2,000**	**19,900**
Iron and Steel Production	8,440	-	-	-	-	-	-	-	8,440
Aluminium Production	3,540	-	-	-	-	-	6,000	-	9,560
SF_6 used in Magnesium Smelters	-	-	-	-	-	-	-	2,000	1,880
d. Consumption of Halocarbons	-	-	-	-	-	**500**	**30**	-	**508**
e. Other & Undifferentiated Production	**10,200**	-	-	-	-	-	-	-	**10,200**
SOLVENT & OTHER PRODUCT USE	**-**	**-**	**-**	**1**	**440**	**-**	**-**	**-**	**442**
AGRICULTURE	**3,460**	**1,100**	**23,000**	**110**	**35,000**	**-**	**-**	**-**	**61,100**
a. Enteric Fermentation	-	860	18,000	-	-	-	-	-	18,100
b. Manure Management	-	240	5,000	14	4,200	-	-	-	9,220
c. Agriculture Soils	3,000	-	-	100	30,000	-	-	-	30,000
Direct Sources	3,000	-	-	80	20,000	-	-	-	30,000
Indirect Sources	-	-	-	20	6,000	-	-	-	6,000
LAND-USE CHANGE AND FORESTRY (non-CO_2 only)[1]	**-**	**110**	**2,208**	**8**	**2,458**	**-**	**-**	**-**	**4,670**
a. Prescribed Burns	-	12	250	-	150	-	-	-	405
b. Wildfires in the Wood Production Forest	-	93	2,000	7	2,300	-	-	-	4,260
WASTE	**271**	**990**	**21,000**	**3**	**980**	**-**	**-**	**-**	**22,000**
a. Solid Waste Disposal on Land	-	970	20,000	-	-	-	-	-	20,400
b. Wastewater Handling	-	18	380	3	920	-	-	-	1,300
c. Waste Incineration	271	-	7	-	57	-	-	-	335
LAND-USE CHANGE AND FORESTRY[1]	**-10,000**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-10,000**
a. Changes in Forest and Woody Biomass Stocks	-10,000	-	-	-	-	-	-	-	-10,000
b. Forest and Grassland Conversion	2,000	-	-	-	-	-	-	-	2,000
c. Abandonment of Managed Lands	-3,000	-	-	-	-	-	-	-	-3,000
d. CO_2 Emissions and Removals from Soil	2,000	-	-	-	-	-	-	-	2,000

Notes:

1 CO_2 emissions and removals in the LUCF sector are not included in the national totals. Non-CO_2 emissions from fires located in the National Parks are not included in the provincial/territorial totals but are reported in the national totals.

Totals may not add due to rounding.

1996 Greenhouse Gas Emission Summary for Canada

GHG Source and Sink Category	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	Total
Global Warming Potential	1		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	**514,000**	**4,200**	**89,000**	**200**	**62,000**	**900**	**6,000**	**1,000**	**673,000**
ENERGY	**473,000**	**2,100**	**44,000**	**35**	**11,000**	**-**	**-**	**-**	**528,000**
a. Stationary Combustion Sources	**296,000**	**180**	**3,800**	**7**	**2,100**	**-**	**-**	**-**	**302,000**
Electricity and Heat Generation	99,100	3	55	2	590	-	-	-	99,700
Fossil Fuel Industries	53,200	84	1,800	1	330	-	-	-	55,300
Petroleum Refining	28,600	-	9	-	89	-	-	-	28,700
Fossil Fuel Production	24,600	84	1,800	1	240	-	-	-	26,600
Mining	8,680	-	4	-	60	-	-	-	8,740
Manufacturing Industries	54,300	2	35	1	360	-	-	-	54,700
Iron and Steel	7,260	-	5	-	64	-	-	-	7,330
Non Ferrous Metals	3,490	-	1	-	15	-	-	-	3,500
Chemical	8,740	-	4	-	48	-	-	-	8,800
Pulp and Paper	11,900	1	15	-	120	-	-	-	12,000
Cement	3,250	-	1	-	14	-	-	-	3,270
Other Manufacturing	19,600	-	8	-	110	-	-	-	19,700
Construction	1,260	-	-	-	10	-	-	-	1,270
Commercial & Institutional	29,400	1	11	1	190	-	-	-	29,600
Residential	47,100	94	2,000	2	550	-	-	-	49,700
Agriculture & Forestry	2,930	-	1	-	20	-	-	-	2,950
b. Transportation Combustion Sources	**164,000**	**34**	**720**	**28**	**8,800**	**-**	**-**	**-**	**173,000**
Domestic Aviation	11,600	1	13	1	350	-	-	-	11,900
Road Transportation	114,000	15	320	19	5,800	-	-	-	120,000
Gasoline Automobiles	47,100	7	140	8	2,600	-	-	-	49,900
Light-Duty Gasoline Trucks	27,100	5	96	9	2,700	-	-	-	29,900
Heavy-Duty Gasoline Vehicles	4,750	1	14	1	220	-	-	-	4,980
Motorcycles	205	-	3	-	1	-	-	-	210
Diesel Automobiles	588	-	-	-	13	-	-	-	602
Light-Duty Diesel Trucks	393	-	-	-	9	-	-	-	402
Heavy-Duty Diesel Vehicles	32,100	2	33	1	290	-	-	-	32,500
Propane & Natural Gas Vehicles	1,930	2	40	-	12	-	-	-	1,980
Railways	5,580	-	6	2	700	-	-	-	6,290
Domestic Marine	4,160	-	6	1	310	-	-	-	4,470
Others	28,400	18	370	5	1,600	-	-	-	30,400
Off-Road	16,300	6	120	5	1,500	-	-	-	17,900
Pipelines	12,200	12	250	-	98	-	-	-	12,500
c. Fugitive Sources	**13,500**	**1,900**	**39,000**	**-**	**-**	**-**	**-**	**-**	**52,700**
Coal Mining	-	84	1,800	-	-	-	-	-	1,770
Oil and Natural Gas	14,000	1,800	37,000	-	-	-	-	-	51,000
Oil	31	650	14,000	-	-	-	-	-	14,000
Natural Gas	27	1,100	23,000	-	-	-	-	-	23,000
Venting	6,900	-	-	-	-	-	-	-	6,900
Flaring	6,600	29	610	-	-	-	-	-	7,200
INDUSTRIAL PROCESSES	**37,900**	**-**	**-**	**40**	**12,000**	**900**	**6,000**	**1,000**	**58,400**
a. Mineral Production	**8,030**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**8,030**
Cement	5,790	-	-	-	-	-	-	-	5,790
Lime	1,900	-	-	-	-	-	-	-	1,900
Limestone and Soda Use	343	-	-	-	-	-	-	-	343
b. Chemical Industry	**6,520**	**-**	**-**	**40**	**12,000**	**-**	**-**	**-**	**18,800**
Ammonia Production	6,520	-	-	-	-	-	-	-	6,520
Nitric Acid Production	-	-	-	3	790	-	-	-	792
Adipic Acid Production	-	-	-	37	11,000	-	-	-	11,500
c. Metal Production	**12,000**	**-**	**-**	**-**	**-**	**-**	**6,000**	**1,000**	**19,300**
Iron and Steel Production	8,290	-	-	-	-	-	-	-	8,290
Aluminium Production	3,730	-	-	-	-	-	6,000	-	9,600
SF_6 used in Magnesium Smelters	-	-	-	-	-	-	-	1,000	1,360
d. Consumption of Halocarbons	**-**	**-**	**-**	**-**	**-**	**900**	**20**	**-**	**908**
e. Other & Undifferentiated Production	**11,400**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**11,400**
SOLVENT & OTHER PRODUCT USE	**-**	**-**	**-**	**1**	**450**	**-**	**-**	**-**	**447**
AGRICULTURE	**2,080**	**1,100**	**23,000**	**120**	**36,000**	**-**	**-**	**-**	**61,700**
a. Enteric Fermentation	-	870	18,000	-	-	-	-	-	18,200
b. Manure Management	-	240	5,100	14	4,300	-	-	-	9,350
c. Agriculture Soils	2,000	-	-	100	30,000	-	-	-	30,000
Direct Sources	2,000	-	-	80	30,000	-	-	-	30,000
Indirect Sources	-	-	-	20	7,000	-	-	-	7,000
LAND-USE CHANGE AND FORESTRY (non-CO_2 only)[1]	**-**	**44**	**920**	**3**	**920**	**-**	**-**	**-**	**1,840**
a. Prescribed Burns	-	13	280	1	170	-	-	-	443
b. Wildfires in the Wood Production Forest	-	31	640	2	760	-	-	-	1,400
WASTE	**274**	**990**	**21,000**	**3**	**990**	**-**	**-**	**-**	**22,100**
a. Solid Waste Disposal on Land	-	970	20,000	-	-	-	-	-	20,400
b. Wastewater Handling	-	18	380	3	930	-	-	-	1,310
c. Waste Incineration	274	-	7	-	58	-	-	-	338
LAND-USE CHANGE AND FORESTRY[1]	**-40,000**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-40,000**
a. Changes in Forest and Woody Biomass Stocks	-40,000	-	-	-	-	-	-	-	-40,000
b. Forest and Grassland Conversion	3,000	-	-	-	-	-	-	-	3,000
c. Abandonment of Managed Lands	-3,000	-	-	-	-	-	-	-	-3,000
d. CO_2 Emissions and Removals from Soil	3,000	-	-	-	-	-	-	-	3,000

Notes:

1 CO_2 emissions and removals in the LUCF sector are not included in the national totals. Non-CO_2 emissions from fires located in the National Parks are not included in the provincial/territorial totals but are reported in the national totals.

Totals may not add due to rounding.

1997 Greenhouse Gas Emission Summary for Canada

GHG Source and Sink Category	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	Total
Global Warming Potential	1		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	**525,000**	**4,200**	**89,000**	**190**	**60,000**	**900**	**6,000**	**1,000**	**682,000**
ENERGY	**485,000**	**2,100**	**44,000**	**36**	**11,000**	**-**	**-**	**-**	**539,000**
a. Stationary Combustion Sources	**301,000**	**180**	**3,700**	**7**	**2,200**	**-**	**-**	**-**	**307,000**
Electricity and Heat Generation	110,700	3	67	2	650	-	-	-	111,000
Fossil Fuel Industries	49,100	78	1,600	1	310	-	-	-	51,000
Petroleum Refining	26,800	-	9	-	88	-	-	-	26,900
Fossil Fuel Production	22,300	78	1,600	1	220	-	-	-	24,100
Mining	8,900	-	4	-	63	-	-	-	8,970
Manufacturing Industries	54,200	2	35	1	360	-	-	-	54,600
Iron and Steel	7,230	-	5	-	63	-	-	-	7,300
Non Ferrous Metals	3,170	-	1	-	14	-	-	-	3,180
Chemical	8,830	-	4	-	48	-	-	-	8,890
Pulp and Paper	11,700	1	15	-	120	-	-	-	11,800
Cement	3,230	-	1	-	13	-	-	-	3,250
Other Manufacturing	20,000	-	8	-	110	-	-	-	20,100
Construction	1,250	-	-	-	10	-	-	-	1,260
Commercial & Institutional	29,800	1	11	1	200	-	-	-	30,000
Residential	43,800	94	2,000	2	530	-	-	-	46,400
Agriculture & Forestry	2,920	-	1	-	21	-	-	-	2,940
b. Transportation Combustion Sources	**170,000**	**34**	**720**	**29**	**9,000**	**-**	**-**	**-**	**180,000**
Domestic Aviation	12,100	1	13	1	370	-	-	-	12,400
Road Transportation	120,000	15	320	19	5,900	-	-	-	126,000
Gasoline Automobiles	47,300	6	130	8	2,600	-	-	-	50,000
Light-Duty Gasoline Trucks	29,100	5	97	9	2,800	-	-	-	32,000
Heavy-Duty Gasoline Vehicles	4,820	1	14	1	220	-	-	-	5,050
Motorcycles	216	-	4	-	1	-	-	-	221
Diesel Automobiles	587	-	-	-	13	-	-	-	600
Light-Duty Diesel Trucks	494	-	-	-	11	-	-	-	505
Heavy-Duty Diesel Vehicles	35,200	2	36	1	320	-	-	-	35,500
Propane & Natural Gas Vehicles	1,790	2	43	-	11	-	-	-	1,840
Railways	5,660	-	7	2	710	-	-	-	6,380
Domestic Marine	4,220	-	6	1	300	-	-	-	4,530
Others	28,900	18	370	5	1,700	-	-	-	31,000
Off-Road	16,700	5	110	5	1,600	-	-	-	18,400
Pipelines	12,200	12	260	-	100	-	-	-	12,500
c. Fugitive Sources	**13,600**	**1,900**	**39,000**	**-**	**-**	**-**	**-**	**-**	**52,800**
Coal Mining	-	78	1,600	-	-	-	-	-	1,640
Oil and Natural Gas	14,000	1,800	38,000	-	-	-	-	-	51,000
Oil	36	690	14,000	-	-	-	-	-	14,000
Natural Gas	27	1,100	23,000	-	-	-	-	-	23,000
Venting	6,900	-	-	-	-	-	-	-	6,900
Flaring	6,600	29	610	-	-	-	-	-	7,300
INDUSTRIAL PROCESSES	**38,300**	**-**	**-**	**34**	**11,000**	**900**	**6,000**	**1,000**	**57,200**
a. Mineral Production	**8,180**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**8,180**
Cement	5,870	-	-	-	-	-	-	-	5,870
Lime	1,960	-	-	-	-	-	-	-	1,960
Limestone and Soda Use	359	-	-	-	-	-	-	-	359
b. Chemical Industry	**6,680**	**-**	**-**	**34**	**11,000**	**-**	**-**	**-**	**17,300**
Ammonia Production	6,680	-	-	-	-	-	-	-	6,680
Nitric Acid Production	-	-	-	3	790	-	-	-	786
Adipic Acid Production	-	-	-	32	9,900	-	-	-	9,890
c. Metal Production	**11,900**	**-**	**-**	**-**	**-**	**-**	**6,000**	**1,000**	**19,200**
Iron and Steel Production	8,100	-	-	-	-	-	-	-	8,100
Aluminium Production	3,790	-	-	-	-	-	6,000	-	9,760
SF_6 used in Magnesium Smelters	-	-	-	-	-	-	-	1,000	1,390
d. Consumption of Halocarbons	**-**	**-**	**-**	**-**	**-**	**900**	**20**	**-**	**883**
e. Other & Undifferentiated Production	**11,500**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**11,500**
SOLVENT & OTHER PRODUCT USE	**-**	**-**	**-**	**1**	**450**	**-**	**-**	**-**	**452**
AGRICULTURE	**1,540**	**1,100**	**23,000**	**120**	**36,000**	**-**	**-**	**-**	**61,300**
a. Enteric Fermentation	-	870	18,000	-	-	-	-	-	18,400
b. Manure Management	-	240	5,000	14	4,300	-	-	-	9,300
c. Agriculture Soils	2,000	-	-	100	30,000	-	-	-	30,000
Direct Sources	2,000	-	-	80	30,000	-	-	-	30,000
Indirect Sources	-	-	-	20	7,000	-	-	-	7,000
LAND-USE CHANGE AND FORESTRY (non-CO_2 only)[1]	**-**	**20**	**420**	**1**	**330**	**-**	**-**	**-**	**753**
a. Prescribed Burns	-	13	280	1	170	-	-	-	443
b. Wildfires in the Wood Production Forest	-	7	140	1	170	-	-	-	310
WASTE	**276**	**1,000**	**21,000**	**3**	**1,000**	**-**	**-**	**-**	**22,600**
a. Solid Waste Disposal on Land	-	1,000	21,000	-	-	-	-	-	20,900
b. Wastewater Handling	-	19	390	3	940	-	-	-	1,330
c. Waste Incineration	276	-	7	-	58	-	-	-	341
LAND-USE CHANGE AND FORESTRY[1]	**-50,000**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-50,000**
a. Changes in Forest and Woody Biomass Stocks	-50,000	-	-	-	-	-	-	-	-50,000
b. Forest and Grassland Conversion	3,000	-	-	-	-	-	-	-	3,000
c. Abandonment of Managed Lands	-3,000	-	-	-	-	-	-	-	-3,000
d. CO_2 Emissions and Removals from Soil	3,000	-	-	-	-	-	-	-	3,000

Notes:

1 CO_2 emissions and removals in the LUCF sector are not included in the national totals. Non-CO_2 emissions from fires located in the National Parks are not included in the provincial/territorial totals but are reported in the national totals.

Totals may not add due to rounding.

1998 Greenhouse Gas Emission Summary for Canada

GHG Source and Sink Category	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	Total
Global Warming Potential	1		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	**535,000**	**4,300**	**90,000**	**180**	**57,000**	**900**	**6,000**	**2,000**	**689,500**
ENERGY	**494,000**	**2,100**	**43,000**	**36**	**11,000**	**-**	**-**	**-**	**548,900**
a. Stationary Combustion Sources	**306,000**	**190**	**4,100**	**7**	**2,200**	**-**	**-**	**-**	**312,500**
Electricity and Heat Generation	122,800	4	82	2	720	-	-	-	123,600
Fossil Fuel Industries	54,300	92	1,900	1	350	-	-	-	56,500
Petroleum Refining	26,900	-	9	-	90	-	-	-	27,000
Fossil Fuel Production	27,400	92	1,900	1	260	-	-	-	29,600
Mining	7,960	-	3	-	58	-	-	-	8,020
Manufacturing Industries	52,000	2	36	1	360	-	-	-	52,400
Iron and Steel	6,940	-	5	-	62	-	-	-	7,000
Non Ferrous Metals	3,390	-	1	-	15	-	-	-	3,410
Chemical	8,520	-	4	-	47	-	-	-	8,570
Pulp and Paper	10,900	1	16	-	120	-	-	-	11,000
Cement	3,270	-	1	-	14	-	-	-	3,290
Other Manufacturing	19,100	-	8	-	110	-	-	-	19,200
Construction	1,110	-	-	-	10	-	-	-	1,120
Commercial & Institutional	27,000	-	10	1	180	-	-	-	27,200
Residential	38,400	95	2,000	2	510	-	-	-	41,000
Agriculture & Forestry	2,590	-	1	-	17	-	-	-	2,610
b. Transportation Combustion Sources	**174,300**	**35**	**740**	**29**	**8,900**	**-**	**-**	**-**	**184,000**
Domestic Aviation	12,600	1	13	1	380	-	-	-	13,000
Road Transportation	120,500	15	310	19	5,800	-	-	-	126,600
Gasoline Automobiles	47,100	6	120	8	2,500	-	-	-	49,700
Light-Duty Gasoline Trucks	30,000	4	94	9	2,700	-	-	-	32,800
Heavy-Duty Gasoline Vehicles	5,240	1	15	1	240	-	-	-	5,490
Motorcycles	227	-	4	-	1	-	-	-	232
Diesel Automobiles	583	-	-	-	13	-	-	-	597
Light-Duty Diesel Trucks	445	-	-	-	10	-	-	-	455
Heavy-Duty Diesel Vehicles	35,200	2	36	1	320	-	-	-	35,600
Propane & Natural Gas Vehicles	1,730	2	44	-	11	-	-	-	1,780
Railways	5,460	-	6	2	680	-	-	-	6,140
Domestic Marine	4,830	-	8	1	310	-	-	-	5,150
Others	30,900	19	410	6	1,800	-	-	-	33,100
Off-Road	18,800	7	150	5	1,700	-	-	-	20,600
Pipelines	12,100	12	250	-	99	-	-	-	12,500
c. Fugitive Sources	**13,800**	**1,800**	**39,000**	**-**	**-**	**-**	**-**	**-**	**52,400**
Coal Mining	-	65	1,400	-	-	-	-	-	1,360
Oil and Natural Gas	14,000	1,800	37,000	-	-	-	-	-	51,000
Oil	39	660	14,000	-	-	-	-	-	14,000
Natural Gas	27	1,100	23,000	-	-	-	-	-	23,000
Venting	7,200	-	-	-	-	-	-	-	7,200
Flaring	6,600	29	610	-	-	-	-	-	7,200
INDUSTRIAL PROCESSES	**38,900**	**-**	**-**	**19**	**5,800**	**900**	**6,000**	**2,000**	**53,300**
a. Mineral Production	**8,680**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**8,680**
Cement	6,060	-	-	-	-	-	-	-	6,060
Lime	1,940	-	-	-	-	-	-	-	1,940
Limestone and Soda Use	677	-	-	-	-	-	-	-	677
b. Chemical Industry	**6,610**	**-**	**-**	**19**	**5,800**	**-**	**-**	**-**	**12,400**
Ammonia Production	6,610	-	-	-	-	-	-	-	6,610
Nitric Acid Production	-	-	-	2	770	-	-	-	771
Adipic Acid Production	-	-	-	16	5,100	-	-	-	5,070
c. Metal Production	**12,100**	**-**	**-**	**-**	**-**	**-**	**6,000**	**2,000**	**19,700**
Iron and Steel Production	8,320	-	-	-	-	-	-	-	8,320
Aluminium Production	3,820	-	-	-	-	-	6,000	-	9,840
SF_6 used in Magnesium Smelters	-	-	-	-	-	-	-	2,000	1,540
d. Consumption of Halocarbons	**-**	**-**	**-**	**-**	**-**	**900**	**19**	**-**	**936**
e. Other & Undifferentiated Production	**11,500**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**11,500**
SOLVENT & OTHER PRODUCT USE	**-**	**-**	**-**	**1**	**460**	**-**	**-**	**-**	**456**
AGRICULTURE	**1,010**	**1,100**	**23,000**	**120**	**37,000**	**-**	**-**	**-**	**60,900**
a. Enteric Fermentation	-	860	18,000	-	-	-	-	-	18,000
b. Manure Management	-	240	5,100	14	4,300	-	-	-	9,370
c. Agriculture Soils	1,000	-	-	100	30,000	-	-	-	30,000
Direct Sources	1,000	-	-	83	30,000	-	-	-	30,000
Indirect Sources	-	-	-	20	7,000	-	-	-	7,000
LAND-USE CHANGE AND FORESTRY (non-CO_2 only)[1]	**-**	**67**	**1,400**	**5**	**1,500**	**-**	**-**	**-**	**2,910**
a. Prescribed Burns	-	13	280	1	170	-	-	-	443
b. Wildfires in the Wood Production Forest	-	54	1,100	4	1,300	-	-	-	2,470
WASTE	**278**	**1,000**	**22,000**	**3**	**1,000**	**-**	**-**	**-**	**23,100**
a. Solid Waste Disposal on Land	-	1,000	21,000	-	-	-	-	-	21,400
b. Wastewater Handling	-	19	390	3	950	-	-	-	1,340
c. Waste Incineration	278	-	7	-	58	-	-	-	343
LAND-USE CHANGE AND FORESTRY[1]	**-30,000**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-30,000**
a. Changes in Forest and Woody Biomass Stocks	-40,000	-	-	-	-	-	-	-	-40,000
b. Forest and Grassland Conversion	3,000	-	-	-	-	-	-	-	3,000
c. Abandonment of Managed Lands	-3,000	-	-	-	-	-	-	-	-3,000
d. CO_2 Emissions and Removals from Soil	2,000	-	-	-	-	-	-	-	2,000

Notes:

1 CO_2 emissions and removals in the LUCF sector are not included in the national totals. Non-CO_2 emissions from fires located in the National Parks are not included in the provincial/territorial totals but are reported in the national totals.

Totals may not add due to rounding.

1999 Greenhouse Gas Emission Summary for Canada

GHG Source and Sink Category	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	Total
Global Warming Potential	1		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	**554,000**	**4,300**	**90,000**	**170**	**54,000**	**900**	**6,000**	**2,000**	**706,000**
ENERGY	**513,000**	**2,100**	**44,000**	**37**	**11,000**	**-**	**-**	**-**	**568,000**
a. Stationary Combustion Sources	**319,000**	**220**	**4,500**	**7**	**2,300**	**-**	**-**	**-**	**326,000**
Electricity and Heat Generation	123,900	4	81	2	700	-	-	-	125,000
Fossil Fuel Industries	62,600	110	2,400	1	410	-	-	-	65,400
Petroleum Refining	27,300	-	9	-	87	-	-	-	27,400
Fossil Fuel Production	35,300	110	2,400	1	330	-	-	-	38,100
Mining	7,390	-	3	-	54	-	-	-	7,450
Manufacturing Industries	52,400	2	36	1	370	-	-	-	52,800
Iron and Steel	7,210	-	6	-	64	-	-	-	7,280
Non Ferrous Metals	3,240	-	1	-	14	-	-	-	3,260
Chemical	8,410	-	4	-	46	-	-	-	8,460
Pulp and Paper	10,800	1	16	-	120	-	-	-	11,000
Cement	3,530	-	2	-	15	-	-	-	3,550
Other Manufacturing	19,100	-	8	-	100	-	-	-	19,300
Construction	1,160	-	-	-	10	-	-	-	1,170
Commercial & Institutional	28,700	1	11	1	190	-	-	-	28,900
Residential	40,500	95	2,000	2	520	-	-	-	43,000
Agriculture & Forestry	2,670	-	1	-	18	-	-	-	2,690
b. Transportation Combustion Sources	**179,000**	**34**	**720**	**29**	**9,100**	**-**	**-**	**-**	**189,000**
Domestic Aviation	13,200	1	13	1	400	-	-	-	13,600
Road Transportation	125,000	14	300	19	5,800	-	-	-	131,000
Gasoline Automobiles	47,300	5	110	8	2,400	-	-	-	49,800
Light-Duty Gasoline Trucks	33,600	5	99	9	2,900	-	-	-	36,600
Heavy-Duty Gasoline Vehicles	4,010	1	12	1	180	-	-	-	4,210
Motorcycles	228	-	4	-	1	-	-	-	233
Diesel Automobiles	591	-	-	-	13	-	-	-	605
Light-Duty Diesel Trucks	489	-	-	-	11	-	-	-	500
Heavy-Duty Diesel Vehicles	36,900	2	38	1	340	-	-	-	37,300
Propane & Natural Gas Vehicles	1,450	2	37	-	9	-	-	-	1,500
Railways	5,780	-	7	2	720	-	-	-	6,510
Domestic Marine	4,650	-	7	1	320	-	-	-	4,970
Others	30,800	19	400	6	1,800	-	-	-	33,000
Off-Road	18,600	7	140	6	1,700	-	-	-	20,500
Pipelines	12,200	12	260	-	100	-	-	-	12,600
c. Fugitive Sources	**14,400**	**1,800**	**38,000**	**-**	**-**	**-**	**-**	**-**	**52,800**
Coal Mining	-	51	1,100	-	-	-	-	-	1,080
Oil and Natural Gas	14,000	1,800	37,000	-	-	-	-	-	52,000
Oil	34	640	13,000	-	-	-	-	-	13,000
Natural Gas	28	1,100	23,000	-	-	-	-	-	23,000
Venting	7,400	-	-	-	-	-	-	-	7,400
Flaring	7,000	30	640	-	-	-	-	-	7,600
INDUSTRIAL PROCESSES	**40,200**	**-**	**-**	**8**	**2,500**	**900**	**6,000**	**2,000**	**51,500**
a. Mineral Production	**9,100**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**9,100**
Cement	6,310	-	-	-	-	-	-	-	6,310
Lime	2,030	-	-	-	-	-	-	-	2,030
Limestone and Soda Use	758	-	-	-	-	-	-	-	758
b. Chemical Industry	**6,850**	**-**	**-**	**8**	**2,500**	**-**	**-**	**-**	**9,380**
Ammonia Production	6,850	-	-	-	-	-	-	-	6,850
Nitric Acid Production	-	-	-	3	790	-	-	-	786
Adipic Acid Production	-	-	-	6	1,700	-	-	-	1,750
c. Metal Production	**12,400**	**-**	**-**	**-**	**-**	**-**	**6,000**	**2,000**	**20,300**
Iron and Steel Production	8,500	-	-	-	-	-	-	-	8,500
Aluminium Production	3,920	-	-	-	-	-	6,000	-	10,100
SF_6 used in Magnesium Smelters	-	-	-	-	-	-	-	2,000	1,670
d. Consumption of Halocarbons	**-**	**-**	**-**	**-**	**-**	**900**	**20**	**-**	**936**
e. Other & Undifferentiated Production	**11,800**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**11,800**
SOLVENT & OTHER PRODUCT USE	**-**	**-**	**-**	**1**	**460**	**-**	**-**	**-**	**459**
AGRICULTURE	**475**	**1,100**	**23,000**	**122**	**38,000**	**-**	**-**	**-**	**61,100**
a. Enteric Fermentation	-	850	18,000	-	-	-	-	-	17,800
b. Manure Management	-	240	5,100	14	4,300	-	-	-	9,410
c. Agriculture Soils	500	-	-	100	30,000	-	-	-	30,000
Direct Sources	500	-	-	90	30,000	-	-	-	30,000
Indirect Sources	-	-	-	20	7,000	-	-	-	7,000
LAND-USE CHANGE AND FORESTRY (non-CO_2 only)[1]	**-**	**35**	**740**	**2**	**670**	**-**	**-**	**-**	**1,410**
a. Prescribed Burns	-	17	350	1	210	-	-	-	560
b. Wildfires in the Wood Production Forest	-	19	390	1	460	-	-	-	851
WASTE	**280**	**1,100**	**23,000**	**3**	**1,000**	**-**	**-**	**-**	**23,800**
a. Solid Waste Disposal on Land	-	1,100	22,000	-	-	-	-	-	22,110
b. Wastewater Handling	-	19	400	3	950	-	-	-	1,350
c. Waste Incineration	280	-	7	-	59	-	-	-	345
LAND-USE CHANGE AND FORESTRY[1]	**-30,000**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-30,000**
a. Changes in Forest and Woody Biomass Stocks	-30,000	-	-	-	-	-	-	-	-30,000
b. Forest and Grassland Conversion	3,000	-	-	-	-	-	-	-	3,000
c. Abandonment of Managed Lands	-3,000	-	-	-	-	-	-	-	-3,000
d. CO_2 Emissions and Removals from Soil	2,000	-	-	-	-	-	-	-	2,000

Notes:

1 CO_2 emissions and removals in the LUCF sector are not included in the national totals. Non-CO_2 emissions from fires located in the National Parks are not included in the provincial/territorial totals but are reported in the national totals.

Totals may not add due to rounding.

2000 Greenhouse Gas Emission Summary for Canada

GHG Source and Sink Category	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	Total
Global Warming Potential	1		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	**577,000**	**4,300**	**91,000**	**170**	**53,000**	**900**	**6,000**	**2,000**	**730,000**
ENERGY	**537,000**	**2,100**	**45,000**	**37**	**11,000**	**-**	**-**	**-**	**593,000**
a. Stationary Combustion Sources	**341,000**	**220**	**4,600**	**8**	**2,400**	**-**	**-**	**-**	**348,000**
Electricity and Heat Generation	135,200	5	100	2	760	-	-	-	136,000
Fossil Fuel Industries	64,000	120	2,500	1	430	-	-	-	66,900
Petroleum Refining	27,700	-	9	-	94	-	-	-	27,800
Fossil Fuel Production	36,300	120	2,500	1	340	-	-	-	39,100
Mining	10,310	-	4	-	77	-	-	-	10,400
Manufacturing Industries	52,600	2	37	1	370	-	-	-	53,000
Iron and Steel	7,120	-	5	-	63	-	-	-	7,190
Non Ferrous Metals	3,180	-	1	-	15	-	-	-	3,190
Chemical	7,820	-	3	-	43	-	-	-	7,860
Pulp and Paper	10,700	1	17	-	130	-	-	-	10,800
Cement	3,410	-	1	-	14	-	-	-	3,430
Other Manufacturing	20,400	-	8	-	110	-	-	-	20,500
Construction	1,070	-	-	-	8	-	-	-	1,080
Commercial & Institutional	33,000	1	13	1	220	-	-	-	33,200
Residential	42,500	95	2,000	2	530	-	-	-	45,000
Agriculture & Forestry	2,550	-	1	-	18	-	-	-	2,570
b. Transportation Combustion Sources	**181,000**	**33**	**690**	**29**	**9,000**	**-**	**-**	**-**	**190,000**
Domestic Aviation	13,300	1	14	1	400	-	-	-	13,700
Road Transportation	126,000	13	280	18	5,600	-	-	-	131,000
Gasoline Automobiles	45,900	5	95	7	2,200	-	-	-	48,300
Light-Duty Gasoline Trucks	34,700	5	96	9	2,800	-	-	-	37,600
Heavy-Duty Gasoline Vehicles	4,170	1	12	1	190	-	-	-	4,370
Motorcycles	233	-	4	-	1	-	-	-	239
Diesel Automobiles	591	-	-	-	13	-	-	-	605
Light-Duty Diesel Trucks	630	-	-	-	14	-	-	-	645
Heavy-Duty Diesel Vehicles	38,300	2	39	1	350	-	-	-	38,700
Propane & Natural Gas Vehicles	1,060	2	36	-	7	-	-	-	1,100
Railways	5,920	-	7	2	740	-	-	-	6,670
Domestic Marine	4,780	-	7	1	320	-	-	-	5,110
Others	31,000	18	380	6	2,000	-	-	-	33,400
Off-Road	20,100	7	150	6	1,900	-	-	-	22,100
Pipelines	11,000	11	230	-	89	-	-	-	11,300
c. Fugitive Sources	**14,800**	**1,900**	**39,000**	**-**	**-**	**-**	**-**	**-**	**54,000**
Coal Mining	-	45	950	-	-	-	-	-	949
Oil and Natural Gas	15,000	1,800	38,000	-	-	-	-	-	53,000
Oil	76	660	14,000	-	-	-	-	-	14,000
Natural Gas	28	1,135	24,000	-	-	-	-	-	24,000
Venting	7,500	-	-	-	-	-	-	-	7,500
Flaring	7,200	31	650	-	-	-	-	-	7,800
INDUSTRIAL PROCESSES	**39,800**	**-**	**-**	**5**	**1,700**	**900**	**6,000**	**2,000**	**50,900**
a. Mineral Production	**8,700**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**8,700**
Cement	6,310	-	-	-	-	-	-	-	6,310
Lime	2,000	-	-	-	-	-	-	-	2,000
Limestone and Soda Use	403	-	-	-	-	-	-	-	403
b. Chemical Industry	**6,850**	**-**	**-**	**5**	**1,700**	**-**	**-**	**-**	**8,540**
Ammonia Production	6,850	-	-	-	-	-	-	-	6,850
Nitric Acid Production	-	-	-	3	800	-	-	-	799
Adipic Acid Production	-	-	-	3	900	-	-	-	900
c. Metal Production	**12,400**	**-**	**-**	**-**	**-**	**-**	**6,000**	**2,000**	**20,900**
Iron and Steel Production	8,510	-	-	-	-	-	-	-	8,510
Aluminium Production	3,890	-	-	-	-	-	6,000	-	10,000
SF_6 used in Magnesium Smelters	-	-	-	-	-	-	-	2,000	2,310
d. Consumption of Halocarbons	**-**	**-**	**-**	**-**	**-**	**900**	**20**	**-**	**936**
e. Other & Undifferentiated Production	**11,900**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**11,900**
SOLVENT & OTHER PRODUCT USE	**-**	**-**	**-**	**1**	**460**	**-**	**-**	**-**	**463**
AGRICULTURE	**62**	**1,100**	**23,000**	**120**	**38,000**	**-**	**-**	**-**	**60,800**
a. Enteric Fermentation	-	840	18,000	-	-	-	-	-	17,700
b. Manure Management	-	240	5,100	14	4,300	-	-	-	9,380
c. Agriculture Soils	60	-	-	100	30,000	-	-	-	30,000
Direct Sources	60	-	-	90	30,000	-	-	-	30,000
Indirect Sources	-	-	-	20	7,000	-	-	-	7,000
LAND-USE CHANGE AND FORESTRY (non-CO_2 only)[1]	**-**	**19**	**400**	**1**	**260**	**-**	**-**	**-**	**660**
a. Prescribed Burns	-	17	360	1	220	-	-	-	581
b. Wildfires in the Wood Production Forest	-	2	36	-	43	-	-	-	79
WASTE	**282**	**1,100**	**23,000**	**3**	**1,000**	**-**	**-**	**-**	**24,300**
a. Solid Waste Disposal on Land	-	1,100	23,000	-	-	-	-	-	22,600
b. Wastewater Handling	-	19	400	3	960	-	-	-	1,360
c. Waste Incineration	282	-	7	-	59	-	-	-	348
LAND-USE CHANGE AND FORESTRY[1]	**-50,000**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-50,000**
a. Changes in Forest and Woody Biomass Stocks	-60,000	-	-	-	-	-	-	-	-60,000
b. Forest and Grassland Conversion	3,000	-	-	-	-	-	-	-	3,000
c. Abandonment of Managed Lands	-3,000	-	-	-	-	-	-	-	-3,000
d. CO_2 Emissions and Removals from Soil	2,000	-	-	-	-	-	-	-	2,000

Notes:

1 CO_2 emissions and removals in the LUCF sector are not included in the national totals. Non-CO_2 emissions from fires located in the National Parks are not included in the provincial/territorial totals but are reported in the national totals.

Totals may not add due to rounding.

2001 Greenhouse Gas Emission Summary for Canada

GHG Source and Sink Category	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	Total
Global Warming Potential	1		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	**566,000**	**4,500**	**93,000**	**170**	**51,000**	**900**	**6,000**	**2,000**	**720,000**
ENERGY	**528,000**	**2,100**	**45,000**	**36**	**11,000**	**-**	**-**	**-**	**584,000**
a. Stationary Combustion Sources	**335,000**	**220**	**4,600**	**8**	**2,400**	**-**	**-**	**-**	**342,000**
Electricity and Heat Generation	136,000	5	100	2	770	-	-	-	137,000
Fossil Fuel Industries	64,500	120	2,400	1	420	-	-	-	67,300
Petroleum Refining	29,000	-	9	-	90	-	-	-	29,100
Fossil Fuel Production	35,500	110	2,400	1	330	-	-	-	38,200
Mining	10,200	-	4	-	78	-	-	-	10,200
Manufacturing Industries	48,500	2	35	1	350	-	-	-	48,900
Iron and Steel	5,830	-	5	-	55	-	-	-	5,890
Non Ferrous Metals	3,480	-	2	-	17	-	-	-	3,500
Chemical	6,440	-	3	-	35	-	-	-	6,470
Pulp and Paper	9,500	1	16	-	110	-	-	-	9,630
Cement	3,270	-	1	-	14	-	-	-	3,290
Other Manufacturing	20,000	-	8	-	110	-	-	-	20,100
Construction	1,000	-	-	-	8	-	-	-	1,010
Commercial & Institutional	32,700	1	13	1	210	-	-	-	32,900
Residential	39,400	94	2,000	2	520	-	-	-	41,900
Agriculture & Forestry	2,190	-	1	-	17	-	-	-	2,210
b. Transportation Combustion Sources	**178,000**	**31**	**650**	**29**	**8,900**	**-**	**-**	**-**	**187,000**
Domestic Aviation	11,800	1	12	1	360	-	-	-	12,100
Road Transportation	127,000	14	290	19	5,700	-	-	-	134,000
Gasoline Automobiles	46,400	5	96	7	2,200	-	-	-	48,700
Light-Duty Gasoline Trucks	36,400	5	100	9	2,900	-	-	-	39,400
Heavy-Duty Gasoline Vehicles	3,930	1	12	1	180	-	-	-	4,130
Motorcycles	236	-	4	-	1	-	-	-	242
Diesel Automobiles	583	-	-	-	13	-	-	-	596
Light-Duty Diesel Trucks	629	-	-	-	14	-	-	-	643
Heavy-Duty Diesel Vehicles	38,200	2	39	1	350	-	-	-	38,600
Propane & Natural Gas Vehicles	1,100	2	36	-	7	-	-	-	1,140
Railways	5,820	-	7	2	730	-	-	-	6,550
Domestic Marine	5,180	-	8	1	330	-	-	-	5,510
Others	27,600	16	330	6	1,700	-	-	-	29,700
Off-Road	17,700	6	130	5	1,700	-	-	-	19,500
Pipelines	9,970	10	210	-	81	-	-	-	10,300
c. Fugitive Sources	**15,300**	**1,900**	**39,000**	**-**	**-**	**-**	**-**	**-**	**54,800**
Coal Mining	-	47	990	-	-	-	-	-	990
Oil and Natural Gas	15,000	1,800	38,000	-	-	-	-	-	54,000
Oil	78	660	14,000	-	-	-	-	-	14,000
Natural Gas	29	1,100	24,000	-	-	-	-	-	24,000
Venting	7,800	-	-	-	-	-	-	-	7,800
Flaring	7,400	31	660	-	-	-	-	-	8,000
INDUSTRIAL PROCESSES	**38,300**	**-**	**-**	**5**	**1,600**	**900**	**6,000**	**2,000**	**49,000**
a. Mineral Production	**8,650**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**8,650**
Cement	6,490	-	-	-	-	-	-	-	6,490
Lime	1,750	-	-	-	-	-	-	-	1,750
Limestone and Soda Use	403	-	-	-	-	-	-	-	403
b. Chemical Industry	**5,920**	**-**	**-**	**5**	**1,600**	**-**	**-**	**-**	**7,520**
Ammonia Production	5,920	-	-	-	-	-	-	-	5,920
Nitric Acid Production	-	-	-	3	800	-	-	-	795
Adipic Acid Production	-	-	-	3	800	-	-	-	802
c. Metal Production	**12,100**	**-**	**-**	**-**	**-**	**-**	**6,000**	**2,000**	**20,300**
Iron and Steel Production	7,920	-	-	-	-	-	-	-	7,920
Aluminium Production	4,160	-	-	-	-	-	6,000	-	10,300
SF_6 used in Magnesium Smelters	-	-	-	-	-	-	-	2,000	2,020
d. Consumption of Halocarbons	**-**	**-**	**-**	**-**	**-**	**900**	**20**	**-**	**936**
e. Other & Undifferentiated Production	**11,700**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**11,700**
SOLVENT & OTHER PRODUCT USE	**-**	**-**	**-**	**2**	**470**	**-**	**-**	**-**	**468**
AGRICULTURE	**-299**	**1,200**	**24,000**	**120**	**36,000**	**-**	**-**	**-**	**60,000**
a. Enteric Fermentation	-	900	19,000	-	-	-	-	-	18,800
b. Manure Management	-	260	5,500	15	4,600	-	-	-	10,100
c. Agriculture Soils	-300	-	-	100	31,000	-	-	-	30,000
Direct Sources	-300	-	-	79	24,000	-	-	-	20,000
Indirect Sources	-	-	-	23	7,000	-	-	-	7,000
LAND-USE CHANGE AND FORESTRY (non-CO_2 only)[1]	**-**	**50**	**1,100**	**3**	**1,000**	**-**	**-**	**-**	**2,080**
a. Prescribed Burns	-	17	360	1	210	-	-	-	575
b. Wildfires in the Wood Production Forest	-	33	690	3	820	-	-	-	1,510
WASTE	**284**	**1,100**	**23,000**	**3**	**1,000**	**-**	**-**	**-**	**24,800**
a. Solid Waste Disposal on Land	-	1,100	23,000	-	-	-	-	-	23,100
b. Wastewater Handling	-	19	400	3	970	-	-	-	1,370
c. Waste Incineration	284	-	7	-	60	-	-	-	350
LAND-USE CHANGE AND FORESTRY[1]	**-40,000**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-40,000**
a. Changes in Forest and Woody Biomass Stocks	-40,000	-	-	-	-	-	-	-	-40,000
b. Forest and Grassland Conversion	4,000	-	-	-	-	-	-	-	4,000
c. Abandonment of Managed Lands	-3,000	-	-	-	-	-	-	-	-3,000
d. CO_2 Emissions and Removals from Soil	2,000	-	-	-	-	-	-	-	2,000

Notes:

1 CO_2 emissions and removals in the LUCF sector are not included in the national totals. Non-CO_2 emissions from fires located in the National Parks are not included in the provincial/territorial totals but are reported in the national totals.

Totals may not add due to rounding.

The printing processes used in producing this document conform to environmental performance standards established by the Government of Canada under *Canada's National Guidelines on Lithographic Printing Services.* These standards aim to ensure the environmental integrity of printing processes through reductions in toxic emissions to the environment, reductions in loading of wastewater, reductions in the quantity of materials sent to landfills, and the implementation of resource conservation procedures.

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