Canada's Greenhouse Gas Inventory

1990–2000

Greenhouse Gas Division
Environment Canada

JUNE 2002

Environment Canada / Environnement Canada

Canada

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Greenhouse Gas Division
Environment 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 in November 1999, 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, 1999, 2000, and 2001. 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.

The Kyoto Protocol, once ratified, 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, April 12, 2002
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, Serge Grenier 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 and Tony Lempriere, our colleagues at Agriculture and Agri-Food Canada, Wayne Lindwall, Marie Boehm, and Henry Janzen, and our colleagues at 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 Steve Graham and Steve Lapp of SGA Energy Limited for augmenting the work of staff within the Greenhouse Gas Division to produce the key source analysis, and to John Nyboer of Simon Fraser University for his detailed analysis of energy use in Canadian industry. The authors also wish to acknowledge the work of Savvas Farassoglou, an engineering student within the Greenhouse Gas Division, without whose contributions this report would not have been possible. Ken Olsen and Pascale Collas managed the development of the national inventory, and Pierre Boileau 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
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	hydrofluorocarbons
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
m	metre
m^3	cubic metre
M-GEM	Mobile Greenhouse Gas Emission Model
MSW	municipal solid waste
Mt	megatonne
MW	megawatt
N	elemental 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
VOC	volatile organic compound

EXECUTIVE SUMMARY

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 2002 marks the 10th anniversary since Canada first published a GHG emissions inventory. Under the 1992 UNFCCC, Canada and other developed countries committed, among other things, to put in place policies and measures with the aim of returning their GHG emissions to their 1990 levels by 2000. At the first meeting of the Conference of the Parties to the UNFCCC in 1995, the Parties agreed that the initial aim of the UNFCCC was inadequate. They agreed that new commitments for the post-2000 period should be concluded by the third Conference of the Parties in Kyoto in December 1997. The emission reductions called for in the Kyoto Protocol, if met, will result in an overall reduction in emissions in developed countries of 5.2% below 1990 levels.

The year 2000, for which emission estimates have been produced in this report, represents the midpoint between 1990 and 2010. The emission estimates illustrate that additional steps are necessary if Canada is to meet its Kyoto Protocol commitments to reduce its GHG emissions by 6% below 1990 levels during the period 2008–2012, should Canada decide to ratify this Protocol.

The Kyoto Protocol will enter into force when no fewer than 55 Parties to the Convention, accounting in total for at least 55% of the total GHG emissions of Annex I countries for 1990, have agreed to ratification. Government of Canada decisions on ratification will occur once a national implementation strategy has been developed.

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 1990–2000. Chapter 2 of this report provides an in-depth analysis of Canada's GHG trends in accordance with the UNFCCC Reporting Guidelines. Appendices A to D detail the methods used to compile Canada's National GHG Inventory. Finally, summary tables of GHG emissions tabulated by jurisdiction, sector, and gas are presented in Appendices E and F.

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);
- 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). 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[2]. A detailed description of the types of methodologies used to estimate trends in emissions is provided in Appendix A.

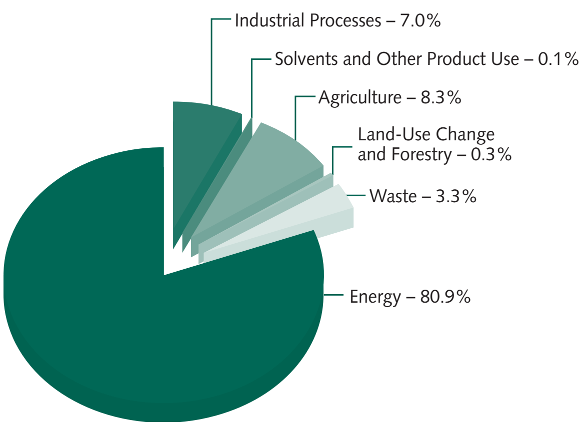
2 Minor differences exist between the UNFCCC and CGHGI sector designations. These are explained in footnotes throughout this report. More details can be found in Appendix A, where the CGHGI methodology is described.

CANADA'S 2000 GREENHOUSE GAS INVENTORY

In 2000, Canadians contributed about 726 megatonnes of CO_2 equivalent (Mt CO_2 eq)[3] of GHGs to the atmosphere[4], which represents about 2% of total global GHG emissions. On a per capita basis, Canada ranks ninth in the world (second in the G8) for CO_2 emissions due to a variety of factors, in particular its energy-intensive economy.

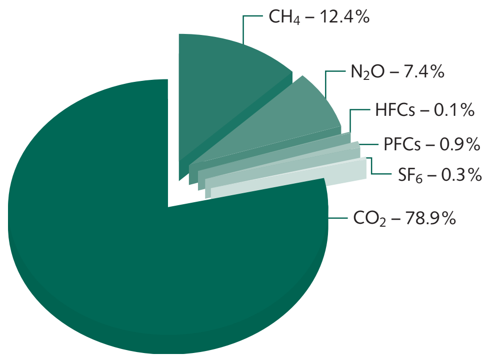
Approximately 73% of total GHG emissions in 2000 resulted from the combustion of fossil fuels. Another 7.4% resulted from fugitive emissions, for a total of almost 81% from the energy sector. A sectoral breakdown of Canada's total emissions for 2000[5] is shown in Figure S-1.

FIGURE S-1: Sectoral Breakdown of Canada's GHG Emissions, 2000



On an individual GHG basis, CO_2 contributed the largest share of 2000 emissions, at 79% (about 571 Mt), while CH_4 accounted for 12% (90 Mt). N_2O accounted for 7% of the emissions (54 Mt), PFCs supplied 1% (6 Mt), and SF_6 and HFCs constituted the remainder (Figure S-2).

FIGURE S-2: Canada's GHG Emissions by Gas, 2000



Net CO_2 removals associated with the LUCF sector are not included in the inventory totals; however, they are estimated to be less than -20 Mt for 2000[6]. Table S-1 shows the emissions for individual gases and sectors in Canada for the year 2000.

3 Each of the GHGs has a unique average atmospheric lifetime over which it is an effective climate-forcing agent. The concept of global warming potential (GWP) has been introduced to equate this climate forcing for different GHGs to that of CO_2. A more detailed explanation is provided in Section 1.4 of this document.

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

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

6 Removals of CO_2 are shown as negative values.

TABLE S-1: Canada's GHG Emissions by Gas and Sector, 2000

GHG Source and Sink Category	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	Total
Global Warming Potential Multiplier	*1*		*21*		*310*	*140–11 700*	*6500–9200*	*23900*	
	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
ENERGY									
FUEL COMBUSTION									
Fossil Fuel Industries	63,900	120	2,500	1.4	430				66,800
Electricity & Heat Generation	128,000	4.4	92	2.4	740				128,000
Mining	9,200	0.2	3.9	0.2	71				9,270
Manufacturing	57,500	1.9	39	1.3	400				57,900
Construction	1,070	0.0	0.4	0.0	8				1,080
Transport									
Light Duty Gasoline Vehicles	46,000	4.5	95	7.2	2,200				48,300
Light Duty Gasoline Trucks	33,600	4.4	93	8.7	2,700				36,400
Heavy Duty Gasoline Vehicles	5,570	0.8	16	0.8	260				5,850
Motorcycles	234	0.2	3.9	0.0	1.4				239
Off Road Gasoline	5,110	5.8	120	0.1	34				5,270
Light Duty Diesel Vehicles	400	0.0	0.2	0.0	9				410
Light Duty Diesel Trucks	133	0.0	0.1	0.0	3				136
Heavy Duty Diesel Vehicles	37,500	1.8	39	1.1	340				37,800
Off Road Diesel	16,100	0.8	17	6.5	2,000				18,100
Propane & Natural Gas Vehicles	1,060	1.7	36	0.0	6.6				1,100
Domestic Aviation	13,300	0.6	13	1.3	400				13,700
Domestic Marine	4,780	0.4	7.3	1.0	320				5,110
Railways	5,920	0.3	6.8	2.4	740				6,670
Vehicles Subtotal	170,000	21	450	29	9,100				179,000
Pipelines	11,000	11	230	0.3	89				11,300
Transport Subtotal	181,000	32	680	30	9,200				190,000
Residential	42,500	95	2,000	1.7	530				45,000
Commercial & Institutional	31,700	0.7	14	0.7	210				31,900
Other	2,550	0.0	0.8	0.1	18				2,570
COMBUSTION SUBTOTAL	517,000	250	5,300	37	12,000				533,000
FUGITIVE									
Solid Fuels (i.e. Coal Mining)		45	950						950
Oil & Gas	15,000	1,800	38,000						53,000
FUGITIVE SUBTOTAL	15,000	1,900	39,000						54,000
ENERGY TOTAL	531,000	2,100	44,000	37	12,000				587,000
INDUSTRIAL PROCESSES									
Non-Metallic Mineral Production	9,080								9,080
Ammonia, Adipic Acid & Nitric Acid Production	6,850			5.5	1,700				8,500
Ferrous Metal Production	8,510								8,510
Aluminum & Magnesium Production	3,890						6,000	2,300	12,000
Undifferentiated Production and Product Use	12,000					900	20		13,000
INDUSTRIAL PROCESSES TOTAL	40,000			5.5	1,700	900	6,000	2,300	51,000
SOLVENT & OTHER PRODUCT USE	0	0	0	1.5	460				500
AGRICULTURE									
Enteric Fermentation		840	18,000						18,000
Manure Management		240	5,100	14	4,300				9,400
Agricultural Soils**	-200			100	30,000				30,000
AGRICULTURE TOTAL	-200	1,100	23,000	120	38,000				60,000
LAND USE CHANGE & FORESTRY*		60	1,000	4	1,000				2,000
WASTE									
Solid Waste Disposal on Land		1,100	23,000						23,000
Wastewater Handling		19	400	3.1	960				1,400
Waste Incineration	280	0.3	6.9	0.2	59				350
WASTE TOTAL	280	1,100	23,000	3.3	1,000				24,000
TOTAL	**571,000**	**4,400**	**91,000**	**170**	**54,000**	**900**	**6,000**	**2,300**	**726,000**
CO_2 from Land Use Change & Forestry**	-20,000								

Notes:

Due to rounding, individual values may not add up to totals (zero values may represent estimated quantities too small to display).

** Only one significant figure shown due to high uncertainty.

* Methane and nitrous oxide emissions from prescribed fires and anthropogenic fires outside the Wood Production Forest. Fires located in national parks are not included in the provincial/territorial total but are reported in the national total.

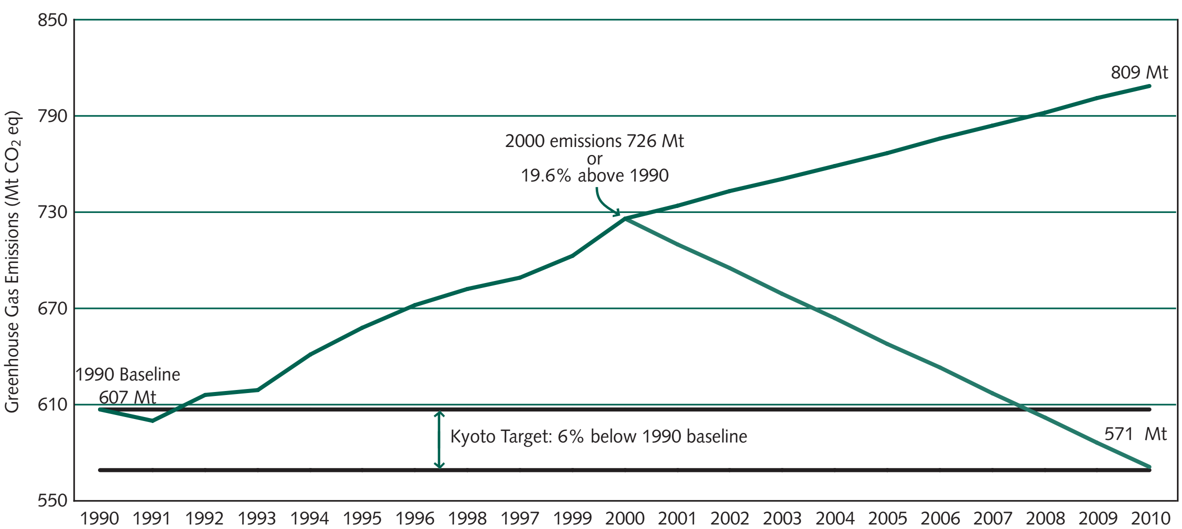
CANADA'S GREENHOUSE GAS TRENDS, 1990–2000

The 1990–2000 data on Canada's GHG emissions (Table S-2) demonstrate progress in reducing emissions in some areas of the economy, but also indicate where more work needs to be done. Total emissions of all GHGs in 2000 were 19.6% above the 1990 level of 607 Mt. Although emissions have been rising since 1990 (Figure S-3), in 1994, emission growth peaked at over 3.6% per year and fell consistently thereafter until 1999, when emissions rose 2% over the previous year. Between 1999 and 2000, emissions rose 3.2%, representing the second-highest annual growth rate of the decade. However, this growth is largely the result of a colder than average winter and increased use of fossil fuels for heating in the residential and commercial sectors. The cumulative average annual growth of emissions over the 1990–2000 period was 1.8%.

Canadian emissions in 2000 increased by 23 Mt over the 1999 level of 703 Mt. The energy sector was responsible for most of the short-term increase, with emissions rising to over 587 Mt. For example, GHG emissions associated with vehicles in 2000 rose by 3 Mt over 1999, an increase of almost 2%. Increasing discharges from light-duty trucks and heavy-duty vehicles contributed to the growth.

These trends reflect the growing numbers of sport utility vehicles (SUVs) and greater freight trucking activity. The 4% short-term increase in energy-related emissions was partially offset by emission reductions of 0.3 Mt (0.7%) from the Industrial Processes sector. Table S-2 summarises Canada's GHG emissions by sector for the years 1990–2000.

FIGURE S-3: Canada's GHG Emission Trends and Forecast, 1990–2000



Sources: Actual Emission Estimates, Baseline (estimates presented in this report); Forecast: McIlveen, N. (2002), personal communication, Analysis and Modelling Group, Natural Resources Canada.

TABLE S-2: Canada's GHG Emission Trends by Sector, 1990–2000

GHG Source and Sink Category	1990	1995	1999	2000
		All Gases kt CO_2 eq		
ENERGY				
FUEL COMBUSTION				
Fossil Fuel Industries	51,500	54,700	65,400	66,800
Electricity & Heat Generation	95,300	101,000	121,000	128,000
Mining	6,190	7,860	7,450	9,270
Manufacturing	54,500	52,900	52,800	57,900
Construction	1,880	1,180	1,170	1,080
Transport				
Light Duty Gasoline Vehicles	53,700	51,300	49,600	48,300
Light Duty Gasoline Trucks	21,700	28,500	35,300	36,400
Heavy Duty Gasoline Vehicles	3,140	4,760	5,660	5,850
Motorcycles	230	214	232	239
Off Road Gasoline	5,010	3,940	5,370	5,270
Light Duty Diesel Vehicles	672	594	414	410
Light Duty Diesel Trucks	591	416	139	136
Heavy Duty Diesel Vehicles	24,600	30,800	37,300	37,800
Off Road Diesel	11,300	12,700	15,700	18,100
Propane & Natural Gas Vehicles	2,210	2,100	1,500	1,100
Domestic Aviation	10,700	10,900	13,600	13,700
Domestic Marine	5,050	4,380	4,970	5,110
Railways	7,110	6,430	6,510	6,670
Vehicles Subtotal	146,000	157,000	176,000	179,000
Pipelines	6,900	12,000	12,600	11,300
Transport Subtotal	153,000	169,000	189,000	190,000
Residential	44,000	44,900	43,000	45,000
Commercial & Institutional	25,800	29,000	28,900	31,900
Other	2,420	2,790	2,690	2,570
COMBUSTION SUBTOTAL	434,000	463,000	512,000	533,000
FUGITIVE				
Solid Fuels (i.e., Coal Mining)	1,900	1,700	1,100	950
Oil & Gas	36,000	48,000	52,000	53,000
FUGITIVE SUBTOTAL	38,000	50,000	53,000	54,000
ENERGY TOTAL	472,000	513,000	564,000	587,000
INDUSTRIAL PROCESSES				
Non Metallic Mineral Production	8,160	7,690	9,100	9,080
Ammonia, Adipic Acid & Nitric Acid Production	17,000	18,000	9,400	8,500
Ferrous Metal Production	7,590	8,440	8,500	8,510
Aluminum & Magnesium Production	11,000	11,000	12,000	12,000
Other & Undifferentiated Production	9,200	11,000	13,000	13,000
INDUSTRIAL PROCESSES TOTAL	53,000	57,000	52,000	51,000
SOLVENT & OTHER PRODUCT USE	400	400	500	500
AGRICULTURE				
Enteric Fermentation	16,000	18,000	18,000	18,000
Manure Management	8,300	9,200	9,400	9,400
Agricultural Soils**	30,000	30,000	30,000	30,000
AGRICULTURE TOTAL	59,000	61,000	61,000	60,000
LAND USE CHANGE & FORESTRY*	2,000	5,000	2,000	2,000
WASTE				
Solid Waste Disposal on Land	19,000	20,000	22,000	23,000
Wastewater Handling	1,200	1,300	1,300	1,400
Waste Incineration	320	330	350	350
WASTE TOTAL	20,000	22,000	24,000	24,000
TOTAL	**607,000**	**658,000**	**703,000**	**726,000**
CO_2 from Land Use Change & Forestry**	-60,000	-20,000	-10,000	-20,000

Notes:

Due to rounding, individual values may not add up to totals (zero values may represent estimated quantities too small to display).

** Only one significant figure shown due to high uncertainty.

* Methane and nitrous oxide emissions from prescribed fires and anthropogenic fires outside the Wood Production Forest. Fires located in national parks are not included in the provincial/territorial total but are reported in the national total.

Table S-3 depicts Canada's total GHG emissions from 1990 to 2000, 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 19.6% increase in GHG emissions during the past decade outpaced increases in both population (which grew 11%) and energy use (which rose 17%). However, the growth in total emissions was well short of the almost 33% growth in GDP between 1990 and 2000 (Statistics Canada, Gross Domestic Product [GDP], expenditure-based, annual [dollars], CANSIM II, Table 384-0002). On average, GDP grew at about 1.8% per year in the mid-1990s and by 4.6% in 2000.

TABLE S-3: Canada's GHG Emissions and Accompanying Variables, 1990–2000

Year	1990	1995	2000
Total GHG (Mt)	**607**	**658**	**726**
Growth Since 1990	N/A	8.4%	19.6%
GDP – Expense[1] (Millions of 1997$)	**764 386**	**834 189**	**1 012 809**
Growth Since 1990	N/A	9.1%	32.5%
Population (000s)[2]	**27 701**	**29 354**	**30 750**
Growth Since 1990	N/A	6.0%	11.0%
Energy Use (PJ)[3]	**9 230**	**9 695**	**10 815**
Growth Since 1990	N/A	5%	17%
Energy Produced (PJ)	**7 752**	**10 277**	**11 729**
Growth Since 1990	N/A	33%	51%
Energy Exported (PJ)	**1 755**	**4 032**	**4 822**
Growth Since 1990	N/A	130%	175%
Emissions Associated with Exports (Mt)	**21.5**	**42.9**	**47.5**
Growth Since 1990	N/A	100%	121%

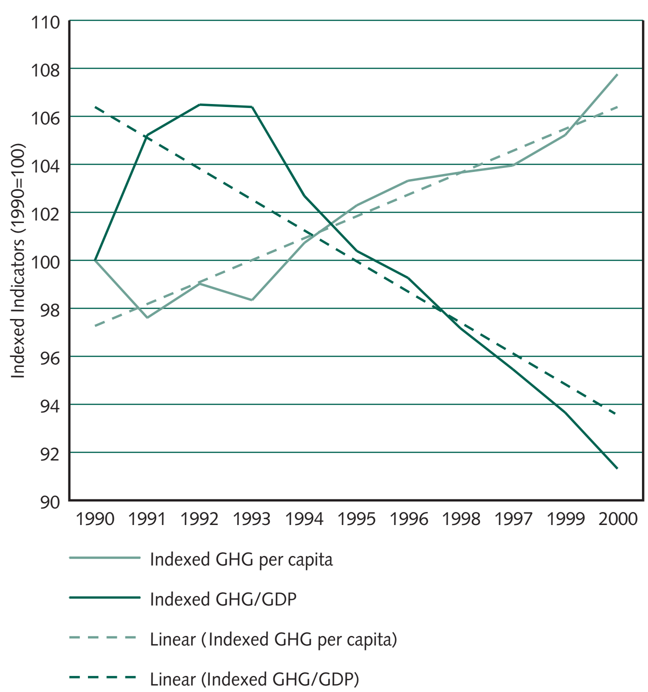
1 Gross Domestic Product [GDP], expenditure-based, annual [dollars], CANSIM II, Table 384-0002.

2 Statistics Canada, Catalogue #91-213.

3 Statistics Canada, Catalogue #57-003.

GHG emissions per unit of GDP decreased over the period 1990–2000, mainly due to a move away from fossil fuels in the industrial, residential, and commercial sectors and to gains in energy efficiency (Figure S-4). Growth in total emissions, having outstripped growth in population, was influenced by changing characteristics in various sectors. Examples include shifts in electrical generation in Ontario from nuclear to coal, expanded coal thermal generation in at least four provinces, increased road freight transport, and increased fossil fuel extraction for export.

FIGURE S-4: Trends in GHG Intensity of GDP and Population, 1990–2000



Overall, the energy sector is responsible for 96.6% of the 119 Mt increase in total Canadian GHG emissions over the period 1990–2000, while representing 81% of the total GHG emissions for 2000. The greatest contributors to the increases in GHG emissions are:

- vehicles, 33 Mt (28% of the increase);
- electricity and steam generation, 33 Mt (28% of the increase); and
- fossil fuel industries, 15 Mt (13% of the increase).

The GHG emission increase associated with the transport sector has been driven by increases in trucking activity and the number of SUVs and vans being used for personal and commercial transportation. For example, emissions from light-duty trucks, which include pickup trucks, SUVs, and vans, have increased by 67% since 1990, while emissions from cars have decreased 10%. On average, light-duty trucks emit 40% more GHGs per kilometre than cars.

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[7] between 1990 and 2000 (Tables S-4 and S-5). In this period, net oil exports grew by 328% to 1037 petajoules (PJ)[8] (over 10 times the growth rate of oil production), while net exports of natural gas increased 150% to 3785 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 almost 65 Mt in 2000[9]. Overall, total energy exported has increased 131% between 1990 and 2000, while emissions associated with exports have increased 134%.

TABLE S-4: Crude Oil: Production, Net Export, and GHG Emission Trends, 1990–2000

Crude Oil	1990	1995	2000
Domestic Production (PJ)	**3568**	**4148**	**4669**
Growth Since 1990	N/A	16%	31%
Energy Exported (PJ)	**1512**	**2443**	**3197**
Growth Since 1990	N/A	62%	111%
Net Energy Export (PJ)	**242**	**1047**	**1037**
Growth Since 1990	N/A	332%	328%
Emissions Associated with Exported Energy (Mt CO_2 eq)	**13.9**	**24.5**	**31.9**
Growth Since 1990	N/A	76%	130%
Emissions Associated with NET Exported Energy (Mt CO_2 eq)	**8.8**	**17.8**	**16.5**
Growth Since 1990	N/A	102%	88%

TABLE S-5: Natural Gas: Production, Net Export, and GHG Emission Trends, 1990–2000

Natural Gas	1990	1995	2000
Domestic Production (PJ)	**4184**	**6129**	**7060**
Growth Since 1990	N/A	46%	69%
Energy Exported (PJ)	**1537**	**3011**	**3846**
Growth Since 1990	N/A	96%	150%
Net Energy Exported (PJ)	**1513**	**2985**	**3785**
Growth Since 1990	N/A	97%	150%
Emissions Associated with Exported Energy (Mt CO_2 eq)	**13.9**	**26.5**	**33.1**
Growth Since 1990	N/A	91%	138%
Emissions Associated with NET Exported Energy (Mt CO_2 eq)	**12.7**	**25.1**	**31.1**
Growth Since 1990	N/A	98%	145%

7 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.

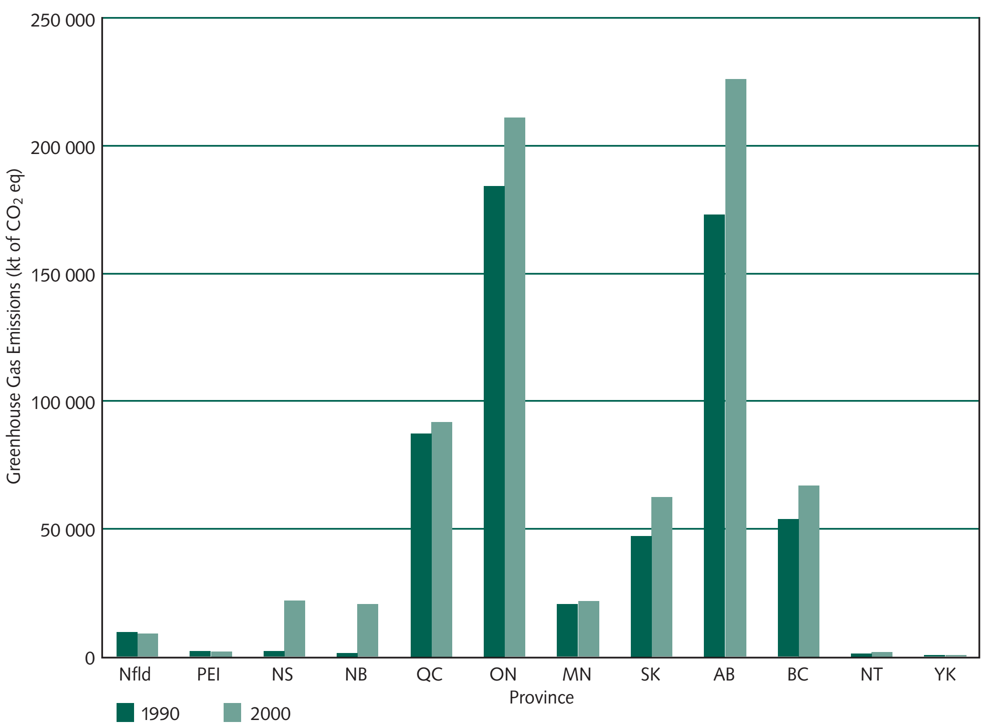
8 A petajoule is a measure of the energy content of fuels.

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

PROVINCIAL/TERRITORIAL GREENHOUSE GAS EMISSIONS

It is important to note that Canada's GHG emissions have a distinct regional distribution, which is linked to the distribution of natural resources and heavy industry within the country. These natural resources and industrial products benefit all regions of North America; however, 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 regional distribution of emissions and the change in these emissions between 1990 and 2000.

FIGURE S-5: Total Provincial/Territorial GHG Emissions, 1990 and 2000[10]



10 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.

RECALCULATION OF ESTIMATES

No significant revisions in emission estimates have been made from the previous inventory (which was prepared in 2001), and emission totals for 1990 have not been revised. The recalculations from last year's inventory are primarily because of updated activity data and a reallocation in industrial process emissions.

ENERGY SECTOR

Estimates for 1999 have been recalculated because the underlying fuel-use data from the *Quarterly Report on Energy Supply-Demand in Canada* (QRESD) (Statistics Canada, #57-003) have been updated. This has resulted in minor changes in all GHG emissions from the energy category for 1999. Emissions for fuel combustion in total have been revised upward less than 1%.

Transportation estimates for 1999 have also been revised slightly (less than 1%) due to updates in vehicle populations and fuel data.

INDUSTRIAL PROCESSES SECTOR

Compared with previous inventories, about 2 Mt of CO_2 has been reallocated from the other industrial processes source category to the ammonia production category. In previous inventories, emissions allocated to ammonia production were reduced to account for CO_2 stored in urea production. Emissions from urea use were accounted for under the other industrial processes category. The IPCC Guidelines recommend that emissions from ammonia production should not be reduced to account for CO_2 captured and used in products with short lifetimes, such as urea and dry ice. Emissions have been reallocated to the ammonia production category accordingly.

SOLVENT AND OTHER PRODUCT USE SECTOR

Population data for 1998 and 1999 were updated, which resulted in a slight revision to all estimates in this category.

AGRICULTURE SECTOR

No recalculations were made.

LAND-USE CHANGE AND FORESTRY SECTOR

Fire data for 1999 were updated, which resulted in a significant increase of 8.4 Mt in CO_2 emissions during that year. Data for the production and trade of wood commodities were also updated for the entire 1990–1999 period; the 1998 industrial roundwood production was adjusted downwards by 4%, with a resulting decrease of approximately 9 Mt in CO_2 emissions associated with harvesting activities.

WASTE SECTOR

Population data for 1998 and 1999 were updated, resulting in a slight revision to all estimates in this category.

1 INTRODUCTION

Greenhouse gases (GHGs) are gases in the atmosphere that trap energy from the sun. Naturally occurring GHGs include water vapour, ozone, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Without them, the Earth's average temperature would be about 33°C lower than it is, making the climate too cold to support life (Schneider, 1989). While these naturally occurring gases are what make life possible, a serious concern today is the enhanced effect on the climate system of increased levels of some of these gases in the atmosphere, due mainly to human activities. These increased levels have resulted in an altering of the observed natural climate processes. Indeed, the global average surface temperature has increased over the 20th century by about 0.6°C (IPCC, 2001a).

1.1 WHAT IS CLIMATE CHANGE?

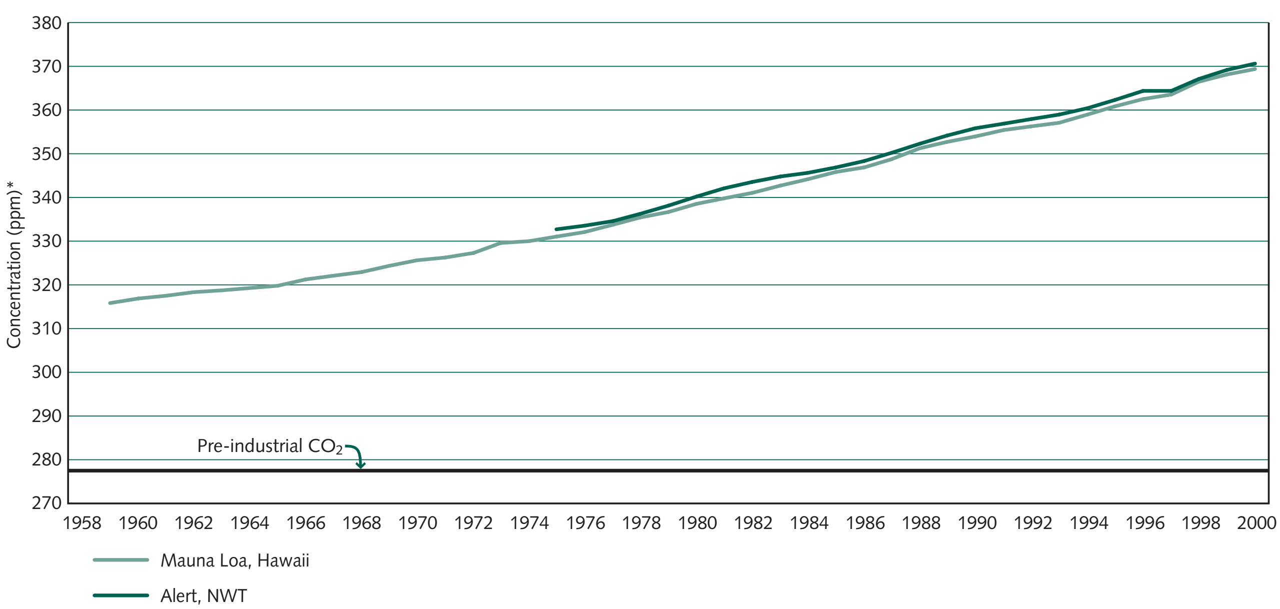
In order to understand climate change, it is important to differentiate between *weather* and *climate. Weather* is the state of the atmosphere at a given time and place and is usually reported as changes in temperature, air pressure, humidity, wind, cloudiness, and precipitation. The term weather is 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.

Therefore, climate change refers to changes in long-term weather patterns caused by natural phenomena or human activities that alter the chemical composition of the atmosphere through the buildup of GHGs that trap heat and reflect it back to the Earth's surface. This results in changes to our climate, including a rise in global temperatures and more frequent extreme weather events.

In fact, 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, land-use change, and agriculture.

FIGURE 1-1: Global Atmospheric Concentrations of Carbon Dioxide



Note: ppm = parts per million

Concentrations of other GHGs generated from human activities have also increased, all of which has led to an additional warming (on average) of the atmosphere and the Earth's surface. Since the mid-1700s, CO_2 concentrations (which account for about 75% of the enhanced greenhouse effect) have increased to a level not seen in about 420 000 years and likely not during the past 20 million years (IPCC, 2001a).

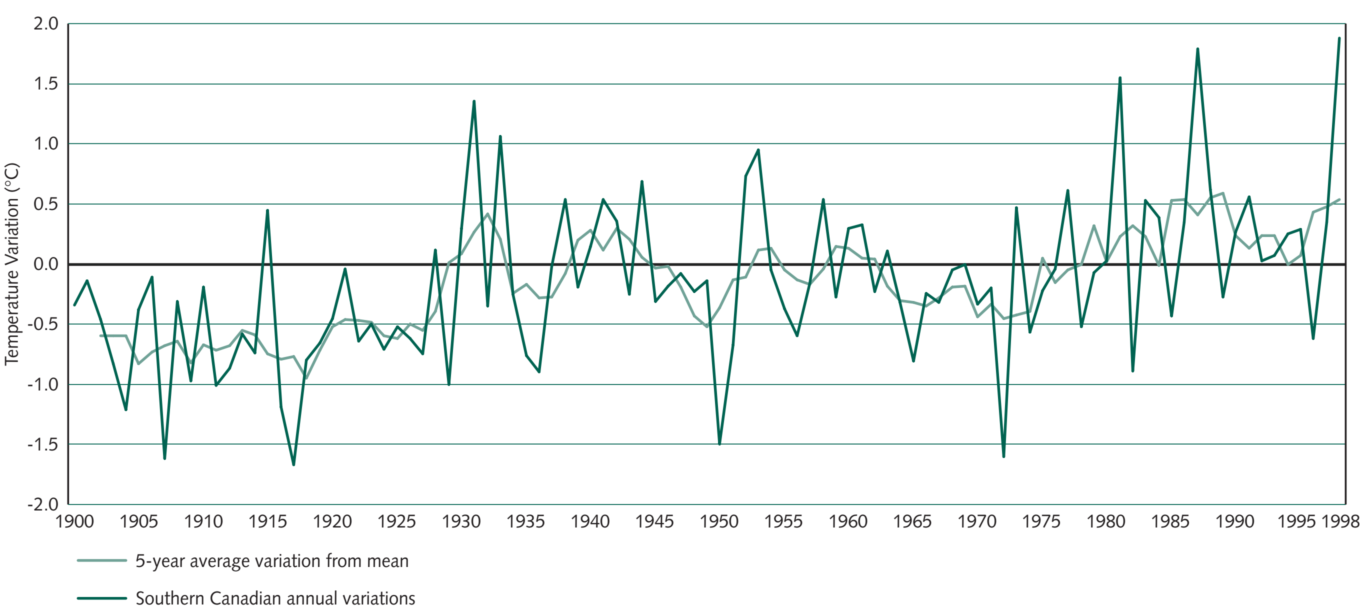
Recent data indicate that the global mean surface air temperature has increased by between 0.2 and 0.6°C since the late 19th century (Figure 1-2), while Canada's mean has increased by about 1°C (IPCC, 1996b, 2001a). Some models predict that the Earth's average temperature might increase by about 0.3°C per decade over the next 100 years if this increasing trend in GHG concentrations is not altered.

A warming of this magnitude could significantly alter the Earth's climate. Storm patterns and severity might increase, a rise in sea level would displace millions of coastal residents, and regional droughts and flooding could occur. Canada's agriculture, forestry, and energy sectors could all be significantly affected.

Predictions of these possible climatic changes are produced by an international group of scientists and approved by an international group of government decision-makers. These two groups together are called the Intergovernmental Panel on Climate Change, or IPCC. In the most recent assessment by the IPCC, *The Science of Climate Change (Third Assessment Report),* progress has been made in reducing uncertainty surrounding possible future climatic changes, particularly with respect to distinguishing and quantifying the magnitude of responses of the climate to different external influences. The IPCC has concluded that the warming over the past 100 years is very unlikely to be due to the internal variability of climate models alone. Moreover, reconstruction of climate data for the past 1000 years also indicates that this warming was unusual and is unlikely to be entirely natural in origin (IPCC, 2001a).

In the IPCC's assessment, computer models have been used to make projections of atmospheric concentrations of GHGs and aerosols, and hence of future climate. These models have indicated that by 2100, atmospheric CO_2 concentrations will be between 540 and 970 parts per million (ppm). This

FIGURE 1-2: Canadian Temperature Variation



is 90–250% above the concentration of 280 ppm in the year 1750[11]. Uncertainties of between -10 and +30% have been calculated for these estimates to account for the magnitude of the climate feedback from the Earth's own climate-regulating mechanisms[12]. This puts the total range of possible atmospheric concentrations at about 490–1260 ppm (75–350% above the 1750 concentration) (IPCC, 2001b).

In addition, computer model predictions of the year 2100 concentrations of non-CO_2 GHGs vary more than those for CO_2, with CH_4 changing by -190 to +1970 parts per billion (ppb) from a present-day concentration of about 1760 ppb. N_2O concentrations are predicted to change by +38 to +144 ppb from a present-day concentration of 316 ppb.

According to the IPCC (2001a), some of the expected impacts of these increased concentrations of GHGs on the climate system include:

- greater extremes of drying and heavy rainfall and increases in the risk of droughts and floods that occur with El Niño events in many different regions;
- sea level rise, through thermal expansion of seawater and widespread loss of land ice. Global mean sea level is projected to rise by 0.09–0.88 m between 1990 and 2100, for the full range of scenarios examined. This is due primarily to thermal expansion and loss of mass from glaciers and ice caps; ice sheets will continue to react to climate warming and contribute to sea level rise for thousands of years after climate has been stabilized;
- weakening of the ocean thermohaline circulation, which leads to a reduction of the heat transfer into high latitudes of the Northern Hemisphere; and
- more rapid warming of land areas than the global average, particularly those at northern high latitudes in the cold season. Most notable of these is the warming in the northern regions of North America.

The IPCC has also noted the following:

- Precipitation has increased by 0.5–1% per decade in the 20th century over most mid and high latitudes of the Northern Hemisphere continents, and it is likely that rainfall has increased by 0.2–0.3% per decade over the tropical (10°N to 10°S) land areas.
- Rainfall has decreased over much of the Northern Hemisphere subtropical (10°N to 30°N) land areas during the 20th century, by about 0.3% per decade.
- Snow cover has decreased by about 10% since the late 1960s, and ground-based observations show that there is very likely to have been a reduction of about two weeks in the annual duration of lake and river ice cover in the mid and high latitudes of the Northern Hemisphere.
- Over the 20th century, there has also been a widespread retreat of mountain glaciers in non-polar regions.
- The rate and duration of warming of the 20th century have been much greater than in any of the previous nine centuries; the globally averaged surface temperature is projected to increase by 1.4–5.8°C over the period 1990–2100 (IPCC, 2001a and b).

In light of new evidence and taking into account the remaining uncertainties, the IPCC has concluded that most of the observed warming over the last 50 years is likely to have been due to the increase in GHG concentrations, which is mainly due to increased human activities.

1.2 WHY MONITOR GREENHOUSE GASES?

Canada tracks its own contribution to the increase in these GHG concentrations by estimating its total national emissions of these gases. The GHGs for which emission estimates have been made in this report are CO_2, CH_4, N_2O, sulphur hexafluoride (SF_6), carbon tetrafluoride (CF_4), carbon hexafluoride (C_2F_6), and hydrofluorocarbons (HFCs).

1.2.1 CARBON DIOXIDE

On a worldwide basis, CO_2 emissions generated from human activities are known to be small; in

11 The year 1750 is selected as a year that is representative of what GHG concentrations were prior to the industrial revolution. This is considered to be a good indicator of the influence that human activities have had on the increase in GHG concentrations.

12 Forests, wetlands, agricultural crops, soils, and oceans all absorb CO_2 from the atmosphere.

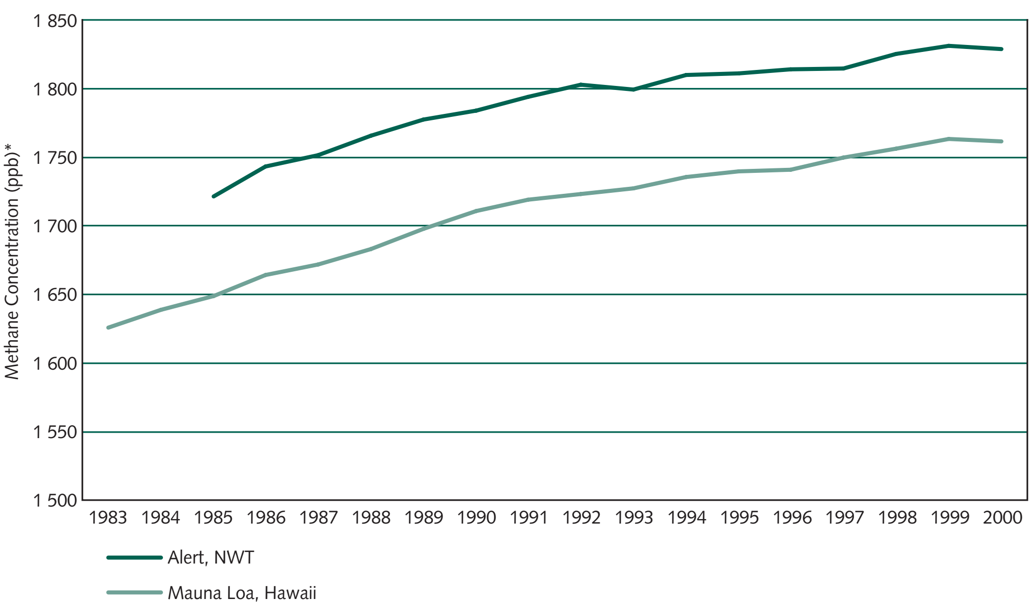
comparison with the gross fluxes of carbon from natural systems, they represent only a fraction (~2%) of total global emissions. However, they are perceived to account for most of the observed accumulated CO_2 in the atmosphere (Sullivan, 1990; Edmonds, 1992). On the basis of available emissions information, the primary sources of CO_2 generated from human activities are fossil fuel combustion (including both stationary and mobile sources), deforestation (resulting in permanent land-use change), and industrial processes, such as cement production. A global CO_2 emission rate of approximately 23.9 gigatonnes (Gt) has recently been estimated by the Carbon Dioxide Information and Analysis Centre (Marland et al., 1999). Deforestation, land use, and ensuing soil oxidation have been estimated to account for about 23% of human-made CO_2 emissions. The primary natural sources include respiration by plants and animals, decomposing organic matter and fermentation, volcanoes, forest/grass fires, and oceans. On a net basis, natural carbon-balancing processes such as photosynthesis and the oceanic reservoir remove most CO_2 (Schneider, 1989). 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).

1.2.2 METHANE

In addition to CO_2, excess global CH_4 emissions resulting from human activities are considered to have caused an increase of about 145% in atmospheric concentrations since the mid-1700s (Figure 1-3) (Thompson et al., 1992).

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).

FIGURE 1-3: Global Atmospheric Concentrations of Methane



Note: ppb = parts per billion

1.2.3 NITROUS OXIDE

The third gas monitored is N_2O. At present, it has been estimated that approximately one-third of global atmospheric N_2O is of human origin, resulting primarily from the application of nitrogenous fertilizers and the combustion of fossil fuels and wood. The atmospheric concentration of N_2O has grown by about 17% since the mid-1700s (Figure 1-4) (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. Plants readily take up N_2O produced in this manner. While it is generally recognized that N_2O emission inventory data are more limited than CO_2 data and highly uncertain, efforts continue to improve the estimates.

1.2.4 HFCs, PFCs, AND SF_6

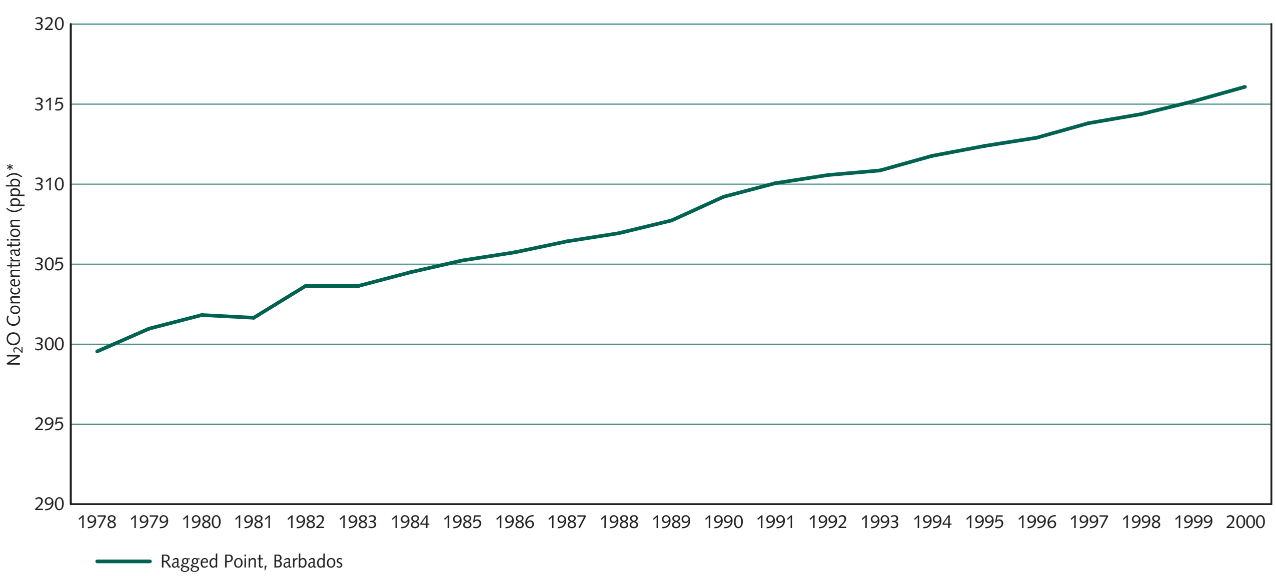
The final group of GHGs that are monitored in this report consists of HFCs (a chlorofluorocarbon, or CFC, substitute), SF_6, and perfluorocarbons (PFCs). These gases are having a lasting effect on atmospheric composition, radiative forcing, and climate. The observed atmospheric concentrations of the substitutes for CFCs are increasing, and some of these compounds are GHGs.

The PFCs (CF_4 and C_2F_6) and SF_6 also have very long atmospheric lifetimes and are strong absorbers of infrared radiation. Therefore, these compounds, even with relatively small emissions, have the potential to influence climate far into the future (e.g., CF_4 resides in the atmosphere for at least 50 000 years) (IPCC, 2001b).

1.3 CANADA'S CONTRIBUTION

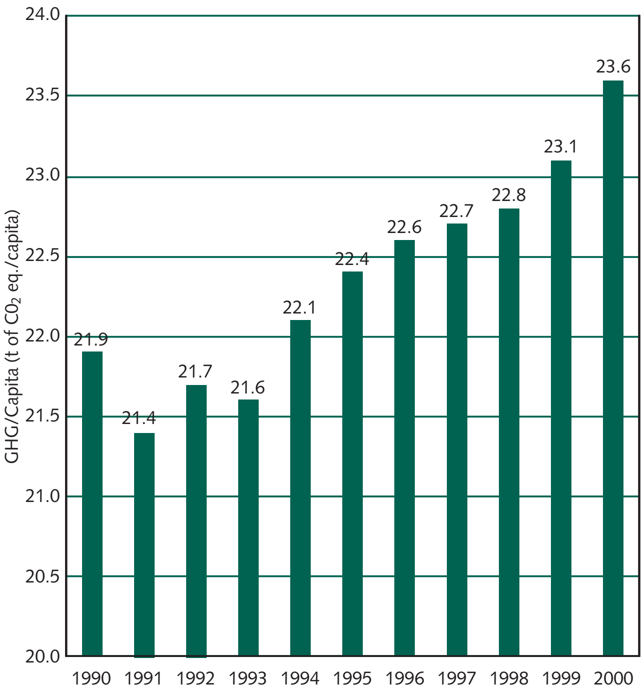
While Canada contributes only about 2% of total global GHG emissions, it is one of the highest per capita emitters, largely the result of its resource-based economy, climate (i.e., energy demands), and size. In 1990, Canadians released 21.9 t CO_2 eq of GHGs per capita. Over the 10-year period from 1990 to 2000, this has increased to 23.6 t CO_2 eq of GHGs per capita (Figure 1-5).

FIGURE 1-4: Global Atmospheric Concentrations of Nitrous Oxide



Note: ppb = parts per billion

FIGURE 1-5: Trend in Canada's Per Capita GHG Emissions, 1990–2000



1.4 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[13] effect of a gas within the atmosphere is a reflection of its ability to cause 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 a trace 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. While any time period can be chosen for comparison, the 100-year GWPs recommended by the IPCC (Table 1-1) are used in this report.

TABLE 1-1: Global Warming Potentials

GHG	Formula	100-year GWP
Carbon Dioxide	CO_2	1
Methane	CH_4	21
Nitrous Oxide	N_2O	310
Sulphur Hexafluoride	SF_6	23 900
Hydrofluorocarbons (HFCs)		
HFC-23	CHF_3	11 700
HFC-32	CH_2F_2	650
HFC-41	CH_3F	150
HFC-43-10mee	$C_5H_2F_{10}$	1 300
HFC-125	C_2HF_5	2 800
HFC-134	$C_2H_2F_4$ (CHF_2CHF_2)	1 000
HFC-134a	$C_2H_2F_2$ (CH_2FCF_3)	1 300
HFC-143	$C_2H_3F_3$ (CHF_2CH_2F)	300
HFC-143a	$C_2H_3F_3$ (CF_3CH_3)	3 800
HFC-152a	$C_2H_4F_2$ (CH_3CHF_2)	140
HFC-227ea	C_3HF7	2 900
HFC-236fa	$C_3H_2F_6$	6 300
HFC-245ca	$C_3H_3F_5$	560
Perfluorocarbons (PFCs)		
Perfluoromethane	CF_4	6 500
Perfluoroethane	C_2F_6	9 200
Perfluoropropane	C_3F_8	7 000
Perfluorobutane	C_4F_{10}	7 000
Perfluorocyclobutane	c-C_4F_8	8 700
Perfluoropentane	C_5F_{12}	7 500
Perfluorohexane	C_6F_{14}	7 400

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

Note: The CH_4 GWP included 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.

13 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 (square metres).

2 EMISSION TRENDS, 1990–2000

2.1 ENERGY SECTOR (2000 GHG EMISSIONS, 587 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 2000 (533 Mt and 54 Mt, respectively). Between 1990 and 2000, fuel combustion-related emissions increased 23%, while emissions from fugitive releases rose 42%. Five-year changes in both fuel combustion and fugitive emissions through the period 1990–2000 are shown in Table 2-1.

TABLE 2-1: Energy GHG Emissions by UNFCCC Sector, 1990–2000

Greenhouse Gas Sources/Sinks	Mt CO_2 Equivalent 1990	1995	2000
1. Energy	**472**	**513**	**587**
A. Fuel Combustion (Sectoral Approach)	**434**	**463**	**533**
1. Energy Industries	147	156	195
2. Manufacturing Industries and Construction	62.6	62.0	68.3
3. Transport	153	169	190
4. Other Sectors	72.2	76.7	79.5
B. Fugitive Emissions from Fuels	**38**	**50**	**54**
1. Solid Fuels	1.9	1.7	0.9
2. Oil and Natural Gas	36	48	53

On a per gas basis for the energy sector, CO_2 accounted for the majority of emissions in 2000 (531 Mt), while CH_4 contributed 44 Mt and N_2O accounted for 12 Mt. The largest contributor to emissions in the energy sector is energy industries (fossil fuel production, electricity, and heat production), which accounted for 33% of energy emissions, with emissions from the transport sector close behind, with 32% of energy-related emissions.

2.1.1 EMISSIONS FROM FUEL COMBUSTION (2000 GHG EMISSIONS, 533 Mt)

Emissions of GHGs from fuel combustion rose from 434 Mt in 1990 to 533 Mt in 2000, a 23% increase. Fuel combustion emissions are divided into the following UNFCCC categories: energy industries[14], 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 (33% growth in GHG emissions). This sector also produced the largest amount of emissions within the energy category for 2000, at 195 Mt. Emissions from other sectors (the main contributors being residential and commercial subsector emissions) increased 10% between 1990 and 2000, as did emissions from the manufacturing industries and construction sector. A more comprehensive account of the changes in emissions is presented in the individual sectoral sections of the energy category below.

2.1.1.1 Energy Industries (2000 GHG emissions, 195 Mt)

The energy industries sector is the largest source of fuel combustion emissions and accounts for 27% of Canada's total GHG emissions. Fuel combustion emissions included in this sector are from stationary sources only, from the production, processing,

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

and refining of energy (electricity generation, oil and natural gas production, refining of petroleum products, etc.). In 2000, emissions from this sector totalled 195 Mt, an increase of 33% 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[15]

This sector accounted for 18% (128 Mt) of Canada's 2000 GHG emissions and was responsible for 28% of the total emissions growth between 1990 and 2000. Overall, emissions have increased almost 35%, or 33 Mt, since 1990.

Hydroelectric and coal-fired generation continue to be the major sources of Canadian electricity, accounting for 60% and 20%, respectively, of total national generation in 2000. Nuclear energy provided 13%, natural gas nearly 5%, and oil 2%. Of this total, nearly 6% was produced by industrial, non-utility generating sources. Total annual production increased over 26% between 1990 and 2000. This rate of growth exceeds the population growth rate of 11% for the same period, pointing to a rapid increase in per capita demand over the period.

In 2000, the dominant proportion of GHG emissions, nearly 80%, was from the use of coal (which has much higher emission intensity than natural gas), while natural gas and oil accounted for 12% and 9%, respectively (Table 2-2). The higher GHG intensity of coal is reflected in the fact that it accounted for only 20% of the total electricity generated in Canada in 2000.

TABLE 2-2: GHG Emissions from Electricity and Heat Generation, 1990–2000

Electricity Generation Source Emissions	Mt CO_2 Equivalent		
	1990	1995	2000
Coal[1]	78.9	83.2	102.4
Oil	12.0	7.7	10.1
Natural Gas	4.4	10.1	15.8

[1] 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 18% from 1990 to 2000, 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 27%, while natural gas production increased more than 387% between 1990 and 1999[16].

Petroleum Refining and Manufacture of Solid Fuels and Other Energy Industries[17]

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

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

16 The most recent information for the year 2000 is not yet available from Statistics Canada.

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

oil). As shown in Table 2-3, between 1990 and 2000, emissions from the petroleum refining sector increased almost 7% (from 26.1 Mt to 27.9 Mt), while emissions from the manufacture of solid fuels and other energy industries sector rose to 38.9 Mt, 53% higher than the 1990 level of 25.4 Mt. The combined effect for the two sectors is an increase of almost 30% in this sector. This growth is due to increases in oil and natural gas production, largely for export.

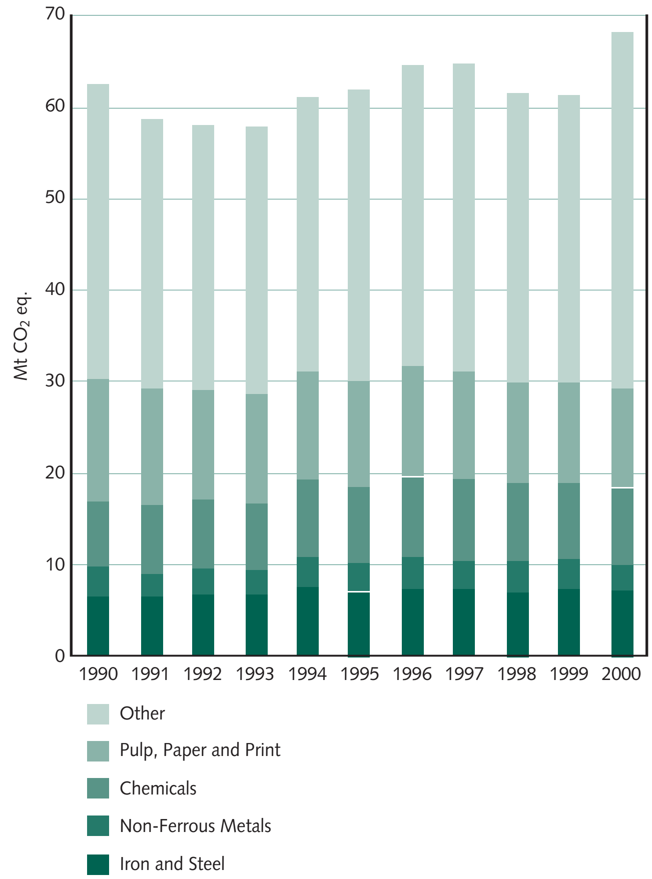
TABLE 2-3: GHG Emissions from Petroleum Refining and Manufacture of Solid Fuels and Other Energy Industries, 1990–2000

GHG Source Category	1990	2000	Percentage Change 1990–2000
Petroleum Refining	26.1	27.9	7.0%
Manufacture of Solid Fuels and Other Energy Industries	25.4	38.9	53.1%
TOTAL	51.5	66.8	29.7%

2.1.1.2 Manufacturing Industries and Construction (2000 GHG emissions, 68 Mt)

Emissions from the manufacturing industries and construction sector include the combustion of fossil fuels by all manufacturing industries, the construction industry and mining[18]. In 2000, GHG emissions were 68 Mt, an increase of 9.2% from the 1990 level of 63 Mt. Over the short term (1999–2000), emissions increased by 11% mainly due to increased emissions in the mining sector. Overall, this sector was responsible for 9.4% of Canada's total GHG emissions for 2000. Figure 2-1 provides an overview of the changes in emissions for the various manufacturing industries and construction between 1990 and 2000.

FIGURE 2-1: GHG Emissions from Manufacturing Industries and Construction by Subcategory, 1990–2000



2.1.1.3 Transport (2000 GHG emissions, 190 Mt)

Transport is a large and diverse sector accounting for 26.3% of Canada's GHG emissions in 2000. The sector includes the 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 agricultural vehicles); and
- pipelines (pipelines, both oil and gas, represent non-vehicular transport).

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

From 1990 to 2000, GHG emissions from transport, driven primarily by energy used for freight transport, rose 25%, or 37.5 Mt. Overall, transport was the second leading emissions-producing sector in 2000, contributing 190 Mt and accounting for over 31% of Canada's emissions growth from 1990 to 2000.

Emissions from light-duty gasoline trucks (LDGT), the subcategory that includes SUVs and vans, have increased 68% since 1990 (from 22 Mt in 1990 to over 36 Mt in 2000), while emissions from cars (light-duty gasoline vehicles, or LDGV) have decreased 10% (from 54 Mt in 1990 to 48 Mt in 2000) (Table 2-4).

Table 2-4: GHG Emissions from Transport, 1990–2000

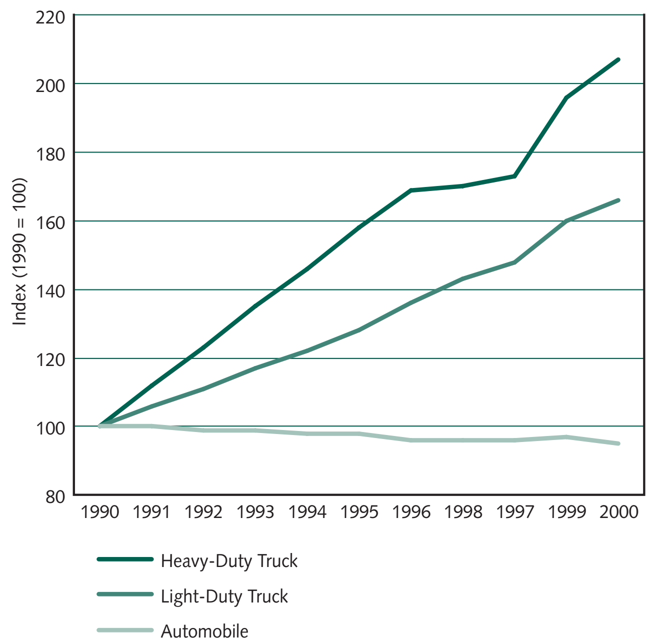
	1990	1995	2000
Light-Duty Gasoline Vehicles	53 700	51 300	48 300
Light-Duty Gasoline Trucks	21 700	28 500	36 400
Heavy-Duty Gasoline Vehicles	3 140	4 760	5 850
Motorcycles	230	214	239
Off-Road Gasoline	5 010	3 940	5 270
Light-Duty Diesel Vehicles	672	594	410
Light-Duty Diesel Trucks	591	416	136
Heavy-Duty Diesel Vehicles	24 600	30 800	37 800
Off-Road Diesel	11 300	12 700	18 100
Propane & Natural Gas Vehicles	2 210	2 100	1 100
Domestic Aviation	10 700	10 900	13 700
Domestic Marine	5 050	4 380	5 110
Railways	7 110	6 430	6 670
Pipelines	6 900	12 000	11 300

For full details of all years, please refer to Appendix E.

The growth in transport sector emissions may be due not only to the 16.8% 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 1990–2000, the increase of 14.7 Mt and 13.2 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 2-2).

FIGURE 2-2: Trends in Vehicle Populations for Canada, 1990–2000



In 2000, emissions from HDDVs contributed nearly 38 Mt to Canada's total GHG emissions (an increase of 54% from 1990 emissions). Although emissions from heavy-duty gasoline vehicles (HDGV) were substantially lower, at 5.8 Mt for 2000, this subcategory exhibited an increase of almost 87% 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.

Many factors affect transport mode choices. For road transport, fuel cost is one of the most influential. Real-cost analysis (in 1998 dollars) of both gasoline and diesel showed a declining price from 1990 to 1998 when adjusted according to the Consumer Price Index (Natural Resources Canada on-line pricing data sheets [e.g., http://nrn1.nrcan.gc.ca/es/erb/od/pips/31486.pdf]; Monaghan, 2001). This decline may be partly responsible for the rapid shift in modes to bulkier, less efficient vehicles, such as vans and SUVs, and to increased use of vehicles (i.e. more vehicle-kilometres travelled).

Off-road fuel combustion emissions[19] in the transport sector also increased between 1990 and 2000. Emissions from off-road gasoline vehicles (snowmobiles, all-terrain vehicles, etc.) rose 5%, from 5.0 Mt to almost 5.3 Mt, whereas emissions from off-road diesel vehicles (excavating, construction, etc.) increased by over 60%, from 11.3 Mt to over 18 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 63.4%, from 6.9 Mt in 1990 to 11.3 Mt in 2000.

2.1.1.4 Other Sectors (2000 GHG emissions, 79.5 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[20]. Overall, this category exhibited increases in GHG emissions of 10%, while individual subsectors within it demonstrated a variety of changes. These changes, which are reflected in Appendix E, 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[21] accounted for 6.2% (45 Mt) and 4.4% (31.9 Mt), respectively, of all GHG emissions in 2000.

As shown in Figure 2-3, residential emissions have not increased significantly between 1990 and 2000, but rather have fluctuated around 45 Mt over this period. More recently, after emission decreases in 1997 and 1998, emissions increased by 2.3% in both 1999 and 2000. Commercial/institutional emissions increased 23% between 1990 and 2000. The combined effect for the two subsectors was an increase of 7 Mt, or 10%. GHG emissions, particularly in the residential subsector, track heating degree-days (HDD)[22] closely (as shown in Figure 2-3). This close tracking indicates the important influence of weather on emissions on a year-to-year basis.

19 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.

20 The UNFCCC other sectors category comprises the following CGHGI sectors: residential, commercial and institutional, and other (listed under energy, fuel combustion in Appendix E).

21 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.

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

FIGURE 2-3: Emissions in the Residential and Commercial Sectors Relative to Heating Degree-Days, 1990–2000

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 2.6 Mt in 2000, an increase of 6% since 1990. In Appendix E, these emissions are allocated to the CGHGI other category, located within the fuel combustion section of the energy sector.

2.1.2 FUGITIVE EMISSIONS FROM FUELS (2000 GHG EMISSIONS, 54 Mt)

As stated previously, 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 considered fugitive emissions. Fugitive emissions have two sources: coal mining and handling, and activities related to the oil and natural gas industry. They constituted 7.4% of Canada's total GHG emissions for 2000 and contributed 13.5% to the growth in emissions between 1990 and 2000.

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 42.4% between 1990 and 2000, from 38 Mt to nearly 54 Mt, with emissions from the oil and natural gas category contributing over 98% of the total fugitive emissions in 2000. Although fugitive releases from the solid fuels sector (e.g., coal mining) decreased by about 965 kt (over 50%) between 1990 and 2000 due to the closing of many mines in eastern Canada, emissions from oil and natural gas increased over 47% 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.

2.2 INDUSTRIAL PROCESSES SECTOR (2000 GHG EMISSIONS, 51 Mt)

This category comprises emissions from industrial processes where GHGs are a direct by-product of those processes. In 2000, industrial process emissions accounted for approximately 7% of all GHG emissions, for a total of 51 Mt, and came from diverse industrial processes defined as follows: mineral products, chemicals industry, metal production[23], consumption of halocarbons and SF_6, and other. Figure 2-4 illustrates the changes in each of these sectors over the period 1990–2000, and Table 2-5 provides a percentage breakdown of the emissions, by subcategory, for 2000.

FIGURE 2-4: GHG Emissions from Industrial Processes by Sector, 1990–2000

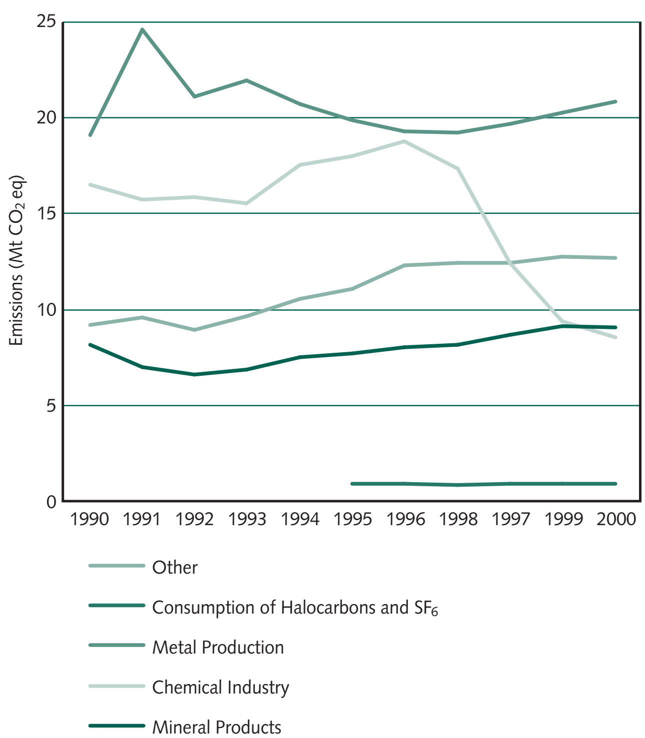


TABLE 2-5: GHG Emissions from Industrial Processes by Subcategory, 2000

Main Category	Subcategory	Mt CO_2 eq
Mineral Products	Cement production	9.1
	Lime production	
	Limestone use	
	Soda ash use	
Chemical Industry	Ammonia production	8.5
	Nitric acid production	
	Adipic acid production	
Metal Production	Iron and steel production	20.9
	Aluminium and magnesium production	
Consumption of Halocarbons and SF_6		0.9
Other		12.7

Emissions from most sources within this sector either remained stable or increased between 1990 and 2000; overall sectoral emissions decreased by 1.8 Mt. The largest single source of emissions in 2000 was the metal production category, with nearly 21 Mt of emissions, as shown in Table 2-5. The other category accounts for the largest increase in emissions (about 38%) 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 1997–2000: total emissions in 2000 were 3.4% 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 48% in the chemical industry subsector emissions over the period 1990–2000.

23 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 Appendix E).

2.3 SOLVENTS AND OTHER PRODUCT USE SECTOR (2000 GHG EMISSIONS, 0.5 Mt)

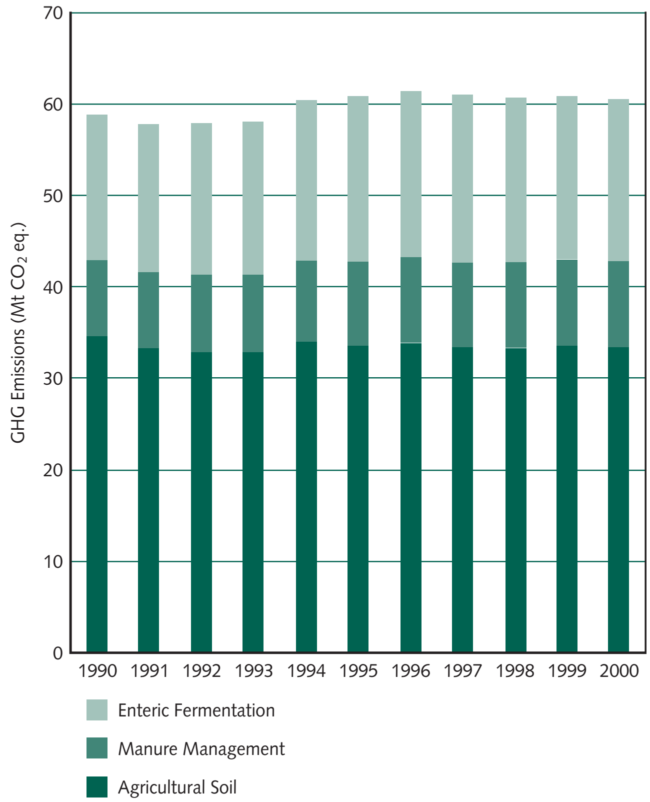
While accounting for only 0.1% (0.5 Mt) of Canada's total GHG emissions in 2000, emissions in the Solvent and Other Product Use sector increased by 11% over 1990 levels. The majority of emissions in this category are related to the use of N_2O as an anaesthetic in various dental applications and as a propellant in aerosol products.

2.4 AGRICULTURE SECTOR (2000 GHG EMISSIONS, 60.5 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 60.5 Mt) of year 2000 emissions for Canada, an increase of 2.7% since 1990. Most of these emissions are from non-energy sources, with N_2O accounting for approximately 62.7% of sectoral emissions, CH_4 for nearly 37.6%, and a net sink of CO_2 from agricultural soils, which remove 0.4% of emissions. 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 by domestic animals[24], manure management practices, and cropping practices that result in release or removals from soils. Relative changes in emissions in each of these categories are shown in Figure 2-5.

FIGURE 2-5: GHG Emissions from Agricultural Sources, 1990–2000



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 significant quantities of CH_4) and manure management (which releases CH_4 and N_2O). These emissions accounted for nearly 4% of Canada's GHG emissions in 2000.
- Soil management and cropping practices contributing emissions of CO_2 (due to decomposition of organic carbon from the soil) and N_2O (due to fertilizer application and cropping practices). Soil-related sources accounted for about 4.6% of total GHG emissions in 2000.

24 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.

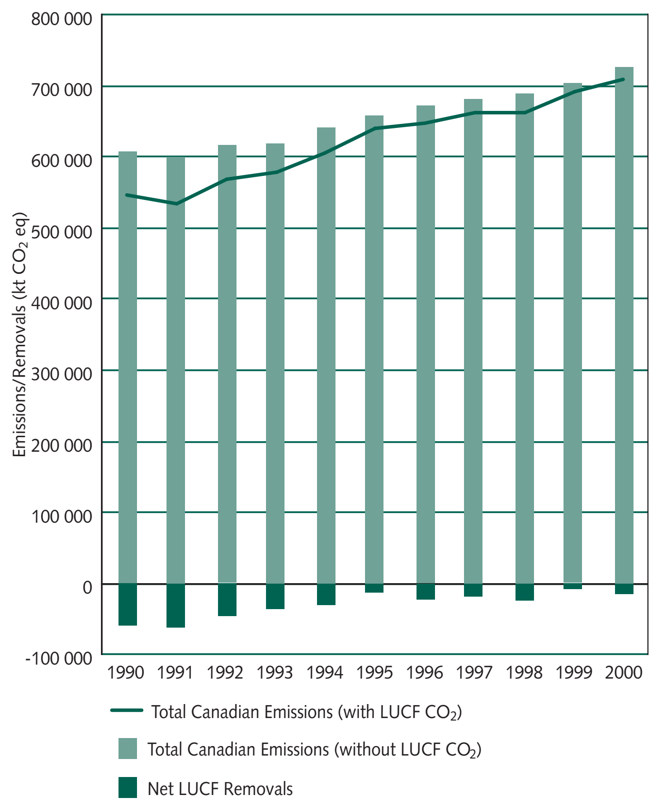
In the 1990–2000 period, livestock emissions increased 11.6%, while emissions from soils declined by 3.5%. Most of the increase (about 95%) in livestock-related emissions is attributable to increased cattle production. Uncertainty in the estimates of emissions from agricultural soils is high, but it is believed that CO_2 emissions have been steadily declining, mainly due to increasing use of conservation tillage.

In the 1999 GHG inventory for the agriculture sector, a few major changes were made in the estimation methodologies. These changes were the result of consultations with Canadian and U.S. agricultural soil and crop experts, federal and provincial soil and crop specialists, and recent changes in the U.S. inventory specifically related to the annual nitrogen excretion rates for various domestic animals. These changes have been carried through for the year 2000 GHG inventory.

2.5 LAND-USE CHANGE AND FORESTRY SECTOR (2000 GHG EMISSIONS, 2.5 Mt)

Estimates of net CO_2 and other GHG fluxes in Canada's Land-Use Change and Forestry (LUCF) sector have been reported on since 1996. The net CO_2 flux amounts to a sink, declining from 61 Mt in 1990 to about 16 Mt in 2000[25]. As per current UNFCCC Reporting Guidelines (IPCC, 1997), CO_2 fluxes in the LUCF sector are excluded from inventory totals. The LUCF net CO_2 removals, if included, would decrease the total Canadian GHG emissions by 10% in 1990 and by 2.3% in 2000 (Figure 2-6).

FIGURE 2-6: Contribution of LUCF Sector to Canada's GHG Emission Totals, 1990–2000



Non-CO_2 fluxes in the LUCF sector, which are composed of CH_4 and N_2O emissions, are included in the national inventory totals. These emissions represent about 0.3% of total GHG emissions for Canada.

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 1990–2000. The general trend indicates a decline in the net removal from 59 Mt in 1990 to about 14 Mt in 2000, an approximate 76% decrease over the decade.

The LUCF sector has distinctive characteristics. GHGs are emitted to the atmosphere through the oxidation of living and dead organic matter and absorbed by vegetation through photosynthesis. Both emissions and removals are large fluxes resulting from minute processes dispersed over

25 These figures are rounded in summary tables to reflect the uncertainty in the estimates. The 16 Mt sink is reflected as 20 Mt in Table S-1.

a vast land area. Land-use changes and land-use practices directly alter the size and rate of these natural exchanges of GHGs between the terrestrial landscape and the atmosphere, both in the present and over long time periods. Understanding and measuring the flux components due to human intervention represent unique scientific and accounting challenges. The methods involve more steps and require more data, factors, and assumptions to derive estimates than in most other inventory sectors. In many cases, data are simply not available, and calculations rely on a wide variety of assumptions and parameters.

Estimates of GHG fluxes in the LUCF sector of the Canadian Greenhouse Gas Inventory (CGHGI) are drawn from an accounting model built from a recent report that produces estimates back to 1990 (Sellers and Wellisch, 1998).

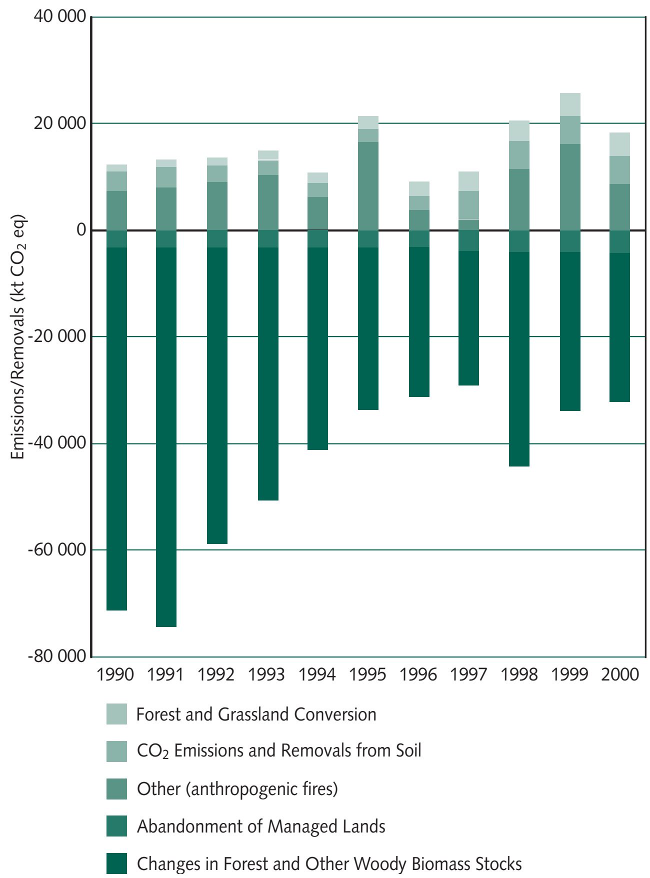
While there is reasonable confidence in the overall trend direction, the flux estimates themselves are characterized by a high degree of uncertainty and should be treated as first approximations only. To reflect this uncertainty, figures in the CGHGI have been rounded. The magnitude of the net forest sink is likely to be significantly underestimated due to the omission in the model of several carbon stocks, notably the forest product sector and forest soils and litter. Work is ongoing to incorporate these carbon pools into the accounting.

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

- changes in forest and other woody biomass stocks;
- forest and grassland conversion;
- abandonment of managed lands;
- CO_2 emissions and removals from soil; and
- other.

Of these five categories, the largest and most influential in terms of total emissions/removals is the first: changes in forest and other woody biomass stocks (Figure 2-7). It generally represents 90% of all CO_2 removals in the LUCF sector and displays a trend similar to the overall one, with sinks declining by half between 1990 and 2000. The two most important components of this category are forest tree growth and harvesting activities. While the CO_2 uptake associated with tree growth has remained fairly constant during the decade, CO_2 release due to harvesting activities has increased significantly, as indicated by a 17% rise in the domestic production of industrial roundwood. The general decline in sinks over the period hence reflects the sensitivity of the accounting model to changes in industrial forestry activities.

FIGURE 2-7: LUCF Sector Emissions and Removals by Subcategory, 1990–2000



Planned improvements of the LUCF inventory include a more explicit account of fire emissions in and outside the wood production forest and the inclusion of all carbon pools in the forest carbon accounting. A new National Forest Inventory, currently under development, will provide better data for monitoring carbon stock changes in Canadian forests.

The only other category displaying a net CO_2 removal is abandonment of managed lands. This removal reflects carbon sequestration in above-ground biomass on agricultural land that is reverting to its natural state (grassland or forest) over a 100-year time horizon. CO_2 removals in this sector increased by approximately 29% for the period 1990–2000, from 3.2 to 4.2 Mt. This minor contribution to sinks (13%) should also be weighted by the large uncertainty associated with poor information on the fate of abandoned farmland in Canada.

The other three categories of the LUCF sector are CO_2 emitters to the atmosphere. The largest contributor is the other category, which includes CO_2 emissions from anthropogenic fires outside the wood production forest (emissions associated with anthropogenic fires in the wood production forest are included in the changes in forest carbon stocks) and non-CO_2 emissions from all anthropogenic forest fires regardless of location. The quantity of GHGs released by fires is based on the area burned annually and displays the large variability typical of natural disturbances. The non-CO_2 GHG emissions of this category are reported in the Canadian inventory totals.

The forest and grassland conversion category accounts for the carbon released from aboveground biomass on forest lands and grasslands converted to other land uses. Emissions more than tripled over the period, from 1.4 Mt in 1990 to nearly 4.4 Mt in 2000. Post-1996 activity data are also the result of projections, whose accuracy will not be confirmed until the release of the next agricultural census in 2001. A further source of uncertainty arises from the method used to obtain estimates of land conversion, which are derived from the net annual changes in the area of agricultural and urban lands in each Canadian province. These net changes may in turn result from very different combinations of land conversion and abandonment. Estimates of GHG emissions derived from a net change in the area of agricultural land almost certainly differ from those based on the difference between emissions from land conversion and removals by abandoned land. Consequently, the estimated emissions and removals in this category are indicative only. A better monitoring of land-use changes in Canada is a priority for improving this component of the LUCF inventory.

In the CGHGI, CO_2 exchanges between soils and the atmosphere in the LUCF sector relate to land-use changes only. They are calculated as the net effect of emissions due to land conversion from forest and grassland to other land uses, on the one hand, and removals due to carbon sequestration in soils of abandoned agricultural lands, on the other. Emissions and removals from agricultural soils and liming are included in the agriculture sector of the inventory. Emissions from soils consistently exceeded removals by soils for the period, with net annual emissions estimated between 2.4 and 5.3 Mt. Emissions tended to decrease until 1995 and increase steeply thereafter, with a sudden doubling of emissions between 1996 and 1997. Based on data from previous years, the model projected a substantial increase in the area of grassland conversion to agricultural lands in 1997.

Overall, the trends observed in the LUCF sector largely reflect changes in industrial forestry activity during the 1990s. However, the methodology itself 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. The Canadian forest product 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.

2.6 WASTE SECTOR (2000 GHG EMISSIONS, 24 Mt)

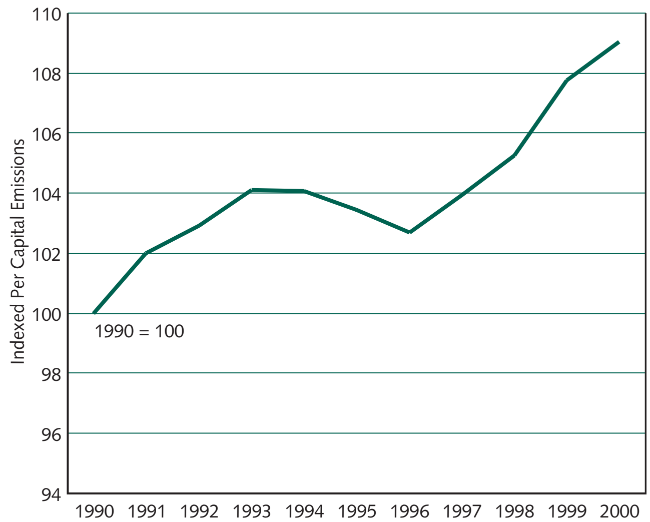
From 1990 to 2000, CO_2 equivalent emissions from waste increased 21%, surpassing the population growth of 11%. By 2000, these emissions represented 3.3% of Canadian GHG emissions, the same percent contribution as in 1990. These emissions consist almost entirely of CH_4 produced by the decomposition of biomass in municipal solid waste (MSW). In 2000, emissions from solid waste disposal on land totalled nearly 22.6 Mt, while municipal wastewater and incinerated material derived from fossil fuel products contributed 1.4 Mt and 0.3 Mt, respectively. The tables in Appendix E summarise the annual changes in each of the three waste sector subcategories between 1990 and 2000.

CH_4 emissions from landfills increased by nearly 22% between 1990 and 2000 despite an increase in landfill gas capture and combustion of almost 33% over the same period. In 2000, 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[26]. 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 9% from 1990 to 2000, due primarily to the increasing emissions from landfills (Figure 2-8). CH_4 capture programs at landfills have made significant contributions to reductions in emissions in 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 2-8, is directly attributable to CH_4 capture programs at landfills.

FIGURE 2-8: Per Capita GHG Emission Trend for Waste, 1990–2000



26 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.

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APPENDIX A: METHODOLOGY

This appendix provides an outline of the methods currently employed by the Greenhouse Gas Division of Environment Canada to construct the Canadian Greenhouse Gas Inventory (CGHGI).

The appendix, structured to match the reporting requirements of the United Nations Framework Convention on Climate Change (UNFCCC), is divided into six main categories (UNFCCC, 2000):

- 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 below have been grouped, as closely as possible, by UNFCCC sector and subsector. Differences between UNFCCC and CGHGI sector designations have been noted.

Where applicable, the methods for each of the following direct greenhouse gases (GHGs) will be delineated:

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

The UNFCCC also requires emissions estimates for the following indirect GHGs:

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

These gases (referred to as the Criteria Air Contaminants) are inventoried separately and estimated using different methodologies from those used for the direct GHGs.

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."

Ideally, an inventory would be compiled from the measured emissions or removals from every source and sink in the country. This is often referred to as a "bottom-up" approach. While it may be the ideal, a comprehensive bottom-up inventory is neither practicable nor possible. Due to the sheer number of sources and sinks, it is virtually impossible for any country to capture them all. Instead, each country can strive to make its inventory as complete as possible using the resources at its command.

In general, the CGHGI is divided between point sources and area sources. Point sources refer to individual sources or facilities. Area sources are those sources or sinks that are too dispersed and/or too numerous to involve individual source information.

Point source emissions may be measured or estimated from information assembled from individual plant or facility throughput and emission factors. However, until recently, GHG emissions and removals have not normally been measured for regulatory or compliance purposes. Emissions or removals, whether for point or area sources, have usually been calculated or estimated.

To date, since few individual facility data have been forthcoming, emissions have been calculated using general or average emission factors, mass-balance approaches, or stoichiometric relationships under averaged conditions. These techniques result in estimates that are compiled in what is generally referred to as a "top-down" method.

For large area sources, carbon budgets – to account for source/sink balances – and modelling estimates – using the best available averaged parameters – are used for some of the large, meteorologically dependent open sources (e.g., forest biomass balances, landfills, and agricultural soils). Other large-scale regional or national emission estimates under averaged conditions have been compiled to date for collective sources such as transportation.

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 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 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. In general, CO_2 emission factors are well developed for many sources, CH_4 emission factors are less well defined, and N_2O, PFC, HFC, and SF_6 emission factors are often limited and less certain.

The methodologies and emission factors described in this document are considered to be the best available to date. Some methods have undergone revision, and some new sources have been added since the release of previously published inventories.

ENERGY

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.

This section is divided into two broad sections based on the processes that generate the emissions: fuel combustion and fugitive emissions.

Fuel combustion includes all combustion activities for the purpose of generating heat or work. Fugitive emissions comprise activity such as the escape or leakage and venting of CH_4 and CO_2 during the extraction, processing, and delivery of fossil fuels.

For all energy sources, CO_2, CH_4, and N_2O are the only GHGs inventoried.

FUEL COMBUSTION ACTIVITIES

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 A-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 Appendix D:

- *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 based upon the physical quantity of fuel combusted, rather than on the energy content of the fuel, provide a more accurate estimate of emissions, since the number of conversions required to derive the estimates are minimized, as 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.

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.

CH_4 Emissions

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.

N_2O Emissions

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.

Biomass Combustion

There are emissions of CO_2 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 or in the sectors or subsectors. 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.

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).

This report 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 Consumers 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 be capable of providing more accurate information at the sector level for future inventories.

Energy Industries

This category includes all stationary fuel combustion emissions from the production, processing, and refining of energy (electricity generation, oil and natural gas production, refining of petroleum products, etc.).

Mobile source fuel combustion emissions are included in the transportation sector. Fugitive and flaring emissions are included under fugitive emissions.

Public Electricity and Heat Production

[In the CGHGI, this sector is titled *Electricity and Heat*.]

This section includes fuel combustion emissions associated with electricity generation and steam production for commercial or public sale.

The UNFCCC Reporting Guidelines require the electricity and heat production sector to include only emissions generated by public utilities. Emissions associated with industrial generation should be reported for the industry that produces the energy under the appropriate industrial sector in the Energy section, regardless if the energy is for sale or internal use. The rationale for this is that it is very difficult to disaggregate emissions in cogeneration facilities (i.e., to separate the electricity component from the heat component). This also reduces uncertainty and simplifies the calculation. Statistics Canada does distinguish industrial electricity generation data, but aggregates the data into one category called industrial electricity generation. As a result, we are unable to reallocate industrial electricity generation emissions to specific industrial subsectors. Emissions associated with all electricity and heat production are therefore lumped together and reported in this sector.

Very few public heat systems exist in Canada, and few data are available on them. Only information on the fuels used to produce steam for commercial sale is readily available. Thus, emissions from this activity have been reported here. It is not clear how much of this steam is sold to the public or how much is produced by combined electricity and heat plants.

Electricity Production

For electricity production, the supply grid in Canada includes hydropower, thermal combustion-derived electricity, nuclear, wind, and tidal power. The total generation of wind, tidal, and solar power is very small. Nuclear, hydropower, wind, solar, and tidal generation are not considered to be 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.

Emission Calculations

The emissions associated with the electricity production sector are calculated using Equation A-1. GHG emissions are estimated based upon the quantities of fossil fuels consumed and, to some extent, the technology used to produce electricity. As noted, all of the fossil fuel energy-use data employed to estimate combustion emissions were derived from the *Quarterly Report on Energy Supply-Demand in Canada* (Statistics Canada, #57-003).

Heat Production

[Also titled *Steam Generation* in the CGHGI.]

This subsector comprises fuel combustion emissions from the production of commercial heat or steam. The facilities for generating the steam are the same (or employ the same technology) as those used for electricity production.

Emission Calculations

Emissions associated with the heat production sector are calculated using Equation A-1. The fuel data are from the steam generation line in the QRESD.

Petroleum Refining

[Included in *Fossil Fuel Industries* in the CGHGI summaries.]

This sector concerns the combustion of fossil fuels by the petroleum refining industry in the production of refined petroleum products.

- The QRESD does not explicitly report all the fuel consumption of the petroleum refining industry. Therefore, fuel usage has been estimated by summing the "producer consumption" of all refined petroleum products with the explicitly reported fuels purchased by the petroleum refining industry (i.e., those designated by SIC 3611 or NAICS 324).
- The UNFCCC Reporting Guidelines require that emissions from the flaring or venting of waste gases during refining be allocated to the fugitive category. However, they have not been estimated due to lack of data.
- Process emissions associated with the production of hydrogen used in refining are allocated to the Industrial Processes section.

Emission Calculations

The fuel combustion emissions associated with the petroleum refining sector are calculated using Equation A-1.

Manufacture of Solid Fuels and Other Energy Industries

[Titled *Other Fossil Fuel Industries and Mining* in the CGHGI.]

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

The other energy industries (or other fossil fuel industries) sector includes all emissions resulting from the combustion of producer-consumed fuels reported in the QRESD, with the exception of refined petroleum products, which are included under petroleum refining.

The producer consumption fuel-use data from the QRESD include natural gas flared in the upstream oil and gas industry.

To avoid double counting, the flaring emissions (estimated under Fugitive Emissions from Fuels, below) are subtracted from the total calculated for the other energy industries sector.

Emissions from transportation fuels are allocated to the transportation sector.

Emission Calculations

The emissions associated with the manufacture of solid fuels and other energy industries sector are calculated using Equation A-1. The fuel-use data are all producer consumption of fossil fuels with the exception of refined petroleum products, reported in the QRESD.

Manufacturing Industries and Construction

[Titled *Manufacturing and Construction* in the CGHGI summaries.]

This sector comprises the combustion of fossil fuels by all manufacturing industries and the construction industry. The UNFCCC has assigned six subsectors under manufacturing industries and construction (UNFCCC, 1999). Several of these differ from the sectors used for the CGHGI.

Emissions from the combustion of fuels by industries within this sector for the generation of electricity or steam for sale are assigned to the energy industries sector. This allocation is contrary to the recommendations of the IPCC Guidelines, which indicate that emissions associated with the production of electricity or heat by industries in this sector should be included. Unfortunately, at present, it is not possible to allocate industrial electricity generation emissions to the appropriate industrial subsectors. Fuel-use data at this level of disaggregation are not available from the QRESD.

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 are not included but are listed separately (see the section CO_2 Emissions from Biomass).

Emissions in this sector from fuels consumed for transportation (e.g., diesel fuel for vehicles) and for industrial processes (e.g., the oxidation of metallurgical coke during the reduction of iron ore) are not included but have been allocated to the appropriate sector in the appropriate category.

Statistics Canada changed its industrial classification system from SIC to NAICS for 1998 data. As a result, some of the specific industrial trends may not align, as the data from 1990 to 1997 are based on SIC and the data from 1998 to the present are based on NAICS. This has no impact on overall emissions.

Iron and Steel

Facilities that conform to SIC 291 or NAICS 3311, 3312, and 33151 are accounted for in this sector.

Emission Calculations

All fuel-use data for this sector were obtained from the QRESD (Statistics Canada, #57-003), reported as iron and steel.

The fuel combustion emissions for each subsector within the manufacturing industries and construction sector are calculated using Equation A-1. Emissions associated with the use of metallurgical coke have been allocated to the Industrial Processes section.

Non-Ferrous Metals

[Titled *Smelting and Refining* in the CGHGI.]

Facilities that conform to SIC 295 or NAICS 3313, 3314, and 33152 are accounted for in this sector.

Emission Calculations

All fuel-use data for this sector were obtained from the QRESD (Statistics Canada, #57-003), reported as smelting and refining.

The fuel combustion emissions for each subsector within the manufacturing industries and construction sector are calculated using Equation A-1.

Chemicals

Facilities that conform to SIC 371 and 3721 or NAICS 3251 and 3253 are accounted for in this sector. The emissions from this category are those that result from the combustion of fuels for energy only.

Emission Calculations

All fuel-use data for this sector were obtained from the QRESD (Statistics Canada, #57-003), reported as chemicals.

The fuel combustion emissions for each subsector within the manufacturing industries and construction sector are calculated using Equation A-1.

Pulp, Paper and Print

[Titled *Pulp and Paper* in the CGHGI.]

Facilities that conform to SIC 271 and 2512 or NAICS 322 are accounted for in this sector.

The common industrial grouping in Canada is pulp and paper, and this is reflected in the QRESD. Therefore, the subsector title was changed to pulp and paper in the CGHGI.

Emission Calculations

All fuel-use data for this sector were obtained from the QRESD (Statistics Canada, #57-003), reported as pulp and paper.

The fuel combustion emissions for each subsector within the manufacturing industries and construction sector are calculated using Equation A-1. Emissions of CH_4 and N_2O from the combustion of biomass are also included.

Food Processing, Beverages and Tobacco

[This sector is not listed in the CGHGI.]

This industrial subcategory is a small energy user and is not disaggregated in the QRESD. Emissions from the food processing, beverage, and tobacco sector are included in the other: manufacturing industries and construction sector.

Other: Manufacturing Industries and Construction

[Titled *Other Manufacturing* in the CGHGI.]

Facilities that conform to SIC 352, 071 10–39, and 401–429 or NAICS 312, 323, 3252, 3254, 3259, 327 (excluding 32731), and 339 are accounted for in this sector. This includes the mining category, which includes marketed fuel combustion emissions from the upstream oil and gas industry.

Emission Calculations

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.

The fuel combustion emissions for each subsector within the manufacturing industries and construction sector are calculated using Equation A-1.

Transport

[Titled *Transport* in the CGHGI.]

This sector comprises the combustion of fuel by all forms of transportation in Canada. The sector has been divided into five distinct subsectors, compared with six in the CGHGI (Table A-1) (IPCC, 1997; UNFCCC, 1999).

TABLE A-1: Table of Concordance for UNFCCC and CGHGI Transport Categories

UNFCCC	CGHGI
a) Civil aviation	Civil aviation
b) Road transportation	Road transport
c) Railways	Railways
d) Navigation	Navigation
e) Other transportation	Off-road (non-rail, ground) transport, pipeline transport

Emission Calculations

The 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). M-GEM is used to calculate all transport emissions with the exception of those associated with the motive energy for propelling fuels in pipelines.

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.

The 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. All emission factors used are listed in the transport emission factor table located in Appendix D.

Civil Aviation

[Titled *Civil Aviation* in the CGHGI.]

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. As noted, emissions arising from fuel sold to foreign airlines are considered to be international bunkers and are reported separately.

Emission Calculations

Methodologies follow a modified IPCC Tier 1 sectoral approach. Emissions are 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, 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

[Titled *Road Transport* in the CGHGI.]

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

(Note: 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.)

Natural Gas and Propane Fuels

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.

Emission Calculations

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.

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 A-2 (as adapted for vehicles):

Equation A-2:

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

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 A-3:

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

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 this inventory, it was assumed that, for the transport sector, all natural gas and propane are used in road transport vehicles only. Although not 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 A-4:

$$Fuel_{Road\ Category} = [\text{Vehicle population}] \times [\text{Average distance driven/year}] \times [\text{Fuel Consumption Ratio}]$$

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 population and distribution data were obtained from a number of sources. Within Environment Canada, a compendium listing populations by vehicle type was assembled for the year 1989 (Environment Canada, 1996). Data for 1995 were also obtained from a commercially available database of light-duty and heavy-duty vehicle populations (DesRosiers, 1996). Interpolation between 1989 and 1995 allowed an estimate of on-road vehicle populations for the intervening years. This has been supplemented by additional data for 1996 through 2000. The above information was sufficient for all vehicle types with the exception of motorcycles. Motorcycle data were obtained from Statistics Canada (#53-219). This source provided population data for all vehicles in the Canadian territories. (Territories are not covered by the commercial databases.)

While a simple division of fuel consumption by vehicle type enables the allocation of emissions of carbon, 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*
- *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. (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.) 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.

Detailed sales information was not available for vehicles other than light-duty gasoline cars and trucks. For the other categories, it was necessary to employ an estimated split of significant emission control technologies. 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 (2001) 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).

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 with M-GEM.

In an effort to improve the accuracy of M-GEM, a 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.

Road transport CO_2 emission factors are fuel dependent (Jaques, 1992) and are listed in Appendix D.

Pollution control devices have a strong effect on CH_4 and N_2O emissions. Emission factors associated with these gases vary with vehicle type. 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 Appendix D. 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 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 the 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.

Railways

[Titled *Railways* in the CGHGI.]

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 electrically driven locomotives are accounted for under electricity production.

Emission Calculations

The methodology is considered to be modified IPCC Tier 1 (IPCC, 1997).

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

Navigation

[Titled *Navigation* in the CGHGI.]

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

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 domestic registered vessels do international travel. Data that would allow an accurate disaggregation of shipping activity by shipping route are not currently available.

Emission Calculations

The methodology is considered to be modified IPCC Tier 1 (IPCC, 1997).

Emissions are estimated using M-GEM.

Fuel consumption data from the QRESD (Statistics Canada, #57-003), reported as marine, are multiplied by fuel-specific emission factors (see Appendix D).

Other: Transport

[Titled *Off-Road (non-rail, ground) Transport and Pipelines* in the CGHGI.]

This subsector comprises vehicles that are not licensed to operate on roads or highways (referred to as non-road or off-road vehicles) and the emissions from the combustion of fuel used to propel products in long-distance pipelines.

Off-Road Transport

(Note: non-road and off-road are used interchangeably.)

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 industries both operate significant numbers of heavy non-road vehicles and are the largest diesel oil users in the group.

Emission Calculations

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. Country-specific emission factors have been used (see Appendix D).

Pipeline Transport

Pipelines (consisting of both oil and gas types) represent the only non-vehicular transport in this sector.

Pipelines (most of which transport natural gas in Canada) use fuel to power motive compressors and other equipment. Oil and gas pipelines use compressors and other equipment equipped with internal combustion engines to transport fuels.

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.

Emission Calculations

The combustion 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.

Other Sectors

There are emissions of CO_2 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 or in the sectors or subsectors. CO_2 is accounted for in the LUCF section as a loss of biomass (forest) stocks.

Commercial/Institutional

[Titled *Commercial/Institutional* in the CGHGI.]

The emissions in this subsector arise primarily from the combustion of fuel to provide heat for commercial buildings. This is closely linked to the outside air temperature.

Emission Calculations

The fuel combustion emissions associated with the commercial/institutional sector are calculated using Equation A-1.

Fuel-use information is from the commercial and public administration data in the QRESD (Statistics Canada, #57-003).

All transportation fuels are reallocated to the transport category.

Residential

The emissions in this subsector arise primarily from the combustion of fuel to heat residential buildings. CH_4 and N_2O emissions from firewood combustion are significant for this subsector. In general, these emissions are a result of the incomplete combustion of biomass in wood stoves and fireplaces.

Emission Calculations

The fuel combustion emissions associated with the residential sector are calculated using Equation A-1.

The emission factors that were employed in estimating the GHG emissions from gaseous and liquid fuels for the current GHG inventory are those as specified for the residential sector in Appendix D.

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

Fossil fuel use information is from the residential data in the QRESD (Statistics Canada, #57-003).

Agriculture/Forestry/Fisheries

[Titled *Other (Agriculture/Forestry)* in the CGHGI.]

This IPCC 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 under either transportation or other manufacturing (i.e., food processing). Mobile emissions associated with this subsector were not disaggregated and are included as off-road or marine emissions reported under transport.

Emission Calculations

The fuel combustion emissions associated with the agriculture and forestry subsector are calculated using Equation A-1.

Fuel-use information is extracted from the agriculture and forestry data in the QRESD (Statistics Canada, #57-003). Transportation fuels are reallocated to the transport category.

Other: Energy – Fuel Combustion Activities

[This subsector is not used to report emissions in the CGHGI.]

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 use has been included under the institutional category due to data limitations in the QRESD (Statistics Canada, #57-003).

FUGITIVE EMISSIONS FROM FUELS

[Titled *Fugitive Emissions* as a subcategory in the CGHGI. The next sector is entitled *Energy Industries: Fugitive Emissions from Fossil Fuels.*]

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 or sale, then the related emissions are considered fuel combustion emissions.

The two sources considered in the inventory are releases associated with coal mining and handling and releases from activities related to the oil and natural gas industry.

In general, fugitive emissions from mobile transportation sources (either during fuelling or after) have not been inventoried.

Solid Fuels

[Not used as a sector title in the CGHGI.]

Coal Mining

[Titled *Coal Mining and Handling* in the CGHGI.]

Coal in its natural state contains varying amounts of CH_4. In coal deposits, CH_4 is either trapped under pressure in porous voids 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, 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.

Emission factors for Canadian coal mines were developed using 1990 emission estimates (King, 1994) and coal production data. These estimates were grouped by province and mine type (surface or underground) and were used to develop aggregate emission factors based on provincial coal production data (Statistics Canada, #45-002).

Emission Calculations

The emissions were estimated by multiplying coal production data (from Statistics Canada, #45-002) by the emission factors in Appendix D.

The method used to estimate emission rates from coal mining (emission factors in Appendix D) 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 (King, 1994).

Underground Mines

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

Emissions from the mine shaft ventilation system were estimated (if measured data were not available) using Equation A-5:

Equation A-5:

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

where:

x = depth of mine in metres

y = cubic metres of CH_4 per tonne coal mined

Measured degasification system emission data were available for all applicable mines.

Surface Mines

For surface mines, it was assumed that the average 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 were estimated in 1990 (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 Appendix D have been so adjusted.

Post-Mining Activity

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 is not known, then it is assumed that the CH_4 content was 1.5 m^3/tonne (the world average CH_4 content of coals).

Solid Fuel Transformation

[Not used as a sector title in the CGHGI.]

Fugitive emissions from metallurgical coking ovens are not estimated due to lack of data. Other sources of solid fuel transformation emissions are not known.

Other: Solid Fuels

[Not used as a sector title in the CGHGI.]

Oil and Natural Gas

The oil and natural gas sector includes fugitive emissions from conventional upstream oil and gas, synthetic oil production, and natural gas distribution. Fuel combustion emissions in the oil and gas industry (when used for energy) are included under the manufacture of solid fuels and other energy industries sector (or *Fossil Fuel Industries* and *Mining* in the CGHGI.)

For Canada, the comprehensive title conventional upstream oil and gas is used rather than using the split between oil and natural gas. This sector title conforms more to the industry norm, as gas is usually produced along with oil.

Emissions are also reported for unconventional crude oil production.

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. Therefore, 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 volatilization 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 depressurization of piping, wells, and vessels could also be a 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.

Emission Calculations

Fugitive emission estimates from the conventional upstream oil and gas industries for 1990–1996 are based on a recent study (Picard and Ross, 1999). Details of the methods 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 by 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 A-2.

TABLE A-2: 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 & 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 & Equipment Failures	Constant at 1995 levels (1996 was an anomalous year)
Surface Casing, Vent Blows, and Gas Migration	Constant at 1996 levels

In the CGHGI, emission estimates are listed in national and provincial tables under the heading Energy – Fugitive Oil and Gas. (Note that this category also includes a very small fugitive contribution from the non-conventional upstream oil and gas industries.)

Unconventional Crude Oil Production

This subsector includes emissions from oil sand open pit mining operations and heavy/synthetic oil upgrading facilities in Canada. The 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.

Emission Calculations

The emission data reported are estimates made by the operators of the unconventional crude oil production facilities at Suncor, Syncrude, and Husky. 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.

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.

Emission Calculations

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 type.

Oil

[See the *Conventional Upstream Oil and Gas* sector.]

Emissions included in this category are conventional light/medium oil, heavy oil, crude bitumen production, unconventional oil, and liquid product transfer.

Natural Gas

[See the *Conventional Upstream Oil and Gas* sector.]

Emissions included in this category are natural gas production, processing, transmission, and distribution, as well as well drilling and servicing, accidents and equipment failures, surface casing vent blows, and gas migration.

Venting and Flaring

[Not used as a sector title in the CGHGI.]

Venting and flaring emissions are the sum of flaring emissions from all activities, as well as the “raw CO_2” releases from the stripping of natural gas.

Venting

[Not used as a sector title in the CGHGI.]

Raw natural gas contains CO_2; this is removed and vented to the atmosphere at processing facilities. These are titled Raw CO_2 Releases and categorized as venting in the Common Reporting Format (CRF).

Emission Calculations

Emissions are calculated based on the data from the CAPP/Environment Canada study (Picard and Ross, 1999). Data from 1997 and 1998 have been extrapolated based on the method described in the section Conventional Oil and Gas.

Flaring

[Not used as a sector title in the CGHGI.]

Emissions for flaring waste gases are included under fugitive emissions and not in the waste or fuel combustion category.

The following subsector is included in the CGHGI.

Natural Gas Flaring

All flaring emissions from the conventional upstream oil and gas industry are included here. The emissions are not included with the individual areas to maintain consistency with the IPCC reporting format.

A flaring emission is any emission associated with the disposal of waste fuel by combustion with no heat recovery. In the conventional upstream oil and gas industry, waste gas is always flared when it is sour (for safety reasons); however, sweet gas is often vented.

Emission Calculations

Emissions are calculated based on the data from the CAPP study (Picard and Ross, 1999). Data from 1997 to the present have been extrapolated based on the method described in the section Conventional Oil and Gas.

Other: Oil and Natural Gas

[Not used as a sector title in the CGHGI.]

MEMO ITEMS

Although not included under a separate heading in the CGHGI, emissions related to these items have been calculated and included in summary tables, where applicable.

International Bunkers

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 recorded 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.

Aviation

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

Multilateral Operations

[Not used as a sector title in the CGHGI.]

CO_2 Emissions from Biomass

As per the IPCC Guidelines, CO_2 emissions from the combustion of biomass used to produce energy are *not* included in the Energy section totals. 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 biomass fuel combustion were reported in this Energy section in the appropriate sectors.

Biomass emissions have been grouped into two main sources: residential firewood, and industrial firewood and spent pulping liquors.

Residential Firewood

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

Emission Calculations

The calculation of GHG emissions from the combustion of residential firewood is based on estimated fuel use and technology-specific emission factors. The 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:

1) Conventional stoves
   - non-airtight
   - airtight, non-advanced technology
   - masonry heaters
2) Stove/fireplace inserts with advanced technology or catalyst control
   - advanced technology fireplaces
   - advanced technology stoves
   - catalytic fireplaces
   - catalytic stoves
3) Conventional fireplaces
   - without glass doors
   - with glass doors (non-airtight)
   - with airtight glass doors
4) Furnaces
   - wood-burning fireplaces
5) Other equipment
   - other wood-burning equipment

The firewood consumption data for the other years were extrapolated based on the number of houses in each province using wood as a principal or supplementary heat source from Statistics Canada #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). These emissions are not included in the national inventory but are reported as memo items.

Emissions were calculated using Equation A-1. The amount of wood burned in each appliance was then multiplied by the emission factors to calculate the GHG emissions.

Industrial Firewood and Spent Pulping Liquors

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. Unfortunately, for 1992, the data for Newfoundland and Nova Scotia were also combined, and there were no comparable data to allow separation. Emissions are listed under Nova Scotia.

Emission Calculations

Data for industrial firewood and spent pulping liquor are available in the QRESD (Statistics Canada, #57-003).

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 is an average for 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 Appendix D).

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 was 41% by weight.
2. There was a 95% conversion of the carbon to CO_2.

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

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

(Note: this EF has been rounded to 1500 g/kg as illustrated in Appendix D.)

Emissions are calculated using Equation A-1, by applying emission factors to quantities of biomass combusted. The CH_4 and N_2O emissions are included in the manufacturing sector of the inventory.

INDUSTRIAL PROCESSES

This section comprises emissions of all GHGs from industrial processes where those gases are a direct by-product of those processes. Emissions from fuel combustion for the express purpose of supplying energy for industrial processes were assigned to the Energy section.

MINERAL PRODUCTS

[Titled *Non-Metallic Mineral Production and Use* in the CGHGI.]

This sector comprises emissions related to the production and use of non-metallic minerals.

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 ➔ 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 section and are not considered here.

Emission Calculations

The emission factor for CO_2 emissions from cement production is based on the lime content of clinker. It was assumed that the clinker produced in Canada has an average lime content of 63.5% (Jaques, 1992) and that all the cement produced in Canada is of the Portland type (see Appendix D).

Cement production data are obtained from the *Canadian Minerals Yearbook* (NRCan, 2000). For provinces where data are confidential, estimates have been made based on plant capacity.

CO_2 emissions are estimated by applying an emission factor of 500 g CO_2/kg cement to the yearly national cement production.

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

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 process releases CO_2. Primarily high-calcium limestone (calcite) is processed in this manner from the quarried limestone to produce quicklime in accordance with the same reaction discussed in the section Cement Production.

Dolomitic limestone (or magnesite) may also be processed at high temperature to obtain dolomitic lime (and release CO_2) in accordance with the following reaction:

$CaCO_3$ • $MgCO_3$ (dolomite) + heat ➔ CaO • MgO (dolomitic lime) + 2CO_2

Emissions from the regeneration of lime from spent pulping liquors at pulp mills are not included in the inventory. Since this CO_2 is biogenic in origin, it is recorded as a change in forest stock in the LUCF section.

Emission Calculations

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).

It was assumed that all lime is produced from high-calcium limestone and that dolomitic lime production is negligible. The quicklime production data are from the *Canadian Minerals Yearbook* (NRCan, 2000).

The emissions are estimated by applying an emission factor of 790 g CO_2/kg quicklime produced in Canada.

Limestone and Dolomite Use

[Titled *Limestone Use* in the CGHGI.]

Limestone is 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 section Cement Production.

No data are available on the fraction of limestone used that is dolomitic. As noted in the section Lime Production, it was assumed that all lime is produced from high-calcium limestone.

Emission Calculations

Data on the consumption of raw limestone by the glass and metallurgical smelting industries were obtained from the *Canadian Minerals Yearbook* (NRCan, 2000). The limestone use (non-dolomitic lime production) emission factor was developed by ORTECH Corporation (1994). Emissions are calculated by applying the emission factor to the limestone use data.

This technique is considered to be the IPCC default method.

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). In Canada, its use appears to be restricted to the glass industry.

CO_2 is emitted as the soda ash decomposes at high temperatures in a glass manufacturing furnace. 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:

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

Only limited production 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.

Depending upon the industrial process used, CO_2 may also be emitted during soda ash production. CO_2 is generated as a by-product, 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).

Emission Calculations

Consumption information was obtained from the publication *Non-Metallic Mineral Product Industries* (Statistics Canada, #44-250).

The emission factors and methods used are the IPCC default values (IPCC, 1997).

Asphalt Roofing

Not estimated.

Road Paving with Asphalt

Not estimated.

Other: Mineral Products

Not estimated.

CHEMICAL INDUSTRY

[Titled *Chemical Production* in the CGHGI.]

This sector comprises process emissions related to the production of chemicals.

Ammonia Production

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. A significant quantity of fertilizer is exported; future work will involve examining methods to account for this. Some of the hydrogen produced for ammonia production is from other chemical process by-products (Jaques, 1992). The gross ammonia production was reduced accordingly.

As far as actual inventory totals are concerned, all CO_2 emissions from non-energy use of fossil fuels are calculated according to the method of undifferentiated non-energy product use (see Other: Industrial Processes); emissions from ammonia production are deducted from the emissions for the non-energy use of natural gas.

Emission Calculations

Total ammonia and urea production data were obtained from the Canadian Fertilizer Institute (Farrel, 1996) and Statistics Canada (#46-006).

An emission factor of 1.56 t CO_2/t NH_3 produced was developed using typical material requirements for ammonia production in Canada (Jaques, 1992). (Note: this was rounded to 1600 g/kg in Appendix D.)

Emissions were calculated by combining the production data with the general emission factor.

Nitric Acid Production

The primary use of nitric acid is in the production of fertilizers. Other uses include the manufacture of explosives and other chemicals.

As nitric acid (HNO_3) is produced from ammonia, N_2O is emitted. N_2O emissions are in proportion 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. 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 global industry, which, in turn, 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).

Emission factors were developed for:

- plants with catalytic converters;
- plants with extended absorption for NO_x abatement type 1; and
- plants with extended absorption for NO_x abatement type 2.

All nitric acid plants in Canada, with the exception of those in Alberta, are the catalytic converter type.

Emission Calculations

For Alberta, it has been assumed that 175 kt 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.

Emission factors are listed in Appendix D.

The method used was the IPCC-recommended method, and the emission factors are within the range published by IPCC (1997).

Adipic Acid Production

Adipic acid is used primarily for the manufacture of nylon. During its production, significant quantities of N_2O are produced and are usually vented to the atmosphere.

There is one adipic acid production facility in Canada. In 1997, emission abatement technology was installed at that plant. That facility also began a program of emissions monitoring in 1997 to determine the performance of the abatement system.

Emission Calculations

The emission estimates for adipic acid production are provided by the Dupont Maitland plant, Canada's only producer of adipic acid. The emissions were 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 listed in Appendix D is appropriate only for pre-1997 production, when no emission controls were in place.

Carbide Production

[This title is not used in the CGHGI.]

Emissions from this source are believed to be reported under Other: Industrial Processes.

Other: Chemical Industry

[This title is not used in the CGHGI.]

METAL PRODUCTION

This sector comprises process emissions related to the production of metals.

Iron and Steel Production

[Titled *Ferrous Metal Production* in the CGHGI.]

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 believed to be included in Other: Industrial Processes.

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.

Emission Calculations

The metallurgical coke data are obtained from Statistics Canada (#57-003), as reported under iron and steel.

This method is based upon the amount of reducing agent used and is similar to the recommended IPCC (1997) method.

CO_2 emissions were estimated by applying the combustion emission factor for metallurgical coke to the amount of metallurgical coke used in the iron and steel industry.

Ferroalloys Production

[This title is not used in the CGHGI.]

Emissions are assumed to be included under Other: Industrial Processes.

Aluminium Production

[The UNFCCC uses the spelling Aluminium.]

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. The latter two, CF_4 and C_2F_6, are classified as PFCs. PFCs are extremely inert and are potent GHGs. CF_4 has a 100-year global warming potential (GWP) of 6500, while C_2F_6 has a GWP of 9200.

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. CO_2 emissions from this source are subtracted from the totals listed under Other: Industrial Processes.

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). The 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. Almost all (95%) of the electricity generated in these provinces is produced by hydraulic generators, which emit virtually no GHGs.

Emission Calculations

CO_2 production-based emission factors for Canadian aluminium smelting were calculated (ORTECH Corporation, 1994) (see Appendix D).

It has been possible to establish average PFC emission rates for all aluminium plants in Canada (Unisearch Associates, 1994) (see Appendix D).

Aluminium production data for each facility were estimated by prorating national production data using published yearly plant capacities (NRCan, 2000).

Emissions for both CO_2 and PFCs were estimated on a plant-specific basis by using the emission factors and aluminium production data for each plant. This is considered an IPCC Tier 3 method, since it is based on measured data (IPCC, 1997).

SF_6 Used in Aluminium and Magnesium Foundries

[Titled *Magnesium Production* in the CGHGI.]

SF_6 is emitted during magnesium production. SF_6 is used in magnesium production as a cover gas to prevent oxidation of the molten metal. It is vented to the atmosphere immediately after use. 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 2000, 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.

Emissions from aluminium and magnesium foundries are not estimated; however, they are considered a minor source in comparison with primary magnesium production.

Some CO_2 emissions are associated with magnesium production. The CO_2 originates from carbonates in the raw magnesium-bearing ore. However, these emissions are estimated to be very small and are not included in the inventory.

Emission Calculations

SF_6 emission data were reported directly by the magnesium producers to the National Pollutant Release Inventory for 1999 and 2000. For other years, the data were collected directly from the producers.

Other: Metal and Miscellaneous Chemical Production

[Titled *Other Metal Production* in the CGHGI.]

Emissions of CO_2 from the oxidation of fossil fuel-based reducing agents in the production of other metals are included in the national inventory. These emissions are included in Other: Industrial Processes.

Emissions from carbon evolving from the processing of carbonate ores are not inventoried due to lack of data. These are assumed to be negligible.

The following sectors and subsectors are not listed in the CGHGI.

OTHER: PRODUCTION

Pulp and Paper

Not estimated.

Food and Drink

Not estimated.

PRODUCTION OF HALOCARBONS AND SF_6

Not occurring.

CONSUMPTION OF HALOCARBONS AND SF_6

[Note: The reporting for *Consumption of Halocarbons and* SF_6 was originally listed in the *Solvent and Other Product Use* section, but the UNFCCC now requires these emissions to be reported in the *Industrial Processes* section.]

The major source of emissions from consumption of halocarbons and SF_6 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 from HFC and PFC by-products from aluminium production. There is no known production of HFCs/PFCs in Canada. The by-product emissions of PFCs from aluminium production are discussed in the Aluminium Production section. All HFCs/PFCs consumed are imported in bulk or in product. No data are available for quantities of HFCs contained in imported equipment for the 1995 HFC estimate, so this source is not included, but it is assumed to be small relative to others.

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 1996–2000 HFC emissions based on detailed activity data provided by the survey. HFC activity data for 1999 and 2000 are currently unavailable; therefore, the activity data were based on available 1998 data.

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 Systems.

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. PFC consumption data used to estimate 1998–2000 emissions were based on 1997 data (only 1995–1997 PFC consumption data were collected).

Consumption of SF_6 from magnesium producers is discussed in the section Metal Production.

Refrigeration and Air Conditioning Equipment

[Titled *AC OEM, AC Service, Refrigeration* in the CGHGI.]

The major source of HFC emissions is AC equipment. From 1990 to 1994, the emissions from this source 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). Emissions from the consumption of PFCs for 1990–1994 were also assumed to be negligible.

Emission Calculations

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).

HFC Estimate for 1995 – Emission Factors and Assumptions

AC OEM – Only original charging losses were estimated using the emission factors for this sector. Other losses were accounted for under AC Service. The IPCC Guidelines employ 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 connected 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 used.

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. Therefore:

Equation A-6:

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 A-7:

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

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 A-8:

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

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 A-3) (IPCC, 1997). The HFC and PFC survey provided quantity of refrigerant charged.

TABLE A-3: 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 A-9:

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

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; it 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 A-4 (IPCC, 1997).

TABLE A-4: 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 in 1995 only 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

[Titled *Foams* in the CGHGI.]

Emission Calculations

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).

HFC Emissions from Foam Blowing

The IPCC Tier 2 methodology presented in the revised IPCC Guidelines was used to estimate 1996–2000 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 A-10:

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

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

[Titled *Fire Extinguishing Equipment* in the CGHGI.]

Emission Calculations

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).

HFC/PFC Emissions from Fire Extinguishing

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 1996–2000 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

[Titled *Aerosols* in the CGHGI.]

Emission Calculations

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).

HFC Emissions from Use in Aerosols

The IPCC Tier 2 methodology presented in the revised IPCC Guidelines was used to calculate 1996–2000 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.

PFC consumption data show that products imported into Canada in aerosol cans contain solvents used as flux remover and precision cleaners for the electronics industry. PFC emissions are therefore reported in the Solvents section.

Solvents

[This sector title is not used in the CGHGI.]

Emissions from HFCs/PFCs Used as Solvents

The IPCC Tier 2 methodology presented in the revised IPCC Guidelines was used to estimate 1996–2000 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

HFC emissions are inventoried in the Consumption of Halocarbons and SF_6 section.

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

Two main uses of PFCs in the semiconductor manufacturing industry are for 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 A-5, provided by the IPCC Good Practice Guidance (Tier 2b). Currently, there is no information on emission control technologies; therefore, it was assumed that 100% of PFCs were released (IPCC/OECD/IEA, 2000).

TABLE A-5: 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

HFC emissions are inventoried in the Consumption of Halocarbons and SF_6 section.

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 its 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 A-11:

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

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

OTHER: INDUSTRIAL PROCESSES

[Titled *Undifferentiated Non-Energy Product Use* in the CGHGI.]

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 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 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 aluminium must therefore be subtracted from the total non-energy emissions to avoid double counting. Similarly, 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 emissions from ammonia production are also subtracted from the total non-energy emissions to avoid double counting.

Emission Calculations

The IPCC average rates of carbon storage in non-energy products were used to develop emission factors (IPCC, 1997) (see Appendix D).

Fuel quantity data were for non-energy fuel usage as reported by Statistics Canada (#57-003).

The method used to calculate the emissions is IPCC Tier 1 default (IPCC, 1997).

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 Statistics Canada (#57-003). In these instances, the natural gas is assumed to undergo 100% oxidation, and the appropriate combustion emission factor is used.

SOLVENT AND OTHER PRODUCT USE

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.

The majority of emissions in this section are also related to the use of N_2O as an anaesthetic and a propellant.

Note: HFCs as replacements for CFCs were originally reported in this section, but the UNFCCC now requires these emissions to be reported in the Industrial Processes section (see Consumption of Halocarbons and SF_6). Emissions related to HFC consumption are not point sources and would be more appropriately categorized as product use emissions.

PAINT APPLICATION

[Not used as a sector title in the CGHGI.]

Not estimated.

DEGREASING AND DRY CLEANING

[Not used as a sector title in the CGHGI.]

Not estimated.

CHEMICAL PRODUCTS, MANUFACTURE AND PROCESSING

[Not used as a sector title in the CGHGI.]

Not estimated.

OTHER: SOLVENT AND OTHER PRODUCT USE

[Not used as a sector title in the CGHGI.]

Not estimated.

Use of N_2O for Anaesthesia

[Titled *Anaesthetic and Propellant Usage* in the CGHGI.]

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.

Emission Calculations

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.

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

N_2O from Fire Extinguishers

[Not used as a sector title in the CGHGI.]

Not known to occur.

N_2O from Aerosol Cans

[Reported under *Anaesthetic and Propellant Usage* in the CGHGI.]

N_2O is used as a propellant for pressure and aerosol products, primarily in the food industry. The largest application is for pressure-packaged whipped cream, along with 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.

It was assumed that all the N_2O used in propellants was emitted to the atmosphere during the year of sale.

Emission Calculations

An emission factor was developed for N_2O used in propellants based upon consumption patterns in Canada in 1990 (see Appendix D).

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

Other: Use of N_2O

[Not used as a sector title in the CGHGI.]

AGRICULTURE

ENTERIC FERMENTATION

Large quantities of CH_4 are produced from herbivores through a process called enteric fermentation. During the normal digestive process, microorganisms break down carbohydrates into simple molecules for absorption into the bloodstream, where CH_4 is produced as a by-product. This process results in CH_4 in the rumen that is emitted by eructation and exhalation. Some CH_4 is released later in the digestive process by flatulation. The animals that generate the most CH_4 are ruminant animals such as cattle.

The IPCC emission factors are based on research conducted in the United States. Emissions of CH_4 by enteric fermentation 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. More research is required in this area to analytically verify the accuracy of using the IPCC cool climate emission factors for Canadian conditions.

Enteric fermentation emissions for each of the animal subsectors are calculated using the same method. Some differences have been noted in regard to the input population data used in certain sectors.

Emission Calculations

CH_4 emissions from enteric fermentation were estimated by multiplying the populations of various animals by average emission rates for each type of domestic animal.

The methodology used is considered IPCC Tier 1.

In general, the IPCC default emission factors for cool climate were used for all regions of Canada (IPCC, 1997). Within the cattle category, emission factors for bulls, beef cows, dairy heifers and beef heifers are country specific.

In general, domestic animal population data were obtained from Statistics Canada (#23-603). Semi-annual or quarterly data were averaged to obtain annual populations. Some exceptions have been noted by appropriate classifications in Table A-6.

TABLE A-6: Animal Categories and Sources of Population Data for Methane Emission Calculations

Category	Sources/Notes
Cattle	See text
• Dairy Cattle	Includes dairy cows and dairy heifers only
• Non-Dairy Cattle	All other cattle
Buffalo	Considered a negligible source in Canada
Sheep	See text Listed under *Other* in the CGHGI Includes lambs
Goats	See text Listed under *Other* in the CGHGI Data were not available on an annual basis from Statistics Canada #23-603. Therefore, data from the 1991 and 1996 farm census (Statistics Canada #93-350 and #93-356) have been used.
Camels and Llamas	Considered a negligible source in Canada
Horses	See text Listed under *Other* in the CGHGI Data were not available from Statistics Canada #23-603. Therefore, for horses, data from the 1991 and 1996 farm census (Statistics Canada #93-350 and #93-356) have been used.
Mules and Asses	Considered a negligible source in Canada
Swine	See text All pigs
Poultry	See text Yearly population data are available from Production of Poultry and Eggs (Statistics Canada, #23-202)
Other	See above

MANURE MANAGEMENT

During the handling of livestock manure, both CH_4 and N_2O are emitted. The magnitude of the emissions is dependent upon the manure properties, the quantity handled, and the handling systems.

Typically, poorly aerated manure handling 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.

Methane Emissions

Shortly after manure is excreted, it begins to decompose. If oxygen is absent, the decomposition will be anaerobic in nature and thus will produce CH_4. The quantity of CH_4 produced varies depending on the waste management system and the amount of manure. Average emission rates have been developed for livestock based on the typical waste management systems and manure production rates for North America.

The IPCC emission factors are based on research conducted in the United States. More research is required in this area to analytically verify the accuracy of using the IPCC cool climate emission factors for Canadian conditions.

Nitrous Oxide Emissions

The production of N_2O during storage and treatment of animal waste occurs during the nitrification and denitrification of nitrogen contained in the manure. Generally, as the degree of aeration of the waste increases, so does the amount of N_2O produced.

Nitrification is the oxidation of ammonium (NH_4^+) to nitrate (NO_3^-), and denitrification is the reduction of NO_3^- to N_2O or N_2.

The amount of manure nitrogen handled by various types of manure management systems was estimated by calculating the manure nitrogen excreted by a particular animal type and multiplying this by the percent usage of the system. Average amounts of annual nitrogen excretion for various domestic animals are based on research conducted in the United States (ASAE, 1999). The nitrogen excretion rates were reduced by 20% to account for the volatilization of NH_3 and NO_x (IPCC, 1997).

It is assumed that no animal waste is burned as fuel in Canada.

The utilization rates of various manure management or animal waste management systems are based upon consultation with industry experts. Unfortunately, as limited data are currently available, the values are solely based on expert opinion.

CH_4 emissions have been reported based on animal type, while N_2O emissions have been calculated based on manure management systems.

Emission Calculations

CH_4 emissions from manure management are estimated using the IPCC default emission factors for a developed country with a cool climate (IPCC, 1997).

Emissions have been estimated by applying animal-specific emission factors to domestic animal populations. The animal populations are the same as those used for the Enteric Fermentation section. This conforms to an IPCC Tier 1 methodology (IPCC, 1997).

N_2O emissions from manure management systems are estimated using the IPCC default emission factors for a developed country with a cool climate (IPCC, 1997).

The emissions are estimated by applying system-specific emission factors to the manure nitrogen handled by each management system. The emission factors are assigned to the following systems that are most common in Canada:

- pasture and paddock;
- liquid systems;
- solid storage or drylot; and
- other systems.

It is assumed that no animal wastes are burned as fuel in Canada. The manure management system usage rates have been estimated based on consultation with industry experts. Unfortunately, there are limited data on system utilization in Canada. As a result, the estimates are based on expert opinion.

According to IPCC Guidelines, the N_2O emissions from pasture and paddock systems are allocated as agricultural soil emissions. The calculation methodology for pasture and paddock systems is the same as for the other manure management systems.

The animal population data used to estimate the total manure nitrogen excreted were the same as those used to calculate enteric fermentation emissions. In general, domestic animal population data were obtained from Statistics Canada (#23-603). Semi-annual or quarterly data were averaged to obtain annual populations. Some exceptions have been noted by appropriate sectors (see Table A-7).

TABLE A-7: Animal Categories, Manure Management Systems, and Sources of Population Data for Manure Nitrogen Emission Calculations

Category	Source/Notes
Cattle	See text
• Dairy Cattle	Includes dairy cows and dairy heifers only
• Non-Dairy Cattle	In general, beef production uses the drylot type of manure management system
Buffalo	Considered a negligible source in Canada
Sheep	See text Listed under *Other* in the CGHGI Includes lambs
Goats	See text Listed under *Other* in the CGHGI Data were not available from Statistics Canada #23-603. Therefore, data from the 1991 and 1996 farm census (Statistics Canada #93-350 and #93-356) have been used.
Camels and Llamas	Considered a negligible source in Canada
Horses	See text Listed under *Other* in the CGHGI Data were not available from Statistics Canada #23-603. Therefore, data from the 1991 and 1996 farm census (Statistics Canada #93-350 and #93-356) have been used.
Mules and Asses	Considered a negligible source in Canada
Swine	See text All pigs
Poultry	See text Production data from *Production of Poultry and Eggs* (Statistics Canada, #23-202) have been used.
Anaerobic Lagoons	Not used as a sector title in the CGHGI
Liquid Systems	See text
Solid Storage and Drylot	See text
Other: Manure Management	See text

RICE CULTIVATION

[Not used as a sector title in the CGHGI.]

Emissions associated with rice cultivation in Canada are considered to be negligible and are not inventoried.

AGRICULTURAL SOILS

Agricultural soil management and cropping practices affect both the carbon and nitrogen cycles in soils. The activities can lead to emissions of CO_2 and N_2O.

Carbon Dioxide Emissions

Soil management practices can lead to an increase or decrease in the organic carbon stored in soils. This change in soil organic carbon results in an emission or removal (sink) of CO_2.

Net CO_2 emissions have decreased since 1990 due to changes in farming practices. The primary reason for the reduced net emissions from soils is believed to be the increasingly common practice of conservation tillage. No-till farming was being practised on over 16% of Canada's croplands in 1996 as opposed to 7% in 1991 (Statistics Canada, #93-350 and #93-356). No-till farming reduces the oxidation of soil organic carbon and therefore increases the carbon stored in soils.

As noted, a change in soil organic carbon is influenced by the conversion of land to agriculture, management practices, soil characteristics, and climate. A key issue around the certainty of estimating carbon in soils is the small annual increment of carbon change relative to an already large carbon pool. In order to develop an estimate of CO_2 emissions that reflects the diverse and myriad complexities that affect carbon fluxes in agricultural soils, the CENTURY computer model was employed (Parton et al., 1987).

Methodologies using the CENTURY model for estimating CO_2 fluxes on agricultural soils in Canada were detailed in Smith et al. (1997a) and Neitzert et al. (1999).

There is a large degree of uncertainty associated with the 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. There has been a growing awareness of limitations of the CENTURY model among soil scientists in Canada and of the need for new models with measurable carbon pools. Canada is currently evaluating different methodologies for estimating and reporting changes in soil carbon.

Nitrous Oxide Emissions

N_2O is emitted as a by-product during soil nitrification and denitrification processes. Even though the uncertainty in the agricultural soil estimates is very high, it appears that N_2O emissions have increased since 1990.

During nitrification and denitrification, a fraction of the available nitrogen is emitted to the atmosphere as N_2O. The amount of N_2O emitted is dependent on the amount of nitrogen available for nitrification/denitrification, the soil type, and the soil condition. There is a very high variability in the emission rates, and the estimation methodologies require more development and research to reduce the associated uncertainty.

Until the acceptance of the revised 1996 IPCC Guidelines, only nitrogen from synthetic fertilizer application was considered for emission calculations. These guidelines have expanded the sources of nitrogen related to agricultural soils.

Emission Calculations

Carbon Dioxide Emissions

The CENTURY model was used to estimate emissions. The emission estimates (as prepared by Smith et al., 1997a) aggregate emissions from each of the western provinces and the eastern provinces. Emissions were divided among the eastern provinces by prorating against the agricultural land area in each province (Smith et al., 1997b; Sellers and Wellisch, 1998).

Since the CENTURY model does not estimate emissions from the liming of soils, liming emissions were estimated according to the IPCC default methodology (IPCC, 1997). The liming emissions were added to the results from the CENTURY model. Liming emissions are small, around 0.3 Mt CO_2 per year.

The activity data for liming (quantity of lime used) are based on unpublished data from provincial fertilizer associations.

Emissions of CO_2 from cultivation of histosols are not estimated. However, Canada is assessing the possible submission of emissions from this source in future inventories.

Nitrous Oxide Emissions

The methodology used is based on the IPCC default and is divided by sources, direct and indirect (see sections Direct Soil Emissions, Animal Production, Indirect Emissions, and Other: Agricultural Soils).

Direct Soil Emissions

[Titled *Direct Sources* in the CGHGI.]

Direct sources are those emissions that are emitted directly from agricultural fields. These emissions result from nitrogen that has entered the soil from:

- synthetic fertilizers;
- animal wastes applied as fertilizer;
- manure application from grazing animals;
- plant biological nitrogen fixation;
- crop residue decomposition; and
- the cultivation of histosols.

Synthetic Fertilizers

Synthetic fertilizers add large quantities of nitrogen to soils and result in N_2O emissions.

Emission Calculations

The methodology used to estimate N_2O emissions is the IPCC Tier 1 methodology.

The emission factor of 1.25% N_2O-N/kg N for all types of fertilizer and the amount of fertilizer nitrogen applied annually were used to estimate N_2O emissions from synthetic fertilizers (IPCC, 1997).

The amount of applied nitrogen is reduced by 10% (IPCC default) to account for losses due to volatilization.

The amount of nitrogen applied is obtained from yearly fertilizer sales data, which are available from regional fertilizer associations (Korol and Rattray, 2000). These data include the amount of fertilizer nitrogen sold by retailers on or before June 30 of the inventory year. It is assumed that all fertilizer sold after June 30 is used in the next inventory year.

Animal Wastes Applied as Fertilizer

The application of animal wastes as fertilizer to soils can increase the rate of nitrification/denitrification and result in enhanced N_2O emissions.

Manure from grazing is not included in this section, but is included in the Grazing Animals section.

Emission Calculations

The IPCC default methodology and emission factors were used (IPCC, 1997).

The amount of nitrogen applied is calculated using the data from the Manure Management section. All manure that is handled by the manure management systems is assumed to be applied as fertilizer.

The amount of manure nitrogen excreted was reduced by the IPCC default value, 20%, to account for the volatilization of NH_3 and NO_x (IPCC, 1997).

In general, domestic animal population data were obtained from Statistics Canada (#23-603). Semi-annual or quarterly data were averaged to obtain annual populations. Some exceptions have been noted by appropriate sectors (see Table A-7).

Plant Biological Nitrogen Fixation

Atmospheric nitrogen fixed by biological nitrogen-fixing plants can undergo the process of nitrification/denitrification in the same manner as nitrogen applied as synthetic fertilizer. Also, the rhizobia in plant nodules can emit N_2O as they fix nitrogen.

Emission Calculations

The methodology used to estimate emissions was the IPCC default.

The emission factor for the nitrogen contained in nitrogen-fixing crops was developed by the IPCC (1997).

The amount of nitrogen in the nitrogen-fixing plants was 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).

Estimates of the dry mass used the IPCC values for the average dry matter fractions of 86% for crops such as wheat, barley, corn, oats, rye, peas, beans, soya, lentils, and tame hay (IPCC, 1997). Silage corn, potatoes, and sugar beets were assumed to contain 30, 25, and 20% of dry mass, respectively. There were no explicit annual statistics available for alfalfa production. That information is combined with tame hay production. Therefore, alfalfa quantities have been estimated by assuming that

60% of tame hay production is alfalfa. In addition, the crop mass of alfalfa and tame hay was assumed to be equal to the reported production.

Crop production data were obtained from Statistics Canada (#22-002).

Crop Residue Decomposition

When crops are harvested, a portion of the crop is left on the field to decompose. The remaining plant matter is a nitrogen source for nitrification/denitrification.

Emission Calculations

Emissions were estimated using the IPCC default methodology and emission factors (IPCC, 1997).

The nitrogen contents for nitrogen-fixing crop residue, 0.03 kg N/dry kg, and other crops, 0.015 kg N/dry kg, were used (IPCC, 1997).

The emission rate of 1.25% N_2O-N/kg N was also the IPCC default (IPCC, 1997).

It was estimated that 55% of the crop mass remains on the field as residue. It is further assumed that the amount of residue burned on the field is negligible in Canada. The crop dry mass is estimated using the average dry matter fractions from the IPCC (1997). The crop production data and dry-mass quantities are the same as those used to estimate plant biological nitrogen fixation.

Cultivation of Histosols

N_2O is also emitted as a result of cultivating organic soils (histosols), due to enhanced mineralization of organic matter.

Previously, it was estimated that approximately 1.5% of 111 million hectares of peatlands in Canada, or 1.7 million hectares, were under cultivation for annual crop production (NRCan, 1995). However, this number is believed to be grossly overestimated. In consultation with regional soils and crop specialists, the area of cultivated histosols in Canada is about 29 802 ha. In the absence of detailed census data, this may represent a close estimate.

Emission Calculations

The IPCC default methodology was used to estimate emissions (IPCC, 1997).

An emission factor of 5 kg N_2O-N/ha per year (IPCC, 1997) was used.

Animal Production

[This title is not used in the CGHGI; it is referred to as *Grazing Animals*.]

These emissions are those associated with the application of manure to soils through grazing animals.

Emission Calculations

The emissions from manure excreted by grazing animals were calculated using the IPCC default methodology (IPCC, 1997).

The excretion rates (ASAE, 1999) plus pasture and paddock system emission factors from the IPCC were used (IPCC, 1997). Animal population data are the same as those used in the Manure Management section.

Indirect Emissions

A fraction of the fertilizer nitrogen that is applied to agricultural fields will be transported off-site by either:

- volatilization and subsequent redeposition; or
- leaching and runoff.

The nitrogen that is transported from the agricultural field will provide additional nitrogen for subsequent nitrification and denitrification to produce N_2O.

The nitrogen leaving an agricultural field may not be available for the process of nitrification/denitrification for many years, particularly in the case of nitrogen leaching into groundwater. A very high level of uncertainty is associated with estimates of emissions from indirect sources. Uncertainty estimates from these sources of emissions may be up to two orders of magnitude (IPCC, 1997).

Volatilization and Subsequent Redeposition

Emission Calculations

The method used to estimate emissions was the IPCC default (IPCC, 1997).

The amount of nitrogen that volatilizes was assumed to be 10% of synthetic fertilizer applied and 20% of manure nitrogen applied.

The amount of nitrogen that was estimated to have volatilized was multiplied by the IPCC emission factor to obtain an emission estimate (IPCC, 1997).

Leaching and Runoff

Emission Calculations

The method used to estimate emissions was modified to reflect low precipitation and high evaporation conditions that occur on the Canadian prairies, where more than 80% of agricultural land is located, as well as fertilizer nitrogen consumed.

The emissions from runoff and leaching were estimated by assuming 15% of the nitrogen applied as synthetic fertilizer or manure was lost by leaching and runoff. The quantity of estimated nitrogen was multiplied by the IPCC emission factor to obtain an emission estimate (IPCC, 1997).

Other: Agricultural Soils

[This title is not used in the CGHGI.]

PRESCRIBED BURNING OF SAVANNAS

[This title is not used in the CGHGI.]

This sector does not apply in Canada.

FIELD BURNING OF AGRICULTURAL RESIDUES

[This title is not used in the CGHGI.]

Field burning of agricultural residues is no longer considered a normal practice in Canadian agriculture. Therefore, the emissions from this source are assumed to be negligible.

OTHER: AGRICULTURE

[Not used as a sector title in the CGHGI.]

Many agricultural activities result in emissions of GHGs. The processes that produce emissions are enteric fermentation related to domestic animals, manure management practices, and cropping practices that result in a release from soils.

GHG emissions from on-farm fuel combustion are included in the Energy section rather than under Agriculture.

All animal population data are based on one-year average data, as opposed to the three-year average recommended by the IPCC Guideline reporting instructions, since the Canadian activity data are considered to be of high quality.

LAND-USE CHANGE AND FORESTRY

This section discusses emissions of GHGs to and removals of GHGs from the atmosphere associated with changes in the way land is used (e.g., clearing of forests for agricultural and urban use) or in the amount of biomass in existing stocks such as managed forests.

Emissions from most anthropogenic activities covered in the LUCF section are included; non-CO_2 gases emitted during the burning of biomass for energy production are addressed in the Energy section. CO_2 emissions from agricultural soils are reported in the Agriculture section.

Background

Vegetation withdraws CO_2 from the atmosphere through the process of photosynthesis. CO_2 is returned to the atmosphere by the respiration of the vegetation and the decay of organic matter in soils and litter. The gross fluxes are large; roughly a seventh of the total atmospheric CO_2 passes into vegetation each year (on the order of 100 billion tonnes of CO_2-C per year). In the absence of significant human disturbance, this large flux of CO_2 from the atmosphere to the terrestrial biosphere is believed to be balanced by the return respiration fluxes. Globally, ecosystems would be in a state of dynamic equilibrium.

Humans interact with land in many different ways. Certain land uses and land-use changes can directly alter the size and rate of natural exchanges of GHGs among terrestrial ecosystems, the atmosphere, and the ocean. Changes in land-use practices today affect both present and future CO_2 fluxes associated with that specific land use; this long-term effect distinguishes land use from fossil fuel consumption for purposes of CO_2 emission analysis.

The size of carbon fluxes and amount of carbon stored in carbon reservoirs change with time. Each ecosystem has its own profile, depending on its own dynamics, climatic factors, and exposure to natural and human disturbances. For example, tree growth and soil formation span decades to centuries of very small annual rates of change.

The 1996 CGHGI was the first attempt by Canada to assess the net flux of CO_2 and other GHGs within the LUCF categories, as per the IPCC Guidelines (IPCC, 1997). The main challenge is deciding how to apply the LUCF methodologies to Canada's circumstances in a way that produces meaningful results. Obtaining adequate information on LUCF to allow reporting with sufficient accuracy and in a fashion that fits the IPCC framework is challenging for a number of reasons. In Canada's case, this assessment involves the estimation of mostly small changes cumulated over a very large land area. Moreover, as land areas are affected by both natural forces and human decisions, the isolation of the human impact of land-use practices and land-use change activities, as is required by the UNFCCC, is a complex task.

The results are presented under the following headings:

1. Changes in Forest and Other Woody Biomass Stocks;
2. Forest and Grassland Conversion;
3. Abandonment of Managed Lands (croplands, pastures, or other managed lands);
4. CO_2 Emissions and Removals from Soil – associated with items 2 and 3 (not required by the IPCC); and
5. Other, which includes:
    - emissions from prescribed fires; and
    - emissions from wildfires caused by humans (not required by the IPCC).

Some land use and land-use change activities were estimated to be net sources, while others were estimated to be net sinks. Commercial forestry and the abandonment of managed land (items 1, 3, and part of 4) currently remove CO_2 from the atmosphere, whereas forest and grassland conversion (item 2 and part of 4) and biomass burning (item 5) all release GHGs to the atmosphere.

OVERVIEW OF THE METHODOLOGY

LUCF activities can have an impact on several forest carbon reservoirs: aboveground and below-ground biomass, litter and woody debris, and soil carbon. Chapter 5 of the IPCC Guidelines (IPCC, 1997) provides methods to estimate the GHG impacts of the LUCF activities that are important from a global perspective.

The IPCC methodology currently omits below-ground biomass, litter, and soil carbon in forest stocks. At present, the available data on these pools for Canada's managed forests are insufficient to support the derivation of flux estimates. However, changes in soil carbon resulting from land-use change activities (see sections Forest and Grassland Conversion and Abandonment of Managed Lands), while not required by the IPCC, are nevertheless reported here in CO_2 Emissions and Removals from Soil. It is important to note that, in keeping with the IPCC Guidelines, emissions and removals of CO_2 from the LUCF sector are not included in the national totals reported internationally.

The following general notes apply to the LUCF estimates:

- CO_2 from LUCF is classified separately and is not included in national inventory sums.
- Removals (i.e., uptake by vegetation and soils) are shown as negative values.
- The forest assessment covers the "managed" forest area, here defined as the wood production forest (see section Changes in Forest and Other Woody Biomass Stocks below).
- Emission estimates greatly depend on the way wood products are treated in the methodology (see section Changes in Forest and Other Woody Biomass Stocks).
- The information on human-caused fires is for outside the wood production forest. CO_2 emissions from fires in the wood production forest are included in net changes in forest stocks.
- Individual sector estimates are given with two significant figures. For CO_2, totals have been rounded to one significant figure, to reflect the relatively high level of uncertainty associated with this category (see Uncertainty below).

UNCERTAINTY

The methods used in the CGHGI for estimating emissions and removals associated with LUCF are more complex than those used in the other

UNFCCC categories. They involve more steps and require more data, factors, and assumptions to derive the final estimates. Therefore, it is advised that the estimates should be treated as first approximations that reflect the direction (i.e., source or sink) and magnitude of emissions and removals. They are characterized by a high degree of uncertainty (over 100% in almost every case). To reflect the uncertainty, rounding to one significant figure has been applied. Estimates of emissions reflect "higher or maximum emissions," while the estimates of removals reflect "lower or minimum removals."

The UNFCCC Reporting Guidelines list four major sources of uncertainty. All of these are considered to apply to the LUCF category. The sources of uncertainty include definitions, methodology, activity data, and underlying scientific understanding. For example, matching Canada's land-use information with the UNFCCC LUCF categories and separating human from natural activities required subjective evaluations in most cases. In addition, there is a lack of time-series data on areas subject to land-use changes in Canada. Accurate data to estimate the changes in stocks and forest growth by age class in the wood production forest area are also unavailable.

CARBON BUDGET MODEL AND IPCC METHODS

The Canadian Forest Service's Carbon Budget Model (CBM-CFS),[27] while more detailed in its assessment of forest carbon stocks than the IPCC methodology, cannot in its current form address all the requirements of the IPCC Guidelines on a operational basis. Under the IPCC Guidelines, forest sector carbon fluxes are assessed together with the effects of land-use change; the CBM model excludes the treatment of non-forest trees, the use of domestic firewood, and the effects of land conversion. However, the model does include all Canadian forestland for which biomass data are available (including the "unmanaged" forest), takes into account the carbon stored in below-ground biomass and dead organic matter, and incorporates the effects of natural disturbances. The retrieval of data that best represent the "managed" or wood production forest (forest areas, biomass accumulation rates, expansion factors, etc.), as opposed to the entire Canadian forest, currently creates technical problems. The outcome of ongoing work conducted by the Canadian Forest Service may in the future warrant the incorporation of CBM outputs in LUCF estimates.

CHANGES IN FOREST AND OTHER WOODY BIOMASS STOCKS

Canada is the second-largest country in the world, occupying an area of approximately 1000 million hectares of land and water. Canada's total forest area (417 million hectares) comprises close to 10% of the world's total forested area. It is composed of a mosaic of ecosystems (i.e., forests of different ages and species, exposed to various climates and disturbances). For the purposes of defining the area of forest affected by human activity, a decision had to be made regarding the area of forestland that should be considered in this assessment. Approximately 58% of the Canadian forest area is classified as timber productive forest. The portion of the timber productive forest that is non-reserved and accessible (148 million hectares) is known as Canada's wood production forest and is generally available for commercial harvest. The wood production forest represents 35% of Canada's total forestlands (Lowe et al., 1996a). The remainder of the timber productive forest is either reserved for other uses or non-accessible. Within the wood production forest, it is considered that the growing area actually contributing to CO_2 removals extends over 122.8 million hectares, once the non-stocked portion and overmature forests have been excluded (Sellers and Wellisch, 1998). Virtually all of the LUCF CO_2 removals can be attributed to the growing portion of the wood production forest. The 1994 update (Lowe et al., 1996a) of the *1991 Canadian Forest Inventory* (Lowe et al., 1994) is the main source of information regarding the area of the wood production forest. Forest information and data will be updated when the 2001 version of the Canadian Forest Inventory becomes available.

Commercial forestry, the occurrence of fires, and fire suppression activities are considered to be the dominant anthropogenic activities occurring in

27 A previous version of Canada's national inventory has reported on the results of this model (Jaques et al., 1997).

Canada's forests that can affect the size of forest stocks and potentially increase or decrease GHG emissions. Commercial forestry includes commercial management, harvest of industrial roundwood and fuelwood, production and use of wood commodities, and establishment and operations of forest plantations. Fires are considered inasmuch as they are directly caused by human activities, whether intentionally or not. At present, this inventory does not account for the effect of fire suppression activities.

The default method used to produce estimates for this sector does not adequately address the fate of carbon stored in wood products. Two alternative methods, the atmospheric flow and stock change methods, currently subject to international discussions, have been preliminarily evaluated in Canada. These methods, while promising, have yet to be approved for inclusion in the IPCC Guidelines. An overview of these two approaches is available in the *Land Use, Land-Use Change and Forestry, a Special Report of the IPCC* (IPCC, 2000).

Some double counting is likely to occur between the estimates in the Changes in Forest and Other Woody Biomass Stocks sector and those reported in the Energy and Waste sections (i.e., CH_4 from landfilled wood wastes and industrial use of biomass fuel). However, considering the key unresolved issues in the methodology used here, one could argue that there might also be considerable double counting of emissions because of the trading of wood products between countries. Therefore, while the double counting issue is acknowledged, there has been no attempt to resolve it, as this must be addressed in the methodology.

Emission Calculations

With the current IPCC method (used to produce the results presented here), the net impact of a removal or emission is calculated as the difference between CO_2 uptake through forest growth and CO_2 emissions resulting from forest harvest. Forest growth is restricted to the net accumulation of aboveground biomass, excluding the accumulation of soil organic matter and litter.

Emissions from harvest include the carbon in both the merchantable (i.e., roundwood) and non-merchantable components (i.e., slash left on the forest floor) and are assumed to be released in the year of harvest.

Curently, forest growth rates are not available by age or maturity class for the wood production forest. Therefore, a long-term average value referred to as the mean annual increment to maturity has been applied to the entire growing area. The mean annual increment to maturity is an average rate of volume increment obtained by dividing the merchantable wood volume per hectare by the stand age at maturity. Using this average rate masks the interannual variability of growth rates due to changing environmental conditions and stand development phases. Since it represents a long-term average and an approximation of current growth, it is considered to be a net value that takes into account mortality and growth reduction due to non-stand-replacing disturbances, competition, and disease. Using the mean annual increment is consistent with the application of a biomass expansion factor derived from standing aboveground biomass at maturity. In fact, this approach excludes the carbon sequestered in biomass that is shedded prior to stand maturity and either decomposes or remains in the ecosystem as coarse woody debris or soil organic matter. The mean annual increment is ultimately derived from forest stand inventory measurements collated by the Canadian Forest Service by forest types and ecosystems (Lowe et al., 1996b).

The net accumulation of aboveground biomass by the wood production forest has been estimated by multiplying the growing forest area by the mean annual volume increment in each ecozone, then by a conversion/expansion factor into total aboveground biomass. The growing forest area was assumed to be constant over the period 1990–2000.

Biomass accumulation from farm woodlots is also assessed and included, although it represents no more than 1–2% of total annual aboveground carbon increment. Based on Canada's *Census of Agriculture* (reported by Statistics Canada), farm woodlots are thought to represent about 12% of total farmland (Sellers and Wellisch, 1998).

Although very minor, the contribution of urban forests was calculated from estimated fractions of non-built-up urban areas and the growth rate of urban trees.

The approach used to derive CO_2 emissions from forest harvest follows closely the current IPCC default methodology. Data input to these calculations includes commodity data series (industrial roundwood production, domestic firewood and charcoal consumption), parameters to account for the bark volume, and wood volume to forest biomass conversion/expansion factors for mature and overmature forest stands (IPCC, 1997; Sellers and Wellisch, 1998).

Alternative Methods for Net Emission/Removal Calculations

CO_2 emissions resulting from the harvest of the wood production forest have been assessed using two other methods that better reflect the Canadian situation: the stock-change method and the flow method. These methods are considered to be improvements over the default method, as they recognize that most of the carbon in harvested biomass converted to wood products is not emitted within the year of harvest. Gross emissions associated with harvest for 2000 range from 169 Mt CO_2 (atmospheric flow method) to 228 Mt CO_2 (current IPCC method).

Both the stock-change and flow approaches address the issue of long-term carbon storage by assigning commodities into one of two groups: products that last for less than five years and products with a life span of five or more years. They differ with respect to their allocation of emissions and removals. The stock-change approach accounts only for the net carbon stock change in the domestic long-term wood product reservoir, after imports and exports. The flow approach tracks CO_2 emissions and removals associated with the harvest, manufacturing, and consumption of wood products within national boundaries. Both approaches are more spatially and temporally realistic than the current default, which does not account for emissions where or when they actually occur. Both include additional sources of emissions from the decay of long-lived products harvested or imported in previous years. The flow method is similar to the approach adopted for fossil fuel emissions, involves few additional calculations, and provides a more accurate reflection of when and where emissions and removals actually occur. The difference between the stock change and flow approaches lies in the treatment of exported products (significant in Canada); in the stock approach, the carbon in exported wood products exits the domestic stocks and hence is included with emissions to the atmosphere.

FOREST AND GRASSLAND CONVERSION

This subsection estimates CO_2 emissions associated with major land-use changes such as forest and grassland conversion to croplands or other agricultural lands or conversion of any of these to urban (settled) areas. Only changes in aboveground carbon are addressed in this section. Changes in soil carbon levels are estimated in the section CO_2 Emissions and Removals from Soil.

Reliable data on the location and rates of land-use changes in Canada are lacking simply because they are not tracked or reported. Areas of land converted to other uses have been determined based on data on net increases in agricultural and urban areas, the only time-series data available. They have been determined as 10-year average values, as specified in the IPCC Guidelines (IPCC, 1997).

This method detects where forest conversion to agricultural land occurs by looking for provinces in which total farmland area increased over the last decade. The result is a conservative estimate of the total area converted, whereby only the net change across the beginning and end of a multi-year period is considered, rather than the total change that might be observed if gross rates of land conversion were observed for individual provinces.

The total area converted was 82 000 ha in 1990 and about 113 000 ha in 2000. It is estimated that about 12 000 ha were deforested in 1990 and 28 000 ha in 2000. The largest converted areas are from grassland to agricultural land and from unimproved farmland to improved farmland. However, deforestation is the dominant source of emissions, since it involves the largest change in aboveground biomass.

The data available are insufficient to allocate the change in biomass density to different routes (on-site burning, off-site burning, and decay) with any degree of confidence. Consequently, emissions of non-CO_2 trace gases associated with on-site burning after land conversion could not be evaluated. It was assumed that all of the change in carbon density was as a result of conversion of lost biomass to CO_2.

Due to data deficiencies, other probable sources of deforestation (for infrastructure or industrial development) have not been included in this assessment.

Emission Calculations

Agricultural land area data were obtained from the *Census of Agriculture's Agricultural Profiles* for each province (Statistics Canada, 1992). Urban area data are obtained from Statistics Canada's Econnections environmental data for each province (Statistics Canada, 1997). Linear regression is used to produce data for between-Census years.

As there is no corresponding information on the converted areas, assumptions were made regarding the sources of newly created agricultural and urban lands. Parameters were applied to apportion the converted total areas into original land type (temperate forest, boreal forest, grassland, other lands) (Jaques, 1992; ESSA Technologies Ltd., 1996).

Biomass densities before conversion are from the Canadian Forest Service (in ESSA Technologies Inc., 1996), and the biomass densities after conversion were based on the IPCC default data (IPCC, 1997). The assumptions that were employed were key to the accuracy of the emission estimates. At this point, these are considered to provide first-order approximations only.

ABANDONMENT OF MANAGED LANDS

Estimates were made for CO_2 removals resulting from the accumulation of aboveground carbon on abandoned, formerly managed lands. These abandoned lands are assumed to return slowly to their natural states. Associated changes in soil carbon are addressed in the section CO_2 Emissions and Removals from Soil.

Abandoned managed lands are interpreted to include agricultural land returning to its native state of grassland or forest and, within the total farmland, improved farmland (i.e., cropland, pasture) returning to unimproved farmland. Abandonment followed by conversion into a grassland ecosystem is assumed to not significantly increase the aboveground biomass. However, conversion into a forest ecosystem is known to increase carbon storage relative to what is stored in a cropland or pasture ecosystem. The IPCC recommends that the uptake be evaluated according to two time horizons:

- lands abandoned for the last 20 years; and
- lands abandoned for 21–100 years.

Since Canada's *Census of Agriculture's Agricultural Profiles* time series covers only 1961 to the present, the assessment for the second time period covers only land abandoned for 20–40 years prior to 2000.

CO_2 removals resulting from the abandonment of managed lands are reported for those lands believed to revert to temperate and boreal forests. The aboveground component of the conversion of agricultural land to temperate forest contributes to the majority of total removals. In the case of the 20-year time horizon, the temporal variations reflect the net changes in agricultural area over time. The temporal variations in removals associated with the 21- to 100-year time horizon reflect data availability in addition to the changes in agricultural land.

Emission Calculations

The total area of abandoned agricultural lands was compiled from reductions in total agricultural land in those provinces where such decreases were observed, based on Census of Agriculture data (Statistics Canada, *Agricultural Profiles 1971 to 1996*).

Due to the lack of actual observations on the fate of the abandoned land, it was assumed that half of the abandoned areas were converted to urban land and the remainder allowed to regrow to the natural state in estimated proportions (ESSA Technologies Inc., 1996; Sellers and Wellisch, 1998).

Biomass growth rates on abandoned lands were developed for temperate and boreal forests (ESSA Technologies Inc., 1996). While they are considerably lower than the IPCC default values, these new values better reflect Canadian conditions and were adopted in the estimation procedures.

A single average rate of regrowth was assumed for the forest areas (although, in reality, growth varies with age, location, and site conditions).

CO_2 EMISSIONS AND REMOVALS FROM SOIL

[Titled CO_2 *Emissions and Removals from Soils from Land-Use Change* in the CGHGI.]

This category estimates CO_2 fluxes to and from soils due to land-use changes (i.e., carbon emissions from land conversion and uptake by soils after land abandonment).

The methods for estimating CO_2 emissions and removals from agricultural soils and liming are discussed in the Agriculture section.

Estimates are considered to be first approximations because of the indirect way in which the land areas are determined and because of the significant assumptions made on annual rates of CO_2 emission or uptake by soils in different ecosystems.

In the CGHGI, emissions and removals for this sector are divided into:

- Soil Carbon Emissions from Land Conversion; and
- Soil Carbon Uptake from Abandonment of Managed Lands.

Soil Carbon Emissions from Land Conversion

Conversion of land from forest or grassland to agricultural or urban land is taken to result in a loss of soil carbon.

Emission Calculations

CO_2 emissions were estimated using a simple methodology based on estimated soil carbon contents prior to land conversion and at equilibrium under the new land use.

The acreage data for converted areas are multiplied by the carbon content of the soil prior to conversion to obtain the total annual potential carbon losses. These are multiplied by the fraction of carbon expected to be released over a 25-year period for each post-conversion land use. It is estimated that 22% of initial soil carbon content under forest or grasslands is lost upon conversion to agriculture (from data in Dumanski et al., 1998). It is assumed that 50% of new urban lands are unpaved and lose soil carbon; the other half are paved, and the soil carbon content does not change over time.

Soil carbon contents prior to conversion and at equilibrium after conversion were obtained from various sources: forest soil contents were derived from estimates provided by the Canadian Forest Service's CBM (CBM-CFS2). They include roots as well as soil, leading to an overestimation of soil carbon content in forests. Soil carbon content of natural grasslands was averaged from soil carbon data in the Canadian grassland ecoclimatic province (Tarnocai, 1996). All data are available and fully referenced in Sellers and Wellisch (1998).

Soil Carbon Uptake from Abandonment of Managed Lands

The abandonment of managed lands and their return to a natural state are taken to result in the slow accumulation of soil carbon. Only abandoned agricultural lands are considered in the present assessment.

Emission Calculations

Fifty percent of the total abandoned land was assumed to be converted to urban use and, hence, not to sequester soil carbon. Rates of soil carbon increase on abandoned lands are obtained by assuming a constant sequestration rate over a 100-year period. This rate is estimated by dividing the difference between soil carbon contents on agricultural and forest soils by 100. The same sequestration rates are applied for land recently abandoned (less than 20 years) and land abandoned for more than 20 years. Soil carbon contents are the same as those used for the calculations of soil carbon emissions due to land conversion.

For each Canadian province, the carbon uptake rates are multiplied by the area of total abandoned land that is not converted to urban use. The forest types to which abandoned agricultural lands are reverting are derived using the same parameters as for apportioning the source of new, improved agricultural lands in each Canadian province. If, for example, in any given province the source of new agricultural lands was believed to be 30% boreal forest and 70% grassland, then the same proportions were applied to derive the area of abandoned agricultural lands growing back to its original ecosystem (excluding abandoned lands that are urbanized).

OTHER: LAND-USE CHANGE AND FORESTRY

The LUCF section of the CGHGI includes sectors and subsectors additional to those required under the IPCC Guidelines. These sectors/subsectors report on emissions from forest fires, a very significant disturbance in Canadian forests and, to a lesser extent, a forest management tool in commercial forests. While drawn from a variety of sources, emission factors and other data used to calculate fire emissions are fully documented in Sellers and Wellisch (1998). Specifically, the accounting approaches were elaborated for the following sources:

1. Fires Caused by Human Activities
   - Prescribed Burning (non-CO_2 gases)
   - Other Fires in the Wood Production Forest (non-CO_2 gases)
   - Other Fires Caused by Human Activities Outside the Wood Production Forest (all gases)
2. Wildfires (all gases)

Prescribed Burning

Prescribed burning is carried out as site preparation for forest regeneration and fire hazard reduction, which are non-energy activities. Apart from CO_2 emissions, burning generates non-CO_2 trace gas emissions. This inventory estimates emissions of CH_4, N_2O, CO, and NO_x from prescribed fires.

CO_2 emissions from prescribed burning are not included in this section, since CO_2 emissions from the oxidation of harvest residues (slash) are already accounted for in the section Changes in Forest and Other Woody Biomass Stocks.

The application of prescribed burning, or silvicultural burns, has dropped significantly in the 1990s. It remains more common in British Columbia. In general, its use is constrained by the prevalence of adequate weather conditions. Prescribed burns are expected to decrease in future years due to government cost-recovery services and concerns over smoke and local air quality.

Emission Calculations

Data on the areas treated with prescribed burning are reported by the Canadian Committee on Forest Fire Management for 1990–1995 and were assumed to be constant up to and including 1998. Preliminary data for 1999 and 2000 were provided by the Canadian Interagency Forest Fire Centre (CIFFC, 2002).

Average fuel consumption data for prescribed burns (weight of biomass burned per hectare) are from Environment Canada (Jaques, 1992).

The emission factors are drawn from a compilation of measurements of fire emissions in North America published by the Canadian Forest Service (Taylor and Sherman, 1996).

Other Fires in the Wood Production Forest

This sector includes non-CO_2 emissions from fires that are believed to be caused by human activity in the wood production forest, other than prescribed burning.

In Canada, forest fire reporting is not structured to directly provide the area burned in the wood production forest. Further, it cannot be confirmed that the input data used in the calculations strictly exclude natural fires or wildfires. It was assumed that any wildfire occurring in the wood production forest could also be indirectly attributed to human activity. It is also believed that most of the forest area burned by wildfires occurs outside the wood production forest. Work is ongoing to ascertain the extent of fires caused by human activities that occur in and outside the wood production forest. It is worth noting that important resources are allocated annually to forest fire suppression activities. Without these activities, the area of forest burned annually would be much larger.

Emission Calculations

Fire frequency and severity are notoriously variable from one year to another, even in intensively protected areas such as the wood production forest.

In the CGHGI, the total area of wood production forest burned annually is calculated as a fixed proportion (15%) of the total area of forestland burned, which is reported annually by the Canadian Council of Forest Ministers (CCFM, 2001). The percentage was derived from estimated fire return intervals in Canada's managed forest between 1980 and 1995 (Kurz, 2000). The provincial breakdown is proportional to the distribution of the wood production forest across provinces (Lowe et al., 1996a). It should be noted that these estimates of the area burned annually in the wood production forest remain approximate.

Emissions are derived from multiplying the area burned by an average fuel consumption parameter (Stocks, 1990) and emission factors for each trace gas (drawn from Taylor and Sherman, 1996).

IPCC default emission factors for trace gases are provided as a ratio of total carbon emitted. The Guidelines do not provide default values for the proportion of total carbon oxidized during a fire. A comparison of Canadian emission factors with IPCC default values hence requires that total carbon emissions be calculated and ratios of trace gas versus CO_2 emissions be derived for Canada.

In this inventory, it is estimated that approximately 97% of the carbon in burned biomass is oxidized during a fire (assuming a 50% carbon content by mass in burned biomass). The IPCC emission factor for carbon as CH_4 (CH_4-C emitted) is 2.6 times higher than the Canadian one (1.2% versus 0.46% of total carbon emitted). Conversely, the ratio of N_2O-N emitted in Canada's emission factors is one order of magnitude higher than the IPCC defaults (0.007 of total nitrogen released in the Guidelines versus 0.0308 in this inventory). Note that the Guidelines apply the same values for controlled fires (e.g., during forest conversion) and wildfires (uncontrolled forest or savanna fires). In Canada, different values are used for prescribed fires and wildfires; only forest fires are considered. In order to harmonize these values, a better knowledge is required of the total nitrogen emissions and the extent of nitrogen oxidation in both controlled fires and wildfires. Additional measurements of fire emissions under natural conditions could best contribute to improving the current estimates.

Other Fires Caused by Human Activities Outside the Wood Production Forest

This sector includes both CO_2 and non-CO_2 emissions from anthropogenic fires outside the wood production forest. In Canada, fire reporting is classified by cause; anthropogenic fires outside the wood production forest are those associated with recreation, residence, railways, other industry, and incendiary and other miscellaneous causes. Fires caused by the forest industry are omitted in this analysis, as they are associated with fires in the wood production forest.

Emission Calculations

As noted earlier, although it is difficult to distinguish between natural and anthropogenic causes of fires, relevant historical data with a moderate degree of confidence were available from the Canadian Forest Service (CCFM, 2001).

Data for 2000 were taken as the average of burned areas over the 1990–1999 period.

For fires both inside and outside the wood production forest, fuel consumption data were those provided by the Canadian Forest Service (Stocks, 1990).

The same emission factors were used as in the emission calculations described in the section Other Fires in the Wood Production Forest.

Wildfires

On average, more than 90% of the total forest area burned annually in Canada is associated with wildfires caused by lightning. An estimated 733 000 ha were burned in 1990, and 1.926 million ha in 1999.

Emission Calculations

Data were based on a 27-year average (1970–1997) of the total forest area burned in Canada, weighted by the proportion of the burned area located in the wood production forest and the proportion of fires ignited by lightning strikes (CCFM, 2001).

Areas burned were multiplied by the average fuel consumption factor for wildfire, 0.0264 kt/ha (Stocks, 1990).

To estimate emissions, the total fuel consumption value was combined with the same average emission factors used in the section Prescribed Burning.

Note that these estimates are not included in the national totals.

WASTE

Much of the waste treated or disposed of is biomass or biomass based. The CO_2 emissions attributable to such wastes are not included in this section. In theory, there are no net emissions if the biomass is sustainably harvested. For example, biomass originating from food wastes is sustainably harvested. CO_2 emitted from the decomposition of food will be consumed by the next year's crop.

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

SOLID WASTE DISPOSAL ON LAND

Emissions are estimated from two types of landfills in Canada:

- municipal solid waste (MSW) landfills; and
- wood waste landfills.

In Canada, there are well over 10 000 landfill sites (Levelton, 1991).

The generation of CH_4 from MSW landfills has increased since 1990; however, more landfill gas is now being captured and combusted.

Wood waste landfills are a minor source compared with MSW landfills. Landfill gas capture is generally not practised at wood waste landfills.

CH_4 emission totals are derived using the following equation:

Equation A-12:

Total CH_4 from landfills = CH_4 produced − CH_4 captured

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. The best practice for reducing CH_4 emissions from this source is through the combustion of wood wastes. Increasing interest has been shown by some of these industries in waste-to-energy projects that produce steam and/or electricity. Wood waste landfills have been identified as a source of CH_4 emissions; however, there is a great deal of uncertainty in the estimates. It is assumed that the actual emissions are most likely of the same order of magnitude as the estimates that have been produced.

The IPCC Guidelines provide two methodologies for estimating emissions from landfills: a default method and a theoretical first-order kinetics method, also known as the Scholl Canyon model (IPCC, 1997). The default method estimates emissions based only upon the waste landfilled in the previous year, whereas the Scholl Canyon model estimates emissions based on the waste that has been landfilled in previous years.

During the past several decades, the composition and amount of waste landfilled in Canada have significantly changed, particularly due to population growth. For this reason, a static model such as the default method is not felt to be appropriate. Therefore, the emissions from MSW landfills and wood waste landfills in Canada are estimated using the Scholl Canyon model.

The Scholl Canyon Model

The following is an explanation of 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 the following:

- *Waste Composition:* Waste composition is probably the most important factor affecting landfill gas generation rates and quantities. The amount of landfill gas produced is dependent on the amount of organic matter landfilled. The rate at which the gas is generated is dependent on the distribution and the types of organic matter in the landfill (Tchobanoglous et al., 1993).
- *Moisture Content:* Since water is required for anaerobic degradation of organic matter, the amount of moisture within a landfill also significantly affects the 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 (Tchobanoglous et al., 1993). 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. For gas generation to continue, the pH of the landfill must not drop below 6.2 (Tchobanoglous et al., 1993).
- *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.

General Methodology

The Scholl Canyon model relies on the following first-order decay equation (IPCC, 1997):

Equation A-13:

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

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)

Managed Waste Disposal on Land

Emission Calculations

The Scholl Canyon model was used to estimate emissions.

In order to estimate CH_4 emissions from landfills, information on several of the factors described above is needed. In addition, information on the amount of CH_4 collected by gas recovery systems is required. 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 a 1996 study prepared for Environment Canada 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, 1998), 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 the temperature are largely controlled by the climatic conditions at the landfills. The k values used to estimate emissions from both types of landfills for the inventory are from a study that acknowledges the limited number of data that were available to estimate the values (Levelton, 1991). The k values are largely based on those determined from 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 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 values of k 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 use in the years since 1990 (ORTECH Corporation, 1994):

Equation A-14:

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

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 that 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 in Equation A-14 above for CH_4 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 again to reflect this difference.

Wood Waste Landfills: Equation A-14 was used to calculate an L_0 value of 118 kg CH_4/t of wood waste, used to estimate emissions from wood waste landfills by the Scholl Canyon model. The data required to calculate this value are from several sources (SEAFOR, 1990; NRCan, 1997; MWA consultants Paprican, 1998; Reid, 1998).

Captured Landfill Gas

Some of the CH_4 that is generated in MSW landfills is captured. 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.

Emission Calculations

The data on the amount of landfill gas captured were provided by Environment Canada's National Office of Pollution Prevention. The capture data are based on estimates supplied by individual landfill operators.

Unmanaged Waste Disposal Sites

As noted, very few, if any, unmanaged waste disposal sites exist in Canada. Therefore, all waste was assumed to be disposed of in managed landfills.

Other: Solid Waste Disposal on Land

[Not used as a sector title in the CGHGI.]

WASTEWATER HANDLING

Only emissions from municipal wastewater treatment were estimated. Emissions from treatment of industrial wastewater were not calculated due to a lack of data on the industries that treat their own wastewater.

Municipal wastewater can be aerobically or anaerobically treated. When wastewater is treated anaerobically, CH_4 is produced. Emissions from aerobic systems are assumed to be 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 according to IPCC Guidelines.

In the CGHGI, the emission estimation methodology for wastewater handling is divided into two areas: CH_4 from anaerobic wastewater treatment and N_2O from human sewage.

Methane Emission Calculations

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 wastewater treated anaerobically.

An emission factor for each province was calculated by multiplying this potential emission rate by the fraction of wastewater treated anaerobically 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).

Nitrous Oxide Emission Calculations

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.

The amount of nitrogen in sewage was estimated based upon 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).

Industrial Wastewater

[Not used as a sector title in the CGHGI.]

Not estimated.

Domestic and Commercial Wastewater

[Not used as a sector title in the CGHGI.]

Included under the section Wastewater Handling.

Other: Wastewater Handling

[Not used as a sector title in the CGHGI.]

WASTE INCINERATION

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. The majority of emissions in this sector result from MSW incineration.

The GHG emissions from incinerators depend on such factors as the amount of waste incinerated, the composition of the waste, the carbon content of the non-biomass waste, and the facilities' operating conditions.

Municipal Solid Waste 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).

Most of the MSW incineration in Canada is completed with energy recovery (RIS, 1996). The GHGs that are emitted from MSW incinerators may include CO_2, CH_4, and N_2O.

As per IPCC Guidelines, the CO_2 emissions from the combustion of biomass waste are not included in this section of the inventory. The only CO_2 emissions included in this section are from the fossil fuel-based carbon waste. Examples of fossil fuel-based carbon wastes are plastic and rubber.

CH_4 emissions from MSW incineration are assumed to be negligible and are not calculated.

The emission estimation methodology is divided by waste type and gas emitted.

Emission Calculations

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:

- *Step 1 – Calculating the Amount of Waste Incinerated:* The amount of waste incinerated each year is based on an Environment Canada study (RIS, 1996). This study contained detailed provincial incineration data for the year 1992. To estimate the amount of MSW incinerated in other years, the 1992 data were extrapolated according to population growth using population data (Statistics Canada, #91-213-XPB).
- *Step 2 – Developing Emission Factors:* The provincial CO_2 emission factors are based on the assumption that the carbon in the 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.
- *Step 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

The 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.

CH_4 emissions from MSW incinerators are very small compared with CH_4 emissions from other waste sources such as landfills. Therefore, they are assumed to be negligible.

Sewage Sludge Incineration

This is not a common method for sewage sludge disposal in Canada.

Two different types of sewage sludge incinerators are used in Canada: multiple hearth and fluidized bed. Prior to incineration in both types of incinerators, the sewage sludge is partially de-watered. 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.

Emission Calculations

The 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. The estimates of the amount of dried solids in the sewage sludge incinerated in the years 1990–1992 are from a study completed in 1994 (Fettes, 1994). The data for the years 1993–1996 were acquired through telephone surveys of the 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. Emissions have been assumed constant since 1996.

OTHER: WASTE

[Not used as a sector title in the CGHGI.]

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APPENDIX B: VERIFICATION AND QUALITY ASSURANCE/QUALITY CONTROL

This appendix provides a description of the quality assurance/quality control (QA/QC) and verification procedures used in the preparation of the greenhouse gas (GHG) inventory. In general, the reference approach and expert review were used as the primary means to ensure the quality of the inventory. 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). This exercise has resulted in priority setting for improvements to the QA/QC performed on the national GHG inventory.

It has been concluded that there are clear areas where the Division can improve upon the current QA/QC procedures for the production of Canada's national GHG inventory. This will bring the inventory more in line with IPCC Good Practice. Clearly, however, priorities must be set in this work plan. At present, these priorities appear to be:

- improved documentation and archiving;
- development of a QA/QC manual;
- a new uncertainty analysis with new QC procedures; and
- development of Tier 2 QC procedures for key sources.

The Division should outline its plan to achieve these objectives and consider available staff time and resources when identifying deliverables and timelines. While it may be possible to implement many of these changes and improvements, a realistic plan must be set out that considers the costs of these efforts and the potential benefits that will be derived.

The methodologies used for the Canadian inventory have been evolving since the development of the first inventory more than 10 years ago. However, they have not changed significantly since the previous United Nations Framework Convention on Climate Change (UNFCCC) submission and publication of the inventory. The inventory and methodologies are published on a regular basis, which has provided an additional opportunity for public and expert review. Canada has also undertaken the process of identifying inventory key sources. The results of this analysis will form the foundation for future inventory improvements.

REFERENCE APPROACH

The reference approach was compared with the sectoral approach as a check of combustion emissions. The check was performed for all years from 1990 to 2000 and is an integral part of the Common Reporting Format (CRF).

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 preprogrammed 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, the totals match within 2–4%. 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.

The activity data used in the sectoral approach and the reference approach are from the same 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 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.

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 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 a virtual composite mixture of ethane, propane, and butane. Dependent upon those 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 accommodate the lack of consistency between the LPG segregation from the stored carbon worksheet – Table 1-A(d) of the CRF – and that of 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.

INVENTORY REVIEW

The general method of verification to ensure quality is achieved through inventory review. Emission data, methods, and activity data are reviewed by industry, academia, and government experts.

Canada's Greenhouse Gas Inventory (CGHGI) has been published several times in the past. The inventory report provides a detailed description of Canada's emission inventory methods. It is distributed in a formal review process to industry, academia, and government (both provincial and federal). The emission estimates for the Energy and agriculture sectors are reviewed in detail by other government departments, such as Natural Resources Canada and Agriculture and Agri-Food Canada, while the Solvent and Other Product Use and Waste sector emissions are reviewed by separate departments within Environment Canada.

The activity data used in the CGHGI are generally from published sources. The energy, population, and agricultural activity data are all published by the national statistics agency (Statistics Canada). The Energy section of Statistics Canada holds bimonthly meetings to discuss data collection and quality issues with relevant government stakeholders such as Environment Canada and Natural Resources Canada (both the Forecasting Division and the Office of Energy Efficiency). The energy efficiency group uses the data for industrial benchmarking initiatives and tracks sectoral energy efficiency. Through this mechanism, the energy data do receive some verification by industry. As a result of this scrutiny, errors have been discovered in historical energy data, which resulted in a complete review of the national energy balances (as described by Coombs, 1999). The energy data used for the CGHGI are also the basis for the national energy and emissions forecast.

KEY SOURCES

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 "one that is prioritised 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 CGHGI according to IPCC approaches.

Good practice first requires that inventories be disaggregated in 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. Recent Canadian inventory uncertainty analysis is not available, therefore requiring key source determination through Tier 1 methods.

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 B-1:

Equation B-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 B-2:

Equation B-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. Additional categories identified as key, however, 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, as unexpectedly high or low emissions are validated before publication. As a result, they 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 under way 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 under way among some important Canadian industries (Rawson, 2001).
- Natural Resources Canada's Emissions Analysis and Modelling Group has developed forecasts of GHG emissions from source categories for a Business-as-Usual (NRCan, 1999) and a Kyoto (NRCan, 2000) scenario based on discussions with governments and other stakeholders.
- 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 important, in that this first step groups 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 if they use the same emission factors based on common emission estimate assumptions. In this analysis, major categories are in keeping with the CRF, such as Fuel Combustion, Fugitive Emissions, Industrial Processes, Agriculture, and Waste[28]. Within these major categories, considerable 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.

At the same time, 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 B-1.

28 Minor categories include Solvent and Other Product Use, as well as International Bunkers. CO_2 emissions from Land-Use Change and Forestry are excluded.

TABLE B.1: Source Category Analysis Summary[1]

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	Trend
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, Trend
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	Trend, 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	Trend
2-B-2	Industrial Processes — Nitric Acid Production	N_2O		
2-B-3	Industrial Processes — Adipic Acid Production	N_2O	Yes	Level, Quality
2-C-1	Industrial Processes — Iron and Steel Production	CO_2	Yes	Trend
2-C-3	Industrial Processes — Aluminium Production	CO_2		
2-C-3	Industrial Processes — Aluminium Production	PFCs	Yes	Trend, Quality
2-C-4	Industrial Processes — Aluminium and Magnesium Production	SF_6	Yes	Quality
2-F	Industrial Processes — Other (Undifferentiated Processes)	CO_2	Yes	Trend
2-F	Industrial Processes — Other (Undifferentiated Processes)	PFCs		
3-E	Consumption of Halocarbons and Sulphur Hexafluoride	HFCs		
4-A	Agriculture — Enteric Fermentation	CH_4	Yes	Level, Trend
4-B	Agriculture — Manure Management	CH_4	Yes	Trend
4-B	Agriculture — Manure Management	N_2O		
4-D	Agriculture — Agricultural Soils	CO_2		
4-D	Agriculture — Agricultural Soils	N_2O	Yes	Trend
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	Trend, 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		

[1] Qualitative Method Used: Tier 1

LEVEL ASSESSMENT

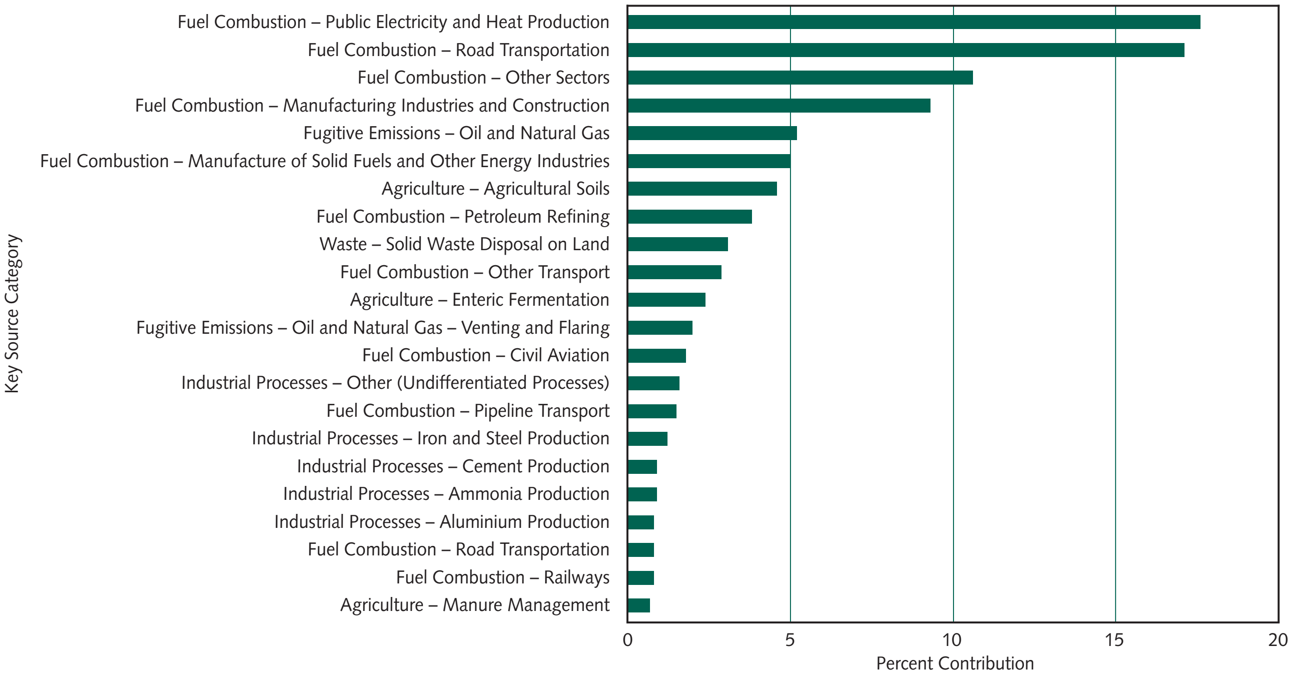
Table B-2 shows key sources indicated by level assessment. Figure B-1 shows the contributions of key sources to level assessment.

TABLE B-2: Key Source Categories by Level Assessment[1]

Source Table	IPCC Categories	Direct Greenhouse Gas	Greenhouse Gas Estimates 1990 Base Year (kt CO_2 equivalent)	2000 Current Year (kt CO_2 equivalent)
1-A-1-a	Fuel Combustion — Public Electricity and Heat Production	CO_2	94 745	127 534
1-A-3-b	Fuel Combustion — Road Transportation	CO_2	102 812	124 429
1-A-4	Fuel Combustion — Other Sectors	CO_2	69 415	76 701
1-A-2	Fuel Combustion — Manufacturing Industries and Construction	CO_2	62 090	67 778
1-B-2-(a+b)	Fugitive Emissions — Oil and Natural Gas	CH_4	25 685	37 622
1-A-1-c	Fuel Combustion — Manufacture of Solid Fuels and Other Energy Industries	CO_2	23 555	36 123
4-D	Agriculture — Agricultural Soils	N_2O	27 365	33 663
1-A-1-b	Fuel Combustion — Petroleum Refining	CO_2	25 977	27 786
6-A	Waste — Solid Waste Disposal on Land	CH_4	18 530	22 583
1-A-3-e	Fuel Combustion — Other Transport	CO_2	14 882	21 202
4-A	Agriculture — Enteric Fermentation	CH_4	15 994	17 696
1-B-2-c	Fugitive Emissions — Oil and Natural Gas — Venting and Flaring	CO_2	9 787	14 698
1-A-3-a	Fuel Combustion — Civil Aviation	CO_2	10 385	13 304
2-F	Industrial Processes — Other (Undifferentiated Processes)	CO_2	9 218	11 744
1-A-3-f	Fuel Combustion — Pipeline Transport	CO_2	6 705	10 957
2-C-1	Industrial Processes — Iron and Steel Production	CO_2	7 585	8 511
2-B-1	Industrial Processes — Ammonia Production	CO_2	5 008	6 845
2-A-1	Industrial Processes — Cement Production	CO_2	5 872	6 306
1-A-3-c	Fuel Combustion — Railways	CO_2	6 315	5 922
1-A-3-b	Fuel Combustion — Road Transportation	N_2O	3 643	5 550
2-C-3	Industrial Processes — Aluminium Production	PFCs	5 975	6 141
4-B	Agriculture — Manure Management	CH_4	4 595	5 079

1 Using Chapter 7 in 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. Tier 1 Analysis – Level Assessment – Sorted by Level.

FIGURE B-1: Contributions of Key Source Categories to Level Assessment



TREND ASSESSMENT

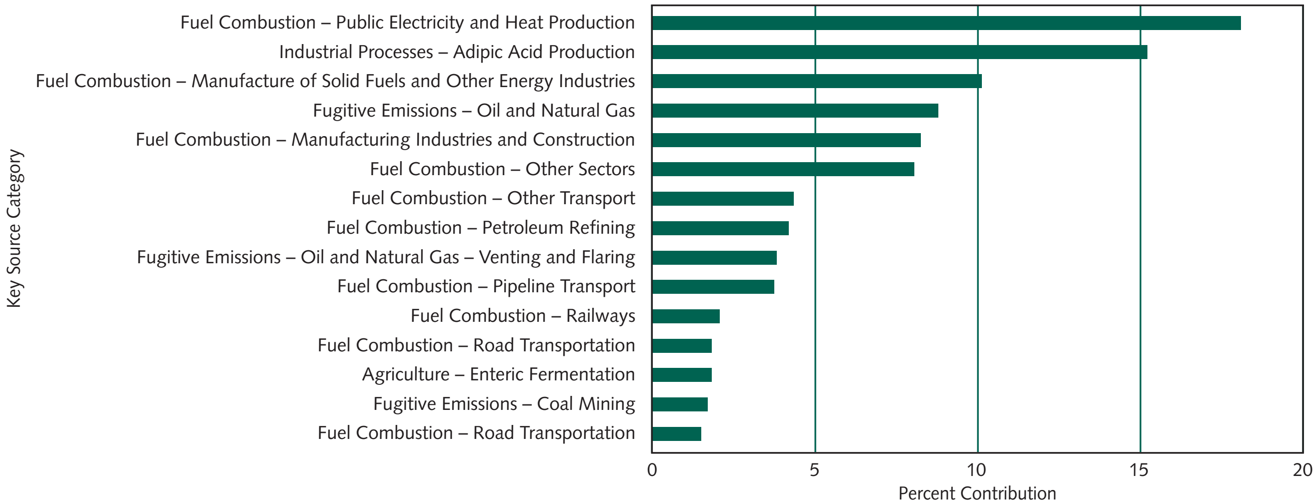
Table B-3 shows key sources indicated by trend assessment. Figure B-2 shows the contributions of key sources to trend assessment.

TABLE B-3: Key Source Categories by Trend Assessment[1]

Source Table	IPCC Categories	Direct Greenhouse Gas	Greenhouse Gas Estimates 1990 Base Year (kt CO_2 equivalent)	Greenhouse Gas Estimates 2000 Current Year (kt CO_2 equivalent)
1-A-1-a	Fuel Combustion – Public Electricity and Heat Production	CO_2	94 745	127 534
2-B-3	Industrial Processes – Adipic Acid Production	N_2O	10 718	900
1-A-1-c	Fuel Combustion – Manufacture of Solid Fuels and Other Energy Industries	CO_2	23 555	36 123
1-B-2-(a+b)	Fugitive Emissions – Oil and Natural Gas	CH_4	25 685	37 622
1-A-2	Fuel Combustion – Manufacturing Industries and Construction	CO_2	62 090	67 778
1-A-4	Fuel Combustion – Other Sectors	CO_2	69 415	76 701
1-A-3-e	Fuel Combustion – Other Transport	CO_2	14 882	21 202
1-A-1-b	Fuel Combustion – Petroleum Refining	CO_2	25 977	27 786
1-B-2-c	Fugitive Emissions – Oil and Natural Gas – Venting and Flaring	CO_2	9 787	14 698
1-A-3-f	Fuel Combustion – Pipeline Transport	CO_2	6 705	10 957
1-A-3-c	Fuel Combustion – Railways	CO_2	6 315	5 922
1-A-3-b	Fuel Combustion – Road Transportation	CO_2	102 812	124 429
4-A	Agriculture – Enteric Fermentation	CH_4	15 994	17 696
1-B-1-a	Fugitive Emissions – Coal Mining	CH_4	1 914	949
1-A-3-b	Fuel Combustion – Road Transportation	N_2O	3 643	5 550

1 Using Chapter 7 of 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. Tier 1 Analysis – Trend Assessment – Sorted by Percent Contribution to Trends.

FIGURE B-2: Contributions of Key Source Categories to Trend Assessment



QUALITATIVE ASSESSMENT

Mitigation Techniques and Technologies

Mitigation techniques are important to good practice, in particular if they are inclined to produce departures from the norm under which activity data and emission factors are estimated. Table B-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 B-4: Key Sources Identified Using 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 Group, 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 Group, 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 B-5 shows key sources identified as a result of having a high emissions growth forecast of over 20% between 1997 and 2020. Designation as key anticipates significant changes in the sector and a need to establish sound estimating practices.

TABLE B-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 Group, 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 attributed to only 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 B-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 B-6: Key Sources with a High Composite Uncertainty

Key Source	GHG	Reference
Agriculture – Agricultural Soils	CO_2	Olsen, 2001
Fuel Combustion – Manufacture 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 Group, National Climate Change Process, Natural Resources Canada, November.

Olsen, K. (2001), Personal communication, Greenhouse Gas Division, Environment Canada, February.

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 B-1.

The first column of Table B-1 indicates the source table. These are found in the UNFCCC CRF. The key for categorization of the tables within the CRF is shown in Table B-7.

TABLE B-7: Categorization of Source Tables

Source Table Number	Description
1-A	Energy – Fuel Combustion Activities
1-B	Energy – Fugitive Emissions from Fuels
2-A	Industrial Processes – Mineral Products
2-B	Industrial Processes – Chemical Industry
2-C	Industrial Processes – Metal Production
2-F	Industrial Processes – Other (Undifferentiated Processes)
3-E	Solvent and Other Product Uses – Consumption of Halocarbons and Sulphur Hexafluoride
4-A	Enteric Fermentation
4-B	Manure Management
4-D	Agricultural Soils
5-E	Land-Use Change and Forestry – Fires Caused by Human Activity
6-A	Solid Waste Disposal on Land
6-B	Wastewater Handling
6-C	Waste Incineration

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 Group, 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 Group, 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.

APPENDIX C: UNCERTAINTY ASSOCIATED WITH EMISSION AND REMOVAL ESTIMATES

Of particular concern with emission inventories is their accuracy. While the uncertainties result from many causes, most are due to the following:

- 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; and
- actual empirical uncertainty of measured emission data and the basic processes leading to emissions.

EARLY UNCERTAINTY ESTIMATES – METHODS AND RESULTS

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).

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 should be noted that individual sector uncertainties can be even greater. In addition – as far as inventories go – the uncertainties associated with CO_2, which dominates the GHG inventory, are very low.

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 reasonable to assume that the uncertainty in the CO_2 and CH_4 emissions are still of the same order.

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 planned for the near future.

ROUNDING PROTOCOL

In the interim, some guidance can be provided as to the approximate level of uncertainty that each of the current emission estimates represents. Thus, engineering approximations of precision have been developed for the new emission categories, and previous studies have been drawn upon for the older categories. Data quality is then reflected in published summary tables by presenting the emissions to an appropriate number of significant figures. The data in the Common Reporting Format (CRF) have not been rounded, since the United Nations Framework Convention on Climate Change (UNFCCC) software is not designed to accommodate this.

The rounding protocol has been determined on the basis of empirical studies (McCann, 1994), published uncertainty estimates (IPCC, 1997), and expert opinion. Generally, the following uncertainty intervals have been used to determine rounding:

- One significant figure: >50% uncertainty
- Two significant figures: 10–50% uncertainty
- Three significant figures: <10% uncertainty

The above-listed uncertainty intervals were usually, but not always, followed. In some cases, emission estimates that have uncertainty marginally outside the specified interval have been shown with a greater number of significant figures than the above listed intervals would dictate. This has been done to maintain consistency between categories within a sector. It should be noted that emissions from agricultural soils, CO_2 from land-use change and forestry, perfluorocarbon (PFC), and hydrofluorocarbon (HFC) emissions have a very high uncertainty (Schiff, 1996; IPCC, 1997), and so only one significant figure has been shown for these estimates.

REFERENCES

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. (1994), *Uncertainties in Canada's 1990 Greenhouse Gas Emission Estimates: A Quantitative Assessment,* prepared for Environment Canada by T.J. McCann and Associates, March.

Schiff, H. (1996), Personal communication with researcher who performed measurements of PFC emissions from aluminium smelters in Canada, 1996.

APPENDIX D: EMISSION FACTORS

This section summarizes 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 D-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. This is expected due to the raw nature of the fuel, which results in higher levels of natural gas liquids (NGLs) in the fuel.

The 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. Emission factors for sectors (Table D-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). 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 D-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 D-1: Natural Gas and Natural Gas Liquids (Energy Stationary Combustion Sources)

	CO_2	CH_4	N_2O
Natural Gas	**g/m³**	**g/m³**	**g/m³**
Electric Utilities	1891 [1]	0.49 [2]	0.049 [2]
Industrial	1891 [1]	0.037 [2]	0.033 [2]
Producer Consumption	2389 [1]	6.5 [3,4]	0.033 [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 by T.J. McCann and Associates, 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 D-2). Emission factors have been developed 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). The 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 D-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 of 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 D-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 of heavy fuel oil use in industry.

TABLE D-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.

Coal emission factors (Table D-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 year, 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).

TABLE D-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[3]	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.

Methane

Emissions of CH_4 from fuel combustion are technology dependent. Emission factors for sectors (Table D-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 D-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 D-4: Methane and Nitrous Oxide Emission Factors for Coals

All Coals	CH_4 g/kg	N_2O g/kg
Utility	0.022 [2]	0.032 [2]
Industry	0.03 [2]	0.02 [2]
Residential	4 [2]	0.02 [2]
Metalurgical Coke	0.03 [2]	0.02 [2]
Coke Oven Gas	**g/m³**	**g/m³**
	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.

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 D-5).

Methane

Emissions of CH_4 from fuel combustion are technology dependent. Emission factors for sectors have been developed (Table D-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 D-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). The rationale for factor selection is also provided in the Transport section of Appendix A.

TABLE D-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]	6E-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 by T.J. McCann and Associates, March.

FUGITIVE EMISSION FACTORS: COAL MINING

Fugitive emissions from coal mining are predominantly CH_4. The emissions result from the release of entrained CH_4 from the coal formation during mining. The emission factors are developed (Table D-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 D-6: Energy: 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.

INDUSTRIAL PROCESSES

Emissions from industrial processes are process and technology specific. The development of the factors for each source (Table D-7) is described in detail in the Industrial Processes section of the inventory report.

TABLE D-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**		**g/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.) (1980), *Industrial Chemicals,* 3rd 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. The 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 D-8).

TABLE D-8: Hydrocarbon Non-Energy Products

Description	CO_2
	g/L feedstock
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	1274

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 D-9) is described in the Solvent and Other Product Use section of Appendix A.

TABLE D-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 (Tables D-10 to D-15) are detailed in the Agriculture section of Appendix A.

TABLE D-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 D-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 D-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 D-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 D-14: Dry Matter Fraction of Various Crops[1]

Specific Crop Type	Dry Matter Faction
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 D-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[2]	0.15 kg N/kg N
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[2]	0.60

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 D-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 carbon sequestration rate.

Methane

Emissions of CH_4 from fuel combustion are technology dependent. The emission factors (Table D-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 D-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

TABLE D-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.

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.

(g/kg biomass consumed). Emission factors for both prescribed burns and wildfires were taken from Taylor and Sherman (1996).

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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.

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APPENDIX E: NATIONAL AND PROVINCIAL GREENHOUSE GAS EMISSION TRENDS, 1990–2000

1990 to 2000 Greenhouse Gas Emission Estimates for Canada, by Sector

GHG Source and Sink Category	1990	1991	1992	1993	1994	1995 All Gases kt CO_2 eq	1996	1997	1998	1999	2000
ENERGY											
FUEL COMBUSTION											
Fossil Fuel Industries	51,500	49,500	52,100	52,600	53,400	54,700	55,300	51,000	56,500	65,400	66,800
Electricity & Heat Generation	95,300	96,700	103,000	93,800	96,000	101,000	99,700	111,000	124,000	121,000	128,000
Mining	6,190	5,030	4,790	7,370	7,490	7,860	8,740	8,970	8,020	7,450	9,270
Manufacturing	54,500	52,100	51,500	49,100	52,200	52,900	54,700	54,600	52,400	52,800	57,900
Construction	1,880	1,630	1,750	1,390	1,400	1,180	1,270	1,260	1,120	1,170	1,080
Transport											
Light Duty Gasoline Vehicles	53,700	51,200	51,600	51,800	52,300	51,300	49,900	50,000	49,700	49,600	48,300
Light Duty Gasoline Trucks	21,700	22,200	24,000	25,600	27,400	28,500	29,900	32,000	32,800	35,300	36,400
Heavy Duty Gasoline Vehicles	3,140	3,320	3,730	4,070	4,480	4,760	4,980	5,050	5,490	5,660	5,850
Motorcycles	230	220	218	219	221	214	210	221	232	232	239
Off Road Gasoline	5,010	4,550	3,640	3,850	3,930	3,940	4,680	4,310	5,840	5,370	5,270
Light Duty Diesel Vehicles	672	633	631	624	617	594	602	600	597	414	410
Light Duty Diesel Trucks	591	507	456	429	432	416	402	505	455	139	136
Heavy Duty Diesel Vehicles	24,600	23,900	24,300	25,700	28,500	30,800	32,500	35,500	35,600	37,300	37,800
Off Road Diesel	11,300	9,960	9,480	10,900	12,000	12,700	13,200	14,100	14,800	15,700	18,100
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
Domestic Aviation	10,700	9,530	9,720	9,410	10,100	10,900	11,900	12,400	13,000	13,600	13,700
Domestic Marine	5,050	5,250	5,100	4,480	4,660	4,380	4,470	4,530	5,150	4,970	5,110
Railways	7,110	6,590	6,890	6,860	7,100	6,430	6,290	6,380	6,140	6,510	6,670
Vehicles Subtotal	146,000	140,000	143,000	146,000	154,000	157,000	161,000	168,000	171,000	176,000	179,000
Pipelines	6,900	7,640	9,890	10,400	10,800	12,000	12,500	12,500	12,500	12,600	11,300
Transport Subtotal	153,000	148,000	152,000	156,000	164,000	169,000	173,000	180,000	184,000	189,000	190,000
Residential	44,000	42,300	43,500	45,500	46,300	44,900	49,700	46,400	41,000	43,000	45,000
Commercial & Institutional	25,800	26,500	27,000	28,100	27,400	29,000	29,600	30,000	27,200	28,900	31,900
Other	2,420	2,760	3,270	3,060	2,560	2,790	2,950	2,940	2,610	2,690	2,570
COMBUSTION SUBTOTAL	434,000	424,000	439,000	437,000	451,000	463,000	475,000	487,000	496,000	512,000	533,000
FUGITIVE											
Solid Fuels (i.e., Coal Mining)	1,900	2,100	1,800	1,800	1,800	1,700	1,800	1,600	1,400	1,100	950
Oil & Gas	36,000	38,000	41,000	43,000	45,000	48,000	51,000	51,000	51,000	52,000	53,000
FUGITIVE SUBTOTAL	38,000	40,000	42,000	44,000	47,000	50,000	53,000	53,000	52,000	53,000	54,000
ENERGY TOTAL	472,000	464,000	482,000	482,000	498,000	513,000	528,000	539,000	549,000	564,000	587,000
INDUSTRIAL PROCESSES											
Non-Metallic Mineral Production	8,160	6,980	6,640	6,880	7,510	7,690	8,030	8,180	8,680	9,100	9,080
Ammonia, Adipic Acid & Nitric Acid Production	17,000	16,000	16,000	16,000	18,000	18,000	19,000	17,000	12,000	9,400	8,500
Ferrous Metal Production	7,590	8,900	9,080	8,760	8,090	8,440	8,290	8,100	8,320	8,500	8,510
Aluminum & Magnesium Production	11,000	13,000	12,000	13,000	13,000	11,000	11,000	11,000	11,000	12,000	12,000
Other & Undifferentiated Production	9,200	9,600	9,000	9,700	11,000	11,000	12,000	12,000	12,000	13,000	13,000
INDUSTRIAL PROCESSES TOTAL	53,000	54,000	53,000	54,000	56,000	56,000	58,000	57,000	53,000	52,000	51,000
SOLVENT & OTHER PRODUCT USE	400	400	400	400	400	400	400	500	500	500	500
AGRICULTURE											
Enteric Fermentation	16,000	16,000	17,000	17,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000
Manure Management	8,300	8,300	8,500	8,500	8,900	9,200	9,300	9,300	9,400	9,400	9,400
Agricultural Soils**	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000
AGRICULTURE TOTAL	59,000	58,000	58,000	58,000	60,000	61,000	61,000	61,000	61,000	61,000	60,000
LAND USE CHANGE & FORESTRY*	2,000	3,000	3,000	3,000	4,000	5,000	2,000	900	3,000	2,000	2,000
WASTE											
Solid Waste Disposal on Land	19,000	19,000	20,000	20,000	20,000	20,000	20,000	21,000	21,000	22,000	23,000
Wastewater Handling	1,200	1,200	1,300	1,300	1,300	1,300	1,300	1,300	1,300	1,300	1,400
Waste Incineration	320	320	330	330	330	330	340	340	340	350	350
WASTE TOTAL	20,000	21,000	21,000	22,000	22,000	22,000	22,000	23,000	23,000	24,000	24,000
TOTAL	**607,000**	**600,000**	**616,000**	**619,000**	**641,000**	**658,000**	**672,000**	**682,000**	**689,000**	**703,000**	**726,000**
CO_2 from Land Use Change & Forestry**	-60,000	-60,000	-50,000	-40,000	-30,000	-20,000	-20,000	-20,000	-30,000	-10,000	-20,000

Notes:

Due to rounding, individual values may not add up to totals (zero values may represent estimated quantities too small to display).

** Only one significant figure shown due to high uncertainty.

* Methane and nitrous oxide emissions from prescribed fires and anthropogenic fires outside the Wood Production Forest. Fires located in national parks are not included in the provincial/territorial total but are reported in the national total.

1990 to 2000 Greenhouse Gas Emission Estimates for Newfoundland, by Sector

GHG Source and Sink Category	1990	1991	1992	1993	1994	1995 All Gases kt CO_2 eq	1996	1997	1998	1999	2000
ENERGY											
FUEL COMBUSTION											
Fossil Fuel Industries	1,050	1,020	865	1,050	572	944	1,080	1,250	3,180	2,030	1,380
Electricity & Heat Generation	1,610	1,280	1,480	1,340	716	1,250	1,160	1,210	1,020	935	920
Mining	1,050	672	581	565	907	900	927	1,050	895	642	915
Manufacturing	497	386	310	330	299	315	269	282	211	252	241
Construction	33	24	27	22	18	18	15	15	13	12	11
Transport											
Light Duty Gasoline Vehicles	770	743	743	749	748	718	700	682	655	663	657
Light Duty Gasoline Trucks	566	569	590	615	638	631	634	639	645	685	700
Heavy Duty Gasoline Vehicles	75	75	78	81	84	83	75	57	68	68	69
Motorcycles	7	6	5	5	5	5	5	4	4	4	4
Off Road Gasoline	70	70	72	65	35	43	43	34	35	36	36
Light Duty Diesel Vehicles	4	3	3	3	3	2	2	2	2	2	2
Light Duty Diesel Trucks	14	13	9	8	7	5	4	6	4	5	5
Heavy Duty Diesel Vehicles	459	484	422	435	464	442	452	482	488	506	533
Off Road Diesel	291	153	157	274	255	247	303	372	392	418	537
Propane & Natural Gas Vehicles	1	2	1	6	2	2	2	3	1	4	1
Domestic Aviation	518	393	449	383	368	396	408	394	361	340	418
Domestic Marine	706	659	613	540	466	562	610	623	647	688	692
Railways	0	0	0	0	0	0	0	0	0	0	0
Vehicles Subtotal	3,480	3,170	3,140	3,160	3,070	3,140	3,240	3,300	3,300	3,420	3,650
Pipelines	0	0	0	0	0	0	0	0	0	0	0
Transport Subtotal	3,480	3,170	3,140	3,160	3,070	3,140	3,240	3,300	3,300	3,420	3,650
Residential	818	759	800	804	741	692	673	691	614	584	553
Commercial & Institutional	326	317	307	329	341	321	312	364	306	316	324
Other	25	42	61	56	54	57	59	76	76	69	48
COMBUSTION SUBTOTAL	8,890	7,670	7,570	7,670	6,720	7,630	7,730	8,230	9,610	8,260	8,040
FUGITIVE											
Solid Fuels (i.e., Coal Mining)	0	0	0	0	0	0	0	0	0	0	0
Oil & Gas	0	0	0	0	0	0	0	0	18	74	120
FUGITIVE SUBTOTAL	0	0	0	0	0	0	0	0	18	74	120
ENERGY TOTAL	8,890	7,670	7,570	7,670	6,720	7,630	7,730	8,230	9,630	8,330	8,160
INDUSTRIAL PROCESSES											
Non-Metallic Mineral Production	59	54	49	65	63	63	59	62	68	62	62
Adipic & Nitric Acid Production	0	0	0	0	0	0	0	0	0	0	0
Ferrous Metal Production	0	0	0	0	0	0	0	0	0	0	0
Aluminum & Magnesium Production	0	0	0	0	0	0	0	0	0	0	0
Other & Undifferentiated Production	19	15	14	14	14	15	15	16	14	22	23
INDUSTRIAL PROCESSES TOTAL	77	69	63	79	77	77	74	78	81	84	85
SOLVENT & OTHER PRODUCT USE	9	9	9	9	9	9	8	8	8	8	8
AGRICULTURE											
Enteric Fermentation	17	17	17	17	16	17	17	16	16	16	15
Manure Management	25	25	25	26	27	28	29	27	28	29	29
Agricultural Soils**	30	30	30	30	40	40	40	40	40	40	40
AGRICULTURE TOTAL	75	73	76	77	79	84	83	79	79	81	80
LAND USE CHANGE & FORESTRY*	30	50	20	30	80	80	30	40	40	50	40
WASTE											
Solid Waste Disposal on Land	340	350	360	360	370	380	380	390	400	400	410
Wastewater Handling	19	19	19	19	19	19	19	18	18	18	18
Waste Incineration	8	8	9	9	8	8	8	8	8	8	8
WASTE TOTAL	360	370	380	390	400	410	410	420	420	430	430
TOTAL	**9,440**	**8,240**	**8,120**	**8,250**	**7,360**	**8,290**	**8,340**	**8,850**	**10,300**	**8,980**	**8,810**

Notes:

Due to rounding, individual values may not add up to totals (zero values may represent estimated quantities too small to display).

Ammonia production emissions are included under undifferentiated production at the provincial level.

Emissions associated with the use of HFCs, PFCs, limestone and soda ash are reported in the national total.

** Only one significant figure shown due to high uncertainty.

* Methane and nitrous oxide emissions from prescribed fires and anthropogenic fires outside the Wood Production Forest. Fires located in national parks are not included in the provincial/territorial total but are reported in the national total.

1990 to 2000 Greenhouse Gas Emission Estimates for Prince Edward Island, by Sector

GHG Source and Sink Category	1990	1991	1992	1993	1994	1995 All Gases kt CO_2 eq	1996	1997	1998	1999	2000
ENERGY											
FUEL COMBUSTION											
Fossil Fuel Industries	0	0	1	2	1	2	2	2	3	1	0
Electricity & Heat Generation	104	94	53	76	60	41	29	39	13	22	58
Mining	1	1	1	0	0	1	1	1	2	2	5
Manufacturing	55	70	77	79	80	72	91	110	91	57	134
Construction	11	10	10	9	9	7	6	5	7	6	6
Transport											
Light Duty Gasoline Vehicles	286	273	264	258	256	253	247	252	249	265	248
Light Duty Gasoline Trucks	146	149	154	161	170	180	192	201	215	227	228
Heavy Duty Gasoline Vehicles	21	24	28	32	36	40	42	39	49	51	54
Motorcycles	1	1	1	1	1	1	1	1	1	1	1
Off Road Gasoline	14	9	8	9	17	11	15	11	8	8	8
Light Duty Diesel Vehicles	3	3	3	3	3	3	3	3	3	3	3
Light Duty Diesel Trucks	2	2	2	1	1	1	1	1	1	1	0
Heavy Duty Diesel Vehicles	80	85	85	90	101	100	106	113	128	144	148
Off Road Diesel	58	52	32	33	49	57	52	64	70	68	86
Propane & Natural Gas Vehicles	1	1	1	1	0	1	1	1	1	2	1
Domestic Aviation	15	12	9	9	9	8	11	12	11	11	10
Domestic Marine	90	114	128	111	91	63	113	72	66	74	86
Railways	0	0	0	0	0	0	0	0	0	0	0
Vehicles Subtotal	717	723	715	709	733	717	785	770	801	854	871
Pipelines	0	0	0	0	0	0	0	0	0	0	0
Transport Subtotal	717	723	715	709	733	717	785	770	801	854	871
Residential	399	363	379	358	339	310	334	349	329	321	318
Commercial & Institutional	161	157	160	158	161	180	184	192	177	171	198
Other	19	20	28	28	27	41	47	51	49	44	32
COMBUSTION SUBTOTAL	1,470	1,440	1,420	1,420	1,410	1,370	1,480	1,520	1,470	1,480	1,620
FUGITIVE											
Solid Fuels (i.e., Coal Mining)	0	0	0	0	0	0	0	0	0	0	0
Oil & Gas	0	0	0	0	0	0	0	0	0	0	0
FUGITIVE SUBTOTAL	0	0	0	0	0	0	0	0	0	0	0
ENERGY TOTAL	1,470	1,440	1,420	1,420	1,410	1,370	1,480	1,520	1,470	1,480	1,620
INDUSTRIAL PROCESSES											
Non-Metallic Mineral Production	0	0	0	0	0	0	0	0	0	0	0
Adipic & Nitric Acid Production	0	0	0	0	0	0	0	0	0	0	0
Ferrous Metal Production	0	0	0	0	0	0	0	0	0	0	0
Aluminum & Magnesium Production	0	0	0	0	0	0	0	0	0	0	0
Other & Undifferentiated Production	3	3	3	3	4	3	3	3	3	3	2
INDUSTRIAL PROCESSES TOTAL	3	3	3	3	4	3	3	3	3	3	2
SOLVENT & OTHER PRODUCT USE	2	2	2	2	2	2	2	2	2	2	2
AGRICULTURE											
Enteric Fermentation	130	130	130	130	130	130	130	130	130	130	130
Manure Management	77	76	74	73	76	78	78	75	75	78	77
Agricultural Soils**	200	200	200	200	200	200	200	200	200	200	200
AGRICULTURE TOTAL	410	400	440	410	420	420	430	430	430	430	430
LAND USE CHANGE & FORESTRY*	1	2	1	2	6	7	2	1	4	2	3
WASTE											
Solid Waste Disposal on Land	61	62	64	65	67	68	69	71	72	73	75
Wastewater Handling	7	7	7	7	7	7	7	7	7	8	8
Waste Incineration	8	8	9	9	9	9	9	9	9	9	9
WASTE TOTAL	77	78	79	81	83	84	86	87	88	90	91
TOTAL	**1,960**	**1,930**	**1,950**	**1,920**	**1,930**	**1,890**	**2,010**	**2,040**	**2,000**	**2,000**	**2,150**

Notes:

Due to rounding, individual values may not add up to totals (zero values may represent estimated quantities too small to display).

Ammonia production emissions are included under undifferentiated production at the provincial level.

Emissions associated with the use of HFCs, PFCs, limestone and soda ash are reported in the national total.

** Only one significant figure shown due to high uncertainty.

* Methane and nitrous oxide emissions from prescribed fires and anthropogenic fires outside the Wood Production Forest. Fires located in national parks are not included in the provincial/territorial total but are reported in the national total.

1990 to 2000 Greenhouse Gas Emission Estimates for Nova Scotia, by Sector

GHG Source and Sink Category	1990	1991	1992	1993	1994	1995 All Gases kt CO_2 eq	1996	1997	1998	1999	2000
ENERGY											
FUEL COMBUSTION											
Fossil Fuel Industries	714	799	790	914	598	699	730	709	701	593	989
Electricity & Heat Generation	6,830	7,010	7,410	7,350	7,190	6,850	7,070	7,520	7,800	8,060	8,830
Mining	36	33	32	22	30	33	39	41	47	49	54
Manufacturing	712	621	633	638	763	870	800	757	779	806	660
Construction	50	37	32	26	30	35	29	30	36	32	28
Transport											
Light Duty Gasoline Vehicles	1,680	1,550	1,570	1,610	1,540	1,640	1,580	1,550	1,370	1,590	1,460
Light Duty Gasoline Trucks	939	908	956	1,020	1,010	1,120	1,150	1,160	1,230	1,350	1,410
Heavy Duty Gasoline Vehicles	136	129	133	137	133	144	141	121	137	138	138
Motorcycles	12	12	11	11	10	10	12	9	10	10	9
Off Road Gasoline	72	56	53	51	210	51	45	71	235	37	37
Light Duty Diesel Vehicles	26	25	26	27	26	29	28	28	25	29	28
Light Duty Diesel Trucks	21	17	15	13	11	10	8	10	8	0	0
Heavy Duty Diesel Vehicles	790	757	797	800	826	854	896	894	951	1,050	1,060
Off Road Diesel	345	306	316	363	382	401	279	402	349	446	499
Propane & Natural Gas Vehicles	7	7	7	8	3	5	6	9	5	14	4
Domestic Aviation	496	492	455	498	483	491	472	454	464	499	485
Domestic Marine	615	698	614	599	631	571	571	597	661	718	670
Railways	67	50	58	57	60	46	34	36	42	60	76
Vehicles Subtotal	5,200	5,000	5,000	5,200	5,300	5,400	5,200	5,300	5,500	5,900	5,900
Pipelines	0	0	0	0	0	0	0	0	0	0	0
Transport Subtotal	5,200	5,000	5,000	5,200	5,300	5,400	5,200	5,300	5,500	5,900	5,900
Residential	2,200	2,000	2,100	2,100	2,000	1,700	1,800	1,900	1,800	1,800	1,800
Commercial & Institutional	810	794	948	789	735	817	809	946	756	865	922
Other	107	191	237	154	148	203	227	250	222	208	237
COMBUSTION SUBTOTAL	16,700	16,400	17,100	17,200	16,800	16,600	16,700	17,500	17,600	18,400	19,400
FUGITIVE	107	191	237	154	148	203	227				
Solid Fuels (i.e., Coal Mining)	1,200	1,300	1,200	1,100	970	830	830	690	510	330	250
Oil & Gas	0	0	3	5	6	6	5	4	4	2	140
FUGITIVE SUBTOTAL	1,200	1,300	1,200	1,100	970	830	830	690	510	330	390
ENERGY TOTAL	17,800	17,800	18,400	18,300	17,700	17,400	17,500	18,200	18,100	18,700	19,800
INDUSTRIAL PROCESSES											
Non-Metallic Mineral Production	199	182	166	228	219	217	210	192	204	207	206
Adipic & Nitric Acid Production	0	0	0	0	0	0	0	0	0	0	0
Ferrous Metal Production	0	0	0	0	0	0	0	0	0	0	0
Aluminum & Magnesium Production	0	0	0	0	0	0	0	0	0	0	0
Other & Undifferentiated Production	100	77	68	59	56	77	70	71	110	79	69
INDUSTRIAL PROCESSES TOTAL	300	260	230	290	280	290	280	260	320	290	270
SOLVENT & OTHER PRODUCT USE	14	14	14	14	14	14	14	14	14	14	14
AGRICULTURE											
Enteric Fermentation	190	190	190	180	180	180	180	190	180	170	170
Manure Management	140	140	130	130	140	140	140	140	140	150	150
Agricultural Soils**	300	300	300	300	300	300	300	300	300	300	300
AGRICULTURE TOTAL	610	600	600	590	620	620	630	620	610	620	610
LAND USE CHANGE & FORESTRY*	40	40	40	40	100	200	40	10	80	30	50
WASTE											
Solid Waste Disposal on Land	540	550	560	580	560	570	590	610	620	630	650
Wastewater Handling	39	39	39	39	39	40	40	40	40	40	40
Waste Incineration	16	16	16	16	16	16	16	16	16	16	16
WASTE TOTAL	590	610	620	630	610	630	650	660	680	690	700
TOTAL	**19,400**	**19,300**	**19,900**	**19,800**	**19,400**	**19,100**	**19,200**	**19,800**	**19,800**	**20,300**	**21,500**

Notes:

Due to rounding, individual values may not add up to totals (zero values may represent estimated quantities too small to display).

Ammonia production emissions are included under undifferentiated production at the provincial level.

Emissions associated with the use of HFCs, PFCs, limestone and soda ash are reported in the national total.

** Only one significant figure shown due to high uncertainty.

* Methane and nitrous oxide emissions from prescribed fires and anthropogenic fires outside the Wood Production Forest. Fires located in national parks are not included in the provincial/territorial total but are reported in the national total.

1990 to 2000 Greenhouse Gas Emission Estimates for New Brunswick, by Sector

GHG Source and Sink Category	1990	1991	1992	1993	1994	1995 All Gases kt CO_2 eq	1996	1997	1998	1999	2000
ENERGY											
FUEL COMBUSTION											
Fossil Fuel Industries	1,130	1,090	1,110	1,250	1,280	997	1,430	1,340	1,210	1,260	1,520
Electricity & Heat Generation	6,000	5,460	6,130	5,170	6,340	6,760	5,990	8,300	9,460	8,200	8,560
Mining	127	82	96	103	115	117	153	121	99	98	133
Manufacturing	1,410	1,400	1,360	1,400	1,380	1,450	1,410	1,340	1,200	1,240	1,320
Construction	69	53	53	35	41	41	40	49	39	36	40
Transport											
Light Duty Gasoline Vehicles	1,570	1,500	1,490	1,490	1,500	1,430	1,450	1,450	1,470	1,460	1,360
Light Duty Gasoline Trucks	705	712	756	797	848	853	914	946	943	1,010	1,050
Heavy Duty Gasoline Vehicles	101	104	111	118	125	126	137	110	126	119	125
Motorcycles	7	6	6	6	7	6	7	7	8	7	8
Off Road Gasoline	14	15	13	14	13	13	11	19	25	14	14
Light Duty Diesel Vehicles	19	18	19	19	19	18	19	19	19	18	18
Light Duty Diesel Trucks	21	17	14	12	12	10	9	16	15	8	6
Heavy Duty Diesel Vehicles	847	837	850	910	1,010	1,090	1,100	1,150	1,160	1,230	1,270
Off Road Diesel	332	381	406	426	487	442	497	483	587	740	925
Propane & Natural Gas Vehicles	5	5	5	9	4	8	8	10	9	16	7
Domestic Aviation	94	92	97	92	108	117	121	190	189	202	216
Domestic Marine	268	264	294	279	304	301	307	307	327	356	403
Railways	132	134	142	131	121	115	113	148	184	203	236
Vehicles Subtotal	4,120	4,080	4,210	4,300	4,560	4,520	4,700	4,860	5,060	5,380	5,640
Pipelines	0	0	0	0	0	0	0	0	0	0	0
Transport Subtotal	4,120	4,080	4,210	4,300	4,560	4,520	4,700	4,860	5,060	5,380	5,640
Residential	1,200	1,190	1,190	1,160	1,050	917	933	957	844	817	853
Commercial & Institutional	587	655	507	461	505	555	495	593	504	490	614
Other	54	65	81	87	87	131	110	119	104	101	66
COMBUSTION SUBTOTAL	14,700	14,100	14,700	14,000	15,400	15,500	15,300	17,700	18,500	17,600	18,800
FUGITIVE											
Solid Fuels (i.e., Coal Mining)	2	1	1	1	1	1	1	0	1	1	1
Oil & Gas	0	0	0	0	0	0	0	0	0	0	29
FUGITIVE SUBTOTAL	2	1	1	1	1	1	1	0	1	1	30
ENERGY TOTAL	14,700	14,100	14,700	14,000	15,400	15,500	15,300	17,700	18,500	17,600	18,800
INDUSTRIAL PROCESSES											
Non-Metallic Mineral Production	78	76	81	88	93	97	96	100	100	105	107
Adipic & Nitric Acid Production	0	0	0	0	0	0	0	0	0	0	0
Ferrous Metal Production	0	0	0	0	0	0	0	0	0	0	0
Aluminum & Magnesium Production	0	0	0	0	0	0	0	0	0	0	0
Other & Undifferentiated Production	75	92	100	110	44	160	160	150	150	140	120
INDUSTRIAL PROCESSES TOTAL	150	170	180	190	140	260	260	250	250	240	230
SOLVENT & OTHER PRODUCT USE	11	11	11	11	11	11	11	11	11	11	11
AGRICULTURE											
Enteric Fermentation	150	150	150	150	150	150	150	140	140	140	140
Manure Management	100	100	100	100	110	110	110	110	110	110	120
Agricultural Soils**	200	200	300	200	200	300	300	300	300	300	300
AGRICULTURE TOTAL	490	490	500	500	500	510	510	510	520	520	530
LAND USE CHANGE & FORESTRY*	20	30	20	30	80	100	30	10	50	20	50
WASTE											
Solid Waste Disposal on Land	450	460	470	480	490	500	510	520	530	540	550
Wastewater Handling	50	51	51	51	51	51	51	51	51	51	52
Waste Incineration	0	0	0	0	0	0	0	0	0	0	0
WASTE TOTAL	500	510	520	530	540	550	560	580	590	590	600
TOTAL	**15,900**	**15,300**	**16,000**	**15,200**	**16,600**	**16,900**	**16,600**	**19,000**	**19,900**	**19,000**	**20,200**

Notes:

Due to rounding, individual values may not add up to totals (zero values may represent estimated quantities too small to display).

Ammonia production emissions are included under undifferentiated production at the provincial level.

Emissions associated with the use of HFCs, PFCs, limestone and soda ash are reported in the national total.

** Only one significant figure shown due to high uncertainty.

* Methane and nitrous oxide emissions from prescribed fires and anthropogenic fires outside the Wood Production Forest. Fires located in national parks are not included in the provincial/territorial total but are reported in the national total.

1990 to 2000 Greenhouse Gas Emission Estimates for Quebec, by Sector

GHG Source and Sink Category	1990	1991	1992	1993	1994	1995 All Gases kt CO_2 eq	1996	1997	1998	1999	2000
ENERGY											
FUEL COMBUSTION											
Fossil Fuel Industries	3,690	3,040	3,140	3,320	3,560	3,330	3,520	3,380	3,450	3,250	3,610
Electricity & Heat Generation	1,510	526	946	295	502	396	425	459	1,560	1,170	579
Mining	734	805	730	798	736	824	825	870	760	759	922
Manufacturing	11,900	10,800	10,800	10,600	11,200	10,800	11,400	11,500	11,300	10,900	11,000
Construction	458	399	371	289	275	188	191	225	188	190	190
Transport											
Light Duty Gasoline Vehicles	13,800	12,800	13,100	13,400	13,600	13,600	13,400	13,100	13,300	13,100	12,800
Light Duty Gasoline Trucks	3,320	3,380	3,750	4,110	4,490	4,730	5,000	5,160	5,450	5,900	5,960
Heavy Duty Gasoline Vehicles	520	508	541	572	604	620	850	796	843	872	905
Motorcycles	45	41	41	43	46	47	49	51	55	59	64
Off Road Gasoline	361	428	292	344	309	211	243	384	203	192	191
Light Duty Diesel Vehicles	247	232	237	241	245	243	238	231	229	221	227
Light Duty Diesel Trucks	95	86	79	74	74	76	75	84	94	25	7
Heavy Duty Diesel Vehicles	5,900	5,980	6,060	6,110	6,560	7,090	7,270	8,000	8,100	8,300	8,290
Off Road Diesel	1,010	454	461	865	1,230	1,020	646	639	770	984	864
Propane & Natural Gas Vehicles	111	112	119	86	55	47	36	45	51	35	36
Domestic Aviation	1,880	1,420	1,720	1,550	1,740	1,670	1,800	1,470	1,640	1,710	1,880
Domestic Marine	1,400	1,440	1,410	1,110	1,280	910	928	1,050	1,590	1,320	1,370
Railways	583	618	628	612	611	556	445	501	740	887	827
Vehicles Subtotal	29,300	27,500	28,500	29,100	30,900	30,800	30,900	31,500	33,100	33,600	33,400
Pipelines	26	28	31	27	27	25	18	26	16	25	108
Transport Subtotal	29,300	27,500	28,500	29,200	30,900	30,800	31,000	31,500	33,100	33,600	33,500
Residential	7,000	6,400	6,600	6,700	6,700	6,300	6,700	6,300	5,600	5,900	6,000
Commercial & Institutional	4,270	4,180	4,500	4,650	4,730	5,070	5,000	5,000	4,670	4,710	5,720
Other	293	380	449	348	330	302	277	289	258	264	262
COMBUSTION SUBTOTAL	59,100	54,000	56,100	56,100	58,900	58,000	59,300	59,500	60,900	60,800	61,800
FUGITIVE											
Solid Fuels (i.e., Coal Mining)	0	0	0	0	0	0	0	0	0	0	0
Oil & Gas	280	320	320	330	380	400	400	410	440	440	440
FUGITIVE SUBTOTAL	280	320	320	330	380	400	400	410	440	440	440
ENERGY TOTAL	59,400	54,300	56,400	56,500	59,300	58,400	59,700	59,900	61,300	61,200	62,300
INDUSTRIAL PROCESSES											
Non-Metallic Mineral Production	1,710	1,410	1,220	1,410	1,670	1,720	1,690	1,720	1,770	1,860	1,860
Adipic & Nitric Acid Production	15	14	15	15	14	15	14	14	13	14	15
Ferrous Metal Production	0	1	8	9	7	7	9	6	9	7	13
Aluminum & Magnesium Production	10,000	10,000	10,000	10,000	10,000	10,000	9,000	9,000	10,000	10,000	10,000
Other & Undifferentiated Production	1,200	730	870	490	720	960	840	810	670	1,000	1,300
INDUSTRIAL PROCESSES TOTAL	13,000	13,000	12,000	13,000	13,000	12,000	12,000	12,000	12,000	13,000	13,000
SOLVENT & OTHER PRODUCT USE	110	110	110	110	110	110	110	110	110	110	110
AGRICULTURE											
Enteric Fermentation	2,400	2,400	2,300	2,400	2,400	2,400	2,500	2,400	2,300	2,200	2,200
Manure Management	2,000	1,900	2,000	2,000	2,000	2,100	2,100	2,100	2,100	2,100	2,100
Agricultural Soils**	4,000	3,000	3,000	3,000	3,000	4,000	4,000	4,000	4,000	4,000	3,000
AGRICULTURE TOTAL	8,000	7,500	7,500	7,700	7,900	8,000	8,100	8,100	8,100	8,000	7,700
LAND USE CHANGE & FORESTRY*	200	200	100	300	800	1,000	300	100	500	200	400
WASTE											
Solid Waste Disposal on Land	5,400	4,900	5,100	5,300	5,200	5,400	5,500	5,600	5,800	6,100	6,300
Wastewater Handling	251	253	254	256	258	259	260	261	262	263	264
Waste Incineration	138	139	141	141	143	144	144	145	145	146	146
WASTE TOTAL	5,800	5,300	5,500	5,700	5,600	5,800	5,900	6,000	6,200	6,500	6,700
TOTAL	**86,100**	**80,500**	**81,900**	**83,500**	**87,000**	**85,900**	**85,900**	**86,200**	**88,200**	**88,700**	**90,400**

Notes:

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Emissions associated with the use of HFCs, PFCs, limestone and soda ash are reported in the national total.

** Only one significant figure shown due to high uncertainty.

* Methane and nitrous oxide emissions from prescribed fires and anthropogenic fires outside the Wood Production Forest. Fires located in national parks are not included in the provincial/territorial total but are reported in the national total.

1990 to 2000 Greenhouse Gas Emission Estimates for Ontario, by Sector

GHG Source and Sink Category	1990	1991	1992	1993	1994	1995 All Gases kt CO_2 eq	1996	1997	1998	1999	2000
ENERGY											
FUEL COMBUSTION											
Fossil Fuel Industries	6,660	5,970	6,530	6,720	6,170	5,950	6,410	6,290	6,470	6,230	6,550
Electricity & Heat Generation	26,600	28,000	27,900	18,800	16,500	18,900	20,600	25,800	33,700	35,800	40,300
Mining	501	675	811	553	651	678	680	658	528	459	469
Manufacturing	22,800	21,500	21,100	20,700	21,900	21,100	21,500	21,900	21,100	21,300	22,600
Construction	573	527	559	337	421	373	444	492	451	477	439
Transport											
Light Duty Gasoline Vehicles	21,000	20,200	20,100	20,300	20,500	20,000	19,500	19,800	19,200	19,400	19,100
Light Duty Gasoline Trucks	7,710	7,960	8,490	9,130	9,740	10,100	10,800	11,600	11,700	13,000	13,700
Heavy Duty Gasoline Vehicles	888	922	981	1,050	1,120	1,160	1,200	1,220	1,270	1,320	1,420
Motorcycles	85	82	80	81	78	73	69	71	72	68	70
Off Road Gasoline	1,180	1,160	941	768	800	997	1,060	1,070	2,330	2,170	2,210
Light Duty Diesel Vehicles	211	200	195	191	186	176	183	185	183	2	2
Light Duty Diesel Trucks	163	124	110	101	92	86	72	90	67	4	4
Heavy Duty Diesel Vehicles	7,350	6,610	6,920	7,580	8,270	9,390	9,770	10,700	10,800	11,900	12,100
Off Road Diesel	2,410	2,230	2,160	2,240	2,330	2,200	2,230	2,400	3,010	3,450	4,600
Propane & Natural Gas Vehicles	544	662	1,110	1,010	585	798	834	711	630	612	389
Domestic Aviation	3,210	2,890	2,670	2,720	2,780	3,070	3,440	3,950	4,310	4,460	4,360
Domestic Marine	939	942	895	689	712	659	712	822	815	684	635
Railways	1,830	1,970	1,940	1,930	1,910	1,690	1,820	1,830	1,580	1,700	1,720
Vehicles Subtotal	47,500	45,900	46,600	47,800	49,100	50,400	51,700	54,400	56,000	58,800	60,300
Pipelines	2,270	2,400	3,250	3,410	3,460	4,040	4,360	4,240	4,060	4,110	3,630
Transport Subtotal	49,700	48,300	49,900	51,200	52,600	54,400	56,000	58,700	60,100	62,900	63,900
Residential	17,400	17,000	18,100	19,400	20,200	19,400	21,400	20,200	16,600	18,000	19,100
Commercial & Institutional	9,170	9,670	10,200	10,200	9,930	9,860	10,900	11,400	10,300	11,500	12,500
Other	781	894	1,110	997	940	1,150	1,130	1,050	936	959	902
COMBUSTION SUBTOTAL	134,000	133,000	136,000	129,000	129,000	132,000	139,000	147,000	150,000	158,000	167,000
FUGITIVE											
Solid Fuels (i.e., Coal Mining)	0	0	0	0	0	0	0	0	0	0	0
Oil & Gas	1,400	1,400	1,400	1,500	1,500	1,500	1,500	1,500	1,600	1,600	1,700
FUGITIVE SUBTOTAL	1,400	1,400	1,400	1,500	1,500	1,500	1,500	1,500	1,600	1,600	1,700
ENERGY TOTAL	136,000	134,000	138,000	130,000	131,000	133,000	141,000	148,000	152,000	159,000	168,000
INDUSTRIAL PROCESSES											
Non-Metallic Mineral Production	3,690	3,020	3,040	2,850	3,190	3,230	3,650	3,690	3,650	3,860	3,710
Adipic & Nitric Acid Production	11,000	10,000	10,000	9,200	11,000	11,000	12,000	10,000	5,100	1,800	980
Ferrous Metal Production	7,590	8,900	9,070	8,740	8,070	8,420	8,280	8,090	8,300	8,490	8,500
Aluminum & Magnesium Production	500	500	500	500	500	540	530	660	660	840	1,100
Other & Undifferentiated Production	4,100	4,100	4,200	3,900	3,900	4,300	4,500	4,300	4,500	4,400	4,200
INDUSTRIAL PROCESSES TOTAL	27,000	27,000	27,000	25,000	27,000	27,000	28,000	27,000	22,000	19,000	18,000
SOLVENT & OTHER PRODUCT USE	160	160	160	160	160	170	170	170	170	170	180
AGRICULTURE											
Enteric Fermentation	3,300	3,300	3,200	3,000	3,100	3,100	3,000	3,200	3,100	3,000	2,900
Manure Management	2,200	2,200	2,200	2,100	2,200	2,300	2,300	2,300	2,300	2,300	2,300
Agricultural Soils**	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000
AGRICULTURE TOTAL	12,000	11,000	11,000	11,000	12,000	12,000	11,000	11,000	12,000	12,000	11,000
LAND USE CHANGE & FORESTRY*	200	300	200	200	600	800	200	60	300	800	400
WASTE											
Solid Waste Disposal on Land	6,700	7,400	7,600	7,800	7,900	7,600	7,200	7,400	7,500	7,600	7,800
Wastewater Handling	380	390	390	400	400	410	410	420	420	430	430
Waste Incineration	80	81	82	79	79	81	82	83	84	85	86
WASTE TOTAL	7,200	7,800	8,000	8,200	8,400	8,100	7,700	7,900	8,000	8,100	8,300
TOTAL	**181,000**	**180,000**	**184,000**	**175,000**	**178,000**	**181,000**	**188,000**	**194,000**	**194,000**	**199,000**	**207,000**

Notes:

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** Only one significant figure shown due to high uncertainty.

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1990 to 2000 Greenhouse Gas Emission Estimates for Manitoba, by Sector

GHG Source and Sink Category	1990	1991	1992	1993	1994	1995 All Gases kt CO_2 eq	1996	1997	1998	1999	2000
ENERGY											
FUEL COMBUSTION											
Fossil Fuel Industries	3	0	1	0	0	1	1	1	1	1	1
Electricity & Heat Generation	570	421	423	290	262	199	326	233	962	546	984
Mining	73	76	58	28	8	13	11	12	34	27	29
Manufacturing	1,040	953	768	707	781	811	832	802	910	1,080	1,130
Construction	63	45	51	38	41	34	32	45	85	76	62
Transport											
Light Duty Gasoline Vehicles	1,980	1,970	1,910	1,810	1,790	1,750	1,650	1,540	1,540	1,520	1,460
Light Duty Gasoline Trucks	868	931	984	1,010	1,080	1,130	1,230	1,260	1,300	1,400	1,430
Heavy Duty Gasoline Vehicles	193	211	224	230	246	258	204	255	250	244	251
Motorcycles	7	8	7	7	7	6	4	5	5	4	4
Off Road Gasoline	347	333	357	402	388	450	436	411	416	431	430
Light Duty Diesel Vehicles	20	20	19	18	17	17	17	16	16	15	15
Light Duty Diesel Trucks	31	30	31	32	33	35	37	30	28	19	14
Heavy Duty Diesel Vehicles	992	989	1,030	1,090	1,160	1,250	1,330	1,320	1,320	1,330	1,360
Off Road Diesel	866	650	564	614	646	817	798	748	688	654	737
Propane & Natural Gas Vehicles	61	64	61	27	71	97	83	120	107	113	36
Domestic Aviation	477	444	410	410	510	543	581	597	516	572	554
Domestic Marine	0	0	0	0	0	0	0	0	0	0	0
Railways	622	537	545	535	572	565	524	449	351	322	311
Vehicles Subtotal	6,500	6,200	6,100	6,200	6,500	6,900	6,900	6,700	6,500	6,600	6,600
Pipelines	847	976	1,220	1,260	1,200	1,300	1,300	1,200	959	1,060	828
Transport Subtotal	7,320	7,160	7,360	7,430	7,720	8,220	8,190	7,940	7,490	7,680	7,430
Residential	1,640	1,550	1,460	1,480	1,420	1,460	1,620	1,440	1,280	1,310	1,390
Commercial & Institutional	1,410	1,430	1,480	1,530	1,430	1,590	1,670	1,650	1,490	1,470	1,680
Other	43	47	52	101	77	77	110	98	72	87	63
COMBUSTION SUBTOTAL	12,200	11,700	11,700	11,600	11,700	12,400	12,800	12,200	12,300	12,300	12,800
FUGITIVE											
Solid Fuels (i.e., Coal Mining)	0	0	0	0	0	0	0	0	0	0	0
Oil & Gas	420	420	430	440	440	460	490	500	510	510	530
FUGITIVE SUBTOTAL	420	420	430	440	440	460	490	500	510	510	530
ENERGY TOTAL	12,600	12,100	12,100	12,100	12,200	12,900	13,300	12,700	12,800	12,800	13,300
INDUSTRIAL PROCESSES											
Non-Metallic Mineral Production	191	179	62	67	71	74	73	76	76	70	72
Adipic & Nitric Acid Production	21	20	21	21	24	27	30	29	27	29	31
Ferrous Metal Production	0	0	0	0	0	0	0	0	0	0	0
Aluminum & Magnesium Production	0	0	0	0	0	0	0	0	0	0	0
Other & Undifferentiated Production	240	220	210	210	210	200	200	210	210	350	370
INDUSTRIAL PROCESSES TOTAL	450	420	300	300	300	300	300	310	320	450	470
SOLVENT & OTHER PRODUCT USE	17	17	17	17	17	17	17	17	17	17	17
AGRICULTURE											
Enteric Fermentation	1,300	1,300	1,400	1,500	1,600	1,700	1,800	1,700	1,700	1,700	1,700
Manure Management	670	690	740	760	820	890	940	910	950	920	920
Agricultural Soils**	5,000	5,000	5,000	5,000	5,000	4,000	5,000	4,000	5,000	4,000	4,000
AGRICULTURE TOTAL	6,800	6,800	6,900	6,800	7,000	6,900	7,300	6,900	7,200	6,900	6,900
LAND USE CHANGE & FORESTRY*	40	100	400	50	200	200	60	30	90	200	100
WASTE											
Solid Waste Disposal on Land	370	420	430	450	460	470	490	500	520	530	550
Wastewater Handling	57	57	57	57	58	58	58	58	58	59	59
Waste Incineration	0	0	0	0	0	0	0	0	0	0	0
WASTE TOTAL	420	470	490	500	520	530	550	560	580	590	600
TOTAL	**20,300**	**19,900**	**20,200**	**19,700**	**20,200**	**20,800**	**21,500**	**20,600**	**21,000**	**20,900**	**21,400**

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1990 to 2000 Greenhouse Gas Emission Estimates for Saskatchewan, by Sector

GHG Source and Sink Category	1990	1991	1992	1993	1994	1995 All Gases kt CO_2 eq	1996	1997	1998	1999	2000
ENERGY											
FUEL COMBUSTION											
Fossil Fuel Industries	3,230	1,630	2,400	3,350	4,630	5,150	3,420	3,760	4,680	4,780	4,400
Electricity & Heat Generation	10,400	10,500	12,000	12,100	12,800	14,100	14,200	15,000	15,100	14,900	14,500
Mining	965	978	969	1,700	1,810	1,690	1,320	1,900	1,810	1,660	2,140
Manufacturing	774	1,340	2,180	1,120	1,530	1,290	1,570	1,060	1,120	903	893
Construction	70	57	80	71	65	73	87	56	65	87	49
Transport											
Light Duty Gasoline Vehicles	1,590	1,600	1,900	1,770	1,640	1,480	1,440	1,490	1,370	1,340	1,290
Light Duty Gasoline Trucks	1,030	1,100	1,400	1,400	1,420	1,400	1,560	1,680	1,500	1,680	1,700
Heavy Duty Gasoline Vehicles	193	242	355	406	459	507	516	595	591	577	555
Motorcycles	2	2	3	3	3	3	3	6	6	6	7
Off Road Gasoline	1,190	1,100	434	561	810	841	807	380	721	639	630
Light Duty Diesel Vehicles	14	14	17	15	13	11	13	13	13	13	13
Light Duty Diesel Trucks	75	87	84	86	99	99	108	122	110	77	98
Heavy Duty Diesel Vehicles	1,400	1,640	1,600	1,660	1,930	1,940	2,120	2,610	2,310	2,410	2,430
Off Road Diesel	1,460	1,460	1,400	1,570	1,710	1,790	1,790	1,500	1,330	1,340	1,500
Propane & Natural Gas Vehicles	65	64	80	63	52	50	44	59	59	49	26
Domestic Aviation	260	224	222	184	179	221	235	202	214	181	165
Domestic Marine	0	0	0	0	0	0	0	0	0	0	0
Railways	600	304	372	369	524	527	579	592	471	441	423
Vehicles Subtotal	7,880	7,840	7,860	8,090	8,840	8,870	9,220	9,260	8,690	8,750	8,830
Pipelines	1,640	1,780	2,430	2,460	2,270	2,600	2,570	2,500	2,660	2,790	2,410
Transport Subtotal	9,520	9,620	10,300	10,600	11,100	11,500	11,800	11,800	11,300	11,500	11,200
Residential	2,150	2,150	2,050	2,130	2,080	2,140	2,450	2,090	1,910	1,950	1,980
Commercial & Institutional	1,010	1,010	926	1,480	1,310	1,210	1,420	1,200	1,250	1,590	1,710
Other	302	274	303	333	327	328	387	349	292	339	281
COMBUSTION SUBTOTAL	28,400	27,600	31,200	32,800	35,600	37,400	36,700	37,100	37,600	37,800	37,200
FUGITIVE											
Solid Fuels (i.e., Coal Mining)	12	11	13	13	13	14	14	15	15	15	14
Oil & Gas	6,100	6,300	6,700	7,400	7,900	8,800	9,600	9,800	9,800	10,000	11,000
FUGITIVE SUBTOTAL	6,100	6,300	6,700	7,400	7,900	8,800	9,600	9,800	9,800	10,000	11,000
ENERGY TOTAL	34,500	33,900	37,900	40,200	43,500	46,200	46,200	46,900	47,400	47,800	47,900
INDUSTRIAL PROCESSES											
Non-Metallic Mineral Production	82	75	0	0	0	0	0	0	0	0	0
Adipic & Nitric Acid Production	0	0	0	0	0	0	0	0	0	0	0
Ferrous Metal Production	0	0	0	0	0	0	0	0	0	0	0
Aluminum & Magnesium Production	0	0	0	0	0	0	0	0	0	0	0
Other & Undifferentiated Production	510	600	690	1,200	990	800	1,700	1,800	2,000	2,000	2,000
INDUSTRIAL PROCESSES TOTAL	590	680	690	1,200	990	800	1,700	1,800	2,000	2,000	2,000
SOLVENT & OTHER PRODUCT USE	15	15	15	15	15	15	15	15	15	15	15
AGRICULTURE											
Enteric Fermentation	2,500	2,500	2,700	2,800	2,900	3,100	3,200	3,300	3,100	3,100	3,000
Manure Management	800	830	880	900	950	970	1,000	1,000	990	980	980
Agricultural Soils**	8,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000
AGRICULTURE TOTAL	11,000	11,000	11,000	10,000	11,000	11,000	12,000	12,000	11,000	11,000	11,000
LAND USE CHANGE & FORESTRY*	100	200	50	600	100	200	60	20	200	200	200
WASTE											
Solid Waste Disposal on Land	420	430	450	460	470	480	490	500	510	520	530
Wastewater Handling	87	87	87	87	87	88	88	88	89	89	89
Waste Incineration	0	0	0	0	0	0	0	0	0	0	0
WASTE TOTAL	500	520	530	550	560	570	580	590	600	610	610
TOTAL	**46,900**	**46,100**	**50,100**	**53,000**	**56,200**	**58,700**	**60,100**	**60,900**	**61,300**	**61,300**	**61,800**

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1990 to 2000 Greenhouse Gas Emission Estimates for Alberta, by Sector

GHG Source and Sink Category	1990	1991	1992	1993	1994	1995 All Gases kt CO_2 eq	1996	1997	1998	1999	2000
ENERGY											
FUEL COMBUSTION											
Fossil Fuel Industries	30,900	32,700	35,100	34,800	34,600	34,600	33,900	31,300	33,000	42,100	44,400
Electricity & Heat Generation	40,200	42,000	45,100	45,800	49,200	49,500	48,600	51,300	51,800	50,100	51,000
Mining	2,400	1,430	1,200	3,200	2,880	3,340	4,280	3,920	3,450	3,450	4,160
Manufacturing	9,400	9,590	9,360	8,260	8,900	9,940	9,920	10,500	10,000	9,650	12,400
Construction	236	202	244	212	206	189	216	211	136	167	171
Transport											
Light Duty Gasoline Vehicles	5,630	5,150	5,070	4,940	5,200	5,040	4,620	4,770	4,960	4,810	4,680
Light Duty Gasoline Trucks	3,650	3,520	3,670	3,770	4,180	4,270	4,260	4,700	4,840	5,130	5,260
Heavy Duty Gasoline Vehicles	649	692	788	869	1,030	1,100	1,100	1,180	1,320	1,340	1,390
Motorcycles	25	24	23	24	26	23	22	24	27	25	26
Off Road Gasoline	1,370	996	1,030	1,020	692	641	1,310	1,170	1,190	1,190	1,080
Light Duty Diesel Vehicles	52	46	44	41	40	36	34	36	38	38	37
Light Duty Diesel Trucks	87	70	61	58	60	54	52	104	85	0	0
Heavy Duty Diesel Vehicles	3,650	3,490	3,580	3,900	4,740	4,920	5,470	6,250	6,240	6,230	6,390
Off Road Diesel	2,670	2,420	1,970	2,450	2,800	3,200	3,720	4,270	4,560	4,590	5,280
Propane & Natural Gas Vehicles	628	628	703	323	514	514	551	478	433	336	272
Domestic Aviation	1,660	1,390	1,450	1,530	1,580	1,660	1,850	1,910	2,040	2,090	2,110
Domestic Marine	0	0	1	1	0	1	0	0	0	0	0
Railways	1,800	1,540	1,560	1,560	1,620	1,240	1,150	1,340	1,360	1,460	1,770
Vehicles Subtotal	21,900	20,000	19,900	20,500	22,500	22,700	24,100	26,200	27,100	27,200	28,300
Pipelines	1,270	1,360	1,920	2,100	2,600	2,670	2,770	3,160	3,250	3,210	2,670
Transport Subtotal	23,100	21,300	21,900	22,600	25,100	25,400	26,900	29,400	30,300	30,400	31,000
Residential	6,630	6,570	6,440	6,610	7,260	7,570	8,670	7,710	7,350	7,450	8,280
Commercial & Institutional	4,950	4,760	4,410	4,540	4,570	5,520	4,970	5,020	4,640	4,580	4,790
Other	468	458	560	574	358	335	410	380	341	348	361
COMBUSTION SUBTOTAL* **	118,000	119,000	124,000	127,000	133,000	136,000	138,000	140,000	141,000	148,000	156,000
FUGITIVE											
Solid Fuels (i.e., Coal Mining)	240	250	270	270	270	300	290	280	290	240	210
Oil & Gas	25,000	26,000	28,000	29,000	30,000	32,000	34,000	33,000	33,000	34,000	34,000
FUGITIVE SUBTOTAL	25,000	26,000	28,000	29,000	31,000	32,000	34,000	34,000	34,000	34,000	34,000
ENERGY TOTAL	143,000	145,000	153,000	156,000	164,000	169,000	172,000	173,000	175,000	182,000	190,000
INDUSTRIAL PROCESSES											
Non-Metallic Mineral Production	869	793	718	914	889	894	795	809	944	1,010	1,070
Adipic & Nitric Acid Production	660	650	660	660	650	660	670	670	660	670	670
Ferrous Metal Production	0	0	0	0	0	0	0	0	0	0	0
Aluminum & Magnesium Production	0	0	0	0	0	0	0	0	0	0	0
Other & Undifferentiated Production	7,300	7,900	7,800	8,500	8,900	8,800	9,700	10,000	9,900	10,000	9,800
INDUSTRIAL PROCESSES TOTAL	8,800	9,300	9,200	10,000	10,000	10,000	11,000	12,000	11,000	12,000	11,000
SOLVENT & OTHER PRODUCT USE	38	39	40	40	41	41	42	43	44	45	45
AGRICULTURE											
Enteric Fermentation	5,100	5,300	5,500	5,600	6,000	6,200	6,200	6,300	6,200	6,400	6,500
Manure Management	1,800	1,800	1,900	1,900	2,000	2,100	2,100	2,100	2,100	2,200	2,200
Agricultural Soils**	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
AGRICULTURE TOTAL	17,000	17,000	17,000	18,000	19,000	19,000	19,000	19,000	19,000	19,000	19,000
LAND USE CHANGE & FORESTRY*	100	200	100	200	600	900	200	70	600	100	300
WASTE											
Solid Waste Disposal on Land	870	930	780	820	860	890	850	880	910	1,000	1,000
Wastewater Handling	140	140	140	140	140	150	150	150	160	160	160
Waste Incineration	0	0	0	0	0	0	0	0	0	0	0
WASTE TOTAL	1,000	1,100	920	960	1,000	1,000	990	1,000	1,100	1,200	1,200
TOTAL	**171,000**	**173,000**	**180,000**	**185,000**	**194,000**	**200,000**	**203,000**	**205,000**	**206,000**	**214,000**	**223,000**

Notes:

Due to rounding, individual values may not add up to totals (zero values may represent estimated quantities too small to display).

Ammonia production emissions are included under undifferentiated production at the provincial level.

Emissions associated with the use of HFCs, PFCs, limestone and soda ash are reported in the national total.

***Fuel combustion emissions from the fossil fuel industry category for Alberta show 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.

** Only one significant figure shown due to high uncertainty.

* Methane and nitrous oxide emissions from prescribed fires and anthropogenic fires outside the Wood Production Forest. Fires located in national parks are not included in the provincial/territorial total but are reported in the national total.

1990 to 2000 Greenhouse Gas Emission Estimates for British Columbia, by Sector

GHG Source and Sink Category	1990	1991	1992	1993	1994	1995 All Gases kt CO_2 eq	1996	1997	1998	1999	2000
ENERGY											
FUEL COMBUSTION											
Fossil Fuel Industries	3,750	3,050	1,910	1,060	1,900	2,650	4,540	2,860	3,470	4,860	3,540
Electricity & Heat Generation	1,170	1,040	1,270	2,340	2,180	2,700	768	1,190	1,870	1,300	2,280
Mining	253	225	271	336	202	163	448	344	324	227	355
Manufacturing	5,930	5,390	4,910	5,250	5,390	6,210	6,810	6,360	5,960	6,570	7,560
Construction	304	268	317	340	283	198	207	126	100	86	76
Transport											
Light Duty Gasoline Vehicles	5,370	5,320	5,300	5,360	5,410	5,320	5,250	5,380	5,450	5,330	5,140
Light Duty Gasoline Trucks	2,770	2,980	3,220	3,490	3,780	3,990	4,140	4,560	4,860	4,840	4,910
Heavy Duty Gasoline Vehicles	355	412	481	558	640	706	708	667	827	913	920
Motorcycles	39	38	39	39	40	39	38	43	45	47	47
Off Road Gasoline	361	361	377	529	564	607	629	665	630	609	603
Light Duty Diesel Vehicles	75	71	68	66	63	59	65	66	69	72	65
Light Duty Diesel Trucks	79	60	49	43	40	37	34	41	39	0	0
Heavy Duty Diesel Vehicles	2,920	2,840	2,890	3,020	3,300	3,530	3,710	3,850	3,750	3,890	3,910
Off Road Diesel	1,740	1,830	1,820	1,760	1,860	2,310	2,560	2,850	2,760	2,790	2,860
Propane & Natural Gas Vehicles	782	769	582	491	622	571	407	403	482	313	331
Domestic Aviation	1,910	1,970	2,010	1,780	2,030	2,430	2,700	2,950	2,970	3,340	3,340
Domestic Marine	1,030	1,130	1,150	1,140	1,180	1,240	1,140	1,040	1,010	1,130	1,240
Railways	1,470	1,430	1,640	1,670	1,680	1,690	1,620	1,470	1,400	1,430	1,300
Vehicles Subtotal	18,900	19,200	19,600	19,900	21,200	22,500	23,000	24,000	24,300	24,700	24,700
Pipelines	845	1,090	1,040	1,110	1,240	1,370	1,490	1,430	1,560	1,390	1,630
Transport Subtotal	19,800	20,300	20,700	21,000	22,400	23,900	24,500	25,400	25,800	26,100	26,300
Residential	4,310	4,180	4,100	4,590	4,370	4,400	4,920	4,530	4,450	4,730	4,600
Commercial & Institutional	2,820	3,070	3,180	3,560	3,290	3,360	3,400	3,290	2,880	2,960	3,200
Other	323	375	374	374	205	155	191	270	253	262	315
COMBUSTION SUBTOTAL	38,600	37,900	37,000	38,900	40,300	43,700	45,800	44,400	45,100	47,100	48,200
FUGITIVE											
Solid Fuels (i.e., Coal Mining)	490	480	360	470	510	570	630	660	550	490	480
Oil & Gas	3,000	3,100	3,500	3,600	4,300	4,900	5,100	5,200	5,400	5,400	5,600
FUGITIVE SUBTOTAL	3,500	3,600	3,800	4,100	4,800	5,400	5,800	5,800	5,900	5,900	6,100
ENERGY TOTAL	42,100	41,500	40,800	43,000	45,100	49,200	51,600	50,200	51,100	53,000	54,300
INDUSTRIAL PROCESSES											
Non-Metallic Mineral Production	843	781	839	947	1,020	1,060	1,070	1,120	1,080	1,040	1,190
Adipic & Nitric Acid Production	0	0	0	0	0	0	0	0	0	0	0
Ferrous Metal Production	0	0	0	0	0	0	0	0	0	0	0
Aluminum & Magnesium Production	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Other & Undifferentiated Production	710	760	570	940	1,100	1,200	660	710	530	680	800
INDUSTRIAL PROCESSES TOTAL	2,800	2,800	2,700	3,200	3,400	3,300	2,900	3,000	2,800	2,900	3,200
SOLVENT & OTHER PRODUCT USE	50	51	52	54	55	57	58	60	60	61	61
AGRICULTURE											
Enteric Fermentation	910	930	950	940	1,000	1,000	1,000	1,000	980	980	960
Manure Management	470	470	480	490	530	550	550	550	560	560	570
Agricultural Soils**	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	900	1,000	1,000
AGRICULTURE TOTAL	2,500	2,400	2,500	2,500	2,600	2,700	2,700	2,700	2,500	2,600	2,500
LAND USE CHANGE & FORESTRY*	2,000	2,000	2,000	2,000	1,000	1,000	700	500	900	600	800
WASTE											
Solid Waste Disposal on Land	3,400	3,700	3,800	3,800	3,900	4,000	4,300	4,400	4,500	4,600	4,700
Wastewater Handling	180	190	190	200	210	210	220	220	220	230	230
Waste Incineration	67	68	70	72	75	77	79	80	81	82	82
WASTE TOTAL	3,600	3,900	4,000	4,100	4,200	4,300	4,600	4,700	4,800	5,000	5,000
TOTAL	**52,700**	**52,700**	**51,600**	**54,400**	**56,600**	**60,600**	**62,500**	**61,300**	**62,100**	**64,100**	**65,900**

Notes:

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Emissions associated with the use of HFCs, PFCs, limestone and soda ash are reported in the national total.

** Only one significant figure shown due to high uncertainty.

* Methane and nitrous oxide emissions from prescribed fires and anthropogenic fires outside the Wood Production Forest. Fires located in national parks are not included in the provincial/territorial total but are reported in the national total.

1990 to 2000 Greenhouse Gas Emission Estimates for Northwest Territories and Nunavut, by Sector

GHG Source and Sink Category	1990	1991	1992	1993	1994	1995 All Gases kt CO_2 eq	1996	1997	1998	1999	2000
ENERGY											
FUEL COMBUSTION											
Fossil Fuel Industries	188	107	11	26	31	31	15	0	0	1	156
Electricity & Heat Generation	215	215	186	197	198	371	351	348	326	302	321
Mining	51	56	41	66	152	103	44	49	64	72	80
Manufacturing	32	21	23	9	14	21	18	10	0	0	2
Construction	8	7	8	7	4	20	1	1	0	1	0
Transport											
Light Duty Gasoline Vehicles	18	17	24	25	28	27	22	27	26	40	44
Light Duty Gasoline Trucks	8	8	12	13	15	16	14	18	18	31	36
Heavy Duty Gasoline Vehicles	1	1	2	2	3	3	3	3	3	6	7
Motorcycles	0	0	0	0	0	0	0	0	0	0	0
Off Road Gasoline	27	21	58	88	85	65	70	85	45	29	32
Light Duty Diesel Vehicles	0	0	0	0	0	0	0	0	0	0	0
Light Duty Diesel Trucks	2	1	1	0	1	1	1	1	3	1	1
Heavy Duty Diesel Vehicles	100	76	59	33	52	97	102	87	230	249	241
Off Road Diesel	27	8	73	214	236	150	285	295	228	172	221
Propane & Natural Gas Vehicles	2	2	3	2	6	4	2	2	2	2	1
Domestic Aviation	100	103	222	245	268	232	272	280	235	152	152
Domestic Marine	0	0	1	1	0	71	90	13	31	8	10
Railways	1	1	2	2	2	2	1	3	2	3	3
Vehicles Subtotal	285	238	457	627	694	669	863	813	823	691	749
Pipelines	0	0	0	0	2	0	0	0	5	4	5
Transport Subtotal	285	238	457	627	697	669	863	813	828	696	754
Residential	166	192	193	230	195	116	191	176	141	94	125
Commercial & Institutional	250	341	332	371	392	454	197	339	214	178	179
Other	2	10	12	2	2	0	0	0	0	0	0
COMBUSTION SUBTOTAL	1,200	1,190	1,260	1,530	1,690	1,780	1,680	1,740	1,570	1,340	1,620
FUGITIVE											
Solid Fuels (i.e., Coal Mining)	0	0	0	0	0	0	0	0	0	0	0
Oil & Gas	58	61	59	61	53	53	50	48	45	44	120
FUGITIVE SUBTOTAL	58	61	59	61	53	53	50	48	45	44	120
ENERGY TOTAL	1,250	1,250	1,320	1,600	1,740	1,840	1,730	1,780	1,620	1,390	1,740
INDUSTRIAL PROCESSES											
Non-Metallic Mineral Production	0	0	0	0	0	0	0	0	0	0	0
Adipic & Nitric Acid Production	0	0	0	0	0	0	0	0	0	0	0
Ferrous Metal Production	0	0	0	0	0	0	0	0	0	0	0
Aluminum & Magnesium Production	0	0	0	0	0	0	0	0	0	0	0
Other & Undifferentiated Production	3	11	2	24	100	84	64	3	1	3	4
INDUSTRIAL PROCESSES TOTAL	3	11	2	24	100	84	64	3	1	3	4
SOLVENT & OTHER PRODUCT USE	1	1	1	1	1	1	1	1	1	1	1
AGRICULTURE											
Enteric Fermentation	0	0	0	0	0	0	0	0	0	0	0
Manure Management	0	0	0	0	0	0	0	0	0	0	0
Agricultural Soils**	0	0	0	0	0	0	0	0	0	0	0
AGRICULTURE TOTAL	0	0	0	0	0	0	0	0	0	0	0
LAND USE CHANGE & FORESTRY*	6	20	70	100	80	400	10	4	20	8	60
WASTE											
Solid Waste Disposal on Land	7	7	8	8	8	9	9	9	10	10	10
Wastewater Handling	7	7	7	7	8	8	8	8	8	8	8
Waste Incineration	0	0	0	0	0	0	0	0	0	0	0
WASTE TOTAL	14	14	15	15	16	16	17	17	18	18	19
TOTAL	**1,280**	**1,300**	**1,400**	**1,760**	**1,930**	**2,390**	**1,820**	**1,810**	**1,660**	**1,420**	**1,830**

Notes:

Due to rounding, individual values may not add up to totals (zero values may represent estimated quantities too small to display).

Ammonia production emissions are included under undifferentiated production at the provincial level.

Emissions associated with the use of HFCs, PFCs, limestone and soda ash are reported in the national total.

** Only one significant figure shown due to high uncertainty.

* Methane and nitrous oxide emissions from prescribed fires and anthropogenic fires outside the Wood Production Forest. Fires located in national parks are not included in the provincial/territorial total but are reported in the national total.

1990 to 2000 Greenhouse Gas Emission Estimates for Yukon, by Sector

GHG Source and Sink Category	1990	1991	1992	1993	1994	1995 All Gases kt CO_2 eq	1996	1997	1998	1999	2000
ENERGY											
FUEL COMBUSTION											
Fossil Fuel Industries	3	3	92	60	50	92	75	81	93	90	82
Electricity & Heat Generation	96	59	54	31	28	55	104	89	33	27	17
Mining	3	3	0	1	2	9	12	4	3	3	0
Manufacturing	2	1	1	2	1	1	0	1	0	0	0
Construction	1	1	1	0	2	4	4	3	2	2	2
Transport											
Light Duty Gasoline Vehicles	33	28	84	85	76	74	68	65	74	73	54
Light Duty Gasoline Trucks	14	13	41	44	42	43	43	44	52	56	44
Heavy Duty Gasoline Vehicles	2	2	7	8	8	8	8	8	10	10	8
Motorcycles	0	0	0	0	0	0	0	0	0	0	0
Off Road Gasoline	4	3	8	9	8	11	10	9	9	6	5
Light Duty Diesel Vehicles	0	0	1	1	1	1	1	1	1	1	0
Light Duty Diesel Trucks	1	1	1	1	1	1	1	1	1	0	0
Heavy Duty Diesel Vehicles	62	68	59	55	105	115	120	70	85	90	90
Off Road Diesel	69	17	116	51	9	7	33	89	11	13	15
Propane & Natural Gas Vehicles	2	2	3	2	6	4	2	2	2	2	1
Domestic Aviation	100	103	18	19	22	25	31	19	27	26	30
Domestic Marine	0	0	0	0	0	0	0	0	0	0	0
Railways	1	1	0	0	0	0	0	0	0	0	0
Vehicles Subtotal	290	239	338	275	277	291	318	307	272	277	248
Pipelines	0	0	0	0	0	0	0	0	0	0	0
Transport Subtotal	290	239	338	275	277	291	318	307	272	277	248
Residential	20	15	12	22	27	17	22	25	32	38	31
Commercial & Institutional	71	68	61	56	49	52	37	36	33	33	37
Other	1	4	8	5	6	8	6	6	8	11	1
COMBUSTION SUBTOTAL	486	393	567	451	442	528	578	551	475	480	418
FUGITIVE											
Solid Fuels (i.e., Coal Mining)	0	0	0	0	0	0	0	0	0	0	0
Oil & Gas	0	20	47	48	45	42	40	38	43	59	53
FUGITIVE SUBTOTAL	0	20	47	48	45	42	40	38	43	59	53
ENERGY TOTAL	486	412	615	499	487	570	618	589	518	538	471
INDUSTRIAL PROCESSES											
Non-Metallic Mineral Production	0	0	0	0	0	0	0	0	0	0	0
Adipic & Nitric Acid Production	0	0	0	0	0	0	0	0	0	0	0
Ferrous Metal Production	0	0	0	0	0	0	0	0	0	0	0
Aluminum & Magnesium Production	0	0	0	0	0	0	0	0	0	0	0
Other & Undifferentiated Production	1	1	1	0	0	2	2	1	0	0	0
INDUSTRIAL PROCESSES TOTAL	1	1	1	0	0	2	2	1	0	0	0
SOLVENT & OTHER PRODUCT USE	0	0	0	0	0	0	0	0	0	0	0
AGRICULTURE											
Enteric Fermentation	0	0	0	0	0	0	0	0	0	0	0
Manure Management	0	0	0	0	0	0	0	0	0	0	0
Agricultural Soils**	0	0	0	0	0	0	0	0	0	0	0
AGRICULTURE TOTAL	0	0	0	0	0	0	0	0	0	0	0
LAND USE CHANGE & FORESTRY*	10	20	6	10	40	50	80	4	200	40	50
WASTE											
Solid Waste Disposal on Land	4	4	4	4	4	4	4	5	5	5	5
Wastewater Handling	3	3	4	4	3	4	4	4	4	4	4
Waste Incineration	0	0	0	0	0	0	0	0	0	0	0
WASTE TOTAL	7	7	7	7	8	8	8	8	8	8	8
TOTAL	**504**	**436**	**629**	**520**	**535**	**628**	**711**	**603**	**759**	**588**	**529**

Notes:

Due to rounding, individual values may not add up to totals (zero values may represent estimated quantities too small to display).

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Emissions associated with the use of HFCs, PFCs, limestone and soda ash are reported in the national total.

** Only one significant figure shown due to high uncertainty.

* Methane and nitrous oxide emissions from prescribed fires and anthropogenic fires outside the Wood Production Forest. Fires located in national parks are not included in the provincial/territorial total but are reported in the national total.

1990 to 2000 Greenhouse Gas Emission Estimates for Northwest Territories, Nunavut and Yukon, by Sector

GHG Source and Sink Category	1990	1991	1992	1993	1994	1995 All Gases kt CO_2 eq	1996	1997	1998	1999	2000
ENERGY											
FUEL COMBUSTION											
Fossil Fuel Industries	191	110	103	85	81	122	90	82	93	91	238
Electricity & Heat Generation	311	274	240	228	226	426	455	437	360	329	338
Mining	54	59	42	67	153	112	57	53	67	75	80
Manufacturing	33	22	24	10	15	21	19	10	0	0	2
Construction	9	8	8	7	6	25	4	3	2	3	2
Transport											
Light Duty Gasoline Vehicles	51	45	107	110	103	101	90	91	100	113	98
Light Duty Gasoline Trucks	22	21	53	57	57	59	57	62	70	86	80
Heavy Duty Gasoline Vehicles	4	4	9	11	11	12	11	11	13	16	15
Motorcycles	0	0	1	1	1	0	0	0	1	1	1
Off Road Gasoline	31	25	67	98	93	76	80	94	53	35	37
Light Duty Diesel Vehicles	1	1	1	1	1	1	1	1	1	1	1
Light Duty Diesel Trucks	3	3	2	1	2	2	2	2	4	1	1
Heavy Duty Diesel Vehicles	162	144	118	88	157	213	222	157	316	339	331
Off Road Diesel	96	24	189	265	244	157	318	383	239	184	236
Propane & Natural Gas Vehicles	3	3	6	5	12	8	4	4	3	3	1
Domestic Aviation	201	206	240	264	289	257	303	299	262	178	182
Domestic Marine	0	0	1	1	0	71	90	13	31	8	10
Railways	2	2	2	2	2	2	1	3	2	3	3
Vehicles Subtotal	575	476	795	902	972	960	1,180	1,120	1,100	968	997
Pipelines	0	0	0	0	2	0	0	0	5	4	5
Transport Subtotal	575	476	795	902	974	960	1,180	1,120	1,100	972	1,000
Residential	186	207	205	252	221	133	213	200	173	133	156
Commercial & Institutional	321	409	393	427	442	506	234	375	247	211	216
Other	3	14	21	7	8	8	6	6	8	11	1
COMBUSTION SUBTOTAL	1,680	1,580	1,830	1,990	2,130	2,310	2,260	2,290	2,050	1,820	2,040
FUGITIVE											
Solid Fuels (i.e., Coal Mining)	0	0	0	0	0	0	0	0	0	0	0
Oil & Gas	58	81	110	110	98	96	90	86	88	100	180
FUGITIVE SUBTOTAL	58	81	110	110	98	96	90	86	88	100	180
ENERGY TOTAL	1,700	1,700	1,900	2,100	2,200	2,400	2,300	2,400	2,100	1,900	2,200
INDUSTRIAL PROCESSES											
Non-Metallic Mineral Production	0	0	0	0	0	0	0	0	0	0	0
Adipic & Nitric Acid Production	0	0	0	0	0	0	0	0	0	0	0
Ferrous Metal Production	0	0	0	0	0	0	0	0	0	0	0
Aluminum & Magnesium Production	0	0	0	0	0	0	0	0	0	0	0
Other & Undifferentiated Production	4	11	2	24	100	86	66	4	2	3	4
INDUSTRIAL PROCESSES TOTAL	4	11	2	24	100	86	66	4	2	3	4
SOLVENT & OTHER PRODUCT USE	1	1	1	1	1	2	2	2	2	2	2
AGRICULTURE											
Enteric Fermentation	0	0	0	0	0	0	0	0	0	0	0
Manure Management	0	0	0	0	0	0	0	0	0	0	0
Agricultural Soils**	0	0	0	0	0	0	0	0	0	0	0
AGRICULTURE TOTAL	0	0	0	0	0	0	0	0	0	0	0
LAND USE CHANGE & FORESTRY*	20	40	70	100	100	500	90	8	300	50	100
WASTE											
Solid Waste Disposal on Land	11	11	11	12	12	13	13	14	14	15	15
Wastewater Handling	10	10	11	11	11	11	11	12	11	11	12
Waste Incineration	0	0	0	0	0	0	0	0	0	0	0
WASTE TOTAL	21	21	22	23	23	24	25	25	26	26	27
TOTAL	**1,780**	**1,740**	**2,030**	**2,280**	**2,470**	**3,020**	**2,530**	**2,410**	**2,420**	**2,010**	**2,350**

Notes:

Due to rounding, individual values may not add up to totals (zero values may represent estimated quantities too small to display).

Ammonia production emissions are included under undifferentiated production at the provincial level.

Emissions associated with the use of HFCs, PFCs, limestone and soda ash are reported in the national total.

** Only one significant figure shown due to high uncertainty.

* Methane and nitrous oxide emissions from prescribed fires and anthropogenic fires outside the Wood Production Forest. Fires located in national parks are not included in the provincial/territorial total but are reported in the national total.

APPENDIX F: CANADA'S GREENHOUSE GAS EMISSIONS BY GAS AND SECTOR, 1990–2000

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 Multiplier	*1* kt	kt	*21* kt CO_2 eq	kt	*310* kt CO_2 eq	*140–11 700* kt CO_2 eq	*6500–9200* kt CO_2 eq	*23900* kt CO_2 eq	kt CO_2 eq
ENERGY									
FUEL COMBUSTION									
Fossil Fuel Industries	49,500	78	1,600	1.0	310				51,500
Electricity & Heat Generation	94,700	1.8	38	1.8	550				95,300
Mining	6,150	0.1	2.7	0.1	37				6,190
Manufacturing	54,100	1.7	36	1.2	370				54,500
Construction	1,860	0.0	0.7	0.1	17				1,880
Transport									
Light Duty Gasoline Vehicles	51,500	8.9	190	6.3	1,900				53,700
Light Duty Gasoline Trucks	20,400	4.0	83	4.2	1,300				21,700
Heavy Duty Gasoline Vehicles	2,990	0.4	9	0.4	140				3,140
Motorcycles	225	0.2	3.8	0.0	1.4				230
Off Road Gasoline	4,860	5.6	120	0.1	32				5,010
Light Duty Diesel Vehicles	656	0.0	0.4	0.0	15				672
Light Duty Diesel Trucks	578	0.0	0.3	0.0	13				591
Heavy Duty Diesel Vehicles	24,300	1.2	25	0.7	220				24,600
Off Road Diesel	10,000	0.5	11	4.0	1,300				11,300
Propane & Natural Gas Vehicles	2,160	1.7	36	0.0	13				2,210
Domestic Aviation	10,400	0.7	14	1.0	320				10,700
Domestic Marine	4,730	0.4	7.4	1.0	310				5,050
Railways	6,310	0.4	7.3	2.5	790				7,110
Vehicles Subtotal	139,000	24	500	20	6,300				146,000
Pipelines	6,700	7	140	0.2	55				6,900
Transport Subtotal	146,000	31	640	21	6,400				153,000
Residential	41,300	100	2,100	1.7	530				44,000
Commercial & Institutional	25,700	0.5	10	0.5	150				25,800
Other	2,400	0.0	0.8	0.1	17				2,420
COMBUSTION SUBTOTAL	422,000	210	4,500	27	8,400				434,000
FUGITIVE									
Solid Fuels (i.e., Coal Mining)		91	1,900						1,900
Oil & Gas	9,800	1,200	26,000						36,000
FUGITIVE SUBTOTAL	9,800	1,300	28,000						38,000
ENERGY TOTAL	431,000	1,600	33,000	27	8,400				472,000
INDUSTRIAL PROCESSES									
Non-Metallic Mineral Production	8,160								8,160
Ammonia, Adipic Acid & Nitric Acid Production	5,010			37.0	11,000				17,000
Ferrous Metal Production	7,590								7,590
Aluminum & Magnesium Production	2,640						6,000	2,900	11,000
Other & Undifferentiated Production	9,200								9,200
INDUSTRIAL PROCESSES TOTAL	33,000			37.0	11,000		6,000	2,900	53,000
SOLVENT & OTHER PRODUCT USE	0	0	0	1.3	420				400
AGRICULTURE									
Enteric Fermentation		760	16,000						16,000
Manure Management		220	4,600	12	3,700				8,300
Agricultural Soils**	7,000			90	30,000				30,000
AGRICULTURE TOTAL	7,000	980	21,000	100	31,000				59,000
LAND USE CHANGE & FORESTRY*		70	1,000	3	1,000				2,000
WASTE									
Solid Waste Disposal on Land		880	19,000						19,000
Wastewater Handling		17	360	2.8	870				1,200
Waste Incineration	250	0.4	9.2	0.2	54				320
WASTE TOTAL	250	900	19,000	3.0	920				20,000
TOTAL	**472,000**	**3,500**	**73,000**	**170**	**53,000**	**0**	**6,000**	**2,900**	**607,000**
CO_2 from Land Use Change & Forestry**	-60,000								

Notes:

Due to rounding, individual values may not add up to totals (zero values may represent estimated quantities too small to display).

** Only one significant figure shown due to high uncertainty.

* Methane and nitrous oxide emissions from prescribed fires and anthropogenic fires outside the Wood Production Forest. Fires located in national parks are not included in the provincial/territorial total but are reported in the national total.

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 Multiplier	*1*		*21*		*310*	*140–11 700*	*6500–9200*	*23900*	
	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
ENERGY									
FUEL COMBUSTION									
Fossil Fuel Industries	47,600	74	1,500	1.0	300				49,500
Electricity & Heat Generation	96,100	1.7	36	1.8	550				96,700
Mining	5,000	0.1	2.3	0.1	32				5,030
Manufacturing	51,700	1.6	34	1.2	360				52,100
Construction	1,610	0.0	0.6	0.1	16				1,630
Transport									
Light Duty Gasoline Vehicles	48,900	8.3	170	6.7	2,100				51,200
Light Duty Gasoline Trucks	20,600	4.0	83	4.9	1,500				22,200
Heavy Duty Gasoline Vehicles	3,170	0.4	9	0.5	150				3,320
Motorcycles	215	0.2	3.6	0.0	1.3				220
Off Road Gasoline	4,420	5.1	110	0.1	29				4,550
Light Duty Diesel Vehicles	618	0.0	0.4	0.0	14				633
Light Duty Diesel Trucks	496	0.0	0.3	0.0	11				507
Heavy Duty Diesel Vehicles	23,600	1.2	24	0.7	210				23,900
Off Road Diesel	8,850	0.5	10	3.6	1,100				9,960
Propane & Natural Gas Vehicles	2,260	2.0	41	0.0	14				2,320
Domestic Aviation	9,240	0.6	11	0.9	280				9,530
Domestic Marine	4,940	0.4	7.9	1.0	300				5,250
Railways	5,850	0.3	6.7	2.4	730				6,590
Vehicles Subtotal	133,000	23	480	21	6,500				140,000
Pipelines	7,430	7	160	0.2	61				7,640
Transport Subtotal	141,000	30	630	21	6,500				148,000
Residential	39,800	95	2,000	1.7	510				42,300
Commercial & Institutional	26,300	0.5	10	0.5	160				26,500
Other	2,740	0.0	0.8	0.1	18				2,760
COMBUSTION SUBTOTAL	411,000	200	4,300	27	8,500				424,000
FUGITIVE									
Solid Fuels (i.e., Coal Mining)		99	2,100						2,100
Oil & Gas	10,000	1,300	27,000						38,000
FUGITIVE SUBTOTAL	10,000	1,400	30,000						40,000
ENERGY TOTAL	422,000	1,600	34,000	27	8,500				464,000
INDUSTRIAL PROCESSES									
Non-Metallic Mineral Production	6,980								6,980
Ammonia, Adipic Acid & Nitric Acid Production	4,940			35.0	11,000				16,000
Ferrous Metal Production	8,900								8,900
Aluminum & Magnesium Production	3,010						6,000	3,300	13,000
Other & Undifferentiated Production	9,600								9,600
INDUSTRIAL PROCESSES TOTAL	33,000			35.0	11,000		6,000	3,300	54,000
SOLVENT & OTHER PRODUCT USE	0	0	0	1.4	420				400
AGRICULTURE									
Enteric Fermentation		770	16,000						16,000
Manure Management		220	4,600	12	3,700				8,300
Agricultural Soils**	7,000			90	30,000				30,000
AGRICULTURE TOTAL	7,000	990	21,000	98	30,000				58,000
LAND USE CHANGE & FORESTRY*		90	2,000	5	1,000				3,000
WASTE									
Solid Waste Disposal on Land		910	19,000						19,000
Wastewater Handling		17	360	2.8	880				1,200
Waste Incineration	260	0.5	9.5	0.2	54				320
WASTE TOTAL	260	930	20,000	3.0	930				21,000
TOTAL	**462,000**	**3,600**	**76,000**	**170**	**52,000**	**0**	**6,000**	**3,300**	**600,000**
CO_2 from Land Use Change & Forestry**	-60,000								

Notes:
Due to rounding, individual values may not add up to totals (zero values may represent estimated quantities too small to display).
** Only one significant figure shown due to high uncertainty.
* Methane and nitrous oxide emissions from prescribed fires and anthropogenic fires outside the Wood Production Forest. Fires located in national parks are not included in the provincial/territorial total but are reported in the national total.

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 Multiplier	*1*		*21*		*310*	*140–11 700*	*6500–9200*	*23900*	
	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
ENERGY									
FUEL COMBUSTION									
Fossil Fuel Industries	50,100	77	1,600	1.0	310				52,100
Electricity & Heat Generation	102,000	2.3	49	1.9	590				103,000
Mining	4,760	0.1	2.2	0.1	33				4,790
Manufacturing	51,100	1.6	34	1.1	360				51,500
Construction	1,730	0.0	0.6	0.1	17				1,750
Transport									
Light Duty Gasoline Vehicles	49,100	8.1	170	7.5	2,300				51,600
Light Duty Gasoline Trucks	22,100	4.2	88	5.9	1,800				24,000
Heavy Duty Gasoline Vehicles	3,560	0.5	10	0.5	160				3,730
Motorcycles	213	0.2	3.6	0.0	1.3				218
Off Road Gasoline	3,540	4.0	85	0.1	23				3,640
Light Duty Diesel Vehicles	617	0.0	0.4	0.0	14				631
Light Duty Diesel Trucks	445	0.0	0.3	0.0	10				456
Heavy Duty Diesel Vehicles	24,100	1.2	25	0.7	220				24,300
Off Road Diesel	8,420	0.4	9	3.4	1,100				9,480
Propane & Natural Gas Vehicles	2,610	2.2	47	0.1	16				2,680
Domestic Aviation	9,430	0.5	11	0.9	290				9,720
Domestic Marine	4,790	0.4	7.5	1.0	300				5,100
Railways	6,120	0.3	7.1	2.5	760				6,890
Vehicles Subtotal	135,000	22	460	23	7,000				143,000
Pipelines	9,610	10	200	0.3	78				9,890
Transport Subtotal	145,000	32	670	23	7,100				152,000
Residential	41,000	94	2,000	1.7	510				43,500
Commercial & Institutional	26,900	0.5	10	0.5	160				27,000
Other	3,250	0.0	1.0	0.1	24				3,270
COMBUSTION SUBTOTAL	426,000	210	4,400	29	9,100				439,000
FUGITIVE									
Solid Fuels (i.e., Coal Mining)		87	1,800						1,800
Oil & Gas	11,000	1,400	30,000						41,000
FUGITIVE SUBTOTAL	11,000	1,500	32,000						42,000
ENERGY TOTAL	436,000	1,700	36,000	29	9,100				482,000
INDUSTRIAL PROCESSES									
Non-Metallic Mineral Production	6,640								6,640
Ammonia, Adipic Acid & Nitric Acid Production	5,110			35.0	11,000				16,000
Ferrous Metal Production	9,080								9,080
Aluminum & Magnesium Production	3,210						7,000	2,200	12,000
Other & Undifferentiated Production	9,000								9,000
INDUSTRIAL PROCESSES TOTAL	33,000			35.0	11,000		7,000	2,200	53,000
SOLVENT & OTHER PRODUCT USE	0	0	0	1.4	430				400
AGRICULTURE									
Enteric Fermentation		790	17,000						17,000
Manure Management		220	4,700	12	3,800				8,500
Agricultural Soils**	6,000			90	30,000				30,000
AGRICULTURE TOTAL	6,000	1,000	21,000	100	31,000				58,000
LAND USE CHANGE & FORESTRY*		70	1,000	4	1,000				3,000
WASTE									
Solid Waste Disposal on Land		930	20,000						20,000
Wastewater Handling		17	360	2.9	890				1,300
Waste Incineration	260	0.5	10.0	0.2	55				330
WASTE TOTAL	260	950	20,000	3.0	940				21,000
TOTAL	**475,000**	**3,700**	**79,000**	**170**	**53,000**	**0**	**7,000**	**2,200**	**616,000**
CO_2 from Land Use Change & Forestry**	-50,000								

Notes:

Due to rounding, individual values may not add up to totals (zero values may represent estimated quantities too small to display).

** Only one significant figure shown due to high uncertainty.

* Methane and nitrous oxide emissions from prescribed fires and anthropogenic fires outside the Wood Production Forest. Fires located in national parks are not included in the provincial/territorial total but are reported in the national total.

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 Multiplier	*1*		*21*		*310*	*140–11 700*	*6500–9200*	*23900*	
	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
ENERGY									
FUEL COMBUSTION									
Fossil Fuel Industries	50,600	77	1,600	1.0	310				52,600
Electricity & Heat Generation	93,200	2.5	53	1.8	550				93,800
Mining	7,320	0.2	3.2	0.2	48				7,370
Manufacturing	48,700	1.5	32	1.1	340				49,100
Construction	1,370	0.0	0.5	0.0	10				1,390
Transport									
Light Duty Gasoline Vehicles	49,100	7.8	160	8.2	2,500				51,800
Light Duty Gasoline Trucks	23,300	4.3	91	6.9	2,100				25,600
Heavy Duty Gasoline Vehicles	3,880	0.5	11	0.6	180				4,070
Motorcycles	214	0.2	3.6	0.0	1.3				219
Off Road Gasoline	3,740	4.3	90	0.1	25				3,850
Light Duty Diesel Vehicles	610	0.0	0.4	0.0	14				624
Light Duty Diesel Trucks	420	0.0	0.2	0.0	9.5				429
Heavy Duty Diesel Vehicles	25,400	1.2	26	0.7	230				25,700
Off Road Diesel	9,640	0.5	10	3.9	1,200				10,900
Propane & Natural Gas Vehicles	1,970	2.0	43	0.0	12				2,030
Domestic Aviation	9,120	0.5	11	0.9	280				9,410
Domestic Marine	4,190	0.3	6.5	0.9	280				4,480
Railways	6,090	0.3	7.0	2.5	760				6,860
Vehicles Subtotal	138,000	22	470	25	7,700				146,000
Pipelines	10,100	10	210	0.3	82				10,400
Transport Subtotal	148,000	32	680	25	7,800				156,000
Residential	42,900	99	2,100	1.7	530				45,500
Commercial & Institutional	27,900	0.5	10	0.6	170				28,100
Other	3,040	0.0	1.0	0.1	22				3,060
COMBUSTION SUBTOTAL	423,000	210	4,500	31	9,700				437,000
FUGITIVE									
Solid Fuels (i.e., Coal Mining)		87	1,800						1,800
Oil & Gas	11,000	1,500	31,000						43,000
FUGITIVE SUBTOTAL	11,000	1,600	33,000						44,000
ENERGY TOTAL	434,000	1,800	37,000	31	9,700				482,000
INDUSTRIAL PROCESSES									
Non-Metallic Mineral Production	6,880								6,880
Ammonia, Adipic Acid & Nitric Acid Production	5,690			32.0	9,900				16,000
Ferrous Metal Production	8,760								8,760
Aluminum & Magnesium Production	3,770						7,000	2,000	13,000
Other & Undifferentiated Production	9,700								9,700
INDUSTRIAL PROCESSES TOTAL	35,000			32.0	9,900		7,000	2,000	54,000
SOLVENT & OTHER PRODUCT USE	0	0	0	1.4	430				400
AGRICULTURE									
Enteric Fermentation		800	17,000						17,000
Manure Management		220	4,600	12	3,900				8,500
Agricultural Soils**	5,000			90	30,000				30,000
AGRICULTURE TOTAL	5,000	1,000	21,000	100	32,000				58,000
LAND USE CHANGE & FORESTRY*		80	2,000	5	1,000				3,000
WASTE									
Solid Waste Disposal on Land		960	20,000						20,000
Wastewater Handling		18	370	2.9	900				1,300
Waste Incineration	260	0.3	6.5	0.2	56				330
WASTE TOTAL	260	970	20,000	3.1	950				22,000
TOTAL	**474,000**	**3,900**	**81,000**	**180**	**54,000**	**0**	**7,000**	**2,000**	**619,000**
CO_2 from Land Use Change & Forestry**	-40,000								

Notes:

Due to rounding, individual values may not add up to totals (zero values may represent estimated quantities too small to display).

** Only one significant figure shown due to high uncertainty.

* Methane and nitrous oxide emissions from prescribed fires and anthropogenic fires outside the Wood Production Forest. Fires located in national parks are not included in the provincial/territorial total but are reported in the national total.

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 Multiplier	*1* kt	 kt	*21* kt CO_2 eq	 kt	*310* kt CO_2 eq	*140–11 700* kt CO_2 eq	*6500–9200* kt CO_2 eq	*23900* kt CO_2 eq	 kt CO_2 eq
ENERGY									
FUEL COMBUSTION									
Fossil Fuel Industries	51,300	81	1,700	1.0	310				53,400
Electricity & Heat Generation	95,400	2.6	54	1.8	570				96,000
Mining	7,440	0.2	3.2	0.2	53				7,490
Manufacturing	51,800	1.6	34	1.1	350				52,200
Construction	1,390	0.0	0.5	0.0	10				1,400
Transport									
Light Duty Gasoline Vehicles	49,400	7.6	160	8.9	2,800				52,300
Light Duty Gasoline Trucks	24,900	4.5	95	7.9	2,500				27,400
Heavy Duty Gasoline Vehicles	4,270	0.6	13	0.6	200				4,480
Motorcycles	216	0.2	3.6	0.0	1.3				221
Off Road Gasoline	3,810	4.4	92	0.1	25				3,930
Light Duty Diesel Vehicles	603	0.0	0.4	0.0	14				617
Light Duty Diesel Trucks	423	0.0	0.2	0.0	9.6				432
Heavy Duty Diesel Vehicles	28,200	1.4	29	0.8	260				28,500
Off Road Diesel	10,600	0.6	11	4.3	1,300				12,000
Propane & Natural Gas Vehicles	1,870	2.0	42	0.0	11				1,920
Domestic Aviation	9,770	0.5	11	1.0	300				10,100
Domestic Marine	4,350	0.3	6.6	1.0	300				4,660
Railways	6,310	0.4	7.3	2.5	790				7,100
Vehicles Subtotal	145,000	22	470	27	8,400				154,000
Pipelines	10,500	10	220	0.3	85				10,800
Transport Subtotal	155,000	33	690	27	8,500				164,000
Residential	43,700	99	2,100	1.8	540				46,300
Commercial & Institutional	27,300	0.5	11	0.6	180				27,400
Other	2,540	0.0	0.8	0.1	19				2,560
COMBUSTION SUBTOTAL	436,000	220	4,600	34	11,000				451,000
FUGITIVE									
Solid Fuels (i.e., Coal Mining)		84	1,800						1,800
Oil & Gas	12,000	1,600	33,000						45,000
FUGITIVE SUBTOTAL	12,000	1,700	35,000						47,000
ENERGY TOTAL	448,000	1,900	39,000	34	11,000				498,000
INDUSTRIAL PROCESSES									
Non-Metallic Mineral Production	7,510								7,510
Ammonia, Adipic Acid & Nitric Acid Production	5,810			38.0	12,000				18,000
Ferrous Metal Production	8,090								8,090
Aluminum & Magnesium Production	3,680						7,000	2,000	13,000
Other & Undifferentiated Production	11,000								11,000
INDUSTRIAL PROCESSES TOTAL	36,000			38.0	12,000		7,000	2,000	56,000
SOLVENT & OTHER PRODUCT USE	0	0	0	1.4	440				400
AGRICULTURE									
Enteric Fermentation		830	18,000						18,000
Manure Management		230	4,800	13	4,100				8,900
Agricultural Soils**	4,000			100	30,000				30,000
AGRICULTURE TOTAL	4,000	1,100	22,000	110	34,000				60,000
LAND USE CHANGE & FORESTRY*		90	2,000	7	2,000				4,000
WASTE									
Solid Waste Disposal on Land		970	20,000						20,000
Wastewater Handling		18	370	2.9	910				1,300
Waste Incineration	270	0.3	6.5	0.2	56				330
WASTE TOTAL	270	980	21,000	3.1	960				22,000
TOTAL	**488,000**	**4,000**	**84,000**	**190**	**60,000**	**0**	**7,000**	**2,000**	**641,000**
CO_2 from Land Use Change & Forestry**	-30,000								

Notes:

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** Only one significant figure shown due to high uncertainty.

* Methane and nitrous oxide emissions from prescribed fires and anthropogenic fires outside the Wood Production Forest. Fires located in national parks are not included in the provincial/territorial total but are reported in the national total.

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 Multiplier	*1*		*21*		*310*	*140–11 700*	*6500–9200*	*23900*	
	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
ENERGY									
FUEL COMBUSTION									
Fossil Fuel Industries	52,600	83	1,700	1.0	320				54,700
Electricity & Heat Generation	100,000	3.0	63	1.9	600				101,000
Mining	7,800	0.2	3.4	0.2	59				7,860
Manufacturing	52,500	1.7	36	1.2	370				52,900
Construction	1,170	0.0	0.4	0.0	10				1,180
Transport									
Light Duty Gasoline Vehicles	48,400	7.1	150	9.0	2,800				51,300
Light Duty Gasoline Trucks	25,800	4.5	95	8.5	2,600				28,500
Heavy Duty Gasoline Vehicles	4,530	0.6	13	0.7	210				4,760
Motorcycles	209	0.2	3.5	0.0	1.3				214
Off Road Gasoline	3,820	4.4	92	0.1	25				3,940
Light Duty Diesel Vehicles	581	0.0	0.3	0.0	13				594
Light Duty Diesel Trucks	407	0.0	0.2	0.0	9.2				416
Heavy Duty Diesel Vehicles	30,500	1.5	31	0.9	280				30,800
Off Road Diesel	11,200	0.6	12	4.5	1,400				12,700
Propane & Natural Gas Vehicles	2,050	2.0	43	0.0	12				2,100
Domestic Aviation	10,500	0.6	12	1.0	320				10,900
Domestic Marine	4,060	0.3	6.0	1.0	310				4,380
Railways	5,710	0.3	6.6	2.3	710				6,430
Vehicles Subtotal	148,000	22	460	28	8,700				157,000
Pipelines	11,700	12	240	0.3	95				12,000
Transport Subtotal	159,000	34	710	28	8,800				169,000
Residential	42,400	95	2,000	1.7	530				44,900
Commercial & Institutional	28,800	0.5	11	0.6	200				29,000
Other	2,770	0.0	0.8	0.1	21				2,790
COMBUSTION SUBTOTAL	448,000	220	4,600	35	11,000				463,000
FUGITIVE									
Solid Fuels (i.e., Coal Mining)		82	1,700						1,700
Oil & Gas	13,000	1,700	35,000						48,000
FUGITIVE SUBTOTAL	13,000	1,800	37,000						50,000
ENERGY TOTAL	461,000	2,000	41,000	35	11,000				513,000
INDUSTRIAL PROCESSES									
Non-Metallic Mineral Production	7,690								7,690
Ammonia, Adipic Acid & Nitric Acid Production	6,480			37.0	12,000				18,000
Ferrous Metal Production	8,440								8,440
Aluminum & Magnesium Production	3,540						6,000	1,900	11,000
Other & Undifferentiated Production	10,000					500	30		11,000
INDUSTRIAL PROCESSES TOTAL	36,000			37.0	12,000	500	6,000	1,900	56,000
SOLVENT & OTHER PRODUCT USE	0	0	0	1.4	440				400
AGRICULTURE									
Enteric Fermentation		860	18,000						18,000
Manure Management		240	5,000	14	4,200				9,200
Agricultural Soils**	3,000			100	30,000				30,000
AGRICULTURE TOTAL	3,000	1,100	23,000	110	35,000				61,000
LAND USE CHANGE & FORESTRY*		100	2,000	9	3,000				5,000
WASTE									
Solid Waste Disposal on Land		970	20,000						20,000
Wastewater Handling		18	380	3.0	920				1,300
Waste Incineration	270	0.3	7.2	0.2	57				330
WASTE TOTAL	270	990	21,000	3.1	980				22,000
TOTAL	**501,000**	**4,200**	**88,000**	**200**	**61,000**	**900**	**6,000**	**1,900**	**658,000**
CO_2 from Land Use Change & Forestry**	-20,000								

Notes:

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** Only one significant figure shown due to high uncertainty.

* Methane and nitrous oxide emissions from prescribed fires and anthropogenic fires outside the Wood Production Forest. Fires located in national parks are not included in the provincial/territorial total but are reported in the national total.

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 Multiplier	*1*		*21*		*310*	*140–11 700*	*6500–9200*	*23900*	
	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
ENERGY									
FUEL COMBUSTION									
Fossil Fuel Industries	53,200	84	1,800	1.1	330				55,300
Electricity & Heat Generation	99,100	2.6	55	1.9	590				99,700
Mining	8,680	0.2	3.7	0.2	60				8,740
Manufacturing	54,300	1.7	35	1.2	360				54,700
Construction	1,260	0.0	0.4	0.0	10				1,270
Transport									
Light Duty Gasoline Vehicles	47,100	6.5	140	8.5	2,600				49,900
Light Duty Gasoline Trucks	27,100	4.6	96	8.6	2,700				29,900
Heavy Duty Gasoline Vehicles	4,750	0.7	14	0.7	220				4,980
Motorcycles	205	0.2	3.4	0.0	1.2				210
Off Road Gasoline	4,540	5.2	110	0.1	30				4,680
Light Duty Diesel Vehicles	588	0.0	0.3	0.0	13				602
Light Duty Diesel Trucks	393	0.0	0.2	0.0	8.9				402
Heavy Duty Diesel Vehicles	32,100	1.6	33	0.9	290				32,500
Off Road Diesel	11,700	0.6	13	4.7	1,500				13,200
Propane & Natural Gas Vehicles	1,930	1.9	40	0.0	12				1,980
Domestic Aviation	11,600	0.6	13	1.1	350				11,900
Domestic Marine	4,160	0.3	6.2	1.0	310				4,470
Railways	5,580	0.3	6.4	2.3	700				6,290
Vehicles Subtotal	152,000	22	470	28	8,700				161,000
Pipelines	12,200	12	250	0.3	98				12,500
Transport Subtotal	164,000	34	720	28	8,800				173,000
Residential	47,100	94	2,000	1.8	550				49,700
Commercial & Institutional	29,400	0.5	11	0.6	190				29,600
Other	2,930	0.0	0.9	0.1	20				2,950
COMBUSTION SUBTOTAL	460,000	220	4,600	35	11,000				475,000
FUGITIVE									
Solid Fuels (i.e., Coal Mining)		84	1,800						1,800
Oil & Gas	13,000	1,800	37,000						51,000
FUGITIVE SUBTOTAL	13,000	1,900	39,000						53,000
ENERGY TOTAL	473,000	2,100	44,000	35	11,000				528,000
INDUSTRIAL PROCESSES									
Non-Metallic Mineral Production	8,030								8,030
Ammonia, Adipic Acid & Nitric Acid Production	6,520			40.0	12,000				19,000
Ferrous Metal Production	8,290								8,290
Aluminum & Magnesium Production	3,730						6,000	1,400	11,000
Other & Undifferentiated Production	11,000					900	20		12,000
INDUSTRIAL PROCESSES TOTAL	38,000			40.0	12,000	900	6,000	1,400	58,000
SOLVENTS & OTHER PRODUCT USE	0	0	0	1.4	450				400
AGRICULTURE									
Enteric Fermentation		870	18,000						18,000
Manure Management		240	5,100	14	4,300				9,300
Agricultural Soils**	2,000			100	30,000				30,000
AGRICULTURE TOTAL	2,000	1,100	23,000	120	36,000				61,000
LAND USE CHANGE & FORESTRY*		40	800	3	800				2,000
WASTE									
Solid Waste Disposal on Land		970	20,000						20,000
Wastewater Handling		18	380	3.0	930				1,300
Waste Incineration	270	0.3	6.9	0.2	58				340
WASTE TOTAL	270	990	21,000	3.2	990				22,000
TOTAL	**513,000**	**4,200**	**89,000**	**200**	**62,000**	**900**	**6,000**	**1,400**	**672,000**
CO_2 from Land Use Change & Forestry**	-20,000								

Notes:

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** Only one significant figure shown due to high uncertainty.

* Methane and nitrous oxide emissions from prescribed fires and anthropogenic fires outside the Wood Production Forest. Fires located in national parks are not included in the provincial/territorial total but are reported in the national total.

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 Multiplier	*1*		*21*		*310*	*140–11 700*	*6500–9200*	*23900*	
	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
ENERGY									
FUEL COMBUSTION									
Fossil Fuel Industries	49,100	78	1,600	1.0	310				51,000
Electricity & Heat Generation	111,000	3.2	67	2.1	650				111,000
Mining	8,900	0.2	3.8	0.2	63				8,970
Manufacturing	54,200	1.7	35	1.2	360				54,600
Construction	1,250	0.0	0.4	0.0	10				1,260
Transport									
Light Duty Gasoline Vehicles	47,300	6.0	130	8.3	2,600				50,000
Light Duty Gasoline Trucks	29,100	4.6	97	8.9	2,800				32,000
Heavy Duty Gasoline Vehicles	4,820	0.7	14	0.7	220				5,050
Motorcycles	216	0.2	3.6	0.0	1.3				221
Off Road Gasoline	4,180	4.8	100	0.1	27				4,310
Light Duty Diesel Vehicles	587	0.0	0.3	0.0	13				600
Light Duty Diesel Trucks	494	0.0	0.3	0.0	11				505
Heavy Duty Diesel Vehicles	35,200	1.7	36	1.0	320				35,500
Off Road Diesel	12,500	0.6	14	5.1	1,600				14,100
Propane & Natural Gas Vehicles	1,790	2.1	43	0.0	11				1,840
Domestic Aviation	12,100	0.6	13	1.2	370				12,400
Domestic Marine	4,220	0.3	6.3	1.0	300				4,530
Railways	5,660	0.3	6.5	2.3	710				6,380
Vehicles Subtotal	158,000	22	460	29	8,900				168,000
Pipelines	12,200	12	260	0.3	100				12,500
Transport Subtotal	170,000	34	720	29	9,000				180,000
Residential	43,800	94	2,000	1.7	530				46,400
Commercial & Institutional	29,800	0.5	11	0.7	200				30,000
Other	2,920	0.0	0.9	0.1	21				2,940
COMBUSTION SUBTOTAL	471,000	210	4,500	36	11,000				487,000
FUGITIVE									
Solid Fuels (i.e., Coal Mining)		78	1,600						1,600
Oil & Gas	14,000	1,800	38,000						51,000
FUGITIVE SUBTOTAL	14,000	1,900	39,000						53,000
ENERGY TOTAL	485,000	2,100	44,000	36	11,000				539,000
INDUSTRIAL PROCESSES									
Non-Metallic Mineral Production	8,180								8,180
Ammonia, Adipic Acid & Nitric Acid Production	6,680			34.0	11,000				17,000
Ferrous Metal Production	8,100								8,100
Aluminum & Magnesium Production	3,790						6,000	1,400	11,000
Other & Undifferentiated Production	12,000					900	20		12,000
INDUSTRIAL PROCESSES TOTAL	38,000			34.0	11,000	900	6,000	1,400	57,000
SOLVENT & OTHER PRODUCT USE	0	0	0	1.5	450				500
AGRICULTURE									
Enteric Fermentation		870	18,000						18,000
Manure Management		240	5,000	14	4,300				9,300
Agricultural Soils**	1,000			100	30,000				30,000
AGRICULTURE TOTAL	1,000	1,100	23,000	120	36,000				61,000
LAND USE CHANGE & FORESTRY*		20	500	1	400				900
WASTE									
Solid Waste Disposal on Land		1,000	21,000						21,000
Wastewater Handling		19	390	3.0	940				1,300
Waste Incineration	280	0.3	6.9	0.2	58				340
WASTE TOTAL	280	1,000	21,000	3.2	1,000				23,000
TOTAL	**525,000**	**4,200**	**89,000**	**190**	**60,000**	**900**	**6,000**	**1,400**	**682,000**
CO_2 from Land Use Change & Forestry**	-20,000								

Notes:

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** Only one significant figure shown due to high uncertainty.

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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 Multiplier	*1*		*21*		*310*	*140–11 700*	*6500–9200*	*23900*	
	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
ENERGY									
FUEL COMBUSTION									
Fossil Fuel Industries	54,300	92	1,900	1.1	350				56,500
Electricity & Heat Generation	123,000	3.9	82	2.3	720				124,000
Mining	7,960	0.2	3.4	0.2	58				8,020
Manufacturing	52,000	1.7	36	1.2	360				52,400
Construction	1,110	0.0	0.4	0.0	10				1,120
Transport									
Light Duty Gasoline Vehicles	47,100	5.5	120	8.0	2,500				49,700
Light Duty Gasoline Trucks	30,000	4.5	94	8.7	2,700				32,800
Heavy Duty Gasoline Vehicles	5,240	0.7	15	0.8	240				5,490
Motorcycles	227	0.2	3.8	0.0	1.4				232
Off Road Gasoline	5,670	6.5	140	0.1	37				5,840
Light Duty Diesel Vehicles	583	0.0	0.3	0.0	13				597
Light Duty Diesel Trucks	445	0.0	0.3	0.0	10				455
Heavy Duty Diesel Vehicles	35,200	1.7	36	1.0	320				35,600
Off Road Diesel	13,100	0.7	14	5.3	1,600				14,800
Propane & Natural Gas Vehicles	1,730	2.1	44	0.0	11				1,780
Domestic Aviation	12,600	0.6	13	1.2	380				13,000
Domestic Marine	4,830	0.4	7.6	1.0	310				5,150
Railways	5,460	0.3	6.3	2.2	680				6,140
Vehicles Subtotal	162,000	23	490	29	8,800				171,000
Pipelines	12,100	12	250	0.3	99				12,500
Transport Subtotal	174,000	35	740	29	8,900				184,000
Residential	38,400	95	2,000	1.7	510				41,000
Commercial & Institutional	27,000	0.5	10	0.6	180				27,200
Other	2,590	0.0	0.8	0.1	17				2,610
COMBUSTION SUBTOTAL	481,000	230	4,800	36	11,000				496,000
FUGITIVE									
Solid Fuels (i.e., Coal Mining)		65	1,400						1,400
Oil & Gas	14,000	1,800	37,000						51,000
FUGITIVE SUBTOTAL	14,000	1,800	39,000						52,000
ENERGY TOTAL	494,000	2,100	43,000	36	11,000				549,000
INDUSTRIAL PROCESSES									
Non-Metallic Mineral Production	8,680								8,680
Ammonia, Adipic Acid & Nitric Acid Production	6,610			19.0	5,800				12,000
Ferrous Metal Production	8,320								8,320
Aluminum & Magnesium Production	3,820						6,000	1,500	11,000
Undifferentiated Production and Product Use	11,000					900	20		12,000
INDUSTRIAL PROCESSES TOTAL	39,000			19.0	5,800	900	6,000	1,500	53,000
SOLVENT & OTHER PRODUCT USE	0	0	0	1.5	460				500
AGRICULTURE									
Enteric Fermentation		860	18,000						18,000
Manure Management		240	5,100	14	4,300				9,400
Agricultural Soils**	700			100	30,000				30,000
AGRICULTURE TOTAL	700	1,100	23,000	120	37,000				61,000
LAND USE CHANGE & FORESTRY*		70	1,000	5	2,000				3,000
WASTE									
Solid Waste Disposal on Land		1,000	21,000						21,000
Wastewater Handling		19	390	3.1	950				1,300
Waste Incineration	280	0.3	6.9	0.2	58				340
WASTE TOTAL	280	1,000	22,000	3.2	1,000				23,000
TOTAL	**534,000**	**4,300**	**90,000**	**180**	**57,000**	**900**	**6,000**	**1,500**	**689,000**
CO_2 from Land Use Change & Forestry**	-30,000								

Notes:

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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 Multiplier	*1*		*21*		*310*	*140–11 700*	*6500–9200*	*23900*	
	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
ENERGY									
FUEL COMBUSTION									
Fossil Fuel Industries	62,600	110	2,400	1.3	410				65,400
Electricity & Heat Generation	121,000	3.9	81	2.3	700				121,000
Mining	7,390	0.2	3.1	0.2	54				7,450
Manufacturing	52,400	1.7	36	1.2	370				52,800
Construction	1,160	0.0	0.4	0.0	10				1,170
Transport									
Light Duty Gasoline Vehicles	47,100	5.0	110	7.7	2,400				49,600
Light Duty Gasoline Trucks	32,500	4.5	95	9.0	2,800				35,300
Heavy Duty Gasoline Vehicles	5,390	0.8	16	0.8	250				5,660
Motorcycles	227	0.2	3.8	0.0	1.4				232
Off Road Gasoline	5,210	6.0	130	0.1	34				5,370
Light Duty Diesel Vehicles	404	0.0	0.2	0.0	9				414
Light Duty Diesel Trucks	136	0.0	0.1	0.0	3.1				139
Heavy Duty Diesel Vehicles	36,900	1.8	38	1.1	340				37,300
Off Road Diesel	13,900	0.7	15	5.6	1,700				15,700
Propane & Natural Gas Vehicles	1,450	1.7	37	0.0	8.8				1,500
Domestic Aviation	13,200	0.6	13	1.3	400				13,600
Domestic Marine	4,650	0.3	7.1	1.0	320				4,970
Railways	5,780	0.3	6.7	2.3	720				6,510
Vehicles Subtotal	167,000	22	460	29	9,000				176,000
Pipelines	12,200	12	260	0.3	100				12,600
Transport Subtotal	179,000	34	720	29	9,100				189,000
Residential	40,500	95	2,000	1.7	520				43,000
Commercial & Institutional	28,700	0.5	11	0.6	190				28,900
Other	2,670	0.0	0.8	0.1	18				2,690
COMBUSTION SUBTOTAL	495,000	250	5,200	37	11,000				512,000
FUGITIVE									
Solid Fuels (i.e., Coal Mining)		51	1,100						1,100
Oil & Gas	14,000	1,800	37,000						52,000
FUGITIVE SUBTOTAL	14,000	1,800	38,000						53,000
ENERGY TOTAL	509,000	2,100	44,000	37	11,000				564,000
INDUSTRIAL PROCESSES									
Non-Metallic Mineral Production	9,100								9,100
Ammonia, Adipic Acid & Nitric Acid Production	6,850			8.2	2,500				9,400
Ferrous Metal Production	8,500								8,500
Aluminum & Magnesium Production	3,920						6,000	1,700	12,000
Undifferentiated Production and Product Use	12,000					900	20		13,000
INDUSTRIAL PROCESSES TOTAL	40,000			8.2	2,500	900	6,000	1,700	52,000
SOLVENT & OTHER PRODUCT USE	0	0	0	1.5	460				500
AGRICULTURE									
Enteric Fermentation		850	18,000						18,000
Manure Management		240	5,100	14	4,300				9,400
Agricultural Soils**	200			100	30,000				30,000
AGRICULTURE TOTAL	200	1,100	23,000	120	38,000				61,000
LAND USE CHANGE & FORESTRY*		60	1,000	4	1,000				2,000
WASTE									
Solid Waste Disposal on Land		1,100	22,000						22,000
Wastewater Handling		19	400	3.1	950				1,300
Waste Incineration	280	0.3	6.9	0.2	59				350
WASTE TOTAL	280	1,100	23,000	3.3	1,000				24,000
TOTAL	**550,000**	**4,300**	**90,000**	**180**	**54,000**	**900**	**6,000**	**1,700**	**703,000**
CO_2 from Land Use Change & Forestry**	-10,000								

Notes:
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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 Multiplier	*1*		*21*		*310*	*140–11 700*	*6500–9200*	*23900*	
	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
ENERGY									
FUEL COMBUSTION									
Fossil Fuel Industries	63,900	120	2,500	1.4	430				66,800
Electricity & Heat Generation	128,000	4.4	92	2.4	740				128,000
Mining	9,200	0.2	3.9	0.2	71				9,270
Manufacturing	57,500	1.9	39	1.3	400				57,900
Construction	1,070	0.0	0.4	0.0	8				1,080
Transport									
Light Duty Gasoline Vehicles	46,000	4.5	95	7.2	2,200				48,300
Light Duty Gasoline Trucks	33,600	4.4	93	8.7	2,700				36,400
Heavy Duty Gasoline Vehicles	5,570	0.8	16	0.8	260				5,850
Motorcycles	234	0.2	3.9	0.0	1.4				239
Off Road Gasoline	5,110	5.8	120	0.1	34				5,270
Light Duty Diesel Vehicles	400	0.0	0.2	0.0	9				410
Light Duty Diesel Trucks	133	0.0	0.1	0.0	3				136
Heavy Duty Diesel Vehicles	37,500	1.8	39	1.1	340				37,800
Off Road Diesel	16,100	0.8	17	6.5	2,000				18,100
Propane & Natural Gas Vehicles	1,060	1.7	36	0.0	6.6				1,100
Domestic Aviation	13,300	0.6	13	1.3	400				13,700
Domestic Marine	4,780	0.4	7.3	1.0	320				5,110
Railways	5,920	0.3	6.8	2.4	740				6,670
Vehicles Subtotal	170,000	21	450	29	9,100				179,000
Pipelines	11,000	11	230	0.3	89				11,300
Transport Subtotal	181,000	32	680	30	9,200				190,000
Residential	42,500	95	2,000	1.7	530				45,000
Commercial & Institutional	31,700	0.7	14	0.7	210				31,900
Other	2,550	0.0	0.8	0.1	18				2,570
COMBUSTION SUBTOTAL	517,000	250	5,300	37	12,000				533,000
FUGITIVE									
Solid Fuels (i.e., Coal Mining)		45	950						950
Oil & Gas	15,000	1,800	38,000						53,000
FUGITIVE SUBTOTAL	15,000	1,900	39,000						54,000
ENERGY TOTAL	531,000	2,100	44,000	37	12,000				587,000
INDUSTRIAL PROCESSES									
Non-Metallic Mineral Production	9,080								9,080
Ammonia, Adipic Acid & Nitric Acid Production	6,850			5.5	1,700				8,500
Ferrous Metal Production	8,510								8,510
Aluminum & Magnesium Production	3,890						6,000	2,300	12,000
Undifferentiated Production and Product Use	12,000					900	20		13,000
INDUSTRIAL PROCESSES TOTAL	40,000			5.5	1,700	900	6,000	2,300	51,000
SOLVENT & OTHER PRODUCT USE	0	0	0	1.5	460				500
AGRICULTURE									
Enteric Fermentation		840	18,000						18,000
Manure Management		240	5,100	14	4,300				9,400
Agricultural Soils**	-200			100	30,000				30,000
AGRICULTURE TOTAL	-200	1,100	23,000	120	38,000				60,000
LAND USE CHANGE & FORESTRY*		60	1,000	4	1,000				2,000
WASTE									
Solid Waste Disposal on Land		1,100	23,000						23,000
Wastewater Handling		19	400	3.1	960				1,400
Waste Incineration	280	0.3	6.9	0.2	59				350
WASTE TOTAL	280	1,100	23,000	3.3	1,000				24,000
TOTAL	**571,000**	**4,400**	**91,000**	**170**	**54,000**	**900**	**6,000**	**2,300**	**726,000**
CO_2 from Land Use Change & Forestry**	-20,000								

Notes:

Due to rounding, individual values may not add up to totals (zero values may represent estimated quantities too small to display).

** Only one significant figure shown due to high uncertainty.

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