Canada's Greenhouse Gas Inventory

1997 Emissions and Removals with Trends

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Environment Canada

April, 1999

Foreword

On December 4th, 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 terms of the UNFCCC and related decisions (specifically decisions 3.CP.1 and 11.CP.4), Parties included in Annex 1 to the Convention are to report *"national inventory data on emissions of greenhouse gases by sources and removals by sinks on an annual basis by 15 April for the period up to the last but one year prior to the year of submission."* In addition, and to the extent possible, Parties are requested to include *"additional and explanatory information."* This report, prepared by staff of the Greenhouse Gas Inventory Division of Environment Canada, and in consultation with a wide range of stakeholders, represents Canada's official greenhouse gas inventory submission to the UNFCCC. 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.

In December of 1997 at the 3rd Conference of the Parties in Kyoto, Japan, Annex 1 Parties to the UNFCCC agreed to differentiated targets that would, overall, reduce greenhouse gas emissions from 1990 levels over a five-year commitment period (2008-2012). 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. In addition, the Kyoto Protocol (Article 3.2) requires that Parties show demonstrable progress by 2005 in meeting their emission reductions. While additional monitoring and reporting guidelines remain to be agreed upon, the emission estimates contained in this report, along with future updates and, where appropriate, additional supplementary information, will be used to monitor and track Canada's progress in meeting this reduction target.

The development of emission inventories is an ongoing and constantly changing process and, as such, methodologies will change with improved techniques and additional measured emission data. This report provides a summary of appropriate methodologies, definitions, emission estimates and emission factors that were used in developing the national and provincial emission estimates for Canada and its provinces. The methods outlined are similar in many respects to those developed by the Intergovernmental Panel on Climate Change (IPCC) and follow the reporting instructions outlined in the 1996 IPCC Revised Guidelines. Although there are many areas for which methods could be improved, given the level of detail and types of information available, the estimates contained in this report are thought to be as accurate a representation of emissions and removals in Canada as is currently possible.

A. Jaques

April 10, 1999

Readers' Comments

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Acknowledgements

This report represents the efforts of several years of continuing work and builds upon the results of previous reports [1,2] published in 1992 and 1997. Many of the same people and organizations that provided input to the earlier inventories have again provided information for this report. Since the publication of the 1990 emissions inventory, an ever increasing number of people have become interested in Climate Change and, more specifically, greenhouse gas emissions. While this interest has sparked a number of research activities, only a limited number have focussed 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. Nevertheless, it is hoped that the emission estimates contained within this report represent the best information available and that they will help in identifying the most appropriate areas for emission reductions, especially in the light of new national commitments.

Of the many people and organizations that provided support and information, the authors are especially indebted to Chia Ha, an engineering intern who played an important role in the development of the historical emission estimates and corresponding methodologies, in addition to producing most of the technical graphics within this document; April Meyer and Pam Simpson, two University of Guelph engineering students who provided considerable contributions to the transportation, electric power and waste methodologies; Ray Desjardins, Henry Janzen, Richard Riznek and Ward Smith of Agriculture and Agri-Food Canada for providing advice and estimates of carbon, methane and nitrous oxide emissions from soils and other areas of the agricultural sector; Ron Rasia, Gary Smalldridge, Serge Grenier and Lucie Cloutier of Statistics Canada, for their help in interpreting Canada's energy supply data; the provincial ministries of energy and environment; Jim Farrell of the Canadian Fertilizer Institute, for providing information and developing estimates of emissions for his industry; Maria Wellisch of MWA, Werner Kurz of ESSA and Dave Boulter and Darcie Booth of the Canadian Forestry Service; Neil McIlveen, Hertsel Labib and Michel Francoeur of Natural Resources Canada; Peter Barton of Canada's Mobile Sources Emissions Division; as well as the Canadian Electrical Association, the Canadian Petroleum Association, the Canadian Gas Association and the Canadian Aluminum Association, the Canadian Industrial Energy End-use Data and Analysis Centre (CIEEDAC); and all of the independent consulting firms that have been involved in emissions work, including TJ McCann and Associates, Steve Graham, Warren Baker; ORTECH International, Senes Consulting, Clearstone Engineering, ICF Kaiser, Jacques Whitford, SAIC, GCSI, and ChemInfo.

The National Climate Change Strategy has acknowledged the need for improved emission inventory data to support the goals outlined in the Kyoto Protocol and has provided funds to improve the tracking, monitoring, reporting, review and verification of emissions and removals data reported by Canada in its National Inventory. Future inventories will be significantly enhanced and the authors are indebted to the organization for its support.

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

1 Jaques, A.P., Canada's Greenhouse Gas Emissions: Estimates for 1990, Environment Canada Report EPS 5/AP/4, December, 1992.
2 Jaques, A.P., F. Neitzert, P. Boileau, Trends in Canada's Greenhouse Gas Emissions 1990-1995, Environment Canada, Ottawa, 1997.

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Executive Summary

This report provides an inventory and summary of trends in anthropogenic (human-induced) emissions from sources and removals from sinks of greenhouse gases for Canada. It also discusses the methodologies used to estimate them.

Inventories are an essential element of any program to address climate change. Without quantifiable estimates of greenhouse gas sources and sinks, it would be impossible to determine impacts or verify progress toward national or international goals. This inventory follows a detailed, comprehensive and consistent approach which has been established to allow the Parties to the United Nations Framework Convention on Climate Change (UNFCCC)[1] to develop estimates on a globally comparative basis. The approach is documented in the publication *IPCC Revised 1996 Guidelines for National Greenhouse Gas Inventories*.[2] Methodologies used to establish the Canadian estimates are consistent with those in the Guidelines. These often follow the more detailed and comprehensive procedures, as opposed to the minimum default approaches, in an effort to improve accuracy.

Naturally occurring greenhouse gases include water vapour, ozone, carbon dioxide, methane, nitrous oxide and other trace compounds. Since pre-industrial times, the measured concentrations of some of these and other, solely human-made, greenhouse gases in the atmosphere have been rising. While the presence of such gases is essential to maintaining a habitable atmosphere, the enhanced effect on the climate system of these increasing levels is of serious concern. On the basis of recent research, the Intergovernmental Panel on Climate Change (IPCC) has identified those anthropogenic gases which appear to represent the greatest threats.

The greenhouse gases which have been estimated for this inventory include all those specified in the IPCC Guidelines. These are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulphur hexafluoride (SF_6), perfluorocarbons (PFCs), and hydrofluorocarbons (HFCs, the CFC substitutes not controlled by the Montreal Protocol on Ozone Depleting Substances). This document discusses estimates for the period from 1980 onwards. The body of the report focuses primarily on the years from 1990 to 1996, since 1990 is the baseline year for the UNFCCC and so far few published details on the underlying trends affecting emissions and removals are available for beyond 1996. However, as the 1997 national inventory has just been completed, estimates including that year are discussed in this summary.[3]

Canada's 1997 Greenhouse Gas Emissions and Removals

Emissions

In 1997, Canadians emitted about 682 Mt CO_2 eq (million metric tonnes carbon dioxide equivalent) of greenhouse gases into the atmosphere. Figure S.1 provides an overview of the major economic areas' contributions. The two largest contributors are the Energy Industries (including electric power and the coal, oil, and natural gas industries) which accounted for about

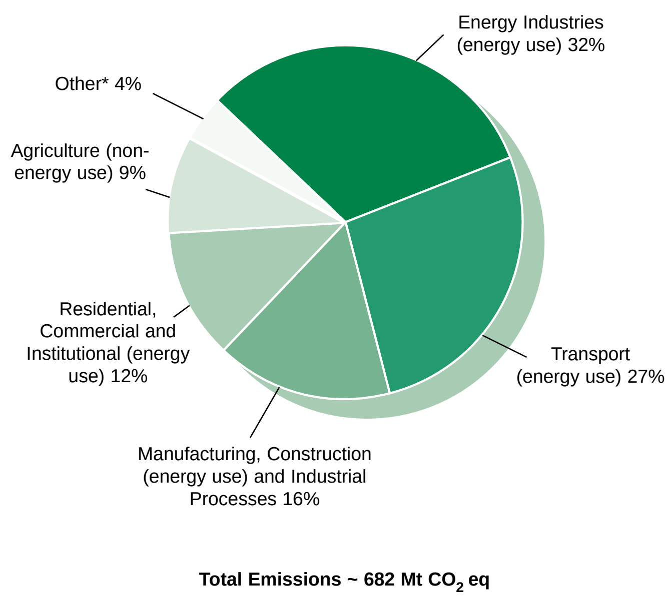


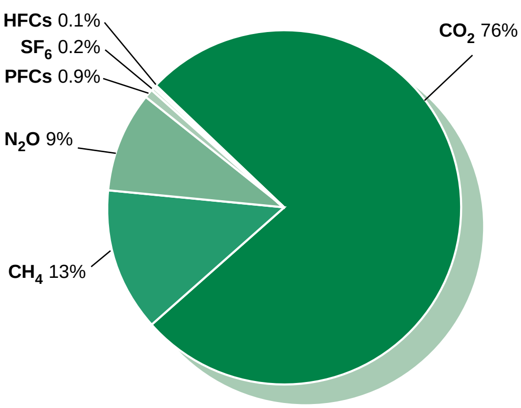
FIGURE S.1
Canada's Greenhouse Gas Emissions by Economic Area for 1997

*Other = Agriculture (energy use), Forestry (energy use), Waste and Solvents.

1 Of which Canada is a signatory nation.
2 IPCC/UNEP/OECD/IEA, 1997.
3 Further detailed tables of the 1997 inventory, including those in the IPCC Common Reporting Framework, are included in the appendices.

32%, and Transportation, which accounted for 27%. Emissions associated with energy production and use (the IPCC Energy sector) account for about 79% of all emissions.

It is clear that carbon dioxide is the dominant gas, accounting for a 76% share of emissions while methane and nitrous oxide contribute the next largest shares, 13% and 9% respectively. The other gases (HFCs, PFCs and SF_6) are responsible for the remainder — about 1% of emissions (Figure S.2).



Total Emissions ~ 682 Mt CO_2 eq

FIGURE S.2
Canada's Greenhouse Emissions by Gas for 1997

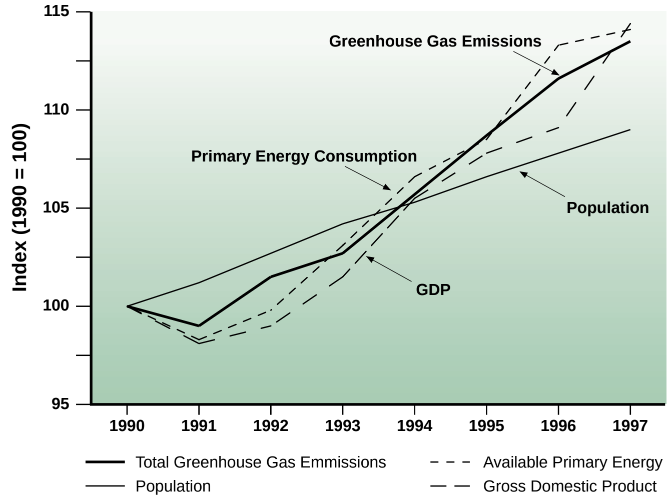


FIGURE S.3
Recent Trends - Emissions and Selected Indicators

Removals

Although not actually included in the inventory totals, net carbon dioxide removals associated with the managed Land Use Change and Forestry Sector are estimated to be -20 Mt CO_2 eq in 1997 (see Table S.2).

Recent Trends

Table S.1 depicts Canada's total greenhouse gas emissions from 1990 to 1997, along with some primary indicators. Table S.2 provides a more detailed summary by gas and Sector. In 1997, emissions were up by 1.5% over 1996 levels. Although this is lower than the 1995/96 year-over-year increase of 2.8%, significant growth is apparent through the seven year period. Emissions have risen by 13.4% since 1990, a compound increase of about 1.8% per year. The increase in green

TABLE S.1 CANADA'S GREENHOUSE GAS EMISSIONS AND ACCOMPANYING VARIABLES

Year	Total Greenhouse Gas (Mt CO_2 eq)	Percent Change from 1990	Gross Domestic Product (1992 $M)	Percent Change from 1990	Population	Percent Change from 1990	Available Primary Energy (Primary Energy Consumption) PJ	Percent Change from 1990
1990	601	0.0%	705 464	0.0%	27 790 593	0.0%	8 779	0.0%
1991	595	-1.0%	692 247	-1.9%	28 120 065	1.2%	8 633	-1.7%
1992	610	1.6%	698 544	-1.0%	28 542 213	2.7%	8 760	-0.2%
1993	617	2.6%	716 123	1.5%	28 946 768	4.2%	9 047	3.1%
1994	635	5.7%	744 220	5.5%	29 255 599	5.3%	9 360	6.6%
1995	653	8.8%	760 309	7.8%	29 617 448	6.6%	9 523	8.5%
1996	671	11.6%	769 730	9.1%	29 969 209	7.8%	9 945	13.3%
1997	682	13.4%	806 737	14.4%	30 286 596	9.0%	10 014	14.1%

Populations: Statistics Canada, Catalogue 91-213.
Gross Domestic Product: Statistics Canada, CANSIM (1998).
Available Primary Energy: Statistics Canada, Catalogue 57-003 and CANSIM (1996).

TABLE S.2 CANADA'S GREENHOUSE GAS EMISSIONS AND REMOVALS: TRENDS BY GAS & SECTOR

		1990	1991	1992	1993	1994	1995	1996	1997
Carbon Dioxide (CO_2)	**kt CO_2 eq**	**461 000**	**452 000**	**466 000**	**467 000**	**480 000**	**495 000**	**508 000**	**520 000**
Energy									
Energy Industries[1]		150 000	150 000	159 000	153 000	157 000	164 000	166 000	175 000
Transportation[2]		147 000	142 000	145 000	149 000	157 000	162 000	167 000	174 000
Residential, Commercial & Institutional		66 800	64 700	64 800	71 400	71 500	71 800	77 000	74 300
Manufacturing & Construction		54 700	51 400	50 700	49 300	50 500	53 900	53 900	53 900
Agriculture & Forestry[3]		3 130	3 160	5 410	3 350	2 700	2 610	2 860	2 920
Industrial Processes									
Cement, Lime Production; Soda Ash Limestone Use[4]		8 160	6 980	6 640	6 880	7 510	7 690	7 840	8 280
Ammonia Production[5]		3 130	3 220	3 320	3 560	3 700	4 050	4 130	4 140
Iron & Steel Production[6]		7 590	8 900	9 080	8 760	8 050	8 500	8 290	8 110
Aluminum Production[7]		2 640	3 010	3 210	3 770	3 680	3 540	3 730	3 790
Undifferentiated Production[8]		10 000	11 000	12 000	13 000	13 000	13 000	15 000	14 000
Agriculture - Soils		7 000	7 000	6 000	5 000	4 000	3 000	2 000	1 000
Waste - Incineration		250	260	260	260	270	270	270	280
Land Use Change & Forestry									
Carbon Cycle* [net removal]		[-40 000]	[-60 000]	[-50 000]	[-30 000]	[-30 000]	[-20 000]	[-30 000]	[-20 000]
Methane (CH_4)	**kt CO_2 eq**	**74 000**	**76 000**	**79 000**	**82 000**	**84 000**	**87 000**	**90 000**	**90 000**
Energy									
Energy Industries[1]		28 000	30 000	32 000	33 000	35 000	37 000	39 000	39 000
Transportation[2]		530	500	490	490	530	560	570	520
Residential, Commercial & Institutional		4 800	4 900	5 300	5 400	5 300	5 200	5 400	5 400
Manufacturing & Construction		31	30	31	29	30	35	33	32
Agriculture & Forestry[3]		1.0	1.0	1.5	1.2	0.9	0.9	1.0	1.1
Agriculture									
Enteric Fermentation		16 000	16 000	16 000	17 000	18 000	18 000	18 000	18 000
Manure Management		4 000	4 000	3 900	4 000	4 200	4 300	4 400	4 200
Waste									
Landfills		19 000	19 000	20 000	20 000	20 000	20 000	20 000	21 000
Wastewater Handling		360	360	370	370	380	380	390	390
Waste Incineration		9.2	9.5	10.2	6.5	6.5	7.2	6.9	6.9
Land Use Change & Forestry									
Human-Induced Burns		1 400	1 800	1 600	1 500	800	1 000	900	900
Nitrous Oxide (N_2O)	**kt CO_2 eq**	**57 000**	**57 000**	**57 000**	**58 000**	**62 000**	**63 000**	**66 000**	**64 000**
Energy									
Energy Industries[1]		900	900	900	900	900	1 000	1 000	1 000
Transportation[2]		6 500	6 600	7 200	7 800	8 600	8 900	9 000	9 100
Residential, Commercial & Institutional		1 000	1 000	1 100	1 100	1 100	1 100	1 100	1 100
Manufacturing & Construction		460	460	470	450	440	510	480	470
Agriculture & Forestry[3]		17	14	20	17	13	13	14	17
Industrial Processes									
Nitric and Adipic Acid Production[9]		11 000	11 000	11 000	10 000	12 000	12 000	12 000	11 000
Solvents		420	420	430	440	440	450	450	460
Agriculture									
Soils		30 000	30 000	30 000	30 000	30 000	30 000	30 000	30 000
Manure Management		3 900	3 900	4 000	4 100	4 400	4 500	4 600	4 600
Waste									
Wastewater Handling		870	880	890	910	920	930	940	950
Waste Incineration		53	54	55	56	56	57	58	58
Land Use Change & Forestry									
Human-Induced Burns		1 100	1 400	1 300	1 300	700	1 100	900	900
HFCs PFCs & SF_6	**kt CO_2 eq**	**8 800**	**9 600**	**8 800**	**9 400**	**8 900**	**8 400**	**7 700**	**7 800**
Industrial Processes									
Aluminum Production (PFCs)		6 000	6 000	7 000	7 000	7 000	6 000	6 000	6 000
Magnesium Production (SF_6)		2 900	3 300	2 200	2 000	2 000	1 900	1 400	1 400
Solvents									
Replacements for Ozone - Depleting Substances (HFCs)		0	0	0	0	0	500	500	500
National Total	**kt CO_2 eq**	**601 000**	**595 000**	**610 000**	**617 000**	**635 000**	**653 000**	**671 000**	**682 000**

1 Energy Industries are the (IPCC) Energy Production and Transformation Industries: coal, oil & gas production, refining & transmission, electricity & steam production and mining.
2 Transportation: Air, Road, Rail, Marine, Off-Road & Pipeline Transport.
3 Agriculture & Forestry: classified as 'Other' under the Energy Sector in tables in the Appendices.
4 Cement, Lime Production; Soda Ash, Limestone Use: classified under Non-Metallic Mineral Production in tables in the Appendices.
5 Ammonia Production: classified under Chemical Industries in the Industrial Processes Sector.
6 Iron & Steel Production: classified under Ferrous Metal Production in tables in the Appendices.
7 Aluminum Production (PFCs): classified under Non-Ferrous Metal Production in tables in the Appendices.
8 Undifferentiated Production: non-energy use of fossil fuel products such as lubricants, asphalt and chemicals.
9 Nitric and Adipic Acid Production: classified under Chemical Production in the Industrial Processes Sector.

Notes:
* Carbon dioxide (CO_2) from Land Use Change and Forestry is not included in Inventory totals.

Due to rounding, individual values may not add up to totals.

house gas emissions has outstripped population growth (which was 1.2% per year) and very closely matches growth in Gross Domestic Product and primary energy consumption, both of which were 1.9% per annum (see Figure S.3). Although there is clearly a link between energy consumption and greenhouse gas emissions, the relationship between GDP and emissions is not necessarily as direct as these recent trends would imply (see Longer-Term Trends on page xv).

In 1997, greenhouse gas emissions are estimated to have been 81 Mt CO_2 eq higher than in the 1990 baseline year. Three economic areas were responsible for most of the increase. These are represented by the Energy Production and Transformation Industries, Transportation, and the Residential and Commercial/Institutional area. The Energy Industries and Transportation (also the largest contributors to emissions in absolute terms) were responsible for the vast majority of the increases, together accounting for over 65 Mt, or about 80% of the total growth.

Energy Industries

Over the period 1990-1997, emissions from the Energy Industries rose by about 36 Mt CO_2 eq. Electricity and steam generation was responsible for 16 Mt of the emission growth. Approximately 6 Mt of this was the consequence of nuclear reactor shutdowns in Ontario (primarily for safety reasons) which began in 1997. The shutdowns resulted in a 25% increase in coal energy consumption by Ontario Hydro in that year alone.

Fugitive releases from conventional oil and gas production also contributed significantly. Estimates show an increase of 15 Mt between 1990 and 1997, a growth of about 40%, largely the result of a rapid expansion of natural gas exports to the United States.

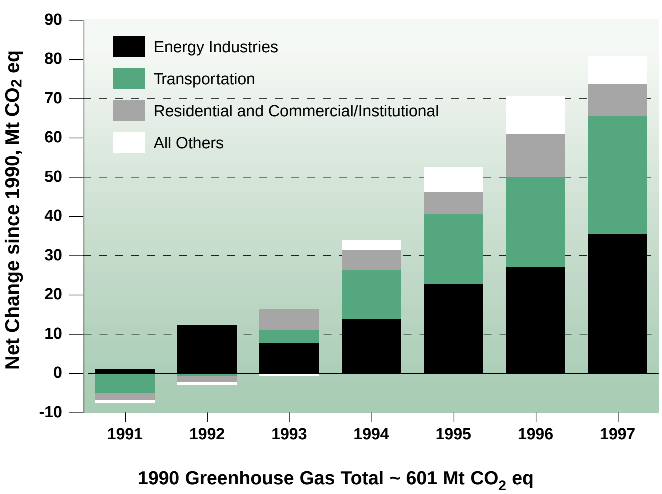


FIGURE S.4
Change in Greenhouse Gas Emissions from 1990 Baseline, 1991-1997

The non-conventional oil (oil sands and bitumen) industry, classed under the 'Mining' category, also experienced strong growth. As a result, fuel combustion emissions associated with mining grew by 6 Mt CO_2 eq, or about 70% from 1990 to 1997.

Transportation

Transportation emissions rose by about 30 Mt CO_2 eq, or 19% from 1990 to 1997. Contributing to this were 10 and 14 Mt increases from light-duty trucks and heavy-duty vehicles, respectively. These statistics are indicative of the trends toward increasing numbers of vans and sport utility vehicles and greater use of trucking for freight transport.

Combustion emissions from natural gas and oil pipeline transport are included in the transportation category. Due to increasing activity in the petroleum industries, such pipeline equipment emissions rose significantly, contributing another 5 Mt to the emission growth in transport.

Residential and Commercial/Institutional

The Residential and Commercial/Institutional area showed an overall increase in greenhouse gas emissions of 8 Mt (15%) over the period. Emission growth in these sectors, resulting from greater fuel consumption, can be partially attributed to the 11% Canada-wide increase in heating-degree-days[4] which occurred between 1990 and 1997, and partially to a 9% growth in population. It is worth noting, however, that these occurances have been counterbalanced by fuel switching and energy-efficiency improvements in the building sector, which led to a dampening of emission growth.

International Perspective

It is interesting to consider Canada's contribution to anthropogenic greenhouse gas (GHG) emissions in light of the global total. Accurate information presenting comparable worldwide data for all gases is so far unavailable; however, complete, consistent international estimates for emissions of the three primary greenhouse gases (carbon dioxide, methane and nitrous oxide) have been developed for 1990.[5] A breakdown by region, and some countries is presented in Table S-3.

4 Statistics Canada, Quarterly Report on Energy Supply-Demand, Catalogue No. 57-003. Note that Canada-wide heating-degree-days are based on the major population centres.

5 EDGAR V2.0; Olivier et al. (1996).

TABLE S.3 GLOBAL EMISSIONS OF PRIMARY GREENHOUSE GASES - SUM OF CO_2, CH_4 AND N_2O IN 1990

	Greenhouse Gas		Population
	Mt CO_2 eq	t per Capita	Millions
Global Total	**33 144**	**6.3**	**5 292**
Oceania**	1.4%	20	23
Canada	1.8%	22	27
Middle East	3.5%	5.6	206
Japan	3.8%	10	124
Eastern Europe	4.0%	11	124
Eastern Asia	4.1%	3.7	370
Africa	6.6%	3.4	643
India*	6.8%	1.9	1 158
Latin America	8.6%	6.5	441
China+	12.6%	3.3	1 263
Western Europe	12.9%	11	375
Former Soviet Union	14.2%	16	289
United States	18.8%	25	250

+ China: Cambodia, China, Hong Kong, Lao Peoples Democratic Republic, Macau, Mongolia, Taiwan and Vietnam.
* India: Bangladesh, Bhutan, India, Maldives, Myanmar (former Burma), Nepal, Pakistan and Sri Lanka.
** Oceania: American Samoa, Australia, Cook Islands, Fiji, French Polynesia, Guam, Kiribati, Marshall Islands, Micronesia, Nauru, New Caledonia, New Zealand, Niue, Northern Mariana Islands, Palau, Solomon Islands, Tonga, Vanuatu and Western Samoa.

Of the global total, some 33,100 Mt CO_2 eq, Canada represents about 1.8% of emissions, Europe 17% and the U.S. 19%. Though not representing a large portion of the global total, Canadian population emission intensity (22 t CO_2 eq per capita in 1990) is rather high, being very close to that of the U.S. and other top, per capita GHG emitters. This can largely be attributed to the fact that the country is characterized by a cold climate, a population sparsely distributed over a large geographic area, and a developed, energy-intensive, resource-based economy.

Although no consistent, reliable projections for the other greenhouse gases appear to be available, a number have been made for carbon dioxide. For example, the U.S. Department of Energy's most recent[6] "business-as-usual" projection is for a 44% increase in world CO_2 emissions above 1990 levels by 2010 and an 81% increase by 2020. This clearly demonstrates that the present international policies in place are not expected to significantly limit emission growth.

In an effort to curb some of these increases and mitigate the potential climate-change impacts, the Kyoto Protocol was drafted in December 1997 by Parties to the UNFCCC. Through this agreement, Annex 1 Parties (a group of over 30 industrialized states) committed themselves to collectively reduce greenhouse gases to an average level of about 5% below 1990 emissions by the period 2008 to 2012. By March 15, 1999, 84 countries had signed the Protocol, although only 7 had ratified it,[7] none of them Annex 1 members. (The Protocol does not enter into force until 55 countries and Annex 1 signatories with carbon dioxide emissions totalling 55% of Annex 1 emissions have ratified it.) Regardless of the future of this Protocol, it does seem clear that greenhouse gas inventories have become the means by which success or failure to reach international commitments will be measured.

Longer-Term Trends

Under the Kyoto Protocol, Canada (an Annex 1 member) adopted a reduction target of 6% below its 1990 baseline.[8] What then, are the country's longer-term emission trends? Figure S.5 illustrates the situation from 1980 to 2010 (with actual estimates up to 1997, and a business-as-usual projection beyond that).

Between 1980 and 1997, Canadian GHG emissions grew by 19%, but this trend can be broken down into two distinct phases. The first half of the 1980s was characterized by falling emissions. Mostly as the result of successful energy-efficiency programs, primary energy consumption *dropped* by about 5% between 1980 and 1986, while GDP *grew* by 17%. This resulted in a 5% decrease in greenhouse gas emissions.

Indicators of greenhouse gas intensity show significant improvement over this first period — emissions per capita fell by 11%, while emissions per unit of Gross Domestic Product dropped by 24%. Beginning in 1987, however, GHG trends reversed themselves and began a steady rise which has continued relatively unabated (with only a single fluctuation) until 1997 (Figure S.5). Total emissions have risen by 25% over 1986 levels. At the same time, population greenhouse gas intensity has worsened, although emissions per unit GDP have at least held steady over this latter period (Figure S.6).

Without additional policy instruments or other adjustments to the underlying structure of the economy, this trend is projected to continue, albeit at a slightly slower rate of increase. The business-as-usual forecast

6 Energy Information Administration, *International Energy Outlook*, 1998.
7 *Signing* represents a nation's intent, whereas *ratification* signifies a commitment to meet its objectives under the agreement.
8 Note that 1990 is the required baseline (reference) year for the primary gases (carbon dioxide, methane and nitrous oxide). However, for the other three gases only (HFCs, PFCs and sulphur hexafluoride) the baseline may, at a country's discretion, be considered to be either 1990 or 1995.

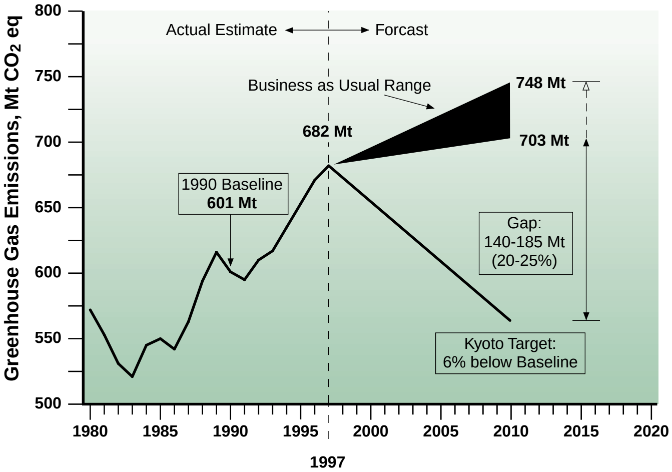


FIGURE S.5

Canadian Emission Trend and Kyoto Protocol Target

Data Sources: Actual Emission Estimates, Baseline - Environment Canada (this publication). Forecast - Natural Resources Canada, 1998.

range is between 703 and 748 Mt CO_2 eq by 2010. Not surprisingly, the largest contributors to this growth are expected to be the Energy Industries and Transportation.[9] Meeting the Protocol target requires a trend reversal such that actual 2010 emissions will be about 25% lower than that projected in this scenario. The difference between Canada's reference forecast and its greenhouse gas target has become known as the 'Gap'.

Breaking the estimates down by major economic area, trends since 1980 clearly show that the Energy Industries and Transportation have historically been the major contributors to both total emissions and

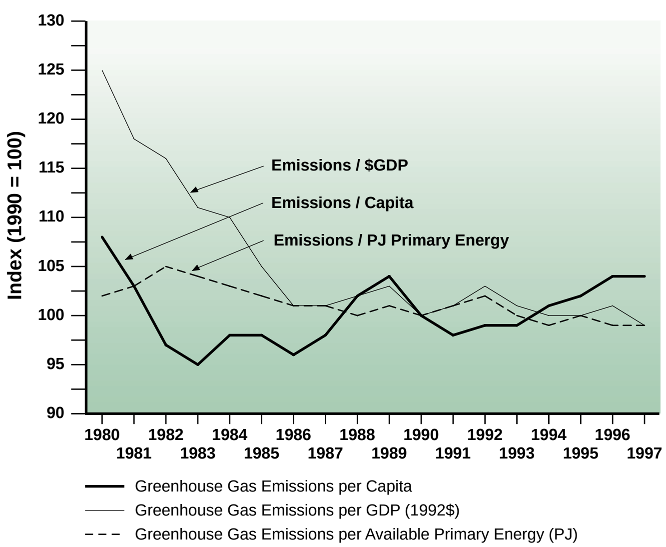


FIGURE S.6

Greenhouse Gas Emission Intensity of Canadian GDP, Population and Energy

emission increases (Figure S.7). In fact, the Energy Industries have been responsible for about three quarters of all GHG growth and Transportation, the remaining quarter. These increases were partially compensated for by small reductions in other categories, notably the Residential and Commercial/Institutional area and Manufacturing Industries. Minor additional increases in emissions, primarily from Landfills, made up the balance of growth.

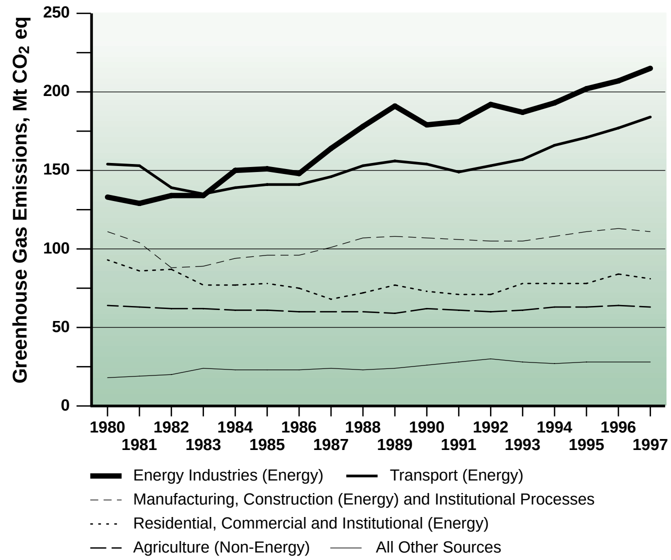


FIGURE S.7

Greenhouse Gas Emission Trends by Economic Area

The Energy Industries

Over the long-term period, emissions from the Energy Industries have grown by more than 60%. Energy Industry sources are represented by combustion-based electricity generation and activities within the fossil fuels industries ranging from well drilling to refining. Rapid expansion in all of these areas has been responsible for the increases in emissions.

Electricity and steam generation is responsible for almost half of the Energy Industries' emissions — 111 Mt CO_2 eq in 1997. Since 1980, coal-based electricity production has become a much larger part of Canada's generation mix, due to the consistently low price of coal energy and the reduced availability of economical hydro resources. Although new hydro (and nuclear) generation has been brought into service, it hasn't kept pace with electricity growth and coal generation has tended to fill the gap. Over the 17-year period, the quantity of coal used for electricity genera-

9 Natural Resources Canada, *Canada's Emissions Outlook, An Events-Based Update for 2010* (Working Paper), 1998.

tion went up 54%,[10] while emissions from Electricity and Steam production rose 55%.[11] Since 1990, heightened environmental concerns and favourable natural gas pricing have resulted in more natural gas-based electricity generation. This has limited the growth of coal use and improved electricity emission intensity. As a result, emissions increased by only 5% between 1990 and 1996, even though total generation grew by 19%. Nonetheless, by 1996 the upward trend in coal-generated electricity had not halted; coal-based production increased by about 8% over the six years. With the beginning of a number of nuclear reactor shutdowns in Ontario in 1997, the trend was exacerbated, and is likely to continue.

Emissions from the balance of the Energy Industries (that is, excluding electric power) were 103 Mt in 1997 — up about 70% from 1980.[12] The petroleum industries (including natural gas) are responsible for the vast majority of these emissions and increasing activity within the sector has had great impact on greenhouse gas levels. Over the period, net total production of crude oil and natural gas went from about 5,900 PJ to 10,900 PJ, an increase of 84%.[13] Emissions from the petroleum industries consist of those from combustion energy — utilized to refine and transmit the fuels, and fugitive releases of methane and carbon dioxide — which emanate (or are purposefully vented) from fuels as they are processed.

Fugitive emissions have grown at the fastest pace — more than 95% over the 17-year time span, from about to 26 Mt CO_2 eq to 51 Mt in 1997. This is illustrated by the increasingly large share of methane (the most prevalent fugitive gas in CO_2-equivalent terms) in the greenhouse gas mix (see Figure S.8). Most of these emissions are associated with the conventional upstream petroleum industries, of which natural gas activities contribute the largest proportion. Telling is the fact that natural gas production rose by 140% between 1980 and 1997. In fact, exports to the USA were responsible for 60% of this increase, and the trend has been escalating. By 1997, close to 50% of Canadian natural gas production was exported.

Although natural gas represents the largest and most quickly growing Canadian energy export (about half of the market in 1995),[14] electricity, oil and oil products form the significant balance. It has been estimated that 60% of the *total* 1990-1995 growth in Canadian greenhouse gas emissions can be attributed to the net export of energy products.[15] This is of note, since it implies that energy-efficiency programs targeted at reducing *domestic* consumption and related greenhouse gas emissions will have limited effectiveness as long as these export trends are not adressed.

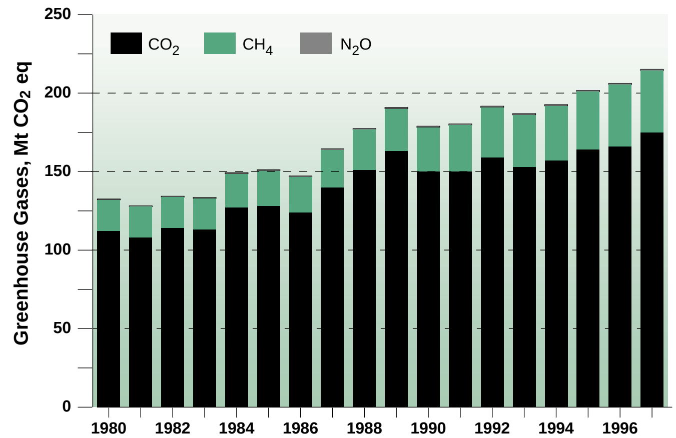


FIGURE S.8
Trends in Emissions from the Energy Industries

Since 1980, easily extractable reserves of conventional Canadian crude oil have been declining. As a result, the energy consumption required to produce a unit of marketable oil has been increasing. Concurrently, highly energy-intensive synthetic oil production has become more cost-competitive with conventional oil. Over the period, synthetic oil and crude bitumen production rose some 400%, increasing their share of the total from 10% in 1980 to 28% in 1997.[16] The result is that greenhouse gas emissions from the Mining category (primarily associated with non-conventional oil production) increased by almost 125% (from 6 to 13 Mt CO_2 eq). It is worth noting that in spite of such large emission growth, the relatively high greenhouse gas intensity of synthetic oil has been declining due to consistent process improvements within the industry.

Transportation

Emissions from Transportation increased by about 30 Mt CO_2 eq from 1980 to 1997. After a significant decline in the 1980s, brought on by rapid improvements in road-vehicle efficiency and reduced engine sizes, emissions languished for a short while, then increased rapidly in the 1990s (see Figure S.7).

10 Statistics Canada, *Quarterly Report on Energy Supply-Demand*, Catalogue No. 57-003.
11 Steam production for commercial sale forms a vanishingly small proportion of this category. Electricity generation accounts for more than 98% of the emissions.
12 The "balance of the Energy Industries" are made up of the total of the following categories: Fossil Fuel Industries, Mining, and Fugitive Emissions. (These categories are listed in tables in the appendices.)
13 Statistics Canada, *Oil and Gas Extraction*, Catalogue No. 26-213 (annual) and *Quarterly Report on Energy Supply-Demand*.
14 In this case, the "market" has been measured in terms of energy, not economic outputs.
15 McCann and Associates, *Fossil Fuel Energy Trade and Greenhouse Gas Emissions*, 1997.
16 Statistics Canada, *Oil and Gas Extraction* (annual), Catalogue No. 26-213.

Transportation was one of the areas which profoundly benefitted from the energy efficiency and technology improvements which took place in the '80s. From 1980 to 1985, emissions fell by 8%. Between 1980 and 1990, new car and light truck fuel efficiency improved by about 20%[17] and greenhouse gas releases from transport showed zero growth, in spite of increasing road-vehicle activity. In fact, over those 10 years gasoline vehicle emissions dropped by about 11%, while the total number of vehicle passenger-kilometres travelled by private autos and trucks increased by 9%.[18]

At the same time, however, it appears that emissions from diesel vehicles and pipeline transport were increasing. By 1990, diesel vehicles were emitting 20% more greenhouse gases than in 1980. Increasing use of freight transport and heavy industrial vehicles, coupled with insufficient compensating efficiency improvements, led to these emission trends. Pipeline utilization also grew at a rapid rate. By 1990, 25%[19] more petroleum energy (natural gas, oil and oil products) was being transferred by pipeline than in 1980, leading to an emission increase of about 75%.[20]

Between 1990 and 1997, the trend in gasoline-powered road transport reversed itself. Continued growth in passenger-vehicle activity, along with lesser efficiency gains and the increasing popularity of larger, more powerful vehicles led to a 7 Mt CO_2 eq rise in emissions. At the same time, diesel vehicle and pipeline transportation trends continued with renewed vigour, driven by increasingly common use of trucks for freight transport and rapid expansion of domestic and foreign petroleum energy markets. Emissions from these latter categories increased by a full 20 Mt CO_2 eq.

The result has been that this 1990-1997 phase was responsible for the whole GHG growth trend in Transportation over the 17-year period. It is worth noting that aviation contributed about 10% to the overall 30 Mt CO_2 eq increase. Growth in this category's emissions occurred only recently — from 1995 onwards. This coincides with a period of increasing competition between airlines and reduced air fares, which has led to greater passenger traffic.

Manufacturing, Construction and Industrial Processes

Emissions from the Manufacturing and Construction categories arise from combusting fuels for the purpose of producing energy, whereas those from Industrial Processes do not. Together, this group of three categories represents 'industries' in the Greenhouse Gas Inventory. From 1980 to 1997, there was no growth in emissions from this area, in spite of a 51% growth in Canadian GDP. Changes in Manufacturing energy use, primarily through fuel switching and efficiency improvements, were responsible for this success story.

Manufacturing consists of two subcategories: *resource-based industries* such as pulp and paper or iron and steel production form the first and *advanced products and services*[21] such as electronics, automobile and aerospace industries form the second. As a result of increasing oil prices in the late 1970s and early '80s, there was a tendency within both of these subcategories to switch to less carbon-intensive energy sources such as natural gas.[22] This trend resulted in immediate reductions in greenhouse gas emissions.

Then, in the mid-1980s, as economic activity grew rapidly, increasing capital was invested in improved machinery and energy-efficient processes. The latter trend occurred primarily within the *advanced products and services industries*, with the most significant impacts of these improvements being felt in the 1990s. From 1990 to 1996 this subcategory, already characterized by low greenhouse gas intensities, saw energy consumption go down by 3% (with commensurate reductions in emissions) in spite of a 12% increase in aggregate economic output. In fact, by 1996, *advanced products and services industries* were responsible for close to 70% of economic activity within the Industrial area, but accounted for only about 20% of the energy use.[23]

During the 1980s, fuel switching assisted in reducing GHG emissions from *resource-based industries* such as pulp and paper, where the tendency was to burn greater quantities of wood products. (Wood and wood products are assumed to be fully regenerative, and therefore are estimated to have zero net carbon dioxide emissions from combustion).[24] However in the 1990s, the energy intensity of these industries, already significantly greater than the *advanced products and services industries* (often by ten times or more) went up further.

17 Transport Canada, *Road Vehicle Safety Division*, 1998.

18 Transport Canada, *Annual Report*, 1997.

19 Statistics Canada, *Pipeline Transportation of Crude Oil and Refined Petroleum Products*, Catalogue No. 55-201 (annual), *Natural Gas Transportation and Distribution*, Catalogue No. 57-205 (annual) and *Quarterly Report on Energy Supply-Demand*, Catalogue No. 57-003.

20 Note that most of the increases occurred in natural gas transmission. One of the likely reasons for the large emission increase is the fact that significantly more energy is required to transmit a gas than a liguid.

21 *Advanced products and services* are labeled as 'Other Industries' in Statistics Canada publications such as *The Quarterly Report on Energy Supply and Demand*.

22 Natural Resources Canada, *Energy Efficiency Trends in Canada 1990-1996*.

23 Ibid

24 This assumption applies to combustion only, not the use of wood products for other purposes. A full discussion can be found in Section 6 – *Land Use Change and Forestry*.

Thus, greenhouse gas emissions from the *resource industries* rose somewhat from 1990 to 1997. Even so, Manufacturing sources still posted a net reduction over both the 1990s and the whole 17-year period.

Counteracting the emission decreases from Manufacturing, greenhouse gas releases from some Industrial Processes rose. Increases were noted from primary Aluminum Production, as a result of growth in metal demand, and from more extensive use of non-energy fossil fuel products[25] (such as lubricants and chemicals) throughout industry.

Residential and Commercial/Institutional

Emissions from this area result primarily from the use of energy to heat buildings, and have declined over the long term. This reduction was about 12 Mt CO_2 eq, or 13%, from 1980 to 1997. The trend has occurred as a result of building energy-efficiency improvements, particularly during the early- to mid-1980s, and fuel switching. In fact, from 1980 to 1987, emissions from Residential and Commercial/Institutional sources declined by a full 25%. They increased again in the late '80s and '90s, but did not return to their former levels in spite of a 23% increase in population and fluctuating climactic conditions.

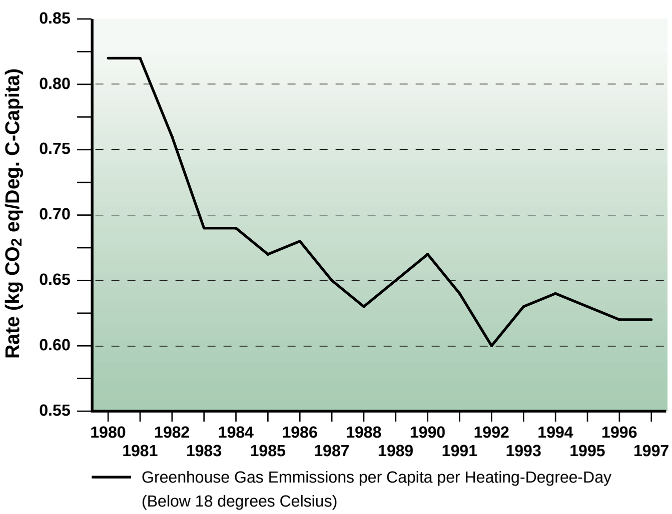


FIGURE S.9
Residential and Commercial/Institutional Emissions per Capita-Degree-Day

Broadly speaking, in the absence of efficiency improvements, heating demand will increase with building floor space and the severity of winter temperatures. The demand for floor space tends to vary with the population, while temperature severity is approximated by the average number of 'heating degree days' over the winter season. The latter value is calculated by determining the average, cross-Canada number of days below 18°C in the population centers and multiplying it by the corresponding number of degrees below this temperature.

To remove the effect of these variables, it is instructive to investigate the trend in terms of GHG emissions per capita degree day (or *emission rate*) (Figure S.9). If efficiency or fuel use patterns were not changing, the graph is expected to show a horizontal line. However, the resultant *emission rate* shows a clearly declining trend, illustrating how building efficiency improvements and fuel switching have led to reduced greenhouse gas levels over the 1980-1997 period.

Agriculture

This area corresponds with that defined as the Agriculture sector by the IPCC.[26] (i.e. energy emissions are not included here.) The overall long-term trend remained flat from 1980 to 1997 (Figure S.10).

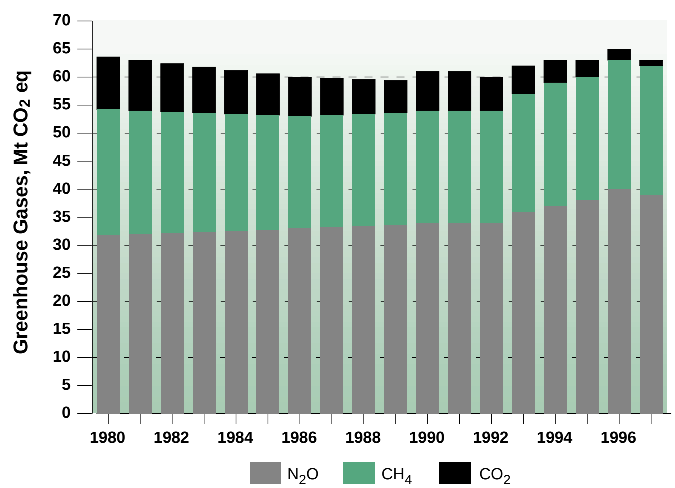


FIGURE S.10
Trends in Emissions from Agriculture

Total emissions, which were 64 Mt CO_2 eq in 1997, did not vary by more than 5% over the period. Of interest is the shift, over time, in the make-up of emissions from Agriculture. Carbon dioxide has declined by approximately 8 Mt, while nitrous oxide has increased by virtually the same amount (about 7 Mt CO_2 eq). This has occurred primarily as result of changing soil-management and fertilizer-application practices.

25 Classed as *Undifferentiated Products* in emission tables. See, for example, Table S.2.

26 As defined in *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*.

Carbon dioxide emissions occur as a result of a direct loss of carbon from agricultural soils. The introduction of no-tillage methods and less summer fallow in many areas of Canada, accompanied by increasing fertilizer application appears to have led to a decline in the loss of organic matter from soils. This trend seems to have accelerated since 1990, and in some provinces agricultural soils have begun to sequester carbon dioxide from the atmosphere. Although the uncertainty of these estimates is rather high, it is predicted that Canadian soils may soon become a net sink for atmospheric carbon removal.

Unfortunately, increasing fertilizer application and other natural 'nitrification' processes have resulted in elevated levels of nitrous oxide emissions from soils. The latest research indicates that much more of the nitrogen contained in the applied fertilizers (and the plants themselves) is eventually released to the atmosphere as nitrous oxide than previously thought. The estimates presented in this document are based on new Canadian research and the most recent IPCC methodologies, both of which attempt to more accurately quantify these releases.

Other Topics of Note

Methodologies

As indicated earlier, Canada's National Greenhouse Gas Inventory has been structured to match the reporting requirements of the Intergovernmental Panel on Climate Change (IPCC). It has been divided into six major sectors defined as: Energy; Industrial Processes; Solvents and Other Products; Agriculture; Land Use Change and Forestry; and Waste. While each of these IPCC sectors is further subdivided within the inventory (for example, Industrial Processes into emissions from the production, processing and use of various mineral, chemical, metal and non-energy products), care has been taken to ensure that no double-counting of emissions has taken place between sectors or within sectors.

A number of estimation methodologies have been updated. The most extensive revisions have occurred in the Agriculture and Land Use Change and Forestry sectors. The Agriculture sector incorporates new methodologies for the estimation of nitrous oxide emissions and are based on the latest *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*. These methods attempt to more accurately quantify nitrous oxide emissions from soils and manure-management systems. Although the result is an improved inventory, emission estimates for this sector have increased more than twofold as compared to the last published report. On the other hand, sector and total emission trends from 1990 onwards have not been significantly altered by this update.

This inventory is the first published version to provide estimates of atmospheric carbon dioxide removals through anthropogenic Land Use Change and Forestry activities. Estimates have been calculated on the basis of IPCC methodologies and a comprehensive compilation of the most recent Canadian land-use and forestry data.

Uncertainty of Estimates

Of particular concern with emission inventories is their accuracy. No inventory can contain values which reflect actual emissions with complete accuracy. Even continuously measured emissions can only be accurate to within the resolution of the measuring equipment. This inventory is based primarily on estimates derived from a combination of national statistics, measured emission factors, and scientific or engineering models. Uncertainties arise from many causes.

A study aimed at determining statistical uncertainty levels for the estimates contained within an earlier version of this inventory has been conducted (McCann & Associates, 1994). The results indicated overall uncertainty levels of about 4% for carbon dioxide levels, 30% for methane and 40% for nitrous oxide estimates. As newer methods are incorporated into the inventory, however, these uncertainty estimates become less applicable. However, they are still believed to be useful as general guides.

Greenhouse Gases and the Use of Global Warming Potentials (GWPs)

The radiative forcing 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 greenhouse gas, while indirect radiative forcing occurs when chemical transformation of the original gas produces a gas or gases that are greenhouse gases, 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 greenhouse gas to trap heat in the atmosphere relative to another gas. By definition, a global warming potential (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 might have on the surface troposphere. The GWP of a greenhouse gas 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 are used in this report.

TABLE S.4 GLOBAL WARMING POTENTIALS

Greenhouse Gas	Global Warming Potential[1] 100 Years
Carbon Dioxide (CO_2)	1
Methane (CH_4)	21
Nitrous Oxide (N_2O)	310
HFCs	
HFC-23	11 700
HFC-32	650
HFC-125	2 800
HFC-134a	1 300
HFC-143a	3 800
HFC-152a	140
HFC-227ea	2 900
Perfluorocarbons (PFCs)	
Carbon Tetrafluoride (CF_4)	6 500
Carbon Hexafluoride (C_2F_6)	9 200
Sulphur Hexafluoride (SF_6)	23 900

(1) IPCC, 1996.
The methane Global Warming Potential (GWP) includes the direct effect and those indirect effects due to the production of tropospheric ozone and stratospheric water vapour. Not included is the indirect effect due to the production of carbon dioxide.

Note: This is only a partial listing of Global Warming Potentials. A more complete table can be found in Appendix G.

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Section 1 - Introduction

The purpose of this document is to provide a summary of trends in anthropogenic (human-induced) sources of atmospheric emissions of greenhouse gases in Canada, as well as to report on current estimation procedures. Greenhouse gases are gases in the atmosphere that trap solar energy. Naturally occurring greenhouse gases include water vapour, ozone, carbon dioxide, methane, nitrous oxide and other trace compounds. 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 as we know it possible, a serious concern today is the enhanced effect on the climate system of increased levels of some of the gases in the atmosphere.

The radiative (greenhouse) gases for which emission estimates have been made are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulphur hexafluoride (SF_6), carbon tetrafluoride (CF_4), carbon hexafluoride (C_2F_6), and hydrofluorocarbons (HFCs).

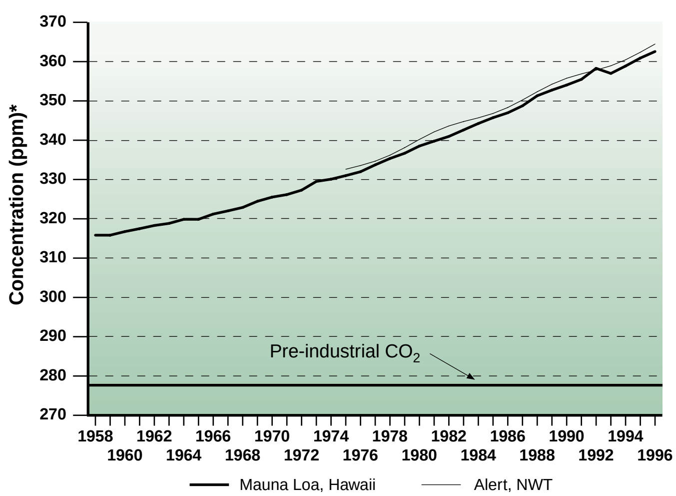

FIGURE 1.1-1

Global Atmospheric Concentration of Carbon Dioxide

*ppm = parts per million

Sources: C.D. Keeling and T.P. Whorf, Scripps Institution of Oceanography, University of California, California, U.S.A. for carbon dioxide measurements taken at Mauna Loa Observatory, Hawaii. Atmospheric Environment Service, Environment Canada for carbon dioxide measurements taken at Alert, NWT, Canada.

Data provided by State of the Environment Program (1999).

1.1 Climate Change

The atmospheric concentrations of greenhouse gases have grown significantly since pre-industrial times (about 1750 AD.): CO_2 from about 280 to almost 360 ppmv, CH_4 from 700 to 1720 ppbv and N_2O from about 275 to about 310 ppbv (IPCC, 1996). These trends can be largely attributed to human activities — mostly fossil fuel use, land-use change and agriculture.

Concentrations of other anthropogenic greenhouse gases have also increased, all of which leads to an additional warming (on average) of the atmosphere and the Earth's surface. Since the mid-1700s, carbon dioxide concentrations (which account for about 75% of the enhanced greenhouse effect) have increased to a level not seen in about 160,000 years (Environment Canada, 1995).

The atmospheric concentration of CO_2 of about 360 ppmv in 1995 represents an increase of almost 30% over the pre-industrial level of about 280 ppmv (IPCC, 1996 b; Bolin, et al., 1979). Recent data indicate that the global mean surface air temperature has increased by between 0.3 and 0.6°C since the late 19th century (IPCC, 1996; IPCC 1996 b), while Canada's mean has increased by about 1°C (see Figure 1.1-2). Some models predict that the Earth's average temperature might increase by about 0.3°C per decade over the next 100 years.

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, regional droughts and flooding could occur. Canada's agriculture, forestry and energy sectors could all be significantly affected.

There is also a large degree of uncertainty associated with climate predictions and, although temperature changes during this century are consistent with predictions of global warming, they also remain within the range of natural variability.

Nevertheless, the balance of evidence — from changes in global mean surface air temperature and from changes in geographical, seasonal and vertical patterns of atmospheric temperature — suggests a discernible human influence on global climate. There are uncertainties in key factors, including the magnitude

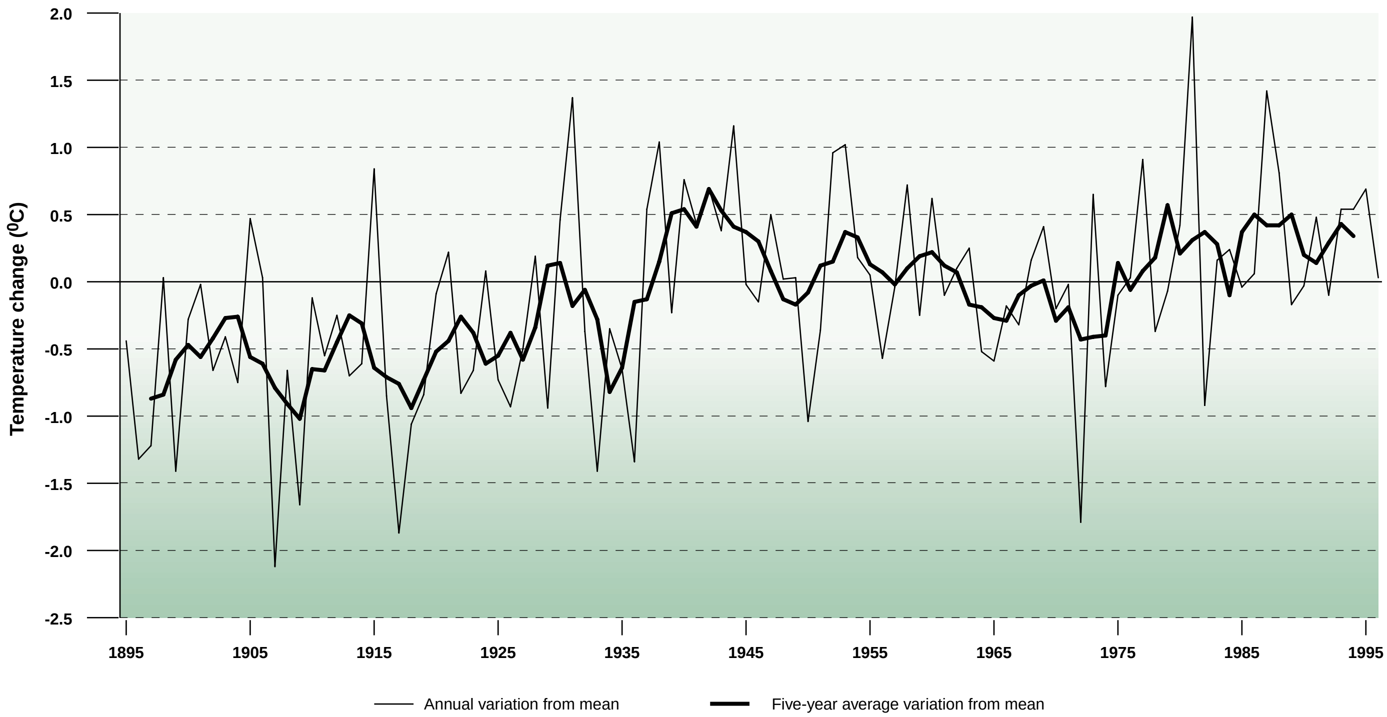

FIGURE 1.1-2
Canadian Temperature Variation

Source: Atmospheric Environment Service, Environment Canada.

Note: This indicator represents annual and five-year average temperature variations from a mean for the respective data sets. The Canadian average annual temperature is -3.6 degrees Celsius and is calculated using the reference period of 1951-80.

and patterns of long-term natural variability. Global sea level has risen by 10 to 25 cm over the past 100 years and much of the rise may be related to the increase in global mean temperature (IPCC, 1996).

1.2 Global Emission Trends

Carbon Dioxide

On a worldwide basis, the anthropogenic emissions of CO_2 are known to be small. In comparison with the gross fluxes of carbon from natural systems they represent only a fraction (~2%) of total global emissions, but 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 anthropogenic sources of CO_2 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 Gt has recently been estimated by the Carbon Dioxide Information and Analysis Centre (Marland, et al., 1999). Deforestation, land use and subsequent 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, decaying organic matter and fermentation, volcanos, 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 carbon dioxide grew from about 6.4 Gt to 23.9 Gt, almost a fourfold increase (Marland, et al., 1999).

Methane

Excess global methane emissions resulting from human activities, are considered to have caused an increase of about 145% in atmospheric concentrations since the mid-1700s (Thompson, et al., 1992).

The current annual rate of accumulation is estimated to range between 40 and 60 Mt CH_4/yr (~14 - 21 ppbv),

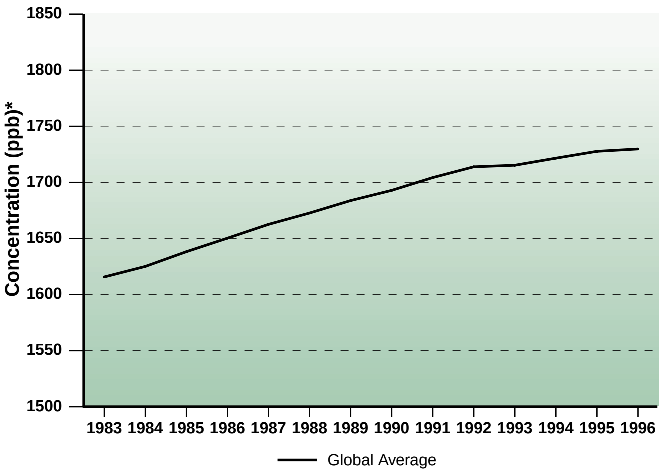

FIGURE 1.2-1
Global Atmospheric Concentration of Methane

*ppb = parts per billion

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

Data provided by State of the Environment Program (1999).

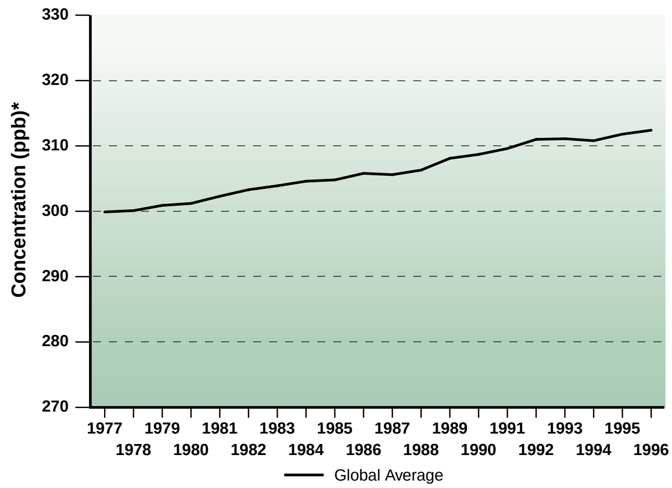

FIGURE 1.2-2
Global Atmospheric Concentration of Nitrous Oxide

*ppb = parts per billion

Source: J. Elkins and A. Clarke, Climate Monitoring and Diagnostics Laboratory. National Oceanic and Atmospheric Administration (NOAA), Colorado, U.S.A.

Data provided by State of the Environment Program (1999).

or approximately 10% of total worldwide methane emissions (Thompson, 1992). The anthropogenic CH_4 emissions, 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 (U.S. 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 methane concentrations at current levels (IPCC, 1996).

Nitrous Oxide

At present, it has been estimated that approximately one third of global atmospheric nitrous oxide is of human origin, resulting primarily from the application of nitrogenous fertilizers and the combustion of fossil fuels and wood. The atmospheric concentration of nitrous oxide has grown by about 15% since the mid-1700s (IPCC, 1996). Total annual emissions from all sources are estimated to be within the range of 10 to 17.5 Mt N_2O, expressed as N (IPCC, 1996 b). Soil and water denitrification under anaerobic conditions is the primary natural source of N_2O. Nitrous oxide produced in this manner is readily taken up by plants. While it is generally recognized that nitrous oxide emission inventory data are more limited than carbon dioxide data and highly uncertain, efforts continue to improve the estimates.

HFCs, PFCs and SF_6

Currently some long-lived gases — particularly hydrofluorocarbons (HFCs, a CFC substitute), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6) — contribute little to radiative forcing, but their projected growth could contribute several per cent to radiative forcing during the 21st century (IPCC, 1996).

Canada's Contribution

While Canada contributes only about 2% of total global greenhouse gas (GHG) emissions, it is one of the highest per capita emitters, largely the result of our resource-based economy, our climate, geographic size and energy-use patterns. In 1990, Canadians released 22 t CO_2 eq of GHGs per capita.[1]

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1 *EDGAR, V 2.0*; Olivier, et al. (1996). This figure, a total of the primary GHGs (CO_2, CH_4, and N_2O) is in tonnes of carbon dioxide equivalent. Though HFCs, PFCs and SF_6 are not included in the estimate, their contribution in 1990 was small enough so as to have had a negligible effect on the per capita figure.

1.3 National Emission Trends

As with all emission inventories, unless the emissions are obtained from continuous emission monitors, all of the emission data must be considered estimates. As such, there is always some uncertainty associated with them. However, in tracking progress or compiling trends, as long as the methodologies used to develop

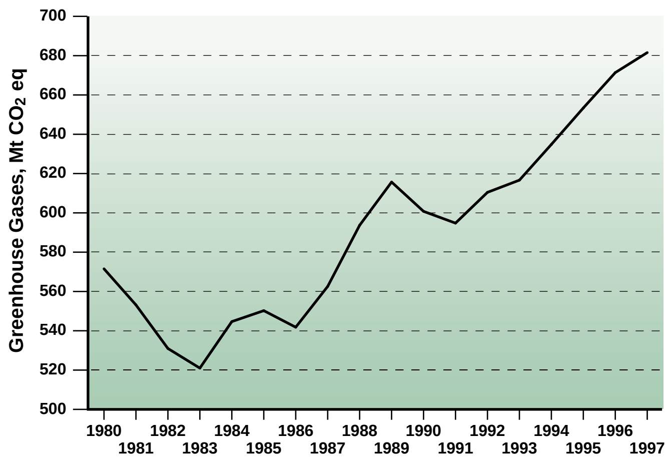
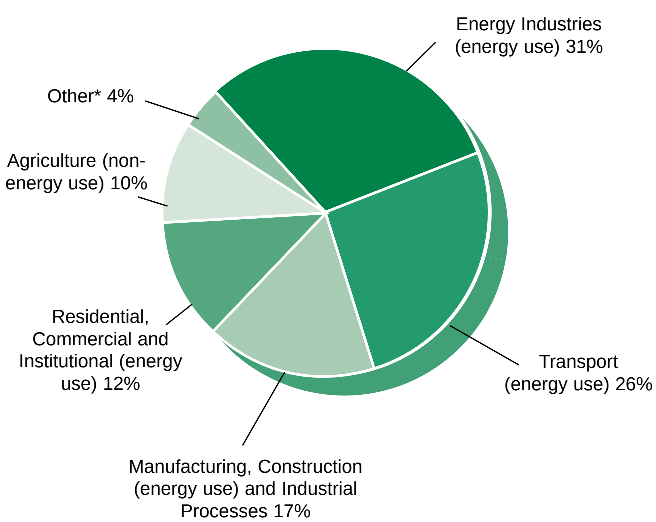


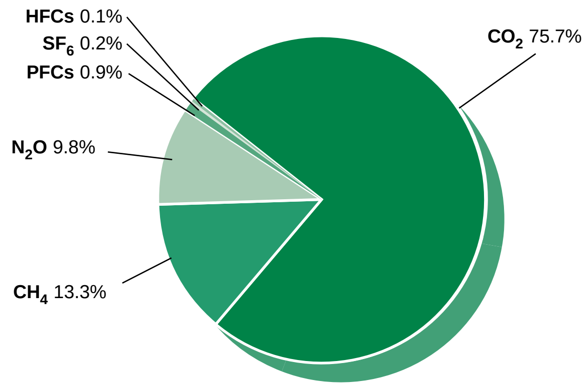
FIGURE 1.3-1
Trend in Canada's Greenhouse Gas Emissions from 1980 to 1997



Total Emissions ~ 671 Mt CO_2 eq

FIGURE 1.3-2
Canada's Greenhouse Gas Emissions by Economic Area for 1996

*Other = Agriculture (energy use), Forestry (energy use), Waste and Solvents.



Total Emissions ~ 671 Mt CO_2 eq

FIGURE 1.3-3
Canada's Greenhouse Gas Emissions by Gas for 1996

the estimates remain consistent, the trends can be considered accurate and a reasonably true measure of performance. Emissions of greenhouse gases are estimated to have risen almost 20% over the 17 years since 1980 to a level of about 682 Mt in 1997 (see Figure 1.3-1). The body of this document focuses on 1996 emissions, since little additional background information exists for 1997. In 1996, emissions are estimated to have been 671 Mt CO_2 eq. Two different depictions are given in Figures 1.3-2 and 1.3-3. It can be seen that carbon dioxide is the dominant gas and energy industries the dominant source.

1.4 Methodology

This report has made use of an internationally agreed to reporting format that groups emissions into six sectors. Definitions of the sectors and details of accepted methodologies for emissions inventories are provided by the Intergovernmental Panel on Climate Change (IPCC) in its *Guidelines for Greenhouse Gas Inventories* (IPCC/OECD/IEA, 1997). The six major sectors are:

- Energy
- Industrial Processes
- Solvents & Other Products Use
- Agriculture
- Land Use Change & Forestry
- Waste

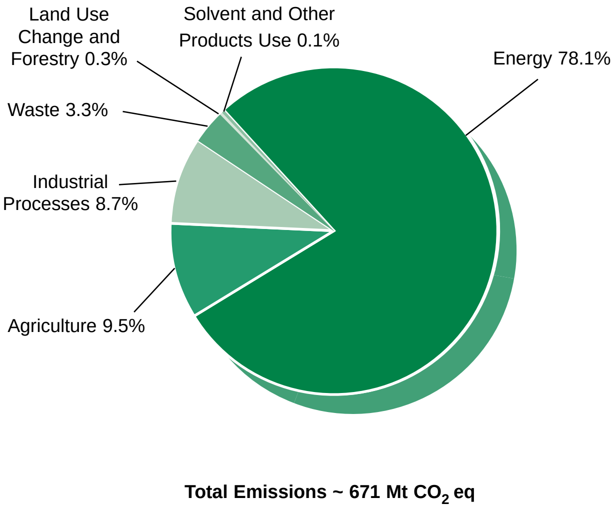


FIGURE 1.4-1
Canada's 1996 Greenhouse Gas Emissions by IPCC Sector

International Bunkers

In Canada, emissions resulting from fuel sold to vessels of foreign registration, regardless of destination, are considered international bunkers.

Emissions for 1996, by IPCC Sector, are shown in Figure 1.4-1. The energy sector includes both combustion-related and fugitive emissions from all energy-related activities, including the production, transport and end-use of fossil fuels. While the combustion of wood and other biomass does result in emissions, only emissions of non-CO_2 gases are included in the energy section. Any emissions of carbon dioxide from the combustion of wood waste, spent pulping liquor, residential combustion of wood, prescribed burning of wood and agricultural biomass are reported in the section on land use change and forestry, and may not result in net emissions if sustainably produced.

It should be noted that, in compliance with international reporting guidelines, emissions attributable to bunkers have been excluded from the totals.

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 that can be used to determine the effect of emissions on ambient air quality (U.S. EPA, 1981).

Because the excess release of greenhouse gases results in longer-term global consequences, rather than more immediate localized effects, usually large-scale regional or international emission estimates under averaged conditions have been compiled to date for collective source/sectors. In general, these 'top-down'[2] compilations have not required the point source detail and geographical resolution that is often incorporated in criteria pollutant inventories. However, as greenhouse gas emission control and resource management strategies develop, there will likely be greater requirements to assess individual source contributions using 'bottom-up' inventory approaches in order to provide and/or predict more accurate emissions data. Similarly, inventory data are often used to establish annual emission trends. Thus, consistency in compiling emissions is an important consideration as long as any methodology uncertainties remain unresolved.

It can normally be expected that the accuracy and utility of an emission inventory will increase as a greater fraction of total emissions is included in the point source data file. That is, data in the point source file are more detailed and often more reliable than the data maintained in the area source files.

Until now, greenhouse gas emissions have not normally been measured for regulatory or compliance purposes.[3] Emissions have usually been calculated with emission factors, mass-balance approaches or stoichiometric relationships under averaged conditions. Carbon budgets, to account for source/sink balances, and modeling 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).

Greenhouse gas emissions may be derived for a given process or combination of operations by one or more of the following methods.

A ***mass-balance*** approach determines atmospheric emission from the difference between the amounts of the component (carbon, for example) 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

2 *Top-down and bottom-up* are terms used to describe the level of detail within an inventory. Here, bottom-up is defined to include point or establishment-level discrete sources, while top-down usually refers to a sectoral level of detail.

3 Though this may change in the future if, for example, the Kyoto Protocol is ratified.

contributions and mineral-processing activities, where sufficient data are available to derive average carbon contents of process streams. Generally, carbon dioxide emissions resulting from fuel combustion are readily estimated by the carbon balance and used to derive emission factors.

Emission factors can be used to estimate the rate at which a pollutant is released to the atmosphere as a result of some process activity or unit throughput. Average values used for a given source category may differ from actual emissions for a specific facility, and may be developed on the basis of source test or other data. Emission factors have been developed by Environment Canada, in consultation with other government departments, industry associations, and other agencies and organizations, for many of the specific source categories. The values summarized in Appendix C reflect the most accurate methodologies currently available, and include information currently being developed for the IPCC.

In general, CO_2 emission factors are well-developed for many sources, CH_4 factors are less well-defined and N_2O, PFC and HFC 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. A complete discussion of the methodologies used can be found in Jaques (1992), and IPCC/OECD/IEA (1997), in accompaniment with this document.

Some methods have undergone revision and some new sources have been added since the release of the previous published inventory. The changes of significance include a higher estimate for emissions from residential wood combustion, revised estimates from the upstream oil and gas *and* transportation categories, and the inclusion of new, higher estimates for nitrous oxide from agricultural soils, animal wastes and wastewater treatment. Also of note is the inclusion of a new estimate of net removals of CO_2 by land use change and forestry activities. The methodology utilized is now compatible with the IPCC Guidelines, though the estimates are not included in inventory totals.

It is significantly important to note that *these latest estimates, and the trends they depict, are considered to supercede all earlier versions*.

Data Development

Although data collection procedures may be straightforward, the assessment of the adequacy of the collected data with regard to representativeness, completeness and accuracy can be demanding — especially when data are from sources which are large and complex, or sources of fugitive emissions exist. Depending on the inventory requirements and use of the data, it may or may not be desired to treat emissions from fuel combustion entirely as area sources. Emissions inventories can be structured in many different ways, making comparisons difficult without a common set of reporting criteria. For these reasons, Canada's emission inventory has tried to follow the reporting Guidelines.

1.5 References

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Section 2 - Energy

Energy-related activities are by far the largest source of greenhouse gas emissions in Canada. The Energy sector includes emissions of all greenhouse gases from the production of fuels and their combustion for the primary purpose of delivering energy. This sector is divided into two broad sections based on the processes which generate the emissions: Fuel Combustion, and Fugitive. Fugitive emissions are leakage and venting of methane (CH_4) and carbon dioxide (CO_2) during the extraction, processing and delivery of fossil fuels. All fugitive emissions are associated with the Energy Industries.

Overall, greenhouse gas emissions from Energy account for about 78% of the national total in 1996 (Figure 2.1). The emissions were 467Mt carbon dioxide, 45 Mt CO_2 eq methane, and 12 Mt CO_2 eq nitrous oxide (N_2O). In 1996, total energy-related emissions were up 13% from 1990. The largest contributor to Energy emissions is the Energy Industries category (both combustion and fugitive). This category accounts for 39% of Energy emissions.

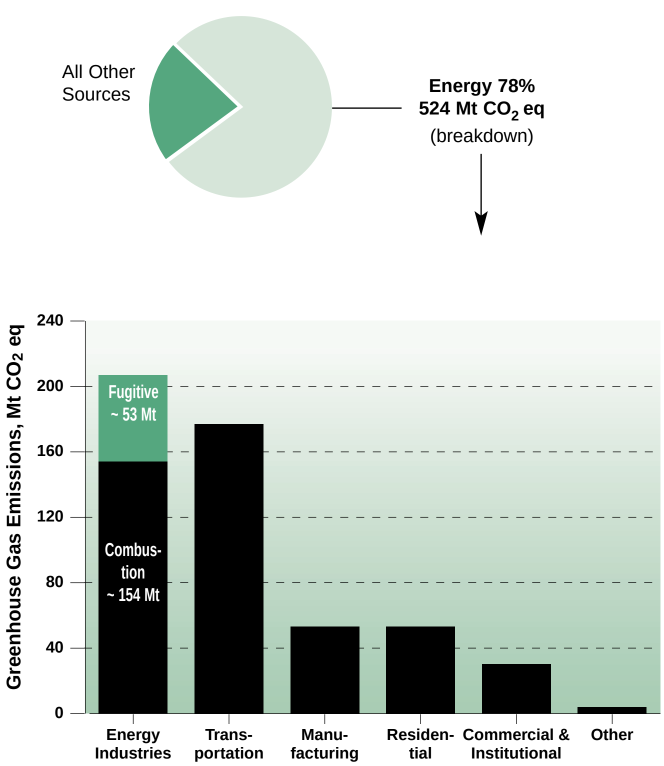

FIGURE 2.1
1996 Energy Sector Greenhouse Gas Sources

A. Fuel Combustion

Emissions of greenhouse gases from the combustion of all fuels used for energy were 471Mt CO_2 eq; this is an increase of 11% since 1990. The largest single source is the transportation sector, with the energy industries (fuel combustion only) running a close second.

Fuel combustion emissions have been divided into the following categories: Energy Industries; Manufacturing; Transportation; Residential; Commercial and Institutional; and Other.

Fuel Combustion Methodology

To estimate emissions from fuel combustion, the following methodology has been adopted. It applies generally to all source categories, although additional refinements and more detailed procedures are often utilized. Such details are described, as applicable, under the appropriate category headings.

The quantities of fuels combusted in various categories are multiplied by technology-specific emission factors. This is consistent with a Tier 2 type methodology, as described by the Intergovernmental Panel on Climate Change (IPCC) Reference Manual (IPCC, 1997).

The basis of the CO_2 emission factor derivations has been discussed in previous publications (Jaques, 1992) and is relatively straightforward. The factors have been obtained and developed from a number of studies conducted by the United States Environmental Protection Agency, and several other agencies, both Canadian 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 (HCs) and particulate formed during combustion are accounted for to some extent, but emissions of carbon monoxide (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 to 20 weeks of emission). The emission factors used are shown in Appendix C.

In some cases emission factors for methane or nitrous oxide are not known (such as for spent pulping liquor). In these cases no emissions have been estimated; they are assumed to be negligible.

Emissions of all gases are estimated on the basis of the same fuel-use (activity) data. Emissions from the flaring of waste gases are not included in the Fuel Combustion section, but rather under Fugitive emissions.

While there are emissions of carbon dioxide from the combustion of biomass used to produce energy, CO_2 emissions from biomass fuels are *not* included in the Energy sector totals. They are accounted for in the Land Use Change and Forestry sector, and will be recorded as a loss of biomass (forest) stocks. Other greenhouse gases (methane and nitrous oxide) from biomass fuel combustion are reported in this Energy section.

All the fossil fuel energy-use data used to estimate combustion emissions are from the *Quarterly Report on Energy Supply-Demand* (QRESD), compiled by the national statistics agency, Statistics Canada. 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. While the QRESD also provides fuel-use estimates at a provincial level, the accuracy of this data is not as high as that of the national data. Statistics Canada generally collects the fuel data for the QRESD by surveying the producers and suppliers of energy.[1] The accuracy of the sectoral end-use data is less than 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.

Statistics Canada has taken measures to improve the quality of the QRESD data by enlarging the Industrial Consumption of Energy survey (see subsection 2.2.1) and by expanding the review and analysis of the energy consumption information in the report. In May 1999, Statistics Canada released revised estimates for the period 1990 to 1997. The updated data set incorporates information from the expanded Industrial Consumption of Energy survey and provides consistent and better quality data on energy consumption, at the sector and industry level. It is expected that the improved data set will result in some upward revision to combustion emissions; however, the general trends will not be altered significantly for most sectors and provinces. The revised Statistics Canada estimates will be incorporated in the next inventory published by Environment Canada.

2.1 Energy Industries

As shown in Figure 2.1, the second largest source of fuel combustion emissions are the Energy Industries, accounting for about one quarter of all national emissions and one third of energy related emissions. This category includes all stationary fuel combustion emissions from the production and refining of energy (electricity generation, oil and natural gas production, refining of petroleum products, etc.). In 1996, combustion emissions from the Energy Industries were 154 Mt CO_2 eq; an increase of 9% over 1990 (Table 2.1-1). The major emission is carbon dioxide (Table 2.1-2).

TABLE 2.1-1 COMBUSTION EMISSION TRENDS FOR ENERGY PRODUCTION AND TRANSFORMATION INDUSTRIES

	GHG CO_2 eq (Mt)						
Sub-Category	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**
Electricity and Steam Generation	95.2	96.5	104	93.8	95.6	100	101
Petroleum Refining	17.2	17.1	17.1	17.1	16.5	16.4	17.0
Other Fossil Fuel Production Industries	21.4	20.3	21.8	22.0	23.6	23.8	22.9
Mining	7.7	7.2	6.9	9.9	10.9	12.0	13.0
Total Energy Industries	**141**	**141**	**149**	**143**	**147**	**153**	**154**

The Energy Industries are divided into four sub-categories: Electricity and Steam Generation, Petroleum Refining, Other Fossil Fuel Industries, and Mining. According to IPCC reporting practice, only fuel-combustion emissions from stationary sources are included here. All mobile sources are included in the Transportation category. Fugitive and flaring emissions are associated with Energy Industries; they are categorized under the Fugitive section.

It is interesting to consider the sum of stationary, mobile and flaring emissions from the Energy Industries. These are shown in Table 2.1-2. With these sources added in, total greenhouse gases climb by an additional 12 Mt CO_2 eq. For descriptions of each sub-category, refer to the appropriate sections below.

1 The producers and suppliers know to a high degree of accuracy the amount of fuels sold, however they know with less certainty to whom the energy is sold or where the fuels are used.

TABLE 2.1-2 **1996 EMISSIONS FROM THE ENERGY INDUSTRIES, INCLUDING FLARING AND MOBILE SOURCES**

	Mt of CO_2 Equivalent				
	Stationary Fuel Combustion			Mobile and Flaring	Total
Industry Sub-Category	**CO_2**	**CH_4 & N_2O**	**IPCC Sub-Category Total**	**GHG**	**GHG**
Electricity and Steam Generation	100	0.8	101	NA	101
Petroleum Refining	17.0	0.0	17.0	NE	17.0
Other Fossil Fuel Industries	22.8	0.1	22.9	6.57(1)	29.5
Mining	12.9	0.1	13.0	5.16(2)	18.2
Totals	**153**	**1.0**	**154**	**11.7**	**166**

(1) Includes flaring emissions.
(2) Includes only diesel and gasoline combustion emissions.
NA – Not applicable.
NE – Not estimated.

2.1.1 Electricity and Heat Production

This section considers emissions associated with the generation of electricity and the production of steam for commercial sale. In the case of steam turbine-generated electricity, the two may be produced simultaneously (combined heat and power). Unfortunately, little statistical data is available on the extent of commercial combined heat and power plants in Canada, so the two types of energy are considered separately.

Electricity Generation

Introduction

In 1996, of 556 TWh of electrical generation, thermal combustion-derived electricity accounted for 115 TWh, about 21% of the supply mix (Statistics Canada, Catalogue No. 57-202). Hydro-powered electricity accounted for about 63% of total generation, and nuclear, 16%. Although responsible for less than a tenth of a percent of generation, wind and tidal power also contribute to the supply mix. Wind plants are situated at various locations throughout the country[2], while the only tidal generator is the Annapolis power plant at the Bay of Fundy in Nova Scotia. Solar electricity is utilized in Canada, but primarily in remote locations. Solar panels are generally not connected to the electrical supply grid and estimates are that total generation has been much lower than that from wind and tidal power. Nuclear, hydro, wind, solar and tidal generation are not considered to be direct emitters of greenhouse gases, so a discussion of emission trends centres around combustion-source electricity.

Two basic systems are used to generate thermal power: steam generation and internal-combustion (gas turbine and reciprocating) engines. Steam-turbine boilers are primarily fired with coal, heavy fuel oil, crude oil, natural gas, wood, or spent pulping liquors. (Initial steam may be produced by light fuel oil, natural gas, kerosene or diesel oil). Reciprocating engines use light oil, natural gas, a combination of both, or diesel oil; gas turbines are fired with natural gas or refined petroleum products. Greenhouse gas emissions are estimated based on the quantities of fossil fuels consumed and, to some extent, the technology utilized to produce electricity (see Fuel Combustion Methodology on page 9).

Emissions

In the case of combustion-based electricity generation, carbon dioxide contributes more than 98% of all greenhouse gas emissions. The trends associated with electric power are shown in Table 2.1.1-1 and Figure 2.1.1-1. From 1990 to 1996, emissions from the sector fluctuated from a level of 94.8 Mt in 1990 to a high of 103 Mt in 1992, dropping, then rising once again to reach 99.3 Mt CO_2 eq in 1996. Net emission growth from 1990 to 1996 was about 5%, while electrical generation in Canada over the same period increased 19%.[3,4] In general, emissions followed trends in the quantity of combustion-generated electricity, but closer inspection reveals that the relationship is not a linear one.

2 Particularly in eastern and western Canada.
3 Statistics Canada, *Electric Power Annual Statistics*, Catalogue No 57-202.
4 It is interesting to note that Canadian electrical energy consumption rose only 7% over this period. Expanded electricity exports, made possible by capacity additions and transmission upgrades in Ontario, Quebec and Manitoba accounted for the balance of generation increases. Net exports to the U.S. rose from less than 1% in 1990 to 7% in 1996. (Natural Resources Canada/CEA, annual.)

TABLE 2.1.1-1 TRENDS IN EMISSIONS FROM ELECTRICITY GENERATION

Year	Greenhouse Gases Mt of CO_2 eq	Electrical Generation, TWh				Combustion Energy Used for Generation					Net Electrical Exports TWh
		Utility	Industrial	Total	Total Combustion	Total, PJ	Coal	Oil	Natural Gas	Other	
1990	94.8	427	40.9	468	105 (22.4%)	1 140	74.7%	12.8%	7.3%	5.2%	1
1991	96.2	452	41.3	493	107 (21.8%)	1 210	78.4%	10.5%	6.2%	4.9%	18
1992	103	464	40.8	504	114 (22.7%)	1 220	73.0%	11.2%	10.9%	4.9%	24
1993	93.3	472	43.7	516	107 (20.7%)	1 170	71.7%	8.7%	13.5%	6.1%	27
1994	94.8	495	44.6	539	111 (20.6%)	1 230	71.9%	6.4%	15.4%	6.3%	44
1995	99.2	497	45.4	543	118 (21.6%)	1 270	70.7%	7.3%	15.4%	6.6%	38
1996	99.3	511	45.1	556	115 (20.7%)	1 240	74.0%	6.6%	12.8%	6.6%	40

Net electrical exports data from Natural Resources Canada/Canadian Electricity Association, *Electric Power in Canada* (annual).
All other Electricity data from Statistics Canada *Electric Power Annual Statistics* (Catalogue No. 57-202)
Combustion Energy data from Statistics Canada Catalogue Number 57-202 and 57-003 (*Quarterly Report on Energy Supply and Demand in Canada* - annual).

Trends in Emissions from Electricity Generation

The 1990 to 1996 interim consisted of two distinct phases. The first, the period from 1990 to 1994, was characterized by a rapid (15%) increase in electricity production accompanied by zero net growth in emissions. The second phase occurred between 1994 and 1996, when an almost opposite trend emerged — greenhouse gas emissions increased by 5% while electricity generation growth over the two years was only about 3%.

The fact that emissions did not grow in spite of rising power generation during the first four years is significant, particularly since electricity use forms approximately one quarter of Canadian secondary energy consumption. In 1994, 20.6% of total electrical energy was produced by combustion energy, almost two percentage points lower than in 1990 (Table 2.1.1-1). This reduced share of combustion-generated electricity is the primary reason that there was no net emission increase. It does not provide a full explanation, however, since the actual quantity of combustion generation rose by about 6 TWh between 1990 and 1994.

The emission intensity trend is illustrated in Figure 2.1.1-1. Overall, greenhouse gas emissions per unit of total electrical energy generated declined over the initial period. The greenhouse gas intensity dropped from about 200 g per kWh in 1990, to just over 180 g per kWh in 1994.

The appearance of a significant sub-trend helps to explain the pattern: greenhouse gas emissions from *combustion*-generated electricity fell from over 900 g/kWh to about 880 g/kWh. The 1994 *combustion* greenhouse gas emission intensity was about 20 g/kWh below the 1990 level. This can be attributed to a shift in generation sources away from oil and toward natural gas. In 1990, 13% of combustion generation was fuelled by oil and 7% by natural gas. In 1994, natural gas's contribution had risen dramatically and accounted for 15%, while oil sources powered only 6% of combustion electrical generation. Generally, greenhouse gas discharges from natural-gas-fired electrical generators are lower than those from oil-fired generators; therefore, the shift in fuel sources caused a reduction in combustion emission intensity.

The movement away from oil and toward natural-gas generation appears to be based on a number of factors, including availability, convenience, favourable pricing, reduced emissions, and the potential for increased efficiency. Dual-cycle gas-fired electric utility power plants and modern industrial co-generation units offer greatly improved conversion efficiencies and, subsequently,

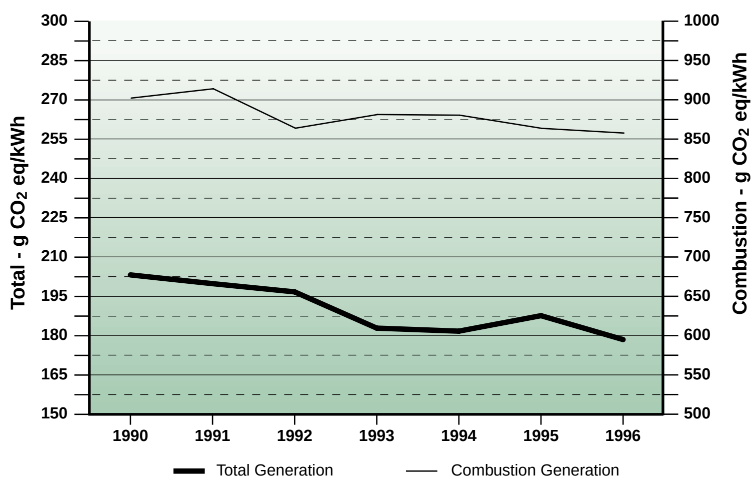

FIGURE 2.1.1-1
Greenhouse Gas Emission Intensity of Canadian Electricity Generation

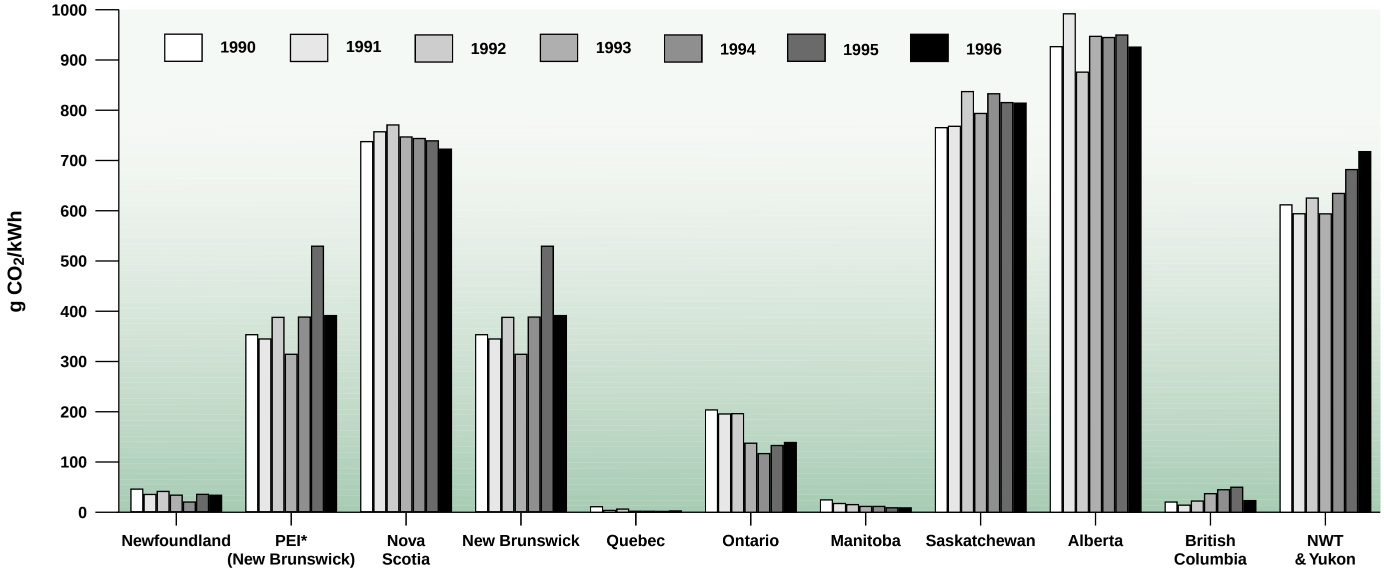

FIGURE 2.1.1-2

Greenhouse Gas Intensity of Electricity Generation by Province

*Prince Edward Island produces (by low-efficiency oil generation) considerably less than 10% of its own electricity; the rest is imported from New Brunswick. As the vast majority of the power is imported, shown here are the emission intensities associated with the New Brunswick source.

lower emissions per unit of energy generated. A concurrent trend within the electric power industry is the encouragement of greater electrical generation by industries and independent power producers (IPPs).[5] Most of the recent capacity additions in this sub-sector have been fuelled by natural gas, providing further impetus for the increased penetration of gas generators.

From 1994 to 1996, in spite of slower growth in electricity demand, requirements for combustion generation rose, as did greenhouse gas emissions. Total combustion-based production, 111 TWh in 1994, peaked at 118 TWh in 1995 and remained a high 115 TWh in 1996. This was accompanied by a shift in the mix of combustion sources; in 1996, natural gas generation lost some of its formerly increasing share to coal. Coal plants tend to have even higher greenhouse gas emission intensities than oil facilities, so this would normally be expected to considerably worsen electricity emission intensity. This does not appear have been the case, however, as both total and combustion-based intensities fell (albeit slightly) once again between 1994 and 1996 (Figure 2.1.1-1). This is likely the result of improved generation efficiency. Calculations based on the available data indicate that the average combustion 'heat rate'[6] (in kJ per kWh of electricity production) fell about 3% over the two years.

In spite of these relatively positive developments during the 1990-1996 period (the increasing share of natural gas combustion generation and the decline in emission intensity), the longer-term picture reveals some less-promising trends. Since 1980, the amount of coal-based electricity generation has been continuously increasing, due to the consistently low price of coal energy and the reduced availability of economical hydro resources. As can be seen in Table 2.1.1-1, coal supplies the majority of combustion generation. Between 1980 and 1997, the quantity of coal used for electricity production went up 54%, while electricity emissions increased about 55%.[7] Even from 1990 to 1996, emissions from coal-based generation rose by about 7 Mt CO_2 eq.

In 1997, this trend was further exacerbated. For safety reasons, Ontario Hydro began a shutdown and maintenance program on a number of its nuclear reactors during the latter half of 1997. The result of this is that more fossil-fuel-based generation, primarily coal, was called upon to supply the missing power. Early estimates are that the shutdown was responsible for about a 4 Mt CO_2 eq increase in greenhouse gas emissions in 1997 alone. The emission impacts of this situation are increasing, as more reactors have been taken out of service since 1997 and will not be returned to service until 2000 at the earliest.

5 Natural Resources Canada/CEA, annual.
6 The 'heat rate' is an indicator of efficiency for a thermal electricity generator.
7 Coal use from Statistics Canada, *Quarterly Report on Energy Supply-Demand*. Emission growth, as calculated here, is based on the sum of both electricity and steam production. However, as electricity emissions outweigh those from steam production by more than 50 times, the error introduced is small.

It must also be noted that Natural Resources Canada has forecast a rise in CO_2 emissions from electric power beyond the year 2000. Although combustion generation is expected to continue becoming more efficient, it is likely that fewer hydro and no nuclear capacity additions will occur. Combustion-based electricity will therefore become more predominant in the mix.

Certain regions in Canada (generally those with few hydro resources) place greater reliance on combustion fuels for electric-power generation. Greenhouse gas emissions are therefore higher in these regions. Figure 2.1.1-2 depicts the provincial variations in emissions per unit of electrical energy.

Steam Generation

Emissions from the production of commercial steam are reported here. Greenhouse gas emissions from this activity are estimated to have been 1.5 Mt CO_2 eq in 1996, considerably larger than the 0.4 Mt emitted in 1990.

Categorization of Electricity and Heat Production

According to the *Intergovernmental Panel on Climate Change Reporting Guidelines* (IPCC, 1997), Electricity and Heat Production should include only energy generated by public utilities. Thus, emissions resulting from industrial generation should be reported under the specific industries (Sections 2.1.2, 2.1.3 and 2.2) which produce the energy. Unfortunately, data that permit this level of breakdown are not readily available, so emissions associated with all electricity and steam production have been reported here.

Very few public heat systems exist in Canada and little data is 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 heat and power plants.

2.1.2 Petroleum Refining

The emissions from the Petroleum Refining subcategory were 17.0Mt CO_2 eq in 1996 and have remained fairly stable since 1990. Over the same time period, the total production of refined petroleum products has increased 5%.

Methodology

The QRESD does not explicitly estimate the fuel consumption of the petroleum refining industry. Here fuel usage has been estimated by summing the 'Producer Consumption' of refined petroleum products with the explicitly reported fuels used by the petroleum refining industry (SIC 3611). The emissions from the flaring or venting of waste gases during refining, according to IPCC Guidelines, should be allocated to the fugitive area. However, they have not been estimated due to lack of data. Emissions associated with the production of hydrogen used in refining are allocated to the Industrial Process section.

The QRESD does not differentiate between catalytic cracker coke and oven-derived petroleum coke, however these are produced by significantly different processes. It is assumed that 40% of the petroleum coke used by refineries is generated in a catalytic cracker.

2.1.3 Other Fossil Fuel Industries and Mining

Emissions from Other Fossil Fuel Industries and Mining were 35.9 Mt CO_2 eq in 1996 and have increased 24% since 1990. Emission trends from these two sub-categories are best discussed together, because they represent overlapping areas. Combined they represent the upstream oil and gas industry (not including transmission systems) and the 'mining' sector.

Methodology

The fuel-use data reported in the QRESD combine *purchased* fuel use by mining, petroleum and natural gas production activities under one catch-all economic sector called 'mining', while producer-consumed fuels (self-generated and used) in the upstream oil and gas industry are allocated separately under 'Producer Consumption', even though they may be consumed at the same establishment.

The Other Fossil Fuel Industry category includes all emissions resulting from the combustion of producer-consumed fuels, with the exception of refined petroleum products, which are included under petroleum refining. The Mining category includes emissions resulting from combustion of the fuels reported under 'mining' (which includes upstream oil and gas as well as metallic and non-metallic mineral mining) in the QRESD.

The 'producer consumption' fuel-use data from the QRESD includes natural gas flared in the upstream oil and gas industry. To avoid double counting the flaring emissions estimated under the fugitive section are subtracted from the total calculated for Other Fossil Fuel Industries.

The decreasing emission trend in Other Fossil Fuel Industries since 1995 is inconclusive since the underlying natural-gas fuel-use data from the QRESD is questionable.

2.2 Manufacturing and Construction

The emissions from the manufacturing category in 1996 are shown in Table 2.2-1. Greenhouse gas emissions from energy use in manufacturing were 53.3Mt CO_2 eq and were at slightly lower levels in 1996 than 1990 in spite of the increased economic output. The emissions declined from 1990 to 1993, reflecting a recession in economic activity over this time period.

TABLE 2.2-1 GREENHOUSE GAS EMISSIONS IN IPCC CATEGORIZATION ($Mt\ CO_2$ eq)

Industry	1990	1991	1992	1993	1994	1995	1996
Pulp and Paper and Sawmills	11.7	11.9	11.4	11.1	11.4	11.0	11.0
Iron and Steel	6.7	6.5	6.7	6.6	6.6	6.4	7.3
Smelting and Refining	3.5	2.9	3.1	3.1	3.0	2.9	3.6
Cement	3.8	3.4	2.9	2.8	3.1	3.7	3.6
Chemicals	6.3	6.3	6.1	6.5	7.7	7.4	7.0
Other Manufacturing	22.4	20.2	20.2	19.3	18.7	22.4	20.9
Total Manufacturing	54.4	51.1	50.4	49.3	50.5	53.8	53.3
Construction	0.7	0.8	0.8	0.5	0.4	0.7	1.1

As can be seen from Table 2.2-2 emissions are primarily carbon dioxide from stationary sources. Emissions from diesel and gasoline are minor sources in manufacturing. Since these belong to the transportation category, they are not included in IPCC totals, but are shown here for interest only.

TABLE 2.2-2 EMISSIONS FROM THE MANUFACTURING INDUSTRIES AND CONSTRUCTION CATEGORY IN 1996 (Mt)

	Stationary (IPCC Categorization)			Mobile(1)	Total
Industry	Fuel combustion CO_2	Fuel combustion CH_4 & N_2O (CO_2 eq)	Total Stationary GHG (CO_2 eq)	GHG CO_2 eq	GHG CO_2 eq
Pulp and Paper and Sawmills	10.8	0.2	11.0	0.4	11.4
Iron and Steel	7.1	0.2	7.3	0.1	7.4
Smelting and Refining	3.6	0.0	3.6	0.1	3.6
Cement	3.6	0.0	3.6	0.0	3.6
Chemicals	7.0	0.0	7.0	0.0	7.1
Other Manufacturing	20.8	0.1	20.9	1.1	22.0
Total Manufacturing	52.8	0.5	53.3	1.8	55.1
Construction	1.1	0.0	1.1	2.1	3.2

(1) Mobile includes diesel, gasoline and aviation fuels sold to industries.

Methodology

The fuel-use data is obtained from the QRESD. Emissions from fuels consumed for transportation (e.g. diesel) and industrial processes (metallurgical coke) are not included and have been reallocated to the Transportation sector and the Industrial Process sector respectively. Also excluded are emissions from the combustion of fuels within industry for the generation of electricity or steam for sale; these have been reallocated to the Energy Industries category. This is contrary to IPCC Guidelines, which indicate that emissions associated with the production of heat or power by industry should be included in their industrial or commercial sub-categories. At present it is not possible to allocate industrial power generation emissions to the respective industrial sub-categories, since the fuel-use data is not available at this level of detail in the QRESD.

Emissions of methane and nitrous oxide from the combustion of biomass are included in stationary combustion totals. The estimation methodology is discussed in detail in Appendix B.

The industrial sub-categories are defined as follows according to Standard Industrial Classification Codes

(1980 SIC): Pulp and Paper and Sawmills, SIC 2512 and 271; Iron and Steel, SIC 291; Smelting and Refining, SIC 295; Cement, SIC 352; Chemicals, SIC 371 and 3721; Other Manufacturing is the remainder of SICs 10 to 39, and Construction is SICs 401 to 429.

2.2.1 Industrial Consumption of Energy Survey

The energy-use data available from the QRESD is only available in broad fuel-use sectors with diminishing accuracy as the level of disaggregation increases. In an effort to provide greater detail and accuracy for reported energy use and emissions from the various industrial sub-sectors, Statistics Canada has been collecting energy-use statistics from end-users through the Industrial Consumers of Energy (ICE) survey since 1995. The ICE survey uses a bottom-up approach to estimate fuel use by industry as opposed to the top down approach used in the QRESD, and is therefore inherently more accurate at the sector level. The ICE survey is also used as a data source for the industrial sectors of the QRESD. The ICE survey is designed to provide estimates of fuel use on a national level. The aggregate manufacturing emissions from ICE do not exactly match the QRESD manufacturing sector due to differences in the statistical methods used to make the estimates. However the difference in the two estimates is small. The data from the QRESD is used as the basis for the national inventory since it is a consistent data set for the 1990-1996 time span. However, the ICE survey can be used to develop emission estimates by industrial sub-category for the period 1995 onwards.

Table 2.2.1-1 provides details of energy-related greenhouse gas emissions from the combustion of fossil fuels in the manufacturing sector based on ICE data. Unfortunately, this level of detail is not available for the 1990 to 1994 period.

2.2.2 Canadian Industry Program for Energy Conservation

Established in 1975, the Canadian Industry Program for Energy Conservation (CIPEC) has been responsible for tracking the energy efficiency improvements made by Canadian industry. In 1992, as part of Canada's efforts to stabilize greenhouse gas emissions, the program began to track energy-related Carbon dioxide emissions. Later, Environment Canada was asked to develop the emission estimates to maintain consistency with the national inventory. The major difference between the IPCC definition of industry and the CIPEC definition is allocation. CIPEC estimates include greenhouse gas emissions from transportation fuels and some energy industries.

TABLE 2.2.1-1 FUEL COMBUSTION EMISSIONS BASED ON ICE SURVEY ENERGY USE DATA (kt CO_2 eq)

SIC (1980)		1995	1996
10	Food	3 260	3 300
11	Beverage	477	520
12	Tobacco Products	30	28
15	Rubber Products	333	398
16	Plastic Products	323	284
17	Leather and Allied Products	29	31
18	Primary Textile	641	646
19	Textile Products	355	347
24	Clothing	151	153
25	Wood	1 970	1 770
26	Furniture and Fixture	196	201
27	Paper and Allied Products	12 900	13 400
28	Printing, Publishing and Allied Industries	275	241
29	Primary Metal	11 500	12 100
30	Fabricated Metal Products (except Machinery and Transportation Equipment)	1 430	1 340
31	Machinery (except electrical machinery)	420	446
32	Transportation Equipment	2 050	2 250
33	Electrical and Electronic Products	382	363
35	Non-Metallic Mineral Products	6 570	6 580
36*	Refined Petroleum and Coal Products	16 200	17 300
37	Chemical Products	9 280	9 110
39	Other Manufacturing	199	208
	Total Manufacturing SIC 10-39 (not including 36)**	53 500	53 700
	Total Manufacturing and Refining (SIC 10-39)	**69 000**	**71 000**

* SIC 36 is not included in IPCC Manufacturing total.
** Total will not exactly match national inventory 'Manufacturing' sum due to statistical differences in fuel-use data.

TABLE 2.2.2-1 ENERGY RELATED CARBON DIOXIDE EMISSIONS FOR CIPEC INDUSTRIES (Mt CO_2 eq)

Economic Sector*	1990	1991	1992	1993	1994	1995	1996
Mining	10.4	10.3	9.7	13.1	14.3	15.7	18.2
Pulp & Paper and Sawmills	12.5	12.6	11.8	11.5	11.7	11.4	11.4
Iron and Steel	6.8	6.6	6.8	6.7	6.7	6.5	7.4
Smelting and Refining	3.5	2.9	3.2	3.1	3.0	3.0	3.6
Cement	3.9	3.4	2.9	2.8	3.1	3.7	3.6
Petroleum Refining	17.2	17.1	17.1	17.1	16.5	16.4	17.0
Chemicals	6.3	6.3	6.1	6.5	7.7	7.4	7.1
Other Manufacturing	23.4	21.0	21.1	20.0	19.6	23.4	22.0
Total	**83.9**	**80.1**	**78.7**	**80.8**	**82.7**	**87.5**	**90.3**

* Economic sectors are as defined in the QRESD.

Emissions from industry, as currently defined by CIPEC, increased about 8% over the period 1990 to 1996. The majority of the increase is in the mining area due to increased production of heavy and synthetic crude oil.

The CIPEC greenhouse gas emission calculations have been made from fuel-use statistics obtained from the QRESD. No adjustments or reallocations have been made, so they match the QRESD sectors identically.

2.3 Transportation

Overview

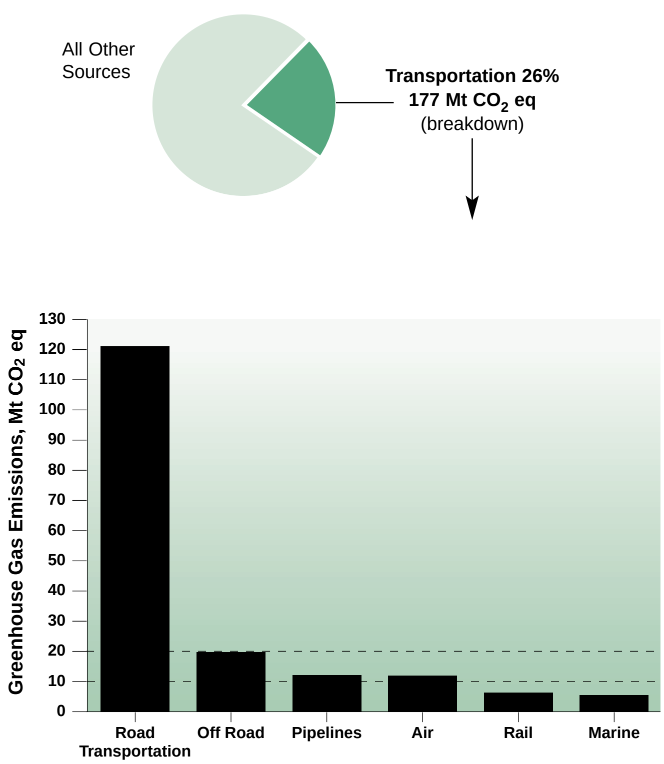

FIGURE 2.3-1
1996 Transportation Category Greenhouse Gas Sources

The Transportation category is responsible for 26% of Canada's 1996 greenhouse gas emissions. Not only does this sector represent one of the largest sources, it contributed 37% of Canada's emission growth from 1990 to 1997, second only to the Energy Industries. After a significant decline in the 1980s, brought on by rapid improvements in road vehicle efficiency and

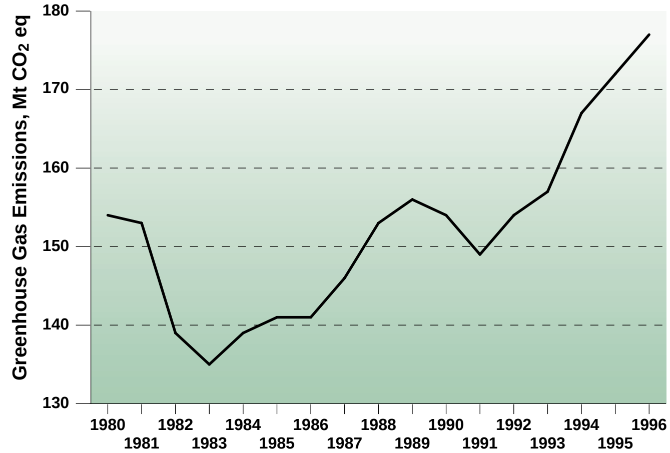

FIGURE 2.3-2
Historical Emission Trends in Transportation

reduced engine sizes,[8] Transportation emissions languished for a short while, then increased rapidly in the 1990s (Figure 2.3-2). In 1990, Transportation is estimated to have emitted 154 Mt CO_2 eq of greenhouse gases; by 1996, this had risen to 177 Mt (a 15% increase) and by 1997 to 184 Mt (a 19% increase over 1990).

The category may be broken into six distinct subcategories: road transport, aviation, marine, rail, off-road (non-rail, ground) transport, and pipeline transport. Only pipelines (consisting of both oil and gas types) represent non-vehicular transport. By far the dominant sub-category is road transport which, at 121 Mt CO_2 eq, comprised 68% of Transportation's emissions in 1996. The road area also appears to have been responsible for the highest proportion of the growth in Transportation emissions. It is, however, illustrative to break down Transportation by mode, which further divides the road sub-category and more clearly delineates growth.

Of the overall 23 Mt CO_2 eq increase in Transportation greenhouse gas (GHG) emissions from 1990 to 1996, heavy-duty road vehicles contributed the largest share at 42%. This was followed by pipeline transport, which contributed 24%, light-duty vehicles, 21%, off-road (non-rail) equipment, 13% and aviation, which contributed 6% of growth. The other Transportation modes (marine, rail and motorcycle vehicles) actually showed a decline, tempering Transportation emission increases by minus 6% over the period.

8 For details, see Natural Resources Canada, *Energy Efficiency Trends in Canada*, 1990-1996.

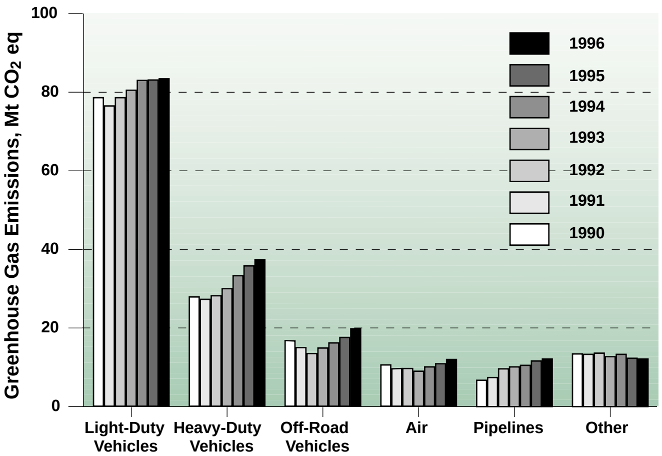

FIGURE 2.3-3
Transportation Emission Trends by Mode

Shifting trends within freight transport have led to the large, 9.5 Mt CO_2 eq growth in GHG emissions from heavy-duty vehicles between 1990 and 1996. The trucking industry has been continually capturing a larger share of freight transport, at the expense of the other major modes (rail and marine). This trend has been ongoing since the 1980s, but exploded from 1992 to 1996, when for-hire trucking's portion of domestic freight activity rose from about 17% to 24%, on a tonne-kilometreage basis (see Table 2.3-1).

Changing transportation regulations since the late-1980s and reduced federal subsidies for the rail system have contributed to this shift, but the bottom line is revenue. In 1995, large, for-hire trucking firms showed revenues of $12.1 billion (CDN), while in the same year the freight-rail industry recorded revenues of $6.4 billion on a considerably larger quantity of shipments.[9] Unfortunately, the energy efficiency of the trucking mode is considerably worse. Even though it accounted for 24% of tonne-km activity in 1996, the trucking industry was responsible for more than 70% of freight transport energy use,[10] implying an energy intensity of almost three times the average. The mode shift to truck traffic has therefore resulted in a significant increase in emissions from freight transport.

TABLE 2.3-1 FREIGHT TRANSPORTATION ACTIVITY TRENDS

Year	Rail	Marine	Trucking (For-Hire)	Air	Total
	Tonne - Kilometres (Billions)				
1990	178.9	53.7	54.7	0.5	287.8
1991	188.3	58.1	47.7	0.4	294.5
1992	177.4	48.1	47.8	0.4	273.7
1993	174.1	42.3	52.0	0.5	268.9
1994	193.2	42.5	60.1	0.4	296.3
1995	181.6	42.5	65.8	0.5	290.4
1996	180.0	40.2	71.5	0.6	292.3

Rail: Class I
Trucking: Class I and II (size threshold changes in 1988 and 1990)
Air: Scheduled services for Canadian air carriers, levels I to IV (1995 – levels I to III only).

Sources: Statistics Canada, Catalogues 52-216, 53-222 and 54-205.

The growth in greenhouse gas emissions from light-duty vehicles, 4.9 Mt CO_2 eq from 1990 to 1996, is instructive when viewed in light of passenger transportation trends over the period. Although 1996 data are not yet available, by 1995 people were travelling significantly more in light vehicles than they were in 1990. According to Transport Canada, the number of passenger kilometres logged by private vehicles increased by about 10% over the five years (Table 2.3-2).[11] Comparing road, air and train modes, it is clear that the vast majority of passenger transport (around 80% of activity) is handled by light cars and trucks in Canada. Thus, any increase in passenger travel by light vehicles makes for a significant growth in total activity and, in turn, greenhouse gas emissions.

TABLE 2.3-2 PASSENGER TRANSPORTATION ACTIVITY TRENDS

Year	Rail(1)	Air(2)	Private Vehicles (Light Cars & Trucks)(3)
	Passenger - Kilometres (Billions)		
1990	1.39	66.8	433.7
1991	1.43	58.1	435.8
1992	1.44	62.2	449.1
1993	1.41	60.8	460.1
1994	1.44	65.7	482.5
1995	1.47	73.5	480.8
1996	1.52	80.1	Not yet available

Sources: (1) Statistics Canada, Catalogue 52-216 annual.
(2) Statistics Canada, Catalogue No. 51-206 XPB (Levels I to III Carriers).
(3) *1996 Annual Report*, Transport Canada, 1997, Section 10.

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9 Statistics Canada, *Canada Yearbook*, 1999 (pp. 413-429).
10 Natural Resources Canada, *Energy Efficiency Trends in Canada*, 1990-1996.
11 Natural Resources Canada estimates the increase in light-duty vehicle passenger kilometre activity to be 20% from 1990 to 1996. See *Energy Efficiency Trends in Canada, 1990-1996*.

Of even greater concern, however, is the shift in the mix of on-road vehicles; the share of light-duty trucks has been increasing significantly, at the expense of automobiles. From 1990 to 1996, the number of light trucks on road had increased by 34%, whereas the number of automobiles had actually *decreased* by about 4%.[12] This reflects the current consumer preference for sport utility vehicles, vans and light pickup trucks, vehicles which operate with lower efficiency and higher emissions per kilometre driven. Its effect is to magnify the impact of greater light-duty vehicle activity. Thus, while greenhouse gas emissions from automobiles dropped by 2.9 Mt, those from light trucks rose by 7.8 Mt CO_2 eq over the period.

Aviation passenger activity increased by close to 20% from 1990 to 1996. This was significant, but as the 13 billion passenger kilometre growth represents only a fraction of the increase in light vehicle activity, the emission increment of 1.4 Mt CO_2 eq was less than 30% of that from light vehicles (see Table 2.3-2 and Figure 2.3-3).

Although rail passenger activity increased, this was small in comparison to other modes, resulting in very little impact on emission trends — most rail fuel is consumed for the purpose of freight transport.

It is interesting to compare the greenhouse gas emission intensity of transportation systems. Though the passenger portion of rail emissions could not be isolated, a comparison can be made between light-duty road vehicles and air transportation, both of which are primarily utilized for passenger transport. Using 1995 activities from Table 2.3-2 and emissions from the national inventory, private light vehicles in Canada appear to have an average greenhouse gas emission intensity of about 170 g per person-km, whereas air transport emits about 150 g per person-km.

It must be pointed out that these figures are based on two assumptions: the first being that virtually all air and light vehicle transport is for the purpose of carrying passengers, and the second being that the vast majority of light vehicles are privately owned. A review of some recent literature covering car and light truck transport[13] reinforces the validity of these assumptions for light vehicles. Studying statistics on air traffic, it can be noted that the primary air carriers showed a ratio of 27.7 kg-km of cargo carried per passenger-km in 1995 — strong evidence that almost all of the weight transported was passengers and their personal luggage. In conclusion, it can be argued that air and light vehicle road transport have similar environmental impacts, at least in terms of greenhouse gas emission intensities.

Pipelines are used to move significant quantities of oil and gas feuls, primarily from western to eastern Canada and to the U.S. Their increasing use for oil transport — pipeline crude oil and refined product volumes were up more than 30% from 1990 to 1996[14] — and natural gas exports — which doubled over the same period[15] — have driven this trend. The result has been a 5.5 Mt CO_2 eq increase in energy-GHG emissions from the pipeline industry (largely as a result of compressor use).

Off road (ground, non-rail) transportation has also contributed significantly to greenhouse gas emission increases within the Transportation category. Such emissions are from both gasoline and diesel fuel, though the largest source is diesel equipment ranging from tractors to logging skidders, construction vehicles and mining vehicles. Most emission growth appears to be tied to the considerable diesel fuel consumption by industry (which rose about 25% between 1990 to 1996). The mining and construction industries, which both operate significant numbers of heavy off-road vehicles, are the largest diesel oil users in the group.

Notes on Methodology

The methodology used to evaluate road transportation greenhouse gas emissions follows a detailed Tier 3 method, as outlined in the IPCC Guidelines (IPCC, 1997). Methodologies for other Transportation subcategories are generally more closely allayed with Tier 1-type methods. Categorizations follow IPCC reporting procedures. In order to handle the complexities and details required to determine methane and nitrous oxide emissions and disaggregate all emissions by vehicle type, an electronic spreadsheet model has been developed. This is known as the Mobile Greenhouse gas Emission Model, or M-GEM, and Canada's Transportation emissions inventory is based upon it. It estimates emissions from all mobile sources, but has been primarily designed to more accurately assess those greenhouse gases emanating from the complex array of road vehicles within the country. Emission factors utilized by the model have been adopted from many sources (see Appendix C), but the emphasis has been on North American research, and Canadian studies have been drawn upon whenever possible.

12 Data from Mobile Greenhouse gas Emissions Model (M-GEM). For sources, see Transportation Methodology, Appendix B.

13 For example: Natural Resources, *Energy Efficiency Trends in Canada, 1990-1996*; Transport Canada (1997, 1998).

14 Statistics Canada, *Pipeline Transportation of Crude Oil and Refined Petroleum Products*, Catalogue No. 55-201.

15 Statistics Canada, *Quarterly Report on Energy-Supply Demand in Canada*, Catalogue No. 57-003.

The M-GEM has been recently thoroughly updated. New Canadian, U.S. and international findings on N_2O and CH_4 emissions have been incorporated, along with more accurate data on vehicle populations. For a description of the Transportation methodology, the M-GEM model and details on the most recent improvements, refer to Appendix B.

2.3.1 Aviation

Emissions from domestic air transport remained relatively stable from 1990 to 1994, but rose rapidly thereafter. By 1996, total greenhouse gas emissions were up 1.4 Mt CO_2 eq or about 13% over 1990. This appears to have followed the trend in aircraft activity (Table 2.3.1-1). In 1990, the major air carriers flew 66.8 billion passenger-km, while in 1996 this had risen to 80.1 billion. The trend seems to have continued unabated into 1997. For that year, inventory data indicates emissions of 13 Mt from civil aviation — a 22% growth from 1990.

TABLE 2.3.1-1 AVIATION EMISSION TRENDS AND PASSENGER ACTIVITY

Year	Total Greenhouse Gases Mt CO_2 eq	Passenger - Kilometres Billions
1990	10.6	66.8
1991	9.6	58.1
1992	9.7	62.2
1993	9.0	60.8
1994	10.1	65.7
1995	10.9	73.5
1996	12.0	80.1

Source: Passenger kilometres: Statistics Canada, Catalogue No. 51-206 XPB (Data for Levels I to III Carriers).

Since the open skies agreement was signed with the United States in 1995 (allowing fuller access to all destinations), transborder flights by Canadian airlines increased substantially and competition between major air carriers increased (Statistics Canada, *Canada Year Book* 1999). Coinciding with these changes in the market, ticket prices dropped and newly-scheduled domestic services by low-cost carriers began to appear. As a result, pricing became competitive with other modes of transport, allowing airlines to capture a greater portion of the passenger market. Greenhouse gas emissions from aviation have increased comme surately.

Categorization and Methodology

All emissions from domestic air transport (commercial, private, agricultural, etc.) are reported here. Excluded are emissions from fuel used at airports for ground transport (which is reported as Off Road, or in IPCC sectoral tables under "Other Transportation"), as well as fuel used in stationary combustion applications at airports. Emissions arising from fuel sold to foreign airlines are considered to be 'International Bunkers'. These are not included in the inventory, but are reported as 'Memo Items' in IPCC Tables (see, for example, Appendix E). Although the IPCC Guidelines call for military air transportation emissions to be reported elsewhere, they have been included in the aviation sub-category (2.3.1) for completeness.

Methodologies follow a modified IPCC Tier 1 sectoral approach, where emissions are based on the quantities of aircraft fuels consumed (see Appendix B for details).

2.3.2 Road Transport

In 1996, road transport was responsible for more than two thirds of transportation-based greenhouse gas emissions. Totalling 121 Mt CO_2 eq, these were 14% greater than the 1990 level. The sub-category consists of four segments: automobiles, light trucks, heavy-duty vehicles (trucks and buses) and motorcycles. Light vehicles, consisting of automobiles and light trucks are responsible for close to three quarters of all emissions from the Road category, while heavy-duty vehicles are responsible for virtually all the rest.

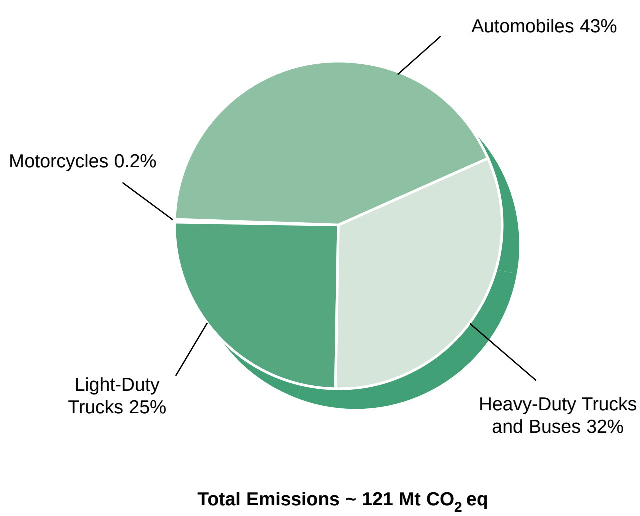

FIGURE 2.3.2-1
1996 Road Transportation Greenhouse Gas Emissions

TABLE 2.3.2-1 DETAILS OF ROAD VEHICLE EMISSIONS IN CANADA FOR 1996

		Category Vehicle Population	Fuel Consumption Ratio	Average Distance Travelled	Total Fuel Consumed	Emissions			
						CO_2	CH_4	N_2O	G.H.G. Total
							CO_2 eq	CO_2 eq	CO_2 eq
			l/100 km	km	Ml	Mt	Mt	Mt	Mt
Gasoline Road Sources									
Light-Duty Gasoline Automobiles	**Sum (*Avg*)**	**10 700 000**	***10.4***	***18 000***	**20 100**	**47.3**	**0.15**	**2.6**	**50.1**
Tier 1 Three-Way Catalyst		1 730 000	10.0	18 000	3 140	7.41	0.02	0.20	7.63
Tier 0 Three-Way Catalyst (new)		0	-	-	-	-	-	-	-
Tier 0 Three-Way Catalyst (aged)		7 080 000	10.1	18 000	13 000	30.7	0.09	2.3	33.1
Oxidation Catalyst		196 000	10.2	18 000	360	0.85	0.00	0.02	0.87
Non-Catalyst		1 680 000	11.9	18 000	3 540	8.34	0.04	0.05	8.43
Light-Duty Gasoline Trucks	**Sum (*Avg*)**	**4 650 000**	***14.3***	***17 000***	**11 400**	**26.9**	**0.09**	**2.6**	**29.6**
Tier 1 Three-Way Catalyst		841 000	14.3	17 000	2 060	4.85	0.01	0.25	5.11
Tier 0 Three-Way Catalyst (new)		0	-	-	-	-	-	-	-
Tier 0 Three-Way Catalyst (aged)		3 140 000	14.1	17 000	7 600	17.9	0.07	2.4	20.4
Oxidation Catalyst		77 000	14.0	17 000	186	0.44	+	0.01	0.45
Non-Catalyst		596 000	15.2	17 000	1 550	3.66	0.02	0.02	3.7
Heavy-Duty Gasoline Vehicles	**Sum (*Avg*)**	**322 000**	***47.5***	***13 000***	**2 020**	**4.77**	**0.01**	**0.21**	**4.99**
Three-Way Catalyst		107 000	43.5	13 000	616	1.45	+	0.19	1.64
Non-Catalytic Controlled		107 000	43.5	13 000	616	1.45	+	0.01	1.46
Uncontrolled		107 000	55.6	13 000	787	1.86	0.01	0.01	1.88
Motorcycles	**Sum (*Avg*)**	**288 000**	***10.3***	***3 000***	**87**	**0.21**	**+**	**+**	**0.21**
Non-Catalytic Controlled		144 000	9.3	3 000	40	0.09	+	+	0.10
Uncontrolled		144 000	11.2	3 000	48	0.11	+	+	0.12
Diesel Road Sources									
Light-Duty Diesel Automobiles	**Sum (*Avg*)**	**107 000**	***11.2***	***18 000***	**218**	**0.60**	**+**	**0.01**	**0.60**
Advanced Control		35 700	10.0	18 000	65	0.18	+	+	0.18
Moderate Control		35 700	10.4	18 000	67	0.18	+	+	0.19
Uncontrolled		35 700	13.3	18 000	86	0.24	+	+	0.24
Light-Duty Diesel Trucks	**Sum (*Avg*)**	**90 800**	***15.1***	***12 000***	**170**	**0.46**	**+**	**0.01**	**0.47**
Advanced Control		30 300	13.9	12 000	52	0.14	+	+	0.14
Moderate Control		30 300	13.9	12 000	52	0.14	+	+	0.14
Uncontrolled		30 300	17.5	12 000	66	0.18	+	+	0.18
Heavy-Duty Diesel Vehicles	**Sum (*Avg*)**	**689 000**	***43.0***	***40 000***	**11 700**	**32.0**	**0.03**	**0.36**	**32.4**
Advanced Control		230 000	41.7	40 000	3 790	10.3	0.01	0.12	10.4
Moderate Control		230 000	41.7	40 000	3 790	10.3	0.01	0.12	10.4
Uncontrolled		230 000	45.5	40 000	4 130	11.3	0.01	0.13	11.4
Natural Gas Vehicles		**-**	**-**	**-**	**205 000**	**0.39**	**0.10**	**+**	**0.48**
Propane Vehicles		**-**	**-**	**-**	**1 360**	**2.09**	**0.02**	**-**	**2.11**
TOTAL (ON-ROAD TRANSPORT)		**-**	**-**	**-**	**-**	**115**	**0.41**	**5.8**	**121**

Fuel-consumption data was arrived at by partitioning fuel from Statistics Canada Catalogue Number 57-003 (Quarterly) according to vehicle type and activity.
CH_4 and N_2O emissions were arrived at by multiplying fuel quantity by percent of catalyst technology, emission factor and Global Warming Potential (GWP) (GWP, CH_4 = 21; GWP, N_2O = 310).
\+ Non-zero values are too small to display.

Environment Canada's Mobile Greenhouse gas Emissions Model (M-GEM) develops GHG emissions on the basis of detailed on-road vehicle population data, emission control characteristics, average vehicle efficiency and driving distance information. It then calculates and assigns emissions, vehicle distances travelled, and fuel consumption ratios to all vehicle types and sub-types. Complete details of the 1996 on-road fleet, its emissions and key characteristics as developed by M-GEM, are presented in Table 2.3.2-1.

Categorization

Categorization of road transport follows IPCC reporting procedure (IPCC, 1997, V1), with the exception that evaporative emissions are not listed separately, but are included with the corresponding combustion sources instead. For reference, a brief description of the standard road vehicle types follows.

Light-duty vehicles are defined to consist of automobiles and light trucks weighing 3900 kg or less. All vehicles primarily designed for carrying passengers are 'automobiles', while those designed for light-weight cargo or which are equipped with special features such as four-wheel drive for off-road operation are considered to be 'trucks'. *Heavy-duty vehicles* are any which weigh more than 3900 kg — virtually all are trucks and buses. *Motorcycles* are defined as all motor vehicles designed to travel with not more than three wheels in contact with the ground and weighing less than 680 kg.

Light-Duty Vehicles

This segment of Road Transport consists of both automobiles and light trucks. Emissions from light-duty vehicles (LDVs) rose by 5% from 1990 to 1996, which generally appears to follow the 11% growth in vehicle-km over the period.[16] In short, more vehicles are being driven greater distances. However, this overall trend is in reality composed of two separate components. While emissions from light-duty trucks have grown by 7.8 Mt CO_2 eq, emissions from automobiles have decreased by 2.9 Mt. This appears to be the result of a shift which has been occurring in the mix of light-duty on-road vehicles.

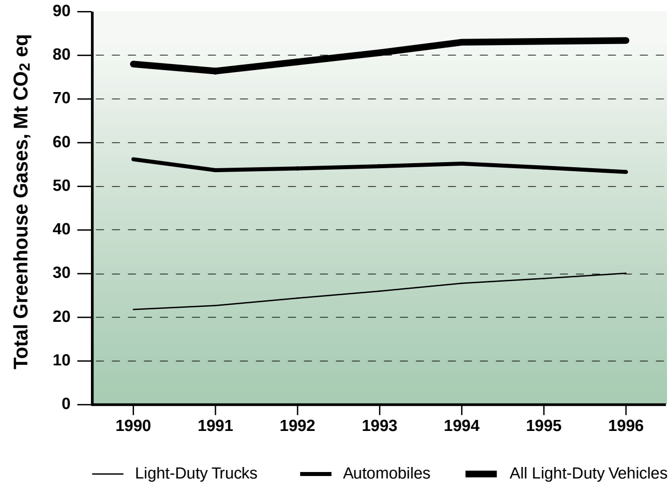

FIGURE 2.3.2-2
Light-Duty Vehicle Emissions Trends

Impact of the Changing Mix of Vehicles

The emission increase from 1990 to 1996 is lower than the growth in vehicle-km because of continued improvements in the fuel efficiency of the on-road fleet. This is primarily due to stock turnover, as opposed to real efficiency improvements in new vehicles. Most of the improvements in automobile fuel economy occurred in the 1980s and the 1996 fleet was made up of a greater proportion of these vehicles than the 1990 fleet. Since the late-1980s, the average fuel economy of new automobiles has remained virtually constant.[17] It would therefore appear that on the basis of this trend alone, future emission changes are likely to at least keep pace with vehicle kilometres driven. In fact, emissions are likely to outpace vehicle-km changes if the sales of vans and light trucks continue at their current rate. The following discussion will attempt to clarify this further.

North American sales of light-duty gasoline trucks, including vans and four-wheel drive vehicles, have been increasing at a much faster pace than automobile sales in the 1990s. Heavenrich and Hellman (1996) reported that from 1975 to 1995, light trucks doubled their market share of light-duty vehicle sales in the U.S. The continuation of this trend is evident.

16 Source: Environment Canada M-GEM model (see Appendix B for details).
17 For a full discussion, see Natural Resources Canada, *Efficiency Trends in Canada 1990 to 1996*.

TABLE 2.3.2-2 DETAILED EMISSION TRENDS FOR AUTOMOBILES AND LIGHT TRUCKS

	Automobiles (Gasoline, Diesel, Natural Gas and Propane)				Light-Duty Trucks (Gasoline and Diesel)			
	CO_2	CH_4	N_2O	Total Greenhouse Gases	CO_2	CH_4	N_2O	Total Greenhouse Gases
Year	Mt	Mt CO_2 eq	Mt CO_2 eq	Mt CO_2 eq	Mt	Mt CO_2 eq	Mt CO_2 eq	Mt CO_2 eq
1990	53.9	0.24	2.0	56.2	21.0	0.08	1.3	22.3
1991	51.4	0.22	2.1	53.7	21.1	0.08	1.5	22.7
1992	51.5	0.22	2.4	54.1	22.5	0.09	1.8	24.4
1993	51.8	0.22	2.6	54.6	23.7	0.09	2.1	26.0
1994	52.2	0.24	2.8	55.2	25.2	0.09	2.5	27.8
1995	51.2	0.27	2.8	54.3	26.1	0.09	2.6	28.9
1996	50.4	0.26	2.6	53.3	27.4	0.09	2.6	30.1

Trucks captured a 30% share of the American light-duty market in 1990, 36% in 1993 and 39% in 1995. Heavenrich and Hellman revealed that the net effect of this market shift is an increase in total fuel consumption, since these vehicles exhibit lower fuel efficiencies than automobiles and are driven almost as far. It appears that a similar trend is occurring in Canada, with a commensurate increase in emissions.

To evaluate the Canadian situation, it is necessary to restrict the analysis to gasoline and diesel vehicles, as the available data on natural gas and propane types is poor. Since gasoline and diesel-fuelled transportation accounted for 97% of all LDV emissions in 1996, this has little effect on the accuracy of the results. According to the most recent information available,[18] from 1990 to 1996 the on-road population of light trucks in Canada rose by 24%. Over the same period, the number of cars being driven actually *declined*. The resultant impact of this trend is that automobiles' share of on-road vehicle kilometres travelled has shrunk from 77% of the LDV total in 1990 to 71% in 1996.

Both the documented lower efficiency of light trucks[19] and their higher greenhouse gas emission rate[20] imply that this trend is resulting in greater greenhouse gas emissions. Although the overall GHG emission rate of light-duty vehicles declined over the period, from about *310 g CO_2 eq/ km* to *290 g CO_2 eq/ km*, this was due to the impact of earlier efficiency improvements working their way into the fleet. In fact, if the mix of automobiles and trucks had remained at 1990 levels, with all other factors held constant, the LDV emission rate in 1996 would have declined an additional 50%.

TABLE 2.3.2-3 SIGNIFICANT INDICATORS - LIGHT-DUTY GASOLINE AND DIESEL VEHICLES

	Automobiles	Light-Duty Trucks	All Light-Duty Vehicles
1990			
Vehicle Population	11 200 000	3 530 000	14 700 000
Average Distance Travelled (*km*)	17 000	16 000	17 000
Average Fuel Consumption Ratio (*l/100km*)	11.5	15.4	12.4
Greenhouse Gas Emission Rate (*g CO_2 eq/km*)	280	390	310
1996			
Vehicle Population	10 800 000	4 740 000	15 500 000
Average Distance Travelled (*km*)	18 000	17 000	18 000
Average Fuel Consumption Ratio (*l/100km*)	10.4	14.3	11.6
Greenhouse Gas Emission Rate (*g CO_2 eq/km*)	260	370	290

18 See Appendix B, Transportation Methodology, for details.

19 For example, Heavenrich and Hellman (1996) or Transport Canada, *Company Average Fuel Consumption for Canadian New Vehicles* (1999).

20 See, for example, Barton and Simpson (1994).

Trends by Gas and the Effect of Control Technologies

Studying the trends by gas (Table 2.3.2-2 on page 23), it is clear that carbon dioxide (CO_2) emissions closely follow the changing patterns in vehicle populations. Carbon dioxide from light trucks rose, while CO_2 from automobiles fell. Methane (CH_4) emissions remained relatively stable over the period, while nitrous oxide (N_2O) emissions from both automobile and trucks grew. In 1996, N_2O emissions from all light-duty vehicles were up 59%.

These trends underscore the effect of emission controls on greenhouse gases. Carbon dioxide releases are not technology-dependent — emissions simply follow fuel-use patterns. However, CH_4 and N_2O emission levels are affected by changes in emission control equipment. Since the 1970s, increasingly improved emission controls have been introduced to vehicles in a trend which has continued unabated through the 1990s (see Appendix B). For most pollutants, vehicles equipped with more sophisticated controls tend to have lower emission rates. Thus, in spite of greater fuel use, CH_4 emissions have not risen significantly. (The small increase from automobiles is due to growing numbers of natural-gas-powered vehicles in the mix, which are estimated to have higher methane emission rates.[21])

The effect of pollution-limiting equipment on N_2O emissions is a more complex matter though. Catalytic emission control units began to become 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' units. The earlier generation of three-way units were part of emission-control packages which have come to be known as 'Tier 0' controls. 'Tier 1', a more advanced technology, was introduced to light-duty vehicles in North America in 1994. Research has shown that, so far, all catalytic control units increase N_2O emissions, as compared to uncontrolled vehicles (Urban and Garbe, 1979; Smith and Carey, 1982; DeSoete, 1989; Barton and Simpson, 1994). However, after their introduction, Tier 0-type catalytic control units were also shown to have deteriorating N_2O emission performance as they aged (DeSoete, 1989; Prigent and DeSoete, 1989). The full effects of aging were noted to occur after about a year of use. Emission factors currently utilized for LDVs equipped with 'aged' Tier 0 controls are about an order of magnitude higher (on a per unit of fuel basis) than those from uncontrolled vehicles (DeSoete, 1989; Barton and Simpson, 1994). As three-way catalytic control equipment began to penetrate the on-road LDV fleet, N_2O emission rates in Canada appear to have worsened considerably. (See Figure 2.3.2-3, which depicts estimates calculated by Environment Canada's M-GEM.)

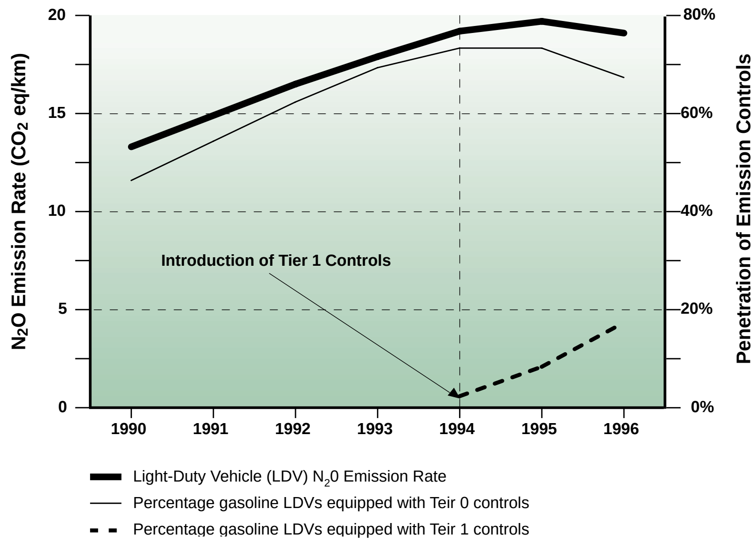

FIGURE 2.3.2-3

Nitrous Oxide Emissions from Light-Duty Vehicles and Penetration of Emission Controls

The picture has improved of late, however, as a result of the appearance of Tier 1 controls. Michaels (1998) has recently reported on EPA tests conducted on a small sample of typical North American vehicles. These were equipped with Tier 1, aged catalytic converters. Average measured emission rates were about 50% lower, under standard conditions, than those reported previously for Tier 0 vehicles (Barton and Simpson, 1994). From 1994 to 1996, as Tier 1 vehicles penetrated the LDV fleet, calculated N_2O emission rates stabilized and appear to have begun dropping (Figure 2.3.2-3). Note that the effect of catalytic convertors dominates N_2O emissions from all light vehicles, even though only gasoline cars and trucks have been equipped with them. This is the case because the emission factors for non-gasoline vehicles are estimated to be about one sixth that of Tier 0 cars and trucks with aged converters and one half that of Tier 1 vehicles.

Natural Gas and Propane Fuels

Although no breakdown by classification is available for natural gas and propane vehicles, it is assumed that virtually all are light-duty types, with the vast majority consisting of automobiles. Fuel use for such vehicles rose significantly from 1990 to 1996 (Table 2.3.2-4).

21 IPCC, 1997. Although CH_4 emission rates are higher for natural gas vehicles, emission rates of other gases are lower.

TABLE 2.3.2-4 TRENDS IN NATURAL GAS AND PROPANE AUTOMOBILES*

	Natural Gas Vehicles		Propane Vehicles	
Year	Fuel Consumption Gl	Greenhouse Gas Emissions Mt CO_2 eq	Fuel Consumption Ml	Greenhouse Gas Emissions Mt CO_2 eq
1990	69.7	0.16	1 020	1.6
1996	205	0.48	1 360	2.1

* Based on limited available data, the vast majority of vehicles using these fuels are assumed to be automobiles.

As emissions on a per unit-energy basis from propane and natural gas are lower than from gasoline and diesel fuel, this trend has contributed to reductions in combustion emissions from cars. However, direct emissions do not necessarily tell the whole story for all alternatively fuelled vehicles. It has been noted elsewhere that significant emissions occur as a result of the processing of various alcohol-based energy sources, so it is important to consider full life-cycle emissions to properly evaluate the impacts of fuel conversion scenarios.[22] Although an investigation of alcohol-fuelled vehicles is, unfortunately, beyond the scope of this document, a study comparing full life-cycle emissions from natural gas, propane and conventionally fuelled vehicles has been conducted (Environment Canada, Meyer, 1997). Results for average on-road automobiles in 1995 indicated that both direct *and* fuel life cycle[23] GHG emission rates, in g/km travelled, were almost 40% lower for a natural-gas-fuelled vehicle than a gasoline type. In the case of propane transport, direct and fuel life-cycle emissions appear to be about 30% lower than those for typical gasoline automobiles. (Diesel vehicles were estimated to have higher emission rates than gasoline.)

Heavy-Duty Vehicles (Trucks and Buses)

This category includes vehicles rated at more than 3900 kg. Table 2.3.2-5 summarizes emissions and shows that total greenhouse gases in 1996 were up 34% from 1990. By far the largest contributors to emissions from this segment are heavy-duty diesel vehicles, which have high fuel-consumption ratios and drive long distances. In 1996, these alone were responsible for 33 Mt CO_2 eq, more than 27% of all on-road emissions.

Greenhouse gas trends associated with this segment of road transport are closely linked with those of trucking activity in Canada, which has been growing substantially. From 1990 to 1996, the number of tonne

TABLE 2.3.2-5 EMISSION TRENDS FOR HEAVY-DUTY VEHICLES (GASOLINE AND DIESEL)

Gas	CO_2	CH_4	N_2O	Total Greenhouse
Year	Mt	Mt CO_2 eq	Mt CO_2 eq	Mt CO_2 eq
1990	27.4	0.034	0.41	27.8
1991	26.9	0.034	0.41	27.3
1992	27.8	0.036	0.44	28.3
1993	29.5	0.038	0.47	30.0
1994	32.7	0.042	0.52	33.3
1995	35.2	0.045	0.56	35.8
1996	36.7	0.047	0.57	37.4

kilometres carried domestically was up 31%, while transborder activity, driven by new free trade agreements with the U.S., increased a full 115%.[24] Taken together, domestic and international activity totalled 77.8 billion tonne-km in 1996, a growth of 55%.

Further evidence of the large increase in activity is provided by analysis of the heavy-duty diesel vehicle population in the country, which is estimated to have grown from about 360 000 to 690 000 vehicles over the period.[25] Although separate data for trucks and buses has been difficult to obtain, it appears relatively clear that bus activity is declining. Natural Resources Canada has estimated an 8% reduction in bus passenger kilometres travelled in 1996 as compared to 1990.[26] Therefore, it seems that bus transport did not contribute to the increasing emissions from this segment.

Motorcycles

These vehicles account for only about 0.2% of greenhouse gas emissions from road transport. In 1996, emissions from motorcycles are estimated to have been 0.21 Mt CO_2 eq, a 9% decline since 1990.

22 Prakash, C., Environment Canada, 1996.
23 Fuel lifecycle emissions are all those associated with the fuel itself: production, refining, transportation and distribution. They do not include emissions associated with the development of infrastructure (such as the manufacture of fuel processing facilities, etc.).
24 Statistics Canada, Catalogue nos. 53-222 and 50-002 (annual).
25 For details, see Appendix B.
26 *Energy Efficiency Trends in Canada, 1990-1996.*

2.3.3 Railways and Marine Transport

Railways

Although emissions *declined* by 12% over the 1990 to 1996 period, railway activity appears to have *grown*. Domestic freight activity increased a slight, but perceptible 0.6%, while passenger activity showed an increase of 9% over the period (see Tables 2.3-1 and 2.3-2 in Transportation Overview).[27] Freight transport far overshadows passenger activity, so growth in domestic activity cannot be considered to be very large.[28] Nevertheless, the greenhouse gas emission intensity of rail transport has clearly gone down. This appears to be the result of improvements in the Canadian railway system. Since 1990, new market conditions have been created by the removal of most economic regulations within the industry and the loss of substantial government subsidies. The two largest rail companies have rationalized operations by abandoning lines and reducing assets. Although rail activity at first went down, new short-line railways have been established, which have become relatively successful. At the same time, overall rationalization within the industry has improved efficiency. For example, while transport activity has increased, the total freight locomotive fleet has been reduced by 7%.[29]

Marine Transport

Only domestic marine transport is discussed in this section. According to IPCC Guidelines (IPCC, 1997) international marine transport emissions should be reported under this category, but classified as 'International Bunkers' and not inventoried. Although not discussed here or included in the Inventory, they have been reported in IPCC tables (see, for example, Appendix E).

Table 2.3.3-1 depicts emission trends. Total greenhouse gases fell some 8% over the period. Domestic activity declined much more substantially — in 1996, 25% less tonne-km were carried on water than in 1990.[30] However, emission calculations are based on estimates of fuel use reported by registered Canadian vessels. Thus, some international travel may inadvertently be included in the domestic inventory. Supporting this hypothesis is the fact that international marine freight activity has increased, which would tend to bolster recorded fuel consumption by Canadian lines making international shipments. To evaluate this properly, a dis-aggregation of shipping activity by country of origin would be required. Unfortunately, the available data does not allow this analysis.[31]

TABLE 2.3.3-1 EMISSION TRENDS FOR RAILWAYS AND DOMESTIC MARINE TRANSPORT

Year	Railways Total Greenhouse Gases Mt CO_2 eq	Domestic Marine Transport Total Greenhouse Gases Mt CO_2 eq
1990	7.11	6.07
1991	6.59	6.49
1992	6.89	6.45
1993	6.86	5.62
1994	7.10	5.94
1995	6.43	5.70
1996	6.29	5.56

2.4 Non-Industrial Stationary Combustion Sources

The categories in this section include Residential, Commercial/Institutional and Agriculture/Forestry. Emission trends are shown in Table 2.4-1.

TABLE 2.4.1 GREENHOUSE GAS EMISSION TRENDS FOR NON-INDUSTRIAL STATIONARY COMBUSTION SOURCES (Mt CO_2 eq)

Category	1990	1991	1992	1993	1994	1995	1996
Residential (Fossil Fuel)	40.9	39.0	38.6	42.9	43.5	42.1	47.1
Residential (Biomass)	5.6	5.7	6.2	6.2	6.1	6.0	6.2
Commercial	24.1	23.9	24.3	26.6	25.3	27.4	27.7
Institutional (Public Administration)	2.1	2.0	2.1	2.2	2.8	2.5	2.5
Agriculture	2.5	2.7	5.2	3.0	2.4	2.6	2.8
Forestry	0.7	0.5	0.2	0.4	0.3	0.0	0.1

Note: Biomass emissions do not include CO_2.

27 Statistics Canada, Catalogue no. 52-216 (annual).

28 Rail freight transport activity was 180 billion tonne-km in 1996, while passenger activity was 1.52 billion passenger kilometers. If it is assumed that passenger and freight transport can be measured on the same scale and furthermore, that the average passenger with luggage weighs a conservative 100 kg, passenger activity amounted to the equivalent of 0.08% of freight activity in 1996.

29 Natural Resources Canada, *Energy Efficiency Trends in Canada, 1990-1996*.

30 Transport Canada Statistics, www.tc.gc.ca/tfacts/StatFor/marine/marine13.htm.

31 Ibid

2.4.1 Residential and Commercial/Institutional

Overview and Long-Term Trends

Emissions from this area, primarily the result of using energy to heat buildings, have declined over the long term. The reduction was about 12 Mt CO_2 eq, or 13%, between 1980 and 1997. This has occurred as a result of building energy-efficiency improvements, particularly during the early- to mid-1980s, and fuel switching. In fact, from 1980 to 1987, emissions from Residential and Commercial/Institutional sources declined by a full 25%.

From 1990 to 1997, however, emissions have risen. This appears to be the result of a combination of more severe winters (in population centers) and population growth. Efficiency improvements have had a tempering effect over this latter period, but have not been sufficient to keep emissions from growing.

Broadly speaking, in the absence of efficiency improvements, heating demand will increase with building floor space and the severity of winter temperatures.[32] The demand for floor space tends to vary with the population, while temperature severity is approximated by the average number of 'heating degree days' over the winter season. This value is calculated by determining the average, cross-Canada number of days below 18ºC and multiplying it by the corresponding number of degrees below this temperature. Figure 2.4.1-1 compares total residential, commercial and institutional emissions with heating degree days from 1980 to 1997.[33] As can be seen, the two trends are similar; however, it can be noted that up to 1987 emissions were falling more quickly than heating degree days, while after that they appear to have risen faster than heating degree days.

To remove the effect of the climactic and population variables, it is instructive to investigate the trend in terms of GHG emissions per capita degree day (or *emission rate*) over the period (Figure 2.4.1-2). If efficiency or fuel-use patterns were not changing, the graph is expected to show a horizontal line. However, the resultant *emission rate* shows a rapidly declining trend, between 1980 and 1987, followed by a slower decline since. This illustrates how building efficiency improvements and fuel switching produced large reductions in emissions in the 1980s, but have only tempered greenhouse gas increases from 1990 on.

Residential

Emissions from this category were 53.3Mt CO_2 eq in 1996. Methane and nitrous oxide emissions from firewood combustion are significant emissions in this category, representing about 6Mt CO_2 eq in 1996. The emissions are from incomplete combustion in woodstoves and fireplaces.

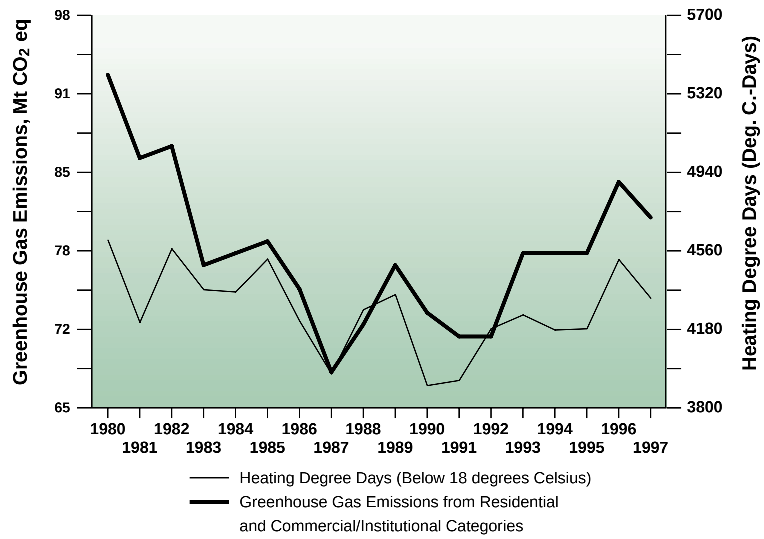

FIGURE 2.4.1-1
Greenhouse Gas Emissions in Relation to Heating Degree Days

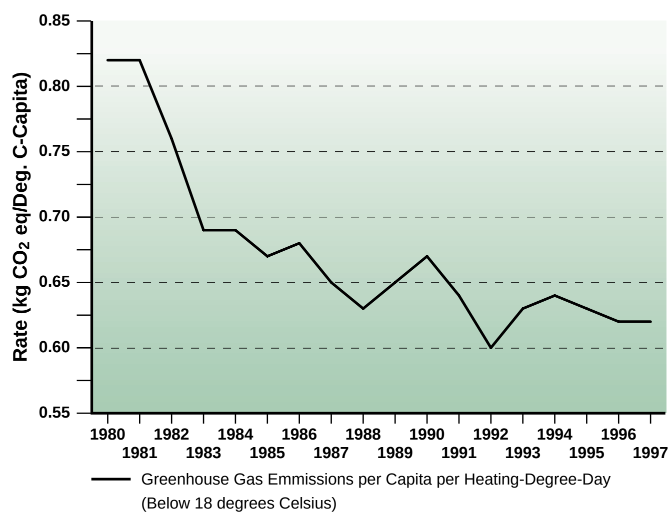

FIGURE 2.4.1-2
Residential and Commercial/Institutional Emissions per Capita-Degree-Day

32 Although building type also influences the heating demand, it is beyond the scope of this analysis.

33 Source, heating-degree-days: Statistics Canada, Catalogue No. 57-003. Canada wide heating-degree-days are based on the major population centres.

Methodology

The methodology for biomass combustion emissions are described in Appendix B. The fossil-fuel-combustion data is from the QRESD. All transportation fuels are reallocated to the transportation category.

Commercial/Institutional

Emissions from this category were 30.2 Mt CO_2 eq in 1996, an increase of 15% from 1990.

Methodology

Emissions resulting from the combustion of transportation fuels are reallocated to the Transportation category. The fossil-fuel-use information is from the 'commercial' and the 'public administration' data recorded in the QRESD.

2.4.2 Other (Agriculture/Forestry)

Emissions from this category were 2.87Mt CO_2 eq in 1996, representing a decrease of 9% since 1990. This category includes emissions from stationary fuel combustion in agriculture and forestry.

Mobile emissions associated with this sub-category have not been disaggregated from other off-road emissions reported on under Transportation. However, it has been possible to make an estimate of emissions arising from gasoline and diesel fuel use in the agriculture sub-category. For interest, these emissions amounted to 9.6 Mt CO_2 eq in 1990 and 10.7 Mt in 1996,[34] an increase of 11%.

Methodology

The fossil-fuel-use data is from the QRESD. Emissions from diesel and gasoline fuel use, which are significant combustion emission sources in the agriculture industry, have been allocated to the Transportation category. According to IPCC Guidelines this category should also include emissions from the fishing industry. These are not included here, due to lack of data, but rather under the marine area of the Transportation category.

2.5 Biomass Burned For Energy — CO_2 Emissions

The carbon dioxide emissions from this source were 66.3 Mt CO_2 in 1996 and have increased 14% since 1990. Of this, 40.4 Mt were from industry and 26.9 Mt were from residential categories. These CO_2 emissions are *not* included in the national inventory total. Emissions of CH_4 and N_2O from combustion of biomass are reported under the manufacturing and residential categories, as appropriate, and are included in the national inventory.

Methodology

The CO_2 emissions are calculated by applying emission factors to quantities of biomass combusted. The methodology is discussed in further detail in Appendix B.

B. Fugitive Emissions

2.6 Energy Industries: Fugitive Emissions from Fossil Fuels

Fugitive emissions from fossil fuels were 53 Mt CO_2 eq in 1996, an increase of 40% since 1990. Fugitive emissions are 73% methane (CH_4) and 27% carbon dioxide (CO_2) on CO_2 -equivalent basis.

Fugitive emissions from fossil fuels are intentional or unintentional releases of greenhouse gases from the production, processing, transmission, storage and delivery of fossil fuels. Released gas which is combusted before disposal (e.g. flaring of natural gases at oil and gas production facilities) are considered fugitive emissions. If the heat generated during combustion is captured and utilized, then the related emissions are considered fuel-combustion emissions. The two sources are coal mining and handling, and activities related to the oil and natural gas industry.

34 Estimated using average off-road emission factors and QRESD fuel data.

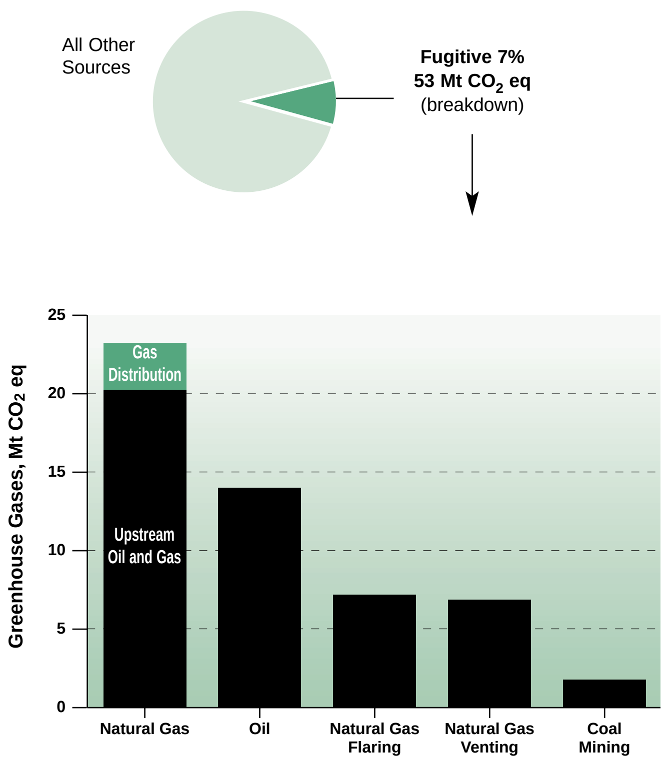

FIGURE 2.6-1
1996 Fugitive Greenhouse Gas Sources

2.6.1 Coal Mining and Handling

The total fugitive emissions from coal mining were 1.8 Mt CO_2 eq in 1996, a decrease of 6% since 1990. This is the result of a reduction in eastern underground coal mining. In 1996, 55% of emissions were from underground mines while only 5% of the coal mined was from underground mines (Statistics Canada, Catalogue No. 45-002).

Coal in its natural state contains varying amounts of methane (CH_4). During coal mining, post-mining activities, and coal handling, the entrapped methane is released to the atmosphere.

Methodology

In coal deposits methane is either trapped under pressure in porous voids within the coal formation or adsorbed to the coal. The pressure and amount of methane in the deposit varies depending on the grade, the depth and the surrounding geology of the coal. During mining, the natural geologic formations are disturbed and pathways are created which release the pressurized methane to the atmosphere. As the pressure on the coal is lowered, the adsorbed methane is released. This results in emissions until the methane in the coal has reached equilibrium with the surrounding atmospheric conditions.

TABLE 2.6.1-1 FUGITIVE EMISSIONS FROM COAL MINING

Year	Methane (Mt CO_2 eq)
1990	1.9
1991	2.1
1992	1.8
1993	1.8
1994	1.8
1995	1.7
1996	1.8

Mining activity emission sources are from the exposed coal surfaces, coal rubble, and the venting of methane from within the formation. Post-mining activities such as preparation, transportation, storage, or final crushing prior to combustion of the coal also release methane. Both mining and post-mining emissions are included in the methodology.

Emissions from Canadian coal mines were estimated for 1990 (King, 1994). These estimates were grouped by province and mine type (surface or underground) to develop aggregate factors based on provincial coal production data obtained from *Coal and Coke Statistics* (Statistics Canada, Catalogue No. 45-002). The developed factors are shown in Table 2.6.1-2. The emissions from coal mining have been estimated by multiplying coal production data (Statistics Canada, Catalogue No. 45-002) by the developed emission factors.

The method used by King to estimate emissions from coal mining is a modified procedure from the Coal Industry Advisory Board. It consists of a mixture of IPCC Tier 3 and Tier 2 type methodologies, depending on availability of mine-specific data. Details of the method used are available in the report by King, but a brief description is provided below.

Underground Mines

King estimated emissions for underground mines on a mine-specific basis using available data. They were estimated by summing emissions from the ventilation system, degasification systems and post-mining activities. Where measured data was not available, estimates were made.

Emissions from the mine shaft ventilation system were estimated (if measured data was not available) by the following formula:

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

where: X is depth of mine in metres
Y is m^3 of methane per tonne coal mined

Measured degasification system emission data were available.

Emissions from post-mining activities were estimated by assuming that 60% of the remaining coal methane (after removal from mine) is emitted to the atmosphere before combustion. If the gas content of the coal is not known, then it is assumed that the methane content was 1.5m^3/tonne (world average methane content of coals).

Surface Mines

For surface mines, King 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. For lignites, gas content values estimated by Hollingshead (1990) were used.

Another significant source of emissions from surface mines is surrounding unmined strata. An attempt was made to account for this by applying a highwall adjustment to account for the degasification of the surrounding unmined strata to a depth of 50m below the mining surface. It was estimated that base emission factors for surface mining should be increased 50% (King, 1994). The factors shown in Table 2.6.1-2 have been adjusted.

TABLE 2.6.1-2 COAL MINING EMISSION FACTORS BY PROVINCE, TYPE OF COAL, AND METHOD OF EXTRACTION

Province	Method	Coal Type	Emission Factor (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 Colombia	Surface	Bituminous	0.58
British Colombia	Underground	Bituminous	4.1

2.6.2 Oil and Natural Gas

Fugitive emissions from the oil and gas industry were 51 Mt CO_2 eq in 1996, 13.5 Mt CO_2 and 37.5 Mt CO_2 eq CH_4. This represents a 42% increase over 1990.

The oil and natural gas area 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 'other fossil fuel industries' and 'mining' categories of the Fuel Combustion section.

Conventional Upstream Oil and Gas

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

Table 2.6.2-1 (on page 31), shows the trends in emissions from the various activities over the period 1990-1996. Emissions from natural gas and heavy oil production have increased 40% and 60%, respectively, since 1990. The emission increase is directly the result of increased production. Emissions from natural gas transmission and processing have increased 20% and 40%, respectively. Emissions from natural gas transmission systems have increased at a slower rate than production, since they are a function of infrastructure rather than the volume of gas transported.

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 blowdown 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 is limited available data and the source is considered negligible.

TABLE 2.6.2-1 FUGITIVE EMISSIONS FROM THE UPSTREAM OIL AND GAS INDUSTRY IN CANADA (Mt CO_2 eq)

Activity	1990	1991	1992	1993	1994	1995	1996
Flaring	5.8	5.7	5.8	6.0	6.1	6.8	7.2
Raw CO_2	4.5	4.8	5.3	5.6	6.2	6.7	6.9
Oil and Gas Well Drilling	0.0	0.0	0.0	0.0	0.1	0.1	0.1
Oil and Gas Well Servicing	0.1	0.1	0.1	0.1	0.2	0.2	0.2
Natural Gas Production	7.7	8.1	8.8	9.5	10	11	11
Light/Medium Oil Production	1.8	1.8	1.8	1.9	2.0	2.0	2.0
Heavy Oil Production	6.4	7.0	8.2	8.2	8.5	9.7	11.0
Crude Bitumen Production	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Natural Gas Processing	0.8	0.9	1.0	1.0	1.1	1.2	1.2
Natural Gas Transmission	4.3	4.4	4.7	4.8	5.0	5.1	5.2
Liquid Product Transport	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Accidents and Equipment Failures	0.1	0.0	0.0	0.1	0.0	0.1	1.0
Surface Casing Vents Blows and Gas Migration	1.4	1.4	1.4	1.5	1.6	1.7	1.8
Total GHG (kt CO_2 eq)	**33**	**34**	**37**	**39**	**41**	**44**	**47**

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 are from wells, gathering systems, field facilities and gas batteries. The majority of emissions are equipment leaks such as leaks from seals; however venting from the use of fuel gas to operate pneumatic equipment and line pigging operations are also significant sources.

Light/Medium Oil Production

This production is defined by wells producing light-or medium-density crudes (<900kg/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. Even though production has decreased since 1990, emissions have increased due to expanding infrastructure.

Heavy Oil Production

Heavy oil is a dense (>900kg/m^3) viscous liquid and requires 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 which 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. The different types of plants included are sweet plants, sour plants which flare waste gas, sour plants which extract elemental sulphur, and straddle plants. Straddle plants are located on transmission lines and recover residual hydrocarbons. They have a similar structure and function so are considered in conjunction with gas processing. The largest source of emissions is from equipment leaks.

Natural Gas Transmission

Virtually all 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 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 are 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: LPG (both surface transport, and high-vapour-pressure pipeline systems), pentane plus (NGL) systems (both by surface transport and low-vapour-pressure pipelines), and crude-oil pipeline systems.

Accidents and Equipment Failures

This area includes emissions resulting 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 blow-outs and spills. Emissions from the disposal and land treatment of spills is 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 which was penetrated but not produced. The emissions from the gas flowing to the surface through the surrounding strata have been estimated.

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 upstream oil and gas industry, waste gas is always flared when it is sour (for safety reasons); however sweet gas is often vented.

Raw CO_2 Releases

Raw natural gas contains carbon dioxide, this is removed and vented to the atmosphere at processing facilities. These are called raw CO_2 releases.

Methodology

Fugitive emission estimates from the conventional upstream oil and gas industries for 1990 to 1996 are based on a recent study. Clearstone Engineering was contracted by the Canadian Association of Petroleum Producers (CAPP) and Environment Canada to prepare a detailed inventory of emissions from the conventional upstream oil and gas industry for the years 1990 to 1996. The estimates are based on the draft version of the report (Picard and Ross, 1998). Details of the calculation method will be available in the final report.

The emission estimate by Clearstone is a rigorous engineering study based on the various products, processes and infrastructure used in the Canadian upstream oil and gas industry. Appropriate emission factors were obtained from published sources (Radian, EPA, etc.) or estimated based on industry-specific information such as the average size of a mud pit, storage tank etc. The activity data used was typical processing plant equipment schedules, production rates, gas-oil ratios etc. collected from various sources such as Alberta Energy and Utilities Board, Natural Resources Canada, provincial energy ministries and so forth. This method would be considered a rigorous IPCC Tier 3 type method.

In the IPCC reporting tables, oil-related emissions are those from light/medium oil production, heavy oil production, crude bitumen production, and liquid product transport. The natural-gas-related emissions are those from well drilling and servicing, gas production, processing, transmission, gas migration, and accidents and equipment failures. Venting and flaring emissions are the sum of flaring emissions from all activities as well as the 'raw carbon dioxide' releases.

Fugitive emissions for 1997 from the Conventional Upstream Oil and Gas Industries are shown in the Executive Summary and Appendix tables. These have been estimated by a simplfied extrapolation methodology. For details, see Appendix B4.

Unconventional Crude Oil Production

Emissions from this area were 0.88 Mt in 1996 a tenfold increase since 1990. The area includes the oil sand open pit mining operations and the heavy/synthetic oil upgrading facilities in Canada. The emissions are primarily methane from the open mine face and from methanogenic bacteria in the mine tailings settling ponds. It is the methanogenic bacteria in the tailings ponds which have produced the huge increase in emissions. This is a newly discovered phenomenon and it is presently being studied by the operators. It is believed that with the planned implementation of new bitumen recovery techniques, the lighter hydrocarbons in the waste stream will be reduced and the emissions will be correspondingly lowered.

Methodology

The emission data is from estimates made by the operators of the Suncor, Syncrude and Husky facilities. This data was compiled in a draft study for the Canadian Association of Petroleum Producers (CAPP) and Environment Canada (McCann, 1998). Descriptions of the methods will be available in the final report. The 1997 emissions were assumed to be constant at 1996 levels.

TABLE 2.6.2-2 FUGITIVE EMISSIONS FROM UNCONVENTIONAL CRUDE OIL PRODUCTION (Mt CO_2 eq)

	1990	1991	1992	1993	1994	1995	1996
Oil Sand Mining and Heavy Oil Upgrading	0.09	0.27	0.34	0.48	0.61	0.71	0.88

Natural Gas Distribution

The fugitive emissions from natural gas distribution systems were 3.0Mt in 1996, a 9% increase since 1990. 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 source is station vents during maintenance, which account for about half the emissions.

TABLE 2.6.2-3 FUGITIVE EMISSIONS FROM NATURAL GAS DISTRIBUTION SYSTEMS (Mt CO_2 eq)

	1990	1991	1992	1993	1994	1995	1996
Distribution Systems	2.8	2.8	2.9	2.8	2.9	3.0	3.0

Methodology

The estimate has been derived from a study by Radian (1997) for the Canadian Gas Association. The study estimated national emissions for 1990 and 1995. Radian surveyed the natural gas distribution companies for schedules of equipment and operation parameters of the systems. Radian calculated emissions based on emission factors from EPA, other published sources, and engineering estimates. The activity data was obtained from published sources and from surveys of distribution system companies. The surveys obtained information on schedules of equipment, operation parameters of equipment, pipeline lengths used in the Canadian distribution system, etc. The method is a rigorous IPCC Tier 3 type. The estimates provided for 1990 and 1995 have been used directly in the national inventory. Estimates for the intervening years were developed by extrapolating 1990 and 1995 results on the basis of the change in length of distribution pipeline in Canada. The length of natural gas pipelines were obtained from Gas Utilities, Transport and Distributions Systems (Statistics Canada, Catalogue No. 57-205).

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Section 3 - Industrial Processes

Included in this sector are emissions of all greenhouse gases from industrial processes where the gases are a direct by-product of the processes. Emissions from combusting fuels for the express purpose of supplying energy for the processes are included in the Energy sector. Industrial processes contributed about 8% of the greenhouse gas emissions in 1996 (see Figure 3-1). Emissions were about 13% above the 1990 levels, mainly due to increased use of undifferentiated non-energy products. The emissions are 66% carbon dioxide (CO_2), 20% nitrous oxide (N_2O), 10% perfluorocarbons (PFCs) and 2% sulphur hexafluoride (SF_6).

The emissions are grouped into the following categories: non-metallic mineral production, chemical production, metal production, and an undifferentiated non-energy products category.

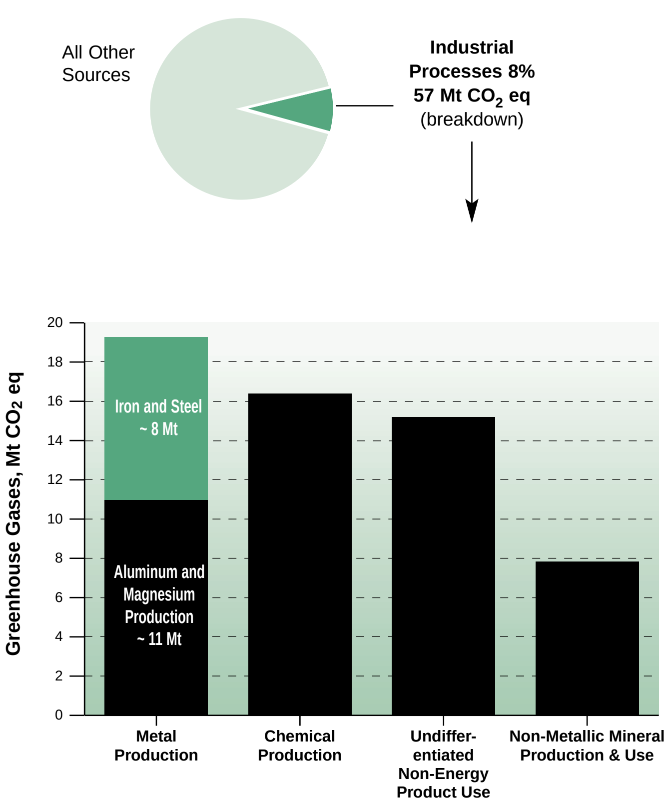

FIGURE 3-1
1996 Industrial Processes Greenhouse Gas Sources

3.1 Non-Metallic Mineral Production and Use

The production of non-metallic minerals generated 7.8 Mt CO_2 emissions in 1996. This was a 5% decrease from 1990. The sources are cement and lime production, limestone and soda ash use. The trends in the subsectors are shown in Table 3.1-1.

TABLE 3.1-1 **EMISSIONS FROM NON-METALLIC MINERAL PRODUCTION (Mt CO_2 eq)**

	1990	1991	1992	1993	1994	1995	1996
Cement Production	5.9	4.7	4.3	4.7	5.3	5.4	5.5
Lime Production	1.8	1.9	1.9	1.9	1.9	2.0	2.0
Limestone Use	0.37	0.36	0.39	0.24	0.22	0.28	0.28
Soda Ash Use	0.07	0.06	0.06	0.06	0.06	0.06	0.06
Total	**8.2**	**7.0**	**6.6**	**6.9**	**7.5**	**7.7**	**7.8**

3.1.1 Cement Production

Emissions from cement production were 5.5 Mt CO_2 in 1996, a 7% decrease from 1990. The trends in emissions are closely related to the activity in the domestic construction industry.

Methodology

Carbon dioxide 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 carbon dioxide in a process called *calcination* or *calcining*:

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

This lime is combined with silica-containing materials to produce clinker (grayish-black pellets about the size of 12mm diameter marbles). The clinker is removed from the kiln, cooled, pulverized, and gypsum is added to produce 'Portland' cement. Almost all of the cement produced in Canada is of the Portland cement type (Ortech, 1994), which contains 60 to 67% lime by weight. Other speciality cements are lower in lime, but are typically used in small quantities. Research is underway on cement formulations that have similar structural properties to Portland cement, but require less lime (Tresouthick and Mishulovich, 1990). Carbon dioxide emissions from cement production are essentially directly proportional to lime content, so production of cements lower in lime yield less CO_2.

The emissions from cement production are estimated by applying an emission factor of 500 g CO_2/kg cement to the yearly national cement production. The emission factor is based on the lime content of clinker. It has been 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. The method is the Intergovernmental Panel on Climate Change (IPCC) default method (IPCC, 1997) and the emission factor is within 1% of the IPCC default. The cement production data is obtained from the *Canadian Minerals Yearbook* (NRCan, 1996).

The emissions resulting from the combustion of fossils fuels to generate the heat to drive the reaction in the kiln fall under the 'Energy' category and are not considered in this section.

3.1.2 Lime Production

Carbon dioxide emissions from lime production in Canada were 2.0 Mt CO_2 eq in 1996, an increase of 10% from 1990.

Methodology

Calcined limestone (quicklime, or CaO) is formed by heating limestone to decompose the carbonates. As with cement production, this is usually done at high temperatures in a rotary kiln and the process releases carbon dioxide. 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 3.1.1, above. 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:

$$CaCO_3 \bullet MgCO_3 \text{ (dolomite)} + \text{heat} \rightarrow CaO \bullet MgO \text{ (dolomitic lime)} + 2CO_2$$

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. The emissions are estimated by applying an emission factor of 790 g CO_2/kg quicklime produced in Canada. It has been assumed that all lime is produced from high-calcium limestone and dolomitic lime production is negligible. The quicklime production data is obtained from the *Canadian Minerals Yearbook* (NRCan, 1996).

Emissions from the regeneration of lime from spent pulping liquors at pulp mills is not included in the inventory since the CO_2 is biogenic in origin and would be recorded as a change in forest stock in the Land Use Change and Forestry section.

3.1.3 Limestone Use

The emissions from limestone use were 0.28 Mt CO_2 eq in 1996, down 0.9 Mt from 1990.

Methodology

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. Since these industries utilize limestone at high temperature, the limestone is calcined to lime, producing CO_2 by the same reaction as described in 3.1.1 and 3.1.2 above.

Emissions are calculated by obtaining data on the consumption of raw limestone by the glass and metallurgical industries from the *Canada Minerals Yearbook* (NRCan, 1996) and applying the non- dolomitic lime production emission factor. This method is the IPCC default. No data is available on the fraction of limestone used that is dolomitic it has been assumed to be negligible.

3.1.4 Soda Ash Production and Use

Emissions from soda ash use in glass manufacture were 0.06 Mt CO_2 in 1996.

Methodology

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 (U.S. Energy Information Administration, 1994). In Canada its use appears to be restricted to the glass industry.

Carbon dioxide is emitted as the soda ash decomposes at high temperatures in the glass furnace. For each mole of soda ash used, one mole of CO_2 is emitted. The mass of CO_2 emitted, then, may be estimated from a consideration of consumption data and the stoichiometry of the chemical process as follows:

$$\begin{aligned} EF &= 44.01 \text{ g/mole } CO_2 / 105.99 \text{ g/mole } Na_2CO_3 \\ &= 415 \text{ kg/tonne } Na_2CO_3 \end{aligned}$$

Consumption information has been obtained from the publication *Non Metalic Mineral Product Industries* (Statistics Canada, Catalogue No. 44-250). Limited data has been published by Statistics Canada since 1993 (due to data suppression). The emissions have been assumed to be constant since 1993. The emission factors and methods used are the IPCC default type.

Carbon dioxide may also be emitted during soda ash production, depending on the industrial process used. Carbon dioxide is generated as a by-product, but is usually recovered and recycled for use in the carbonation stage. According to Canadian industry, no emissions are associated with the production of soda ash in Canada (General Chemical Canada Inc., 1994).

3.2 Chemical Production

Emissions from major chemical production processes were 16 Mt CO_2 eq in 1996. This is an increase of 7% since 1990. The increase is primarily due to the increase of ammonia and nitric acid production (see Table 3.2-1).

TABLE 3.2-1 CHEMICAL PRODUCTION EMISSIONS (Mt CO_2 eq)

	1990	1991	1992	1993	1994	1995	1996
Ammonia Production (CO_2)	3.2	3.2	3.3	3.6	3.7	4.1	4.1
Adipic Acid Production (N_2O)	11	10	10	9.1	11	11	11
Nitric Acid Production (N_2O)	0.78	0.77	0.78	0.78	0.77	0.78	0.79
Total	**15**	**14**	**14**	**13**	**15**	**16**	**16**

3.2.1 Ammonia Production

Emissions from ammonia production were 4.1 Mt in 1996, an increase of 28%. One of the main uses is in the manufacture of fertilizer.

Methodology

Most of the ammonia produced in Canada is manufactured by the Haber-Bosch process, where nitrogen and hydrogen are reacted to produce ammonia. The hydrogen is usually produced by the steam reformation of natural gas. This reaction produces carbon dioxide as a by-product. An emission factor of 1.56 t CO_2/t NH_3 produced was developed (Jaques, 1992) using typical material requirements for ammonia production in Canada.

A large proportion of the manufactured ammonia, however, is used for the production of urea, consuming much of the carbon dioxide that would otherwise be released to the atmosphere. The carbon in urea may either become sequestered in plants or released to the atmosphere after its application to soils. This, however, is an agricultural application and is taken into account under CO_2 emissions from soils in Section 5. The carbon used in urea production is deducted from the total carbon dioxide calculated to be produced from ammonia production. Although contrary to IPCC recommended procedure, this adjustment is necessary since it prevents double counting of agricultural soil emissions.[1]

Some of the hydrogen produced for ammonia production is from other chemical process by-products. It has been estimated that 0.5 Mt of the ammonia is produced from sources other than natural gas (Jaques, 1990); the gross ammonia production figure used has been reduced accordingly.

Total ammonia and urea production numbers were obtained from the Canadian Fertilizer Institute (CFI, 1996) and *Industrial Chemicals and Synthetic Resins* (Statistics Canada, 1997).

3.2.2 Nitric Acid Production

The primary use of nitric acid is in the production of fertilizers. Other uses are in the manufacture of explosives and other chemicals. Emissions from nitric acid production were 0.79 Mt CO_2 eq in 1996, roughly the same as 1990.

1 This methodology is used for the sole purpose of allocating the quantity of CO_2 emitted by ammonia production. As far as actual inventory totals are concerned all carbon dioxide emitted from non-energy use of fossil fuels is calculated according to the method of undifferentiated non-energy product use (see subsection 3.5).

Methodology

As nitric acid (HNO_3) is produced from ammonia (NH_3), nitrous oxide (N_2O) is emitted. Nitrous oxide 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. Emissions of N_2O were estimated using information provided by global industry, which in turn were based on company-specific measurements and calculations (ICI, 1991; Norsk Hydro, 1991). These originally reported emissions ranged from 2 to 20 kg of N_2O/t of ammonia consumed in the production of HNO_3. Emissions from Canadian plants are at the low end of this range (Collis, 1992), so Canada-specific emission factors were developed, based on the type of abatement technology.

Emission factors have been developed for:

1) plants with catalytic converters – 0.66 kg N_2O/t HNO_3
2) plants with extended absorption for NO_X abatement type 1 – 9.4 kg N_2O/t HNO_3
3) plants with extended absorption for NO_X abatement type 2 – 12 kg N_2O/t HNO_3

All plants in Canada with the exception of those in Alberta are the catalytic converter type. 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 was from catalytic converter type plants. The estimation method is the IPCC recommended method and the factors are within the range published by IPCC.

3.2.3 Adipic Acid Production

Adipic acid is used primarily for the manufacture of nylon. During its production, significant N_2O is produced and is usually vented to the atmosphere. Nitrous oxide emissions from adipic acid production were 11 Mt CO_2 eq in 1996. Emissions have remained fairly constant since 1990. With the 1997 installation of emission-abatement technology at the sole production plant in Canada, N_2O emissions are expected to decline sharply in future inventories.

Methodology

Thiemens and Trogler have analyzed the process whereby N_2O is emitted during the manufacture of adipic acid for nylon production. Approximately 0.303 kg N_2O/kg of product are released. The emission estimates from this source are provided by the sole producer of adipic acid in Canada, Dupont Maitland facility. The emissions are calculated based on production of adipic acid. With the start up in 1997 of the facility's abatement technology, emissions began to be monitored. In future inventories, these measured results will be reported.

3.3 Metal Production

The production of metal resulted in 19 Mt CO_2 eq of process emissions in 1996. This was about the same as the 1990 levels. The sources are iron and steel, aluminum, and magnesium production. There have been significant reductions in emissions from magnesium production due to improved production techniques which have offset the increases in ferrous metal production emissions.

TABLE 3.3-1 METAL PRODUCTION EMISSIONS (Mt CO_2 eq)

	1990	1991	1992	1993	1994	1995	1996
Ferrous metal (Iron and Steel) production	7.6	8.9	9.1	8.8	8.0	8.5	8.3
Aluminum production	9	9	10	11	11	10	10
Magnesium production	2.9	3.3	2.2	2.0	2.0	1.9	1.4
Total	**19**	**21**	**21**	**22**	**21**	**20**	**19**

3.3.1 Ferrous Metal (Iron and Steel) Production

Ferrous metal production accounted for 8.3 Mt CO_2 eq emissions in 1996. This represents an increase of 9% from 1990.

Methodology

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 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 steel production. Steel is subsequently made from pig iron and/or scrap steel using electric arc, basic oxygen, or cupola furnaces.

The emissions have been estimated by applying the combustion emission factor for metallurgical coke (Appendix C) to the amount of metallurgical coke used in the iron and steel industry. The metallurgical coke use data is from the *Quarterly Report on Energy Supply-Demand* (Statistics Canada, 57-003). This method is based on the amount of reducing agent used and is similar to the recommended IPCC method. This estimate does not include emissions from the production of steel in electric arc or basic oxygen type furnaces. The emissions resulting from the oxidation of carbon based anodes are included under subsection 3.5, Undifferentiated Non-Energy Product Use. Emissions from the combustion of fuels such as coke oven gas are not reported here, but rather under the Energy sector.

3.3.2 Aluminum Production

Trends and Overview

Emissions from aluminum production were 10 Mt CO_2 eq in 1996, a 10% increase from 1990. The emissions are about 40% CO_2, with the remainder being perfluorocarbons (CF_4 and C_2F_6). The production of aluminum has increased since 1994, however emissions have decreased due to improved production methods.

Plants are characterized by the type of anode technology utilized. In general, older plants with 'Søderberg' technology have higher emissions than newer plants, which usually use pre-baked anodes. The trend in the Canadian aluminum 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.

Between 1990 and 1996, perfluorocarbon (PFC) emissions per tonne of aluminum have been reduced. This has been taken into account in the data presented in Figure 3.3.2-1. However, plant improvements do not seem to have reduced CO_2 emissions rates per tonne of primary aluminum produced.

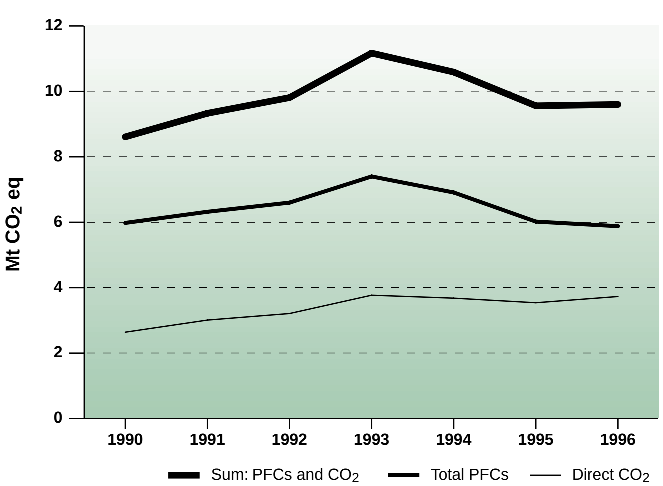

FIGURE 3.3.2-1
Greenhouse Gas Emissions from Primary Aluminum Smelting in Canada

Background and Methodology

Primary aluminum is produced in two steps. First, bauxite ore is ground, purified and calcined to produce alumina. Next, the alumina is electrically reduced to aluminum 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 aluminum is evolved while the anode is consumed in the reaction. The aluminum forms at the cathode and gathers on the bottom of the pot.

Three greenhouse gases — carbon dioxide, carbon tetraflouride (CF_4) and carbon hexaflouride (C_2F_6) — are known to be emitted during the reduction process; the latter two, CF_4 and C_2F_6 , are classified as perfluorocarbons (PFCs). PFCs are extremely inert, potent greenhouse gases: CF_4 has a 100-year global warming potential (GWP) of 6 300, while the GWP for C_2F_6 is 12 500.

As the anode is consumed, carbon dioxide 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 is evolved 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 prebaked electrodes, during anode production and manufacture. Ortech (1994) has calculated production based emission factors for Canadian aluminum smelting (Appendix C). Based on these factors, CO_2 emissions from aluminum smelting are 3.7 Mt CO_2in 1996.[2]

Primary aluminum 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 (AE), when alumina levels are low. If the concentration of alumina at the anode is reduced to below about 2% (by weight), an AE may begin.

2 Carbon dioxide emissions from this source are subtracted from the undifferentiated non- energy product use (see subsection 3.5).

In theory, when an AE occurs, the cell resistance increases very suddenly (within a fiftieth of a second). As a result, the voltage rises and the temperature goes up, forcing the molten flourine salts in the cell to chemically combine with the carbon anode (Laval University Analytical Chemistry Group, 1994).

During the AE, 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:

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

and

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

A study of PFC emissions has been conducted to measure actual outputs from a number of plants (Unisearch, 1994). Data was obtained for the four representative types of aluminum smelting technologies used in Canada. The use of these results then made it possible to establish average emission rates for all aluminum plants in Canada. Emissions for both CO_2 and PFCs are estimated on a plant specific basis by using the factors and aluminum production data for each plant. Aluminum production data are estimated by prorating national aluminum production data by yearly plant capacities as published in the *Canada Minerals Yearbook* (NRCan, 1997). This can be considered an IPCC Tier 3 method, since it is based on measured data.

Perfluorocarbon emissions can be controlled by methods such as computerized aluminum feeders. Sensors detect alumina concentration and automatically feed more to the pot when levels become low. In this way, anode events can be controlled (Oye and Hugen, 1990). Computers can be programmed to detect the onset of AEs 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 (Oye and Hugen, 1990).

Although aluminum production consumes extremely large quantities of electrical energy, currently estimated to be 13.5 kWh per kg of aluminum (Association de l' Industrie d' Aluminum du Quebec, 1993), greenhouse gas emissions associated with this consumption are not necessarily high. All of Canada's primary aluminum 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 greenhouse gases. Energy-related emissions are not considered in this section (see 2.1.1 for a full discussion of electrical energy production).

3.3.4 Magnesium Production

Sulphur hexafluoride process emissions from Canadian magnesium production dropped from 2.9 Mt CO_2 eq in 1990 to 1.4 Mt CO_2 eq in 1996. This is the direct result of improved production techniques by Norsk Hydro at Becancour plant. The emissions are from the use of SF_6 as a cover gas during the production of magnesium.

Methodology

Sulphur hexafluoride (SF_6) is used in magnesium production as a cover gas to prevent oxidization 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 greenhouse gas, with a 100-year global warming potential of 24 900. The material is not manufactured in Canada, but imported; therefore there are no SF_6 production-related emissions in Canada.

Emissions are estimated by SF_6 consumption data reported by the magnesium producers. There are two magnesium producers in Canada, Norsk Hydro and Timminco Metals. Norsk Hydro has aggressively improved their production technologies to minimize the consumption of SF_6 while production has in fact increased over the same period.[3]

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

3.4 Other Metal Production

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 under the undifferentiated category (subsection 3.5). Emissions from carbon evolving from the processing of ores are not inventoried due to lack of data. These are assumed to be small.

3 Norsk Hydro in Norway is researching the possibility of replacing SF_6 with SO_2 as the cover gas; this would further reduce emissions.

3.5 Undifferentiated Non-Energy Product Use

Emissions from the use of undifferentiated products was 15 Mt CO_2 eq in 1996, a 50% increase from 1990. Such product use was the main source of emission increases in the Industrial Processes sector from 1990 to 1996. These emissions are from the *non-energy* use of fossil fuels and are not accounted for under any of the industrial processes discussed above.

Methodology

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 the iron and steel industry, 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. Average rates of carbon storage in non-energy products have been obtained (IPCC, 1997) and were used to develop emission factors, which are shown in Appendix C. This methodology is the IPCC Tier 1 default type discussed in the IPCC guidelines under energy (IPCC, 1997).

Emission factors are applied to fuel quantity data as obtained from Statistics Canada and are categorized as non-energy fuel usage (Statistics Canada, Catalogue No. 57-003). In some cases industry- and process-specific data is available, for example, the use of natural gas to produce hydrogen in the oil upgrading and refining industries (recorded as 'natural gas transformed to refined products' and 'natural gas interproduct transfer' by Statistics Canada). In these cases the natural gas is assumed to undergo 100% oxidation and the combustion emission factor is used.

The use of petroleum coke in anodes for the production of aluminum is recorded by Statistics Canada with all other non-energy uses of petroleum coke. The carbon dioxide emissions from aluminum must therefore be subtracted from the total non-energy emissions to avoid double counting. Similarly, the use of natural gas 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.

3.6 References

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Section 4 - Solvent and Other Product Use

The emissions from Solvent and Other Product Use accounted for 0.1% of Canada's total greenhouse gas emissions in 1996. Emissions were 0.9 Mt CO_2 eq in 1996. Emissions have increased significantly since 1990; hydrofluorcarbons (HFCs) were not used to any significant degree in Canada before 1995. Chlorofluorocarbons (CFCs) are greenhouse gases, but are not included under the UNFCCC[1] and as a result are not inventoried here. Solvent and Other Product Use emissions are distinguished from industrial process emissions since they generally are area sources while industrial process emissions are point sources. The major emissions are from the use of HFCs as replacements for CFCs and the use of nitrous oxide as an anaesthetic (see Figure 4-1).

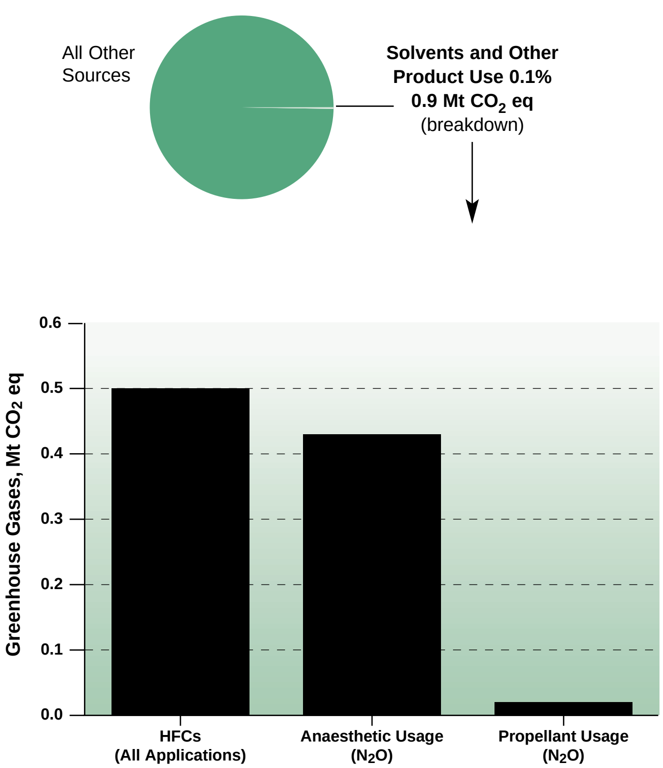

FIGURE 4-1
1996 Solvent and Other Product Use Greenhouse Gas Sources

4.1 Anaesthetic and Propellant Usage

Emissions from anaesthetic and propellant use were 0.43 Mt and 0.02 Mt CO_2 eq respectively in 1996. Nitrous oxide is used in medical applications, primarily as a carrier gas but also as an anaesthetic in various dental and veterinary applications. Nitrous oxide is also used as a propellant for pressure and aerosol products, primarily in the food industry. The largest application is for pressure-packaged whipped cream, 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.

TABLE 4.1-1 N_2O EMISSIONS FROM ANAESTHETICS AND PROPELLANTS

Year	Anaesthetic Usage kt CO_2 eq	Propellant Usage kt CO_2 eq
1990	400	21
1991	400	21
1992	410	21
1993	410	21
1994	420	22
1995	420	22
1996	430	22

Methodology

An emission factor for nitrous oxide emissions from anaesthetics has been estimated on the basis of consumption patterns in Canada. It has been assumed that all of the nitrous oxide used for anaesthetics will eventually be released to the atmosphere. Based on population statistics and the quantity of nitrous oxide consumed in these applications in 1990 (Fettes, 1994), an emission rate of 46.22 g per capita has been developed. This emission rate is slightly lower than the emission rate developed for the United States.

An emission factor has been developed for N_2O used in propellants. Based on consumption patterns in Canada in 1990, an emission factor of 2.38 g N_2O per capita has been derived. It is assumed that all the propellant was emitted to the atmosphere during the year of sale. The population data used is from Annual Demographic Statistics (Statistics Canada, Catalogue No. 91-213).

1 United Nations Framework Convention on Climate Change.

4.2 Emissions Related to SF_6, PFC and HFC Consumption for all Uses Except Primary Metal Manufacture

Emissions from HFC (hydrofluorocarbon) use have been estimated to be 0.5 Mt CO_2 eq in 1996. The major source is air conditioning (AC) equipment. At the time of inventory preparation, 1996 HFC usage data was not available; as a result, emissions were assumed to be identical to those in 1995. Environment Canada is collecting new data and this will be available for the next inventory. The estimation methodology will be revised to conform to the new data set. 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).

Sulphur hexafluoride (SF_6) is used as an insulator gas in high voltage equipment and perfluorocarbons (PFCs) are used in some industrial solvents and cleaners. Emissions of SF_6 and PFCs other than from primary metal manufacture are not estimated due to lack of data. Current consumption of PFCs is believed to be insignificant in comparison to the by-product emissions of PFCs from primary aluminum manufacture. Sulphur hexaflouride emissions from primary magnesium manufacture is thought to be much larger than all other sources of SF_6 emissions.

TABLE 4.2-1 TOTAL CANADIAN HFC EMISSIONS (kt CO_2 eq)

		1996						
	GWP	Aerosol	Foam	AC OEM	AC Service	Refriger-ation	Flooding Systems	All Applic-ations
HFC-23	11700	-	-	-	-	1	-	1
HFC-32	650	-	-	-	-	0	-	0
HFC-125	2800	-	-	-	-	50	-	50
HFC-134a	1300	20	10	100	200	50	-	400
HFC-143a	3800					40	-	40
HFC-152a	140	0	-	-	-	0	-	1
HFC-227ea	2900	-	-	-	-	-	20	20
Totals		**20**	**10**	**100**	**200**	**100**	**20**	**500**

HFC Methodology

The only source estimated is HFC consumption emissions, as there is no known production of HFCs in Canada. The estimation procedure used for this source has been adapted from the Intergovernmental Panel on Climate Change (IPCC) default method (IPCC, 1997). Total potential emissions (Tier 1) can be estimated by the Tier 1 methodology but in this case it must be assumed that no HFC's are destroyed and that all the product distributed in one year is emitted during that year. This method greatly overestimates emissions since most of the HFCs consumed are not emitted until the manufactured product is retired.

The data required for a Tier 2 method was not available, so the methodology has been adapted to make a more representative estimate of actual emissions. The HFC use data was available in the following groups: Aerosols, Foams, AC OEM, AC Service, Refrigeration, and Total Flooding Systems. Emission factors have been developed for each use and are shown in Table 4.2-2.

The factors have been based on loss rates, adapted from the IPCC methodology (IPCC, 1997). No data are available for quantities of HFCs contained in imported equipment, so this source is not included, but it is assumed to be small, relative to the others.

TABLE 4.2-2 HFC EMISSION FACTORS (kg LOSS PER kg CONSUMPTION)

Aerosols	Foams	AC OEM	AC Service	Refrigeration	Total Flooding Systems
0.8	1	0.04	1	0.1	0.35

Derivation of factors

Aerosols – It has been assumed there is a six-month time lag on emissions from the time of production of an aerosol (IPCC, 1997). It was also assumed that 1994 aerosol production was 50% of 1995's. As a result, the emission rate is less than 1995 production.

Foams – It has been assumed that all foams produced are open cell.

AC Original Equipment Manufacture – Only original charging losses have been accounted for here. (Other losses have been accounted for under servicing). IPCC indicates a 2 to 5% loss rate. For Canada, a rate of 4% was assumed.

AC Service – It was assumed that most service HFCs are used to replace 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 has been 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,

HFC (refrig.) = charge + operating loss

Operating loss is about 0.17Charge, according to IPCC, 1997. Therefore, assuming the total charge remains constant for the short term:

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

or,

Charge = HFC (refrig)/1.17

Assuming assembly leakage is minimal,

Emission = operating loss = 0.17Charge

Thus,

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

The HFC consumption data is collected by the Commercial Chemicals Branch of Environment Canada (Bovet, 1996). Consumption of HFCs in Canada in 1996 is shown in Table 4.2-3 and totalled about 5 Mt CO_2 eq. The table illustrates the potential emissions using the Tier 1 method.

TABLE 4.2-3 TOTAL CANADIAN HFC CONSUMPTION DATA (t POLLUTANT)

	1996						
	Aerosol	Foam	AC OEM	AC Service	Refriger-ation	Flooding Systems	All Applic-ations
HFC-23					0.56		0.56
HFC-32					0.05		0.05
HFC-125					181.17		181.17
HFC-134a	18.4	7.9	2 336.71	131.09	375.44		2 869.46
HFC-143a					106.46		106.46
HFC-152a	2.3				20.91		23.24
HFC-227ea						16.71	16.71

4.3 References

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Section 5 - Agriculture

Many agricultural activities result in emissions of greenhouse gases. The processes that produce emissions are enteric fermentation of domestic animals, manure management practices, and cropping practices which result in a release from soils. Greenhouse gas emissions from on-farm fuel combustion are included in the Energy sector rather than under Agriculture.

In 1996, the Agriculture sector contributed 9% of greenhouse gas emissions in Canada. The major sources are enteric fermentation, manure management, and agricultural soils. Figure 5-1 shows a breakdown of agriculture's contribution to the national greenhouse gas total in CO_2 equivalents. Agriculture contributes 60% of Canada's total nitrous oxide, 25% of methane, and 4% of carbon dioxide. Emissions from Agriculture have increased 4% from 1990 to 1996.[1] The increase has been mainly the result of increased beef production.

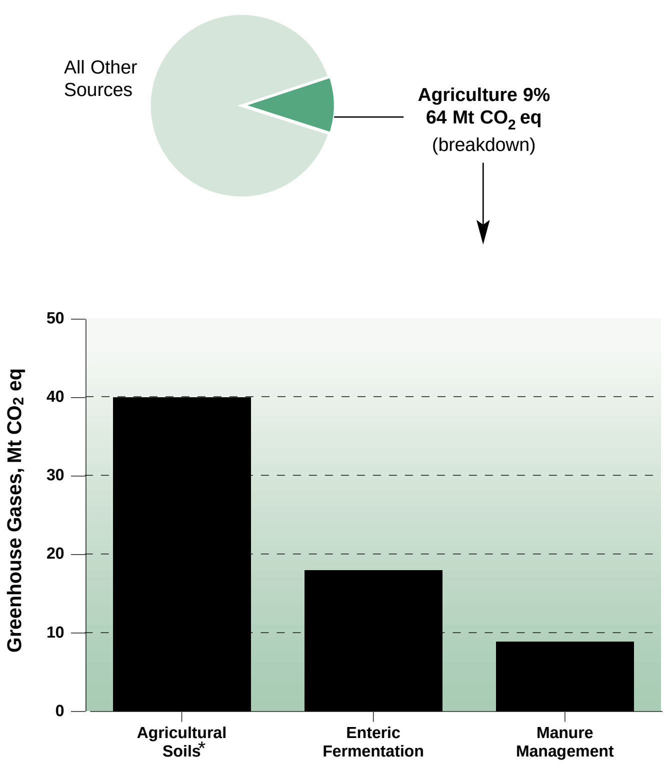

FIGURE 5-1
1996 Agriculture Sector Greenhouse Gas Sources

*Agricultural Soils includes carbon dioxide (CO_2) and nitrous oxide (N_2O) emissions.

5.1 Enteric Fermentation

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

Emissions from this source were 18 Mt CO_2 eq in 1996 and have increased 14% since 1990 due to increased beef production (see Table 5.1).

TABLE 5.1 ENTERIC FERMENTATION EMISSIONS (Mt CO_2 eq)

Animal Type	1990	1991	1992	1993	1994	1995	1996
Dairy Cattle	4.1	4.0	3.3	3.8	3.8	3.8	3.8
Non-Dairy Cattle	11	12	12	12	13	14	14
Swine	0.32	0.33	0.34	0.34	0.35	0.38	0.38
Poultry	Not Estimated						
Other	0.26	0.26	0.27	0.27	0.26	0.26	0.26
Total	**16**	**16**	**16**	**17**	**18**	**18**	**18**

Dairy cattle – Includes diary cows and dairy heifers only.
Other –Includes sheep, goats and horses.

Methodology

Methane emissions from enteric fermentation are estimated by multiplying the populations of various animals by average emission rates for each type of domestic animal. The methodology used is an IPCC Tier 1[2] type. The IPCC default emission factors for cool climate were used and are presented in Table 5.1-2.

1 Although it should be noted that from 1996 to 1997, emissions dropped 1.3%.

2 Intergovernmental Panel on Climate Change (IPCC). International methodological standards are based on the *Revised 1996 IPCC Guidelines for National GHG Inventories* (1997).

TABLE 5.1-2 METHANE EMISSION FACTORS FOR LIVESTOCK AND MANURE

	Enteric Fermentation (kg CH_4/head/year)	Manure Management (kg CH_4/head/yr)
Cattle		
Bulls	75	1
Dairy Cows	118	36
Beef Cows	72	1
Dairy Heifers	56	36
Beef Heifers	56	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

Source: IPCC 1997.

In previous inventories, emission factors from Cassada and Safley (1990) were used; however, through consultation with Canadian researchers (Desjardins, 1998) the methodology has been revised to use the IPCC emission factors. The IPCC emission factors are based on research conducted in the U.S. Emissions of methane 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 emission factors for Canadian conditions.

Domestic animal population data has been obtained from *Livestock Statistics* (Statistics Canada, Catalogue No. 26-603) on a semi-annual or quarterly basis and averaged to obtain annual populations. Where data has not been available in document 26-603 (for example horses, goats) data from the 1991 and 1996 farm census (Statistics Canada, Catalogue No. 93-350 and 93-356) have been used. In the case of poultry, no population data are available on a yearly basis. Production data from *Production of Poultry and Eggs* (Statistics Canada, Catalogue No. 23-202) is used to prorate populations based on the farm census population data (Statistics Canada, Catalogue No. 93-350).

5.2 Manure Management

During the handling of livestock manure both methane and nitrous oxide are emitted. The amount of emissions is dependent on the manure properties, quantities, and the handling systems. Poorly aerated systems generate large quantities of methane but little nitrous oxide, while well-aerated systems generate little methane but greater nitrous oxide.

The total methane emissions were 4.4 Mt CO_2 eq and the total nitrous oxide emissions were 4.6 Mt CO_2 eq for 1996. Emissions from manure management increased 13% from 1990 to 1996. Emissions have increased primarily due to increased beef production, which uses dry lot manure management systems (see Table 5.2-1). Nitrous oxide emissions from this source were not estimated in previous inventories.

TABLE 5.2-1 MANURE-MANAGEMENT EMISSIONS (Mt CO_2 eq)

Animal Type	1990	1991	1992	1993	1994	1995	1996
Methane							
Dairy Cattle	1.5	1.5	1.2	1.4	1.4	1.4	1.4
Non-Dairy Cattle	0.21	0.21	0.22	0.23	0.24	0.25	0.25
Swine	2.1	2.2	2.3	2.3	2.4	2.5	2.5
Poultry	0.17	0.17	0.17	0.17	0.19	0.19	0.20
Other*	0.003	0.003	0.003	0.003	0.003	0.003	0.003
Total Methane	**4.0**	**4.0**	**3.9**	**4.0**	**4.2**	**4.3**	**4.4**
Nitrous Oxide							
Dairy Cattle	0.41	0.39	0.34	0.37	0.37	0.37	0.37
Non-Dairy Cattle	3.1	3.1	3.3	3.3	3.5	3.7	3.7
Swine	0.22	0.22	0.23	0.23	0.24	0.25	0.26
Poultry	0.11	0.11	0.11	0.11	0.12	0.12	0.13
Other*	0.087	0.090	0.090	0.090	0.090	0.090	0.090
Total Nitrous Oxide	**3.9**	**3.9**	**4.0**	**4.1**	**4.4**	**4.5**	**4.6**
Total GHG	**7.9**	**8.0**	**7.9**	**8.2**	**8.5**	**8.8**	**8.9**

*Horses, goats and sheep.

Methodology

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 methane. The quantity of methane 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.

Emissions have been estimated by applying animal-specific emission factors to domestic animal populations. This is considered an IPCC Tier 1 methodology. Methane emissions from manure management are estimated using the IPCC default emission factors (shown in Table 5.2-2) for a developed country with a cool climate. The animal population data used is the same as that used in the Enteric Fermentation subsection.

Previous inventories used emission factors from Cassada and Safley (1990); however, upon consultation with Agriculture Canada researchers (Desjardins, 1998,) the IPCC factors were deemed to be the most representative for Canada. Further research is needed to verify the suitability of these emission factors for Canada.

Nitrous Oxide Emissions

The production of nitrous oxide during storage and treatment of animal waste occurs during the nitrification and denitrification[3] of nitrogen contained in the waste. Generally, as the degree of aeration of the waste increases, so does the amount of nitrous oxide produced.

Emissions of nitrous oxide from animal-waste-management systems have been estimated using the IPCC default methodology and emission factors (see Table 5.2-2). The emissions are estimated by applying a system-specific emission factor (EF3) to the manure nitrogen handled by each management system. The amount of manure nitrogen handled by the systems are estimated by calculating the manure nitrogen excreted by a particular animal type and multiplying this by the percent usage of the system. The nitrogen excretion rates are reduced by 20% to account for volatilization of NH_3 and NO_3 (IPCC, 1997). It is assumed that no animal waste is burned as fuel in Canada. The excretion rates and the usage of animal waste management systems are shown in Table 5.2-2. The utilization rates of various animal-waste-management systems has been based on consultation with industry experts. Unfortunately, as limited data is presently available, the values are based on expert opinion.

The animal population data used to estimate the total manure nitrogen (N) excreted are the same as that used in the Enteric Fermentation subsection.

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

TABLE 5.2-2 MANURE-MANAGEMENT SYSTEM USAGE AND EMISSION FACTORS

		Percent of Manure Nitrogen (N) from AWMS (1)			
Animal Type	N Excretion rate kg N/ head/ year(1)	Pasture & Paddock	Liquid System	Solid Storage or Dry Lot	Other System
Dairy Cows	70.5	20	53	27	0
Non-Dairy Cows	56.4	42	1	56	1
Swine	15	0	90	10	0
Poultry	0.45	44	4	0	95
Sheep and Goats	6.8	1	0	46	10
Treatment-System-Specific Emission Factor (2)					
		kg N_2O-N/kg N excreted			
EF3		0.02	0.001	0.02	0.005

(1) Monteverde C. A. et al., 1998.
(2) IPCC, 1997.
AWMS – Animal Waste Management System.

5.3 Agricultural Soils

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

In the case of carbon dioxide, 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 carbon dioxide. In 1996 net CO_2 emissions from soils were 2 Mt (see Table 5.3-1 on page 50). This has decreased over 5 Mt 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 practiced on over 16% of Canada's (annual) crop lands in 1996 as opposed to 7% in 1991 (Statistics Canada, Catalogue No. 93-350 and 93-356). No-till farming reduces the oxidation of soil organic carbon and therefore increases the carbon stored in soils.

Nitrous oxide is emitted as a by-product during soil nitrification and denitrification processes. In 1996, nitrous oxide emissions were about 40 Mt CO_2 eq from soils (see Table 5.3-1). Even though the uncertainty in the agriculture soil estimates is very high, it appears that nitrous oxide emissions have increased since 1990.

Overall emissions from agricultural soils have remained stable since the increases in nitrous oxide have offset the decreases in carbon dioxide emissions.

3 Nitrification is the oxidation of NH_4 to NO_3 and denitrification is the reduction of NO_3 to N_2.

TABLE 5.3-1 AGRICULTURAL SOIL EMISSIONS (Mt CO_2 eq)

	1990	1991	1992	1993	1994	1995	1996
Carbon Dioxide	7	7	6	5	4	3	2
Nitrous Oxide							
Synthetic Fertilizer Application	3	3	4	4	4	4	5
Animal Wastes as Fertilizer	3	3	3	3	3	3	3
Grazing Animals	3	3	3	3	3	3	3
Biological Nitrogen Fixation	4	4	3	4	4	4	4
Crop Residue Decomposition	9	9	8	8	8	8	9
Cultivation of Histosols	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Indirect Nitrous Oxide	9	9	10	10	11	11	11
Total Nitrous Oxide	**30**	**30**	**30**	**40**	**40**	**40**	**40**
Total GHG	**40**	**40**	**40**	**40**	**40**	**40**	**40**

Note: Data shown to one significant figure to reflect uncertainty.

5.3.1 Carbon Dioxide Methodology

The 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 relatively small annual increment of carbon change 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, a computer modeling approach (the CENTURY model), described in a separate report (Parton et al., 1987) has been selected. The CENTURY model is considered more appropriate for estimating the rate of change of soil organic carbon in Canada than procedures from the IPCC Guidelines. A detailed description of the methodology is available in a separate report by Smith (Smith W., et al., 1997). Following is a brief summary of the CENTURY model methodology.

The CENTURY model accounts for several agricultural management practices including planting, fertilizer application, tillage, grazing and organic-matter addition. Several data sources are required to fulfill the extensive requirements of the model. On a Soil Landscape of Canada (SLC) polygon basis, Statistics Canada agricultural census data were used to obtain crop cover and percentage of conventional and no-tillage practiced for census years (which are at five-year intervals). Fifteen percent of the total polygons were used, and the results were then prorated to estimate the total. The yearly crop coverage from 1990 to 1996 was taken from Statistics Canada core data. Soil data were derived from the Canadian Soil Information System (CanSIS). Recent fertilizer consumption and low- and no-till rates were derived from data and studies by Agriculture and Agri-Food Canada. The practice of biomass burning has been decreasing significantly in the past few decades and has not been included in the model because it is assumed to be negligible. The addition of manure to agricultural fields and soil erosion have not been considered, as the model cannot handle such heterogeneous patterns. Based on these inputs the CENTURY model was used to determine annual estimates for the period 1990 to 1996, with forecasts to 2010.

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 would improve the reliability of the model in predicting soil carbon change in response to no-till practices in the prairies (McConkey, 1998). The prairies represent 85% of the farm land in Canada.

An estimate for 1997 was made by linear interpolation of the 1996 and 2000 estimates. The CENTURY model output as run by Smith aggregates emissions from the eastern provinces. Emissions were divided among eastern provinces by prorating against the agricultural land area in each province (Smith et al., 1997b; Sellers and Wellisch, 1998).

The CENTURY model does not take into account emissions from the liming of soils. Liming emissions are small, around 0.3 Mt CO_2. This source has been estimated according to the IPCC default methodology and added to the results from the CENTURY model. The method is detailed in a report by MWA Consultants (Sellers and Wellisch, 1998). The activity data (quantity of lime used) is based on unpublished data from Provincial Fertilizer Associations. (Activity data was not available for 1997 so emissions from this source were assumed to remain constant at 1996 levels.)

5.3.2 Nitrous Oxide Methodology

During nitrification and denitrification processes a fraction of the available nitrogen is emitted to the atmosphere as nitrous oxide. The amount of nitrous oxide emitted is dependant 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. The estimation methodology used is based on the IPCC default and is divided into two broad emission types: direct and indirect.

Estimates of nitrous oxide emissions from soils have increased dramatically over previous inventories. In the past only nitrogen from synthetic fertilizer application was considered. In this inventory the sources of nitrogen have been expanded and as a result emissions have increased substantially.

Direct Sources

Direct sources are those emissions which are emitted directly from agricultural fields. These emissions are from nitrogen which has entered the soil from synthetic fertilizer, manure application, plant biological nitrogen fixation, crop residue decomposition, and the cultivation of histosols.

Synthetic fertilizers

Synthetic fertilizers add large quantities of nitrogen to soils, and as a result nitrous oxide is emitted. The methodology used to estimate emissions is the same as in past inventories and is similar to the IPCC default Tier 1 methodology. The average nitrogen-loss rates for various types of fertilizer have been compiled and are shown in Table 5.3.2-1; these loss rates have been applied to the amount of fertilizer nitrogen applied annually. (Note the IPCC default uses a single loss rate regardless of fertilizer type). The amount of applied nitrogen is reduced by 10% (IPCC default) to account for losses due to volatilization.

TABLE 5.3.2-1 FERTILIZER USE AND RELATED N_2O EMISSIONS (1996)

Fertilizer Material	Quantity (Tonnes) [1]	Nitrogen Content (Tonnes) [1]	% Loss of N as N_2O [2]	N_2O (Tonnes)
Urea	1 373 291	631 714	0.3	3 000
Ammonia Sulphate	191 022	40 115	0.1	60
Ammonium Nitrate	261 463	88 897	0.3	400
Anhydrous Ammonia	641 736	526 224	1.6	10 000
Nitrogen Solutions	243 497	68 994	0.1	100
Calcium Nitrate	28 462	7 528	0.2	20
Monoammonium Phosphate	985 348	108 388	0.1	200
Diammonium Phosphate	180 686	32 523	0.1	50
Other Fertilizers	330 382	71 818	0.1	100
Totals	**4 829 045**	**1 576 201**		**20 000**

Source: [1] Agriculture and Agri-Food Canada, 1997.
[2] Monteverde, C.A. et al., 1998.

The amount of nitrogen applied is obtained from yearly fertilizer sales data, which are available from regional fertilizer associations (Agriculture and Agri-Food Canada, 1997). The data records 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.

The largest source of emissions is anhydrous ammonia, due to the high use and high nitrogen loss rate of this fertilizer type.

Animal Wastes Applied as Fertilizer

The application of animal wastes as fertilizer to soils can increase the rate of nitrification/ denitrification and result in nitrous oxide emissions. The IPCC default methodology and emission factor (EF1) of 1.25% N_2O-N/kgN have been used. The amount of nitrogen applied is calculated using the excretion rate data from Table 5.2-2 and the animal population data used in the manure management section. All the nitrogen handled by the systems is assumed to be applied as fertilizer. Manure is not used as a fuel to any significant degree in Canada. Manure from grazing is not included in this section, but is included under the grazing animals section. The amount of manure nitrogen excreted was reduced 20% to account for volatilization of NH_3 and NO_3 (IPCC default).

Grazing Animals

The emissions from manure excreted by grazing animals are calculated using the IPCC default methodology. The excretion rates and pasture paddock system emission factors from Table 5.2-2 are used. It is assumed that 20% of the excreted nitrogen is lost due to volatilization (IPCC, 1997). The animal population data used to estimate the amount of manure nitrogen excreted is the same as that shown in the Enteric Fermentation subsection.

Biological Nitrogen Fixation

Atmospheric nitrogen fixed by biological nitrogen fixing plants can undergo nitrification/denitrification in the same manner as nitrogen applied as synthetic fertilizer. Also, the ribozobia in plant nodules can emit nitrous oxide as they fix nitrogen. The methodology used to estimate emissions from this source is the IPCC default. A combined emission rate of 1.25% N_2O-N/kgN (EF1, IPCC default) of the nitrogen contained in nitrogen-fixing crops (IPCC, 1997) is used. The amount of nitrogen in the nitrogen-fixing plants is estimated from production data, assuming the crop mass is twice the mass of the edible portion and assuming it contains 0.03 kgN/kg dry mass (IPCC, 1997). The dry mass is estimated using the average dry matter fractions shown in Table 5.3.2-2 and the crop production data is from crop production surveys (Statistics Canada, Catalogue No. 22-002). There are no explicit annual statistics available for alfalfa production as the data is rolled up in tame hay production; alfalfa quantities have been estimated by assuming 60% of tame hay production is alfalfa. In addition the crop mass of alfalfa and tame hay is assumed to be equal to the reported production (rather than double) to account for multiple harvests in one season.

TABLE 5.3.2-2 DRY MATTER FRACTION OF CROPS (kg/kg)

Crop Type	Dry Matter Fraction
Wheat	0.855
Barley	0.85
Maize	0.845
Oats	0.85
Rye	0.85
Peas	0.87
Beans	0.87
Soya	0.87
Lentils	0.87
Sugarbeet	0.15
All Others	0.85

Source: IPCC, 1997.

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. Emissions are estimated using the IPCC default methodology and emission factors. It is assumed that biological nitrogen-fixing crop residue has 0.03 kgN/dry kg and other crops have 0.015 kgN/dry kg (IPCC 1997). The emission rate is estimated at 1.25% N_2O-N/kgN (IPCC, 1997). It is estimated that 55% of the crop mass remains on the field as residue. It is further assumed that the amount of residue which is burned on the field is negligible in Canada. The crop dry mass is estimated using the average dry matter fractions shown in Table 5.3.2-2. The crop production data and dry-mass quantities are the same as those described under Biological Nitrogen Fixation.

Cultivation of Histosols

Nitrous oxide is also emitted as a result of cultivating organic soils (histosols), due to enhanced mineralization of old nitrogen-rich organic matter. The IPCC default methodology has been used to estimate emissions from this source. In Canada there are over 111 million hectares of peatlands. It is estimated 0.014% is presently under cultivation (Natural Resources Canada, 1995). An emission factor (EF2) of 5 kg N_2O-N/ha/yr (IPCC, 1997) is used.

Only national data is available for the area under production, so total provincial production rates were used to prorate provincial emissions. Production data was only available from 1990 to 1996 and this data is no longer published. Emissions for 1997 have been assumed to be the same as those for 1996.

Indirect Sources

A fraction of the fertilizer nitrogen that is applied to agricultural fields will be transported off site by either a) volatilization and subsequent redeposition, or b) leaching and runoff. The nitrogen that is transported from the agricultural field will provide additional nitrogen for subsequent nitrification and denitrification reactions which will produce N_2O. The method used to estimate these emissions is the IPCC default. The emission factors shown in Table 5.3.2-3 were used.

Volatilization and Subsequent Redeposition

The amount of nitrogen that volatizes was assumed to be 10% of synthetic fertilizer applied and 20% of manure nitrogen applied. The amount of nitrogen estimated to have volatized was multiplied by EF4 (Table 5.3.2-3) to obtain an emission estimate.

Leaching and Runoff

The emissions from runoff and leaching were estimated by assuming 30% of the nitrogen applied as synthetic fertilizer or manure was lost by leaching or runoff; this amount was then multiplied by EF5 (Table 5.3.2-3) to obtain an emission estimate.

TABLE 5.3.2-3 IPCC DEFAULT INDIRECT EMISSION FACTORS

EF4	0.01 kg N_2O N/kg NH_3N and NO_X N emitted
EF5	0.025 kg N_2O N/kg N leaching/runoff

Source: IPCC, 1997.

The nitrogen leaving the agricultural field may not be available for 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. IPCC estimates this uncertainty to be up to two orders of magnitude.

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Section 6 - Land Use Change and Forestry

Overview

This section discusses emissions from all sources that change the way land is used (clearing of forests for agricultural and urban use, including open burning of cleared biomass), or affect the amount of biomass in existing stocks such as forests. Emissions from all anthropogenic activities related to the Land Use Change and Forestry sector are covered with the exception of non-CO_2 gases from energy-related activities, which are addressed in Section 2 – Energy.

Vegetation withdraws carbon dioxide from the atmosphere through the process of photosynthesis. Carbon dioxide 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 carbon dioxide passes into vegetation each year (on the order of 100 billion tonnes 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 balanced by the return respiration fluxes.

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 greenhouse gases (GHG) among terrestrial ecosystems, the atmosphere and the ocean. The fact that changes in land use today affect both present and future CO_2 fluxes associated with that specific land use, is one characteristic that distinguishes land use from fossil fuel consumption for purposes of CO_2 emissions analysis. Ecosystems are in a state of dynamic equilibrium. 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 state of succession, climatic factors and exposure to natural and human disturbances. Tree growth and soil formation take many years to complete (i.e. decades to centuries), making their annual rates of change very small.

The 1996 inventory is the first attempt by Canada to report on an assessment of the net carbon dioxide flux and other GHGs within the Land Use Change and Forestry (LUCF) categories, as per the 1996 Revised IPCC Guidelines (IPCC, OECD, IEA, 1997). Carbon dioxide emissions from agricultural soils, for which estimates were provided in previous reports, are reported under Section 5 – Agriculture.

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. Chapter 5 of the IPCC Guidelines provides methods to measure the GHG impacts of the LUCF activities that are important from a global perspective. In Canada's case, this assessment involves the estimation of small changes within the context of a very large land area. The main challenge is deciding how to apply the LUCF methodologies to Canada's circumstances in a way that produces meaningful results. Moreover, as land areas are affected by both natural forces and human decisions, the isolation of the human impact of land-use and land-use-change activities, as is required under the Framework Convention on Climate Change, is a complex and significant task.

The results are presented according to the following categories:

1. Changes in forest and other woody biomass stocks;
2. Forest and grassland conversion, loosely defined as deforestation;
3. Abandonment of croplands, pastures, or other managed lands;
4. Soils CO_2 emissions and removals associated with 2 and 3;
5. Emissions from human-induced fires; and
6. Emissions from wild fires (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 (1, 3, and part of 4) currently remove CO_2 from the atmosphere, whereas land conversion to forest and grassland (2 and part of 4) and biomass burning (5 and 6) all release emissions. All estimates in this section are drawn from Sellers and Wellisch (1998). It is important to note that emissions and removals of CO_2 from land use change and forestry reported in this chapter are *not* included in Canada's national total GHG emissions inventory as per the IPCC Reporting Guidelines (IPCC/OECD/IEA, 1997).

LUCF activities can have an impact on three different carbon (C) reservoirs: above-ground biomass, below-ground biomass and soil carbon. For forestry stocks, the IPCC methodology currently ignores below-ground biomass and soil carbon. Current data on these pools for the wood production forest in Canada are inadequate. Changes in soil C are taken into account, however, for land-use-change activities (see subsections 6.2 and 6.3).

Carbon Budget Model and IPCC Methods

Canada is the second largest country in the world, occupying an area of approximately 1000 million hectares of land and water. Approximately 45% of Canada's current land cover is comprised of forests and about 35% of the total forest area is referred to as the 'wood production forest' (non-reserved, accessible forest).

The Canadian Forestry Service's carbon budget model (CBM-CFS2[1]), while more detailed in its assessment of forest carbon stocks than the IPCC methodology, does not address all of the requirements of the IPCC. Under the IPCC Guidelines, forest sector carbon fluxes are assessed together with the effects of land use change. On the one hand, the model includes all Canadian forest land for which biomass data are available (including the 'unmanaged' forest), and takes into account the carbon stored in root biomass below ground as well as the effects of natural disturbances. On the other hand, the CBM model excludes the treatment of non-forest trees, the use of domestic firewood, and the effects of land conversion. The retrieval of data that best represent the 'managed' or 'wood production forest' (forests areas, biomass accumulation rates, expansion factors etc.), as opposed to the entire Canadian forest, has made it difficult for Canada to report on this category of its inventory.

Overview of Emissions and Removals from Land Use Change and Forestry

Table 6.1 provides 1996 results as emissions and removals for each of the sub-categories in this section for CO_2, CH_4 and N_2O (in CO_2 equivalent) while Figure 6-1 illustrates the results graphically. Total CO_2 removals by sinks from Canada's anthropogenic LUCF activities in 1996 were estimated to be about 297 Mt of CO_2 , while total CO_2 emissions from sources were estimated to be about 265 Mt CO_2. Emissions estimates greatly depend on the way wood products are treated in the methodology (see subsection 6.1.3).

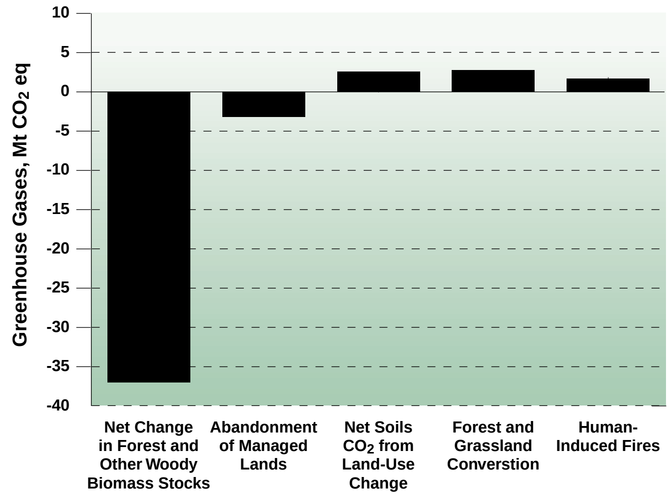

FIGURE 6-1
1996 Land Use Change and Forestry Greenhouse Gas Sources and Sinks

TABLE 6.1 1996 EMISSIONS AND REMOVALS* FROM LAND USE CHANGE AND FORESTRY BY CATEGORY

	Net CO_2 Mt	CH_4 Mt $C0_2$ eq	N_2O Mt $C0_2$ eq
Net Change in Forest and Woody Biomass Stocks	-37		
Land Conversion	2.8		
Abandonment of Managed Lands	-3.2		
Net Emissions from Soils from Land Use Change	2.6		
Human-Induced Fires**	6.0	0.88	0.87
Total *	**-30**	**1.7**	

* Removals are shown as negative values.
** Outside Wood Production Forest (WPF). CO_2 from fires in WPF is included in Net Change in Forest Stocks.
*** Excludes 6 Mt of carbon dioxide (CO_2) from *Human-Induced Fires Outside WPF.*
Note: a. Individual category estimates are given to 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.
b. CO_2 from Land Use Change and Forestry is classified separately and is not included in inventory sums.

6.1 Changes in Forest and Other Woody Biomass Stocks

Canada's total forest area (417 Mha) comprises close to 10% of the world's total forested area. It is composed of a mosaic of ecosystems — forests of different ages, of

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

different 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 forest land 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, is known as Canada's wood production forest and is available for commercial harvest (148 Mha). The wood production forest represents 35% of Canada's total forest lands (CCFM, 1997). 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, represents 122.8 Mha, once overmature forests have been excluded (Sellers and Wellisch, 1998). The Canadian Forest Inventory *1991* (1994 revision), is the main source of information regarding the area of the wood production forest.Commercial forestry is considered to be the dominant anthropogenic activity occurring in Canada's forests that can affect the size of forest stocks and potentially increase or decrease GHG emissions. This includes commercial management, harvest of industrial roundwood and fuelwood, production and use of wood commodities, and establishment and operations of forest plantations.

6.1.1 Methodology

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 defined as the accumulation of above-ground biomass. All emissions from harvest, both the merchantable (i.e. roundwood) and non-merchantable components (i.e. un-used slash) are assumed to be released in the year of harvest. This method does not adequately address the fate of carbon stored in wood products. Two alternate methods, the atmospheric flow and stock change methods, presently subject to international discussions, have been preliminarily evaluated in Canada. Comparative results are presented in section 6.1.3.

The accumulation of above-ground biomass by the wood production forest has been estimated by multiplying the following factors: forest area, biomass accumulation rate per area, biomass density, and the expansion factor to account for all of the above-ground components. The most difficult task was obtaining these data for the wood production forest, as a subset of the entire forest. For the growing forest area, a value of 122.8 Mha was assumed to be constant over the period 1990-1996.

As forest growth rates are not available by age class for the wood production forest — a significant and critical data gap — a long-term average value referred to as the 'mean annual increment (m.a.i) at maturity' has been applied to the entire growing area. The m.a.i. is defined as the mature volume per hectare divided by the age. Use of this growth rate is believed to be the greatest source of uncertainty in the estimation of CO_2 removals by the forest. 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 forest losses by competition, insects, disease, fires and other disturbances. The m.a.i. value, retrieved by ecozones, is assumed to be constant from 1990 to 1996.

Apart from growth within the wood production forest, biomass accumulation from farm woodlots is also assessed and included, although it represents no more than 1 to 2% of total annual above-ground C increment. Farm woodlots are thought to represent about 12% of total farmland (Sellers and Wellisch, 1998). The area of treed land has been estimated based on Census of Agriculture data (reported by Statistics Canada). For the years between census dates, data were estimated by linear regression. As far as urban forests are concerned, no accurate data are available and their contribution to the total biomass increment was estimated to be very minor. Therefore, their impact was neglected.

Carbon dioxide emissions from forest harvest have been obtained for the current IPCC method by a fairly long series of calculations, involving data such as industrial roundwood consumption and commodity data, a number of factors to account for the bark volume, expansion factors, firewood and charcoal consumption data, commodity oxidized and not oxidized in inventory year, etc. For detailed calculations, the reader should refer to Sellers and Wellisch (1998).

6.1.2 Trends

Table 6.1.2-1 includes gross removals from the forest, emissions from harvest and the net CO_2 removals for the 1990-1996 period. Total gross CO_2 removals in 1996 were estimated to be about 290 Mt, with very little fluctuation evident between 1990 and 1996, due to the lack of data. Virtually all of the total removal can be attributed to the growing portion of the wood production forest. The small fluctuation is due to estimated yearly variations in farm woodlot areas. Total emissions from oxidation in 1996 were 250 Mt CO_2, 28% of which were derived from oxidation of slash and 72% from the oxidation of total roundwood production. Net removals from forests amounted to 40 Mt in 1996, compared to 50 Mt in 1990 (rounded figures).

The increase in roundwood and slash oxidation is explained by the growth rate of industrial roundwood production, equal to about 1% annually.

TABLE 6.1.2-1 EMISSIONS AND REMOVALS* FROM CHANGES IN FOREST AND OTHER WOODY BIOMASS STOCKS 1990-1996

Mt CO_2 eq	1990	1991	1992	1993	1994	1995	1996
Removals by WPF**	-280	-280	-280	-280	-280	-280	-280
Removals by farm woodlots	-5.2	-5.2	-5.2	-5.3	-5.3	-5.3	-5.4
Total Removals	**-290**	**-290**	**-290**	**-290**	**-290**	**-290**	**-290**
Emissions from oxidation of total roundwood production	180	160	170	180	180	180	180
Emissions from oxidation of slash	69	63	66	69	73	73	71
Total emissions * **	**240**	**230**	**240**	**250**	**260**	**260**	**250**
Net Removals	**-50**	**-60**	**-50**	**-40**	**-30**	**-30**	**-40**

* Removals are shown as negative values.
** WPF = wood production forest 122.8 Mha.
*** Using current IPCC method.
Note: Individual category estimates are given to two significant figures. Totals have been rounded to one significant figure to reflect the relatively high level of uncertainty associated with this category.

Some double counting is likely to occur between Changes in Forest and Other Woody Biomass Stocks and the Energy and Waste sectors (i.e. methane from landfilled wood wastes and industry use of biomass fuel). Given the nature of the methodology used in deriving the estimates for the LUCF categories, it was virtually impossible to extract the share of emissions that could be attributed to wood waste or biomass fuel in this module. 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 at the level of the methodology.

6.1.3 Alternative Methods: the stock change and atmospheric flow methods

Carbon dioxide emissions resulting from the sustained yield harvest of the wood production forest have been assessed using two other methods, not yet approved for inclusion in the IPCC Guidelines: the stock-change method and the flow method. Net CO_2 removals obtained with all three methods are compared in Figure 6.1.3-1. Another method, the production method, has been proposed more recently, but has not yet been assessed for Canada. All methods are considered to be improvements over the default method, as they recognize that most of the harvested biomass converted to wood products is not emitted within the year of harvest. Gross emissions in 1996 range from 178 (flow) to 253 Mt CO_2 (current).

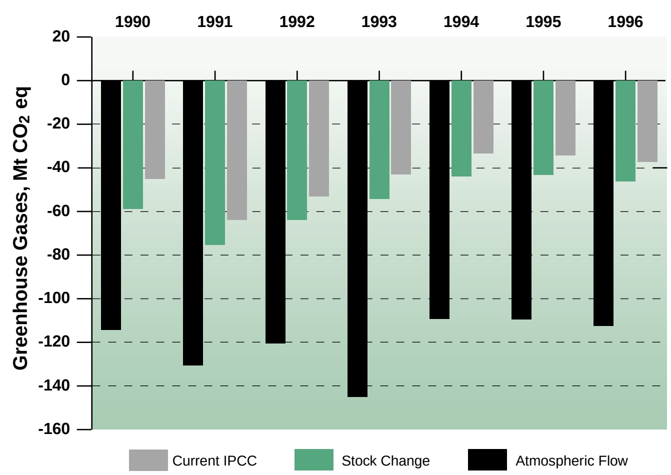

FIGURE 6.1.3-1
Comparison of Net Carbon Dioxide Removals from Changes in Forest Stocks with the current IPCC Method, Stock Change and Atmospheric Flow Methods

Both the stock and flow methods address the product lifespan issue by assigning commodities into one of two groups: (1) products that last for less than five years, and (2) products that exist for five or more years. They differ with respect to their allocation of emissions and removals. The stock-change method assigns all of the change in forest reservoir to the country in which harvesting occurs, without regard to where the forest products are exported. The flow method assigns the emissions and removals to the country where C-CO_2 is emitted or taken from the atmosphere. The default method is unrealistic both spatially and temporally as emissions are not related to the country where they actually occur, or when they occur. The stock-change method is similar to the default approach, but includes additional sources of stock emissions and removals for the country based on inherited emissions from the decay of long-lived products, and additional pool calculations based only on usage of wood products in the producing country. The flow method is similar to the approach adopted for fossil fuel emissions, and involves a few more calculations, but provides a better reflection of when and where emissions and removals actually occur.

6.2 Forests and Grasslands Conversion

This subsection estimates CO_2 emissions associated with land use changes such as conversion from forests and grasslands to croplands or other agricultural lands, and conversion of forests, grassland, agricultural and 'other' areas for urban development. Only changes in above-ground carbon are addressed. Changes in soil carbon levels are estimated in subsection 6.4. Other sources of deforestation have not been included in this assessment owing to deficiencies in data.

6.2.1 Methodology

Reliable data on 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 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. Agricultural land area data is obtained from the Census of Agriculture's Agricultural Profiles for each province. Urban area data are obtained from Statistics Canada's Econnections environmental data for each province. 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 additional agricultural and urban lands. Factors, originally developed by ESSA (1996) and Environment Canada (1989), are applied to apportion the converted total areas into original land type (temperate forest, boreal forest, grassland etc.). Biomass densities before conversion have been obtained from ESSA (1996), whereas the biomass densities after conversion were based on the IPCC default data. Converted areas, all conversion factors, and other factors can be found in Sellers and Wellisch (1998).

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

This methodology is forced to rely on data on the net rate of forest conversion to agriculture, a potentially significant source of error. It detects where forest conversion to agricultural land occurs by looking for provinces in which total farmland area increases during the measurement period. 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 land conversion was observed on an annual basis for individual provinces. Assumptions are key to the accuracy of the emissions estimates and are considered to provide first-order approximations only.

Preliminary work of the National Sinks Table and Forest Sector Table of the National Climate Change Process to improve the estimates of deforestation suggests that the estimates reported here are likely to underestimate the extent of deforestation in Canada. The Tables' work will also address other sources of deforestation excluded in this report.

6.2.2 Trends

Total area converted equals 81 kha in 1990 and about 80 kha in 1996. It is estimated that about 12 kha were deforested in 1990, and over 17 kha in 1996. The largest converted areas are from grassland to agricultural land, and 'unimproved farmland' to 'improved farmland'. However, deforestation is the dominant source of emissions since it has the largest change in above-ground biomass. The CO_2 emissions associated with land conversion for the period 1990-1996 are presented in Table 6.2.2-1, broken down by land type converted to agriculture or urban land. Total emissions in 1996 are estimated to be about 3 Mt CO_2 and 1 Mt in 1990. As indicated in the above methodology, these land-use-change values are first approximations and require validation to increase confidence in the results. Nevertheless, the results seem to indicate that increasing CO_2 emissions associated with land conversion can be explained by the expansion of agricultural lands, since it is assumed that some of this growth has resulted in forest losses. Also, urban areas are growing at the expense of grasslands.

TABLE 6.2.2-1 CO_2 EMISSIONS* FROM FOREST AND GRASSLAND CONVERSION BY LAND TYPES CONVERTED 1990-1996

Land Type Converted to Agriculture or Urban Land Mt CO_2 eq	1990	1991	1992	1993	1994	1995	1996
Temperate Forest	0.58	0.54	0.57	0.87	1.23	1.56	1.97
Boreal Forest	0.65	0.67	0.64	0.59	0.55	0.5	0.5
Grassland	0.06	0.06	0.07	0.07	0.09	0.11	0.11
Agriculture and other **	0.13	0.13	0.15	0.17	0.19	0.21	0.25
Total Emissions	**1.0**	**1.0**	**1.0**	**2.0**	**2.0**	**2.0**	**3.0**

* Above-ground biomass only.
** Other includes land in transition already subject to human activity.
Note: Individual category estimates are given to two significant figures. Totals have been rounded to one significant figure to reflect the relatively high level of uncertainty associated with this category.

6.3 Abandonment of Managed Lands

This subsection provides an assessment of CO_2 removals resulting from the accumulation of above ground 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 subsection 6.4.

6.3.1 Methodology

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 above-ground biomass. However, conversion into a forest ecosystem is known to increase C storage relative to what is stored in cropland or pasture. The IPCC recommends that the uptake be evaluated according to two time horizons: lands abandoned for the last 20 years, and lands abandoned for 20 to 100 years. As the Census of Agriculture time series only goes back to 1961, the assessment for the second time period only covers 9 to 30 years, not 80 years.

Abandoned agricultural lands area is compiled from reductions in total agricultural land in those provinces where such decreases are observed, based on Census of Agriculture data. Since no data exist on the specific fate of the abandoned land, significant assumptions have to be made: half of the abandoned areas is considered to be converted to urban land; the remainder is assumed to regrow to the natural state in the proportions estimated by ESSA (1996), as found in Sellers and Wellisch (1998). Biomass growth rates on abandoned lands have been developed for temperate and boreal forests by ESSA (1996). While they are considerably lower than the IPCC default values, they better reflect Canadian conditions. Single average growth rates are assumed for the forest areas (although, in reality, growth varies with age and location).

6.3.2 Trends

Table 6.3.2-1 provides temporal trends in CO_2 removals by land abandoned, divided for temperate and boreal forests. The above-ground 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 changes in agricultural area over time. The temporal variations in removals associated with the 21- to 200-year time horizon reflect data availability in addition to the changes in agricultural land.

TABLE 6.3.2-1 CO_2 REMOVALS* FROM ABANDONMENT OF MANAGED LANDS BY NEW LAND TYPES 1990-1996

Land Converted to	1990	1991	1992	1993	1994	1995	1996
Temperate Forest	-3.1	-3.2	-3.2	-3.1	-3.1	-3.1	-3.0
Boreal Forest	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11
Total Removals	**-3.0**	**-3.0**	**-3.0**	**-3.0**	**-3.0**	**-3.0**	**-3.0**

* Above-ground growth only. Removals are shown as negative values.
Note: Individual category estimates are given to two significant figures. Totals have been rounded to one significant figure to reflect the relatively high level of uncertainty associated with this category.

6.4 Carbon Dioxide Emissions and Removals from Soils from Land Use Change

This category estimates CO_2 emissions and removals from soils from land use change as presented in Table 6.4-1. Carbon dioxide from agricultural soils and liming are reported in Section 5 – Agriculture. The net estimate in this category results from emissions from soils from land conversion and removals by soils from land abandonment. Estimates are considered to be first approximations because of the indirect way the land areas are determined and because of the significant assumptions made on annual rates of emissions or uptake by soils in different land types.

TABLE 6.4-1 CO_2 EMISSIONS AND REMOVALS* FROM SOILS DUE TO LAND USE CHANGE 1990-1996

Mt CO_2 eq	1990	1991	1992	1993	1994	1995	1996
Emissions from Land Conversion	7.1	7.5	6.8	6.5	6.2	5.9	6.2
Removals from Abandoned Lands	-3.6	-3.7	-3.6	-3.6	-3.6	-3.5	-3.5
Net Total Emissions/ Removals	**4.0**	**4.0**	**3.0**	**3.0**	**3.0**	**2.0**	**3.0**

*Removals are shown as negative values.

Note: Individual category estimates are given to two significant figures. Totals have been rounded to one significant figure, to reflect the relatively high level of uncertainty associated with this category.

6.4.1 Soil Carbon Emissions from Land Conversion

Conversion of land from forest or grassland to agricultural land generally results in a loss of soil carbon. Carbon dioxide emissions have been estimated by the methodology used in ESSA (1996). Converted areas are multiplied by the carbon content of the soil prior to conversion to obtain the total annual potential C losses. These are then multiplied by the fraction of C expected to be released over a 25-year period. Values for forest systems are assumed to include roots as well as soil, leading to an overestimation of soil carbon content in forests. Total CO_2 emissions from land conversion have been estimated to be about 7 Mt in 1990 and 6 Mt in 1996.

6.4.2 Soil Carbon Uptake from Abandonment of Managed Lands

The abandonment of managed lands and their return to a natural state generally result in the slow accumulation of soil carbon. Rates of carbon uptake are those estimated by ESSA (1996). For forests, rates are assumed to include roots as well as soil, which overestimates the removals strictly attributed to soil. These rates are multiplied by the total abandoned land area which is not converted to urban use. Carbon removals by soils from abandoned lands in both 1990 and 1996 have been estimated to be about 4 Mt of CO_2.

6.5 Fires Caused by Human Activities

This subsection assesses CO_2 emissions and trace gas emissions of CH_4 and N_2O from fires that can be attributed to human activities, whereas wildfires are addressed in subsection 6.6. Non-CO_2 emissions from human-induced fires are added to Canada's total GHG emissions. Detailed methodology and data can be found in Sellers and Wellisch (1998). Emissions factors and fuel consumption by fires are given in Appendix C.

Data on burned areas from the various fires over the period 1990-1996 are presented in Table 6.5-1.

TABLE 6.5-1 BURNED AREAS FROM ANTHROPOGENIC SOURCES 1990-1996

Anthropogenic Sources	1990	1991	1992	1993	1994	1995	1996
(kha)							
Prescribed fires	106	137	106	95	36	20	30
Other fires in wood production forest	142	221	221	221	221	221	221
Other fires outside of the wood production forest	102	109	147	166	47	266	139

6.5.1 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 (CH_4, N_2O) as reported below. Carbon dioxide emissions from prescribed burning are not included in this sub-category as they are already part of slash emissions in subsection 6.1– Changes in Forest and Other Woody Biomass Stocks. Areas exposed to prescribed burning are reported by the Canadian Committee on Forest Fire Management for 1990 to 1995.

The application of prescribed burning has dropped significantly in the 1990s and is being practiced mostly in British Columbia (B.C.). Prescribed burns can be expected to decrease in future years due to government cost-recovery services and concerns over smoke and local air quality. For 1996, the area exposed was assumed to be equal to the B.C. total for 1994. Average fuel consumption data for prescribed burns (weight of biomass burned per hectare) are from Environment Canada (1992). Emission factors for each trace gas have been developed by Taylor (1996) and are revised values from those used in Jaques et al. (1997).

6.5.2 Other Fires in the Wood Production Forest

This sub-category includes non-CO_2 emissions from fires which are thought to be caused by human activity in the wood production forest, other than prescribed burning. Although it cannot be confirmed that none of these statistics include natural or wildfires, it seems reasonable to assume that the so-called 'wildfires' in these areas could also be indirectly attributed to human activity principally because they occur in the managed forest. The fact that most of wildfires inventoried occur outside the wood production forest, or managed forest, tends to reduce the uncertainty associated with this approximation.

Historical data for the wood production forest from 1961 to 1990 is obtained from Econnections (Statistics Canada, 1996-97). Fire frequency is quite variable, even in the wood production forest where fire protection is carried out. Long-term average from 1961 to 1990 was used to estimate burned areas for 1991 to 1996.

Since the 'mean annual increment to maturity' of forests (see subsection 6.1), an average value over a long period of time, already takes into account some disturbances, including fires, the CO_2 emissions from human-induced fires are already included under 6.1 – Changes in Forest and Other Woody Biomass Stocks and are therefore not reported here.

6.5.3 Other Fires Caused by Human Activities Outside the Wood Production Forest

This subsection includes both CO_2 and non-CO_2 emissions from fires attributed to human activities outside the wood production forest area, such as in the domains of recreation, residence, railways, other industry, incendiary and from miscellaneous causes. Again, 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 Compendium of Canadian Forestry Statistics (1993, 1995, 1997). Data from 1996 was taken as the average of burned areas over 1990-1995 period. For fires both inside and outside the wood production forest, fuel consumption data were those provided in Stocks (1990). Emission factors for CO_2 as well as individual trace gases were those provided in Taylor (1996).

6.5.4 Trends

As the same factors are used throughout 1990-1996 period, the trends depend only on the burned areas. All four trace gas emission trends follow a similar pattern. As shown in Table 6.5.4-1, approximately two thirds of the emissions from human-induced fires were from prescribed fires in 1990. As the practice of setting prescribed fires becomes less and less common, as previously mentioned, accidental fires have come to represent the majority of emissions from this category.

TABLE 6.5.4-1 TOTAL TRACE GAS EMISSIONS FROM HUMAN-INDUCED FIRES 1990-1996

Anthropogenic source/gas Mt CO_2 eq	1990	1991	1992	1993	1994	1995	1996
Prescribed Fires (1)							
CH_4	1.0	1.3	0.98	0.88	0.34	0.19	0.28
N_2O	0.16	0.74	0.59	0.53	0.22	0.12	0.16
subtotal GHG	1.2	2.0	1.6	1.4	0.55	0.31	0.44
Other Fires in WPF* (1)							
CH_4	0.24	0.37	0.37	0.37	0.37	0.37	0.37
N_2O	0.28	0.43	0.43	0.43	0.43	0.43	0.43
subtotal GHG	0.51	0.80	0.80	0.80	0.80	0.80	0.80
Other Fires outside WPF*							
CO_2	*4.4*	*4.7*	*6.3*	*7.2*	*2.0*	*11*	*6.0*
CH_4	0.17	0.18	0.24	0.28	0.08	0.44	0.23
N_2O	0.22	0.22	0.28	0.34	0.09	0.53	0.28
subtotal GHG	4.8	5.1	6.8	7.8	2.2	12	6.5
TOTAL (excluding CO_2 Emissions)	**2.1**	**3.2**	**2.9**	**2.8**	**1.5**	**2.1**	**1.7**

* Wood Production Forest
(1) CO_2 emissions from fires in WPF are included in net removals in Sub-Section 6.1 "Changes in Forest and Other Woody Biomass Stocks".
Note: Due to rounding, individual values may not add up to totals. Individual category estimates are given to two significant figures.

6.6 Wild Fires

While these emissions go beyond the greenhouse gas impacts of anthropogenic activities reported under the Framework Convention on Climate Change, the following are interesting trends of CO_2, CH_4, N_2O, CO and NO_x emissions associated with wildfires. Fires occurring outside the wood production forest are primarily caused by lightning strikes. The area burned in 1990 totalled 728 kha. The 1996 figure (2,616 kha) is extrapolated using a 25-year fire average (1970-1995) in the wood production forest, although wildfires are taking place outside these areas (Canadian Council of Forest Ministers, 1997). Areas burned are multiplied by the average fuel consumption factor for wildfire, 0.0264 kt per hectare (Stocks, 1990). The fuel consumption value is then combined with the average emission factors as found in Appendix C. Resulting emission estimates for 1990-1996 for the three greenhouse gases as well as CO and NO_x can be found in Table 6.6-1. Note that these values are not inventoried in national totals.

TABLE 6.6-1 EMISSIONS FROM WILDFIRES (NATURALLY OCCURRING FIRES)

Emission Mt	1990	1991	1992	1993	1994	1995	1996
CO_2	31	59	30	72	260	270	110
CH_4 (CO_2 eq)	1.2	2.3	1.2	2.8	10	10	4.3
N_2O (CO_2 eq)	1.6	2.8	1.2	3.4	12	12	5.3
CO	1.7	3.2	1.6	3.9	14	14	6.1
NO_x	0.03	0.06	0.03	0.08	0.28	0.29	0.12

Note: Individual category estimates are given to two significant figures.

6.7 Uncertainty

Methodologies for estimating emissions and removals from land use change and forestry are more complex than those used in the other IPCC categories; involving more steps, and requiring more data, factors and assumptions. Results should be treated as first estimates 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 number has been applied. Estimates of emissions reflect 'higher or maximum emissions' while the estimates of removals reflect 'lower or minimum removals'.

The IPCC lists four major sources of uncertainty which are all relevant to the LUCF chapter: definitions, methodology, activity data and underlying scientific understanding. For example, matching Canada's land-use information with the IPCC categories or separating human from natural activities, is tainted by subjectivity. There is a lack of time series data on areas subject to land use change in Canada. Accurate data to estimate the changes in stocks in the wood production forest area are also missing, data on forest growth by age class in particular.

6.8 References

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Section 7 - Waste

The Waste sector contributed approximately 3% of the total greenhouse gases emitted in 1996 (see Figure 7-1). The major sources are solid waste disposal on land, wastewater handling, and waste incineration which contributed approximately 91%, 6%, and 2%, respectively, of waste sector greenhouse gas emissions in 1996. Within the Waste sector, methane (CH_4) was the most significant greenhouse gas, accounting for approximately 95% of emissions.

Much of the waste treated or disposed of is biomass or biomass-based. The carbon dioxide (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.[1] 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 Land Use Change and Forestry sector.

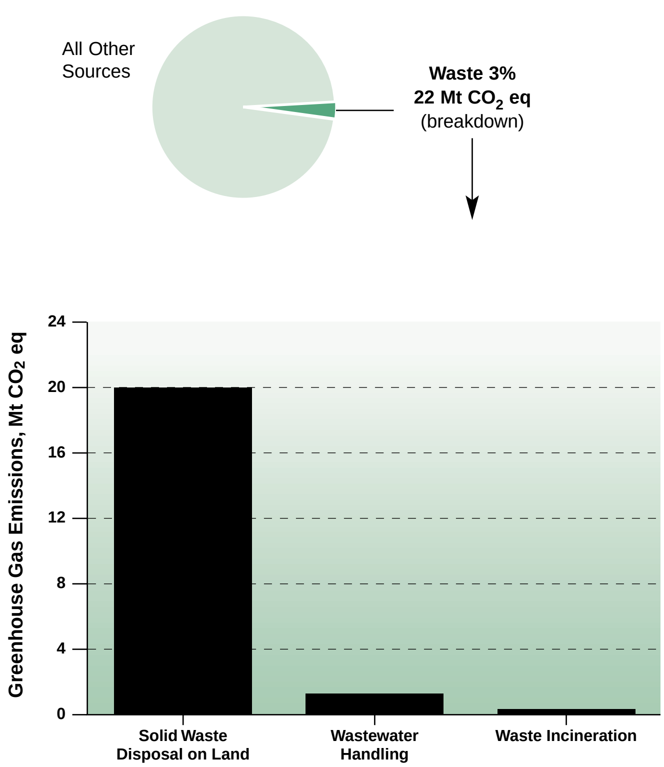

FIGURE 7-1
1996 Waste Sector Greenhouse Gas Sources

7.1 Solid Waste Disposal on Land

The emissions from solid waste disposal on land were 20 Mt CO_2 eq in 1996 an increase of 5% since 1990. The generation of methane from municipal solid waste (MSW) landfills has increased almost 20% from 1990; however, more landfill gas is now being captured and combusted which has significantly reduced emission growth (Table 7.1-1). Emissions are estimated from two types of landfills in Canada, municipal solid waste (MSW) landfills and wood waste landfills. Emissions from wood waste landfills have increased 20% over 1990, however they are a minor source compared to MSW landfills. Landfill gas capture is not practiced at wood waste landfills, so it has had no reduction effect on emissions from this source.

TABLE 7.1-1 EMISSION TRENDS FOR MUNICIPAL SOLID WASTE LANDFILLS

	Municipal Solid Waste			CH_4 Emitted	
Year	CH_4 Produced Mt CO_2 eq	CH_4 Captured Mt CO_2 eq	CH_4 Emitted Mt CO_2 eq	Wood Waste Mt CO_2 eq	Total Mt CO_2 eq
1990	21	4.4	17	1.5	19
1991	22	4.5	18	1.6	19
1992	23	4.7	18	1.6	20
1993	23	4.8	18	1.7	20
1994	24	5.1	19	1.7	20
1995	24	5.6	18	1.8	20
1996	25	6.1	19	1.8	20

Total methane from landfills = produced - captured.
Due to rounding, individual values may not add up to totals.

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, only methane emissions from managed landfills were estimated for the inventory. Residential, Institutional, Commercial, Industrial, Construction and Demolition wastes are disposed of in MSW landfills.

1 Biomass originating from food wastes are sustainably harvested. Carbon dioxide emitted from the decomposition of food will be consumed by the next year's crop.

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 most obvious means of reducing methane 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, which produce steam and/or electricity.

It should also be noted that although wood waste landfills have been identified as a source of methane emissions, there is a great deal of uncertainty in the estimates. The actual emissions are most likely of the same order of magnitude as the estimates.

7.1.1 Methodology

Two methodologies for estimating emissions from landfills are presented in the Intergovernmental Panel on Climate Change (IPCC) Guidelines: 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 on 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 has significantly changed. For this reason, a static model such as the default method is not appropriate; therefore the emissions from MSW landfills and wood waste landfills in Canada are estimated using the Scholl Canyon model. A detailed methodology is discussed in Appendix B.

7.1.2 Captured Landfill Gas

Some of the methane that is generated in MSW landfills is captured. The captured quantity is subtracted from the estimate generated by the Scholl Canyon model to calculate net methane emissions from landfills. The data on the amount of landfill gas captured for the years 1990 through to 1996 was provided by the Environment Canada National Office of Pollution Prevention. See Table 7.0 for a national summary. The capture data is based on estimates supplied by individual landfill operators.

It is also worth noting that any electricity generation from the combustion of CH_4 from landfills achieves a twofold gain with respect to decreasing greenhouse gas emissions. It reduces emissions of methane from landfills and may also offset the use of fossil-fuel combustion for electricity generation. The potential to reduce greenhouse gas emission in this manner could be significant.

7.2 Wastewater Handling

Emissions were 1.3 Mt CO_2 eq in 1996 an increase of 8% from 1990 (Table 7.2-1). The emissions have essentially followed the same trend as Canada's population.

TABLE 7.2-1 EMISSION TRENDS FOR WASTEWATER TREATMENT

Year	CH_4 Mt CO_2 eq	N_2O Mt CO_2 eq	Total GHG Mt CO_2 eq
1990	0.36	0.87	1.2
1991	0.36	0.88	1.2
1992	0.37	0.89	1.3
1993	0.37	0.91	1.3
1994	0.38	0.92	1.3
1995	0.38	0.93	1.3
1996	0.39	0.94	1.3

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 and the amount of wastewater treated.

Municipal wastewater can be aerobically or anaerobically treated. When wastewater is treated anaerobically, methane is produced. Emissions from aerobic systems are assumed to be negligible. Both types of systems generate nitrous oxide (N_2O) through the nitrification and denitrification of sewage nitrogen (IPCC, 1997). Carbon dioxide is also generated by both types of treatment but, as discussed earlier, CO_2 emissions originating from the decomposition of food are not inventoried.

7.2.1 Methodology

The emission estimation methodology for wastewater handling is divided into two areas: methane from anaerobic wastewater treatment, and nitrous oxide from human sewage.

Methane Emissions from Anaerobic Wastewater Treatment

The default method in the IPCC Guidelines was not followed because the required data are not available. A method developed by Ortech (1994) has been used to calculate an emission factor. Based on the amount of organic matter generated per person and the conversion of organic matter to methane, it has been estimated that 4.015 kg CH_4/person/year could potentially be emitted from wastewater treated anaerobically. An emission factor for each province has been calculated by multiplying this potential emission rate by the fraction of wastewater treated anaerobically in each province (NIMWWS, 1981). Emissions are calculated by multiplying the emission factors by the population of the respective province as recorded by Statistics Canada (Catalogue No. 91-213).

Nitrous Oxide Emissions from Human Sewage

The nitrous oxide emissions are 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 nitrogen in sewage has been estimated based on the following two assumptions: protein is 16% nitrogen, and Canadian protein consumption is 40.15 kg/person/year. This resulted in an emissions factor of 0.101 kg N_2O/person/year. Emissions are estimated on a provincial basis by multiplying the emission factor by the population of each province as recorded by Statistics Canada (Catalogue No. 91-213).

7.3 Waste Incineration

Emissions from waste incineration were 0.34 Mt CO_2 eq in 1996 an increase of 6% from 1990. The majority of emissions are from MSW incineration as can be seen in Table 7.3-1. The emissions have followed the same trend as the growth in Canada's population.

TABLE 7.3-1 WASTE INCINERATION EMISSIONS

	MSW			Sewage Sludge	Total
Year	CO_2 Mt	N_2O Mt CO_2 eq	GHG Mt CO_2 eq	CH_4 Mt CO_2 eq	GHG Mt CO_2 eq
1990	0.25	0.05	0.30	<0.01	0.32
1991	0.26	0.05	0.31	<0.01	0.32
1992	0.26	0.06	0.32	0.01	0.33
1993	0.26	0.06	0.32	<0.01	0.33
1994	0.27	0.06	0.33	<0.01	0.33
1995	0.27	0.06	0.33	<0.01	0.34
1996	0.27	0.06	0.33	<0.01	0.34

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

A combustion chamber of a typical mass-burn MSW incinerator is comprised 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 incinerated in Canada is completed with energy recovery (Environment Canada, 1996). The greenhouse gases that are emitted from MSW incinerators may include carbon dioxide, methane and nitrous oxide. The CO_2 emissions from the combustion of biomass waste are not included in this section of the inventory, as previously discussed. The only CO_2 emissions included in this section of the inventory are from the fossil-fuel-based carbon waste. Examples of fossil-fuel-based carbon wastes are plastic and rubber. Methane emissions from MSW incineration are assumed to be negligible and are not calculated.

Incineration is not frequently used as a method of sewage sludge disposal. It is not an ultimate disposal; it converts the sludge to gases and ash, which must be landfilled or land applied as fertilizer. 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 methane emissions are estimated from sewage sludge incineration.

7.3.1 Methodology

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

Carbon Dioxide Emissions from MSW Incineration

The IPCC Guidelines do not specify a method to calculate CO_2 emissions from incineration of fossil-fuel-based waste. The following three-step method has been developed.

Step 1: Calculating the Amount of Waste Incinerated
The amount of waste incinerated each year is based on an Environment Canada study (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 are adjusted according to population growth using Statistics Canada population data (Catalogue No. 91-213).

Step 2: Developing Emission Factor
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 have been determined using typical percent weight carbon constants (Tchobanoglous, 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 carbon dioxide to carbon.

Step 3: Calculating Carbon Dioxide Emissions
Emissions are calculated on a provincial level by multiplying the amount of waste incinerated by the appropriate emission factors. National emissions are calculated by summing the provincial emissions.

Nitrous Oxide and Methane Emissions from MSW Incineration

The emissions of N_2O from MSW incineration are estimated using the IPCC default method. An average factor was calculated assuming that the five stokers factors (IPCC, 1997) are most representative. To estimate emissions, the calculated factor has been multiplied by the amount of waste incinerated by each province. National emissions are the sum of the provincial emissions. Methane emissions from MSW incinerators are very small compared to CH_4 emissions from other waste sources such as landfills. Therefore, they are assumed to be negligible.

Methane Emissions from Sewage Sludge Incineration

The emissions are dependent on the amount of dried solids incinerated. To calculate the CH_4 emissions, the amount of dry solids incinerated are multiplied by an appropriate emission factor. The estimates of the amount of dried solids in the sewage sludge incinerated in the years 1990 to 1992 are from a study completed by Senes (1994) for Environment Canada. The data for the years 1993 to 1996 has been 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 methane have been considered in calculating emissions from sewage sludge incineration. Emissions for 1997 are assumed to be constant at 1996 levels.

7.4 Composting

Composting in Canada is done by municipal or private facilities, and by individuals with backyard composers. In general, composting aims to achieve aerobic degradation of decomposable wastes. Large composting facilities operated by a municipality or a private organization are usually run by a knowledgeable staff and are considered to be aerobic, producing CO_2 emissions only. Backyard composters may not always be completely aerobic due to the lack of public knowledge of composting. Therefore, some backyard composters may generate methane but it is not estimated for the inventory.

The amount of methane generated by backyard composters is not estimated since the emissions are most likely negligible (as compared to landfills) and the uncertainty involved with the estimates would be high. Approximately 10% of the organic waste generated in 1996 was composted, and only approximately 10% of that was composted in backyard composters; only a small number of the composters in operation are likely to have been anaerobic for any length of time (Antler, 1997; Environment Canada, 1996). Therefore, the amount of methane produced would be negligible compared to the CH_4 produced by landfills. The high uncertainty would be due to the inability to accurately estimate the number of composters in use, amount of waste composted in each unit, the number of composters that went anaerobic, and the length of time they were anaerobic.

However, the benefits of composting in terms of greenhouse gas reduction should be noted. Disposing of organic waste in composters reduces the waste available for methane generation in landfills. The reduction in methane generation in landfills from this diversion of organic waste has a much larger effect on the total amount of methane generated from waste than the amount that may be emitted from backyard composters.

7.5 References

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Appendices

The following seven appendices provide additional information to that found in the main body of the report. Full summary tables for National Greenhouse Gas Emissions are provided in Appendix A. Appendix B presents a description of methodologies too detailed to elaborate on in the main text. Appendix C provides a full listing of emission factors used for Canadian greenhouse gas estimates, while Appendix D discusses the accuracy of the estimates. A set of standard IPCC Sectoral Summary Tables, covering 1997 emissions, is given in Appendix E. Appendix F provides details on emissions by province and territory for the 1990 to 1996 time period and Appendix G consists of a list of standard 100 year Global Warming Potentials.

List of Appendices

CANADA'S GREENHOUSE GAS EMISSION ESTIMATES FROM 1990 TO 1997

GHG Source and Sink Category	1990 All Gases kt CO_2 eq	1991 All Gases kt CO_2 eq	1992 All Gases kt CO_2 eq	1993 All Gases kt CO_2 eq	1994 All Gases kt CO_2 eq	1995 All Gases kt CO_2 eq	1996 All Gases kt CO_2 eq	1997 All Gases kt CO_2 eq
Energy								
Fuel Combustion								
Fossil Fuel Industries	38 600	37 300	38 900	39 100	40 000	40 200	39 900	37 400
Electricity and Steam Generation	95 200	96 500	104 000	93 800	95 600	100 000	101 000	111 000
Mining	7 650	7 210	6 850	9 930	10 900	12 000	13 000	13 300
Manufacturing	54 400	51 100	50 400	49 300	50 500	53 700	53 300	53 400
Construction	730	829	844	496	448	739	1 120	973
Transportation								
Gasoline Automobiles	53 800	51 200	51 600	51 800	52 200	51 200	50 100	50 200
Light-Duty Gasoline Trucks	21 800	22 200	24 000	25 500	27 300	28 400	29 600	31 500
Heavy-Duty Gasoline Vehicles	3 170	3 380	3 820	4 200	4 650	4 970	4 990	5 470
Motorcycles	230	220	217	219	220	214	210	222
Off-Road Gasoline Vehicles	5 080	4 550	3 640	3 770	3 930	3 900	4 690	4 330
Diesel Automobiles	664	625	622	616	607	585	604	593
Light-Duty Diesel Trucks	598	522	480	462	477	472	469	493
Heavy-Duty Diesel Vehicles	24 700	23 900	24 400	25 800	28 600	30 800	32 400	35 900
Off-Road Diesel Vehicles	11 600	10 400	9 830	11 100	12 300	13 700	15 100	15 300
Propane and Natural Gas Vehicles	1 730	1 920	1 940	2 150	2 370	2 480	2 590	2 020
Domestic Air	10 600	9 580	9 720	9 030	10 100	10 900	12 000	13 000
Domestic Marine	6 070	6 490	6 450	5 620	5 940	5 700	5 560	6 160
Rail	7 110	6 590	6 890	6 860	7 100	6 430	6 290	6 380
Vehicles Subtotal	**147 000**	**142 000**	**144 000**	**147 000**	**156 000**	**160 000**	**165 000**	**172 000**
Pipelines	6 690	7 410	9 590	10 100	10 500	11 600	12 100	12 200
Transportation Subtotal	**154 000**	**149 000**	**153 000**	**157 000**	**166 000**	**171 000**	**177 000**	**184 000**
Residential	46 500	44 700	44 800	49 100	49 600	48 100	53 300	50 200
Commercial and Institutional	26 100	25 900	26 400	28 700	28 200	30 000	30 200	30 700
Other	3 150	3 170	5 440	3 370	2 710	2 620	2 870	2 940
Combustion Subtotal	**426 000**	**416 000**	**431 000**	**431 000**	**444 000**	**459 000**	**471 000**	**484 000**
Fugitive								
Solid Fuels (i.e. Coal Mining)	1 900	2 100	1 800	1 800	1 800	1 700	1 800	1 600
Oil and Gas	36 000	38 000	41 000	43 000	45 000	48 000	51 000	51 000
Fugitive Subtotal	**38 000**	**40 000**	**42 000**	**44 000**	**47 000**	**50 000**	**53 000**	**53 000**
Energy Total	**464 000**	**455 000**	**473 000**	**475 000**	**491 000**	**509 000**	**524 000**	**537 000**
Industrial Processes								
Non-Metallic Mineral Production	8 160	6 980	6 640	6 880	7 510	7 690	7 840	8 280
Ammonia, Adipic Acid & Nitric Acid Production	15 000	14 000	14 000	13 000	15 000	16 000	16 000	15 000
Ferrous Metal Production	7 590	8 900	9 080	8 760	8 050	8 500	8 290	8 110
Aluminum and Magnesium Production	11 000	13 000	12 000	13 000	13 000	11 000	11 000	11 000
Other & Undifferentiated Production	10 000	11 000	12 000	13 000	13 000	13 000	15 000	14 000
Industrial Processes Total	**52 000**	**54 000**	**54 000**	**55 000**	**57 000**	**56 000**	**59 000**	**56 000**
Solvent & Other Product Use	**400**	**400**	**400**	**400**	**400**	**900**	**900**	**900**
Agriculture								
Enteric Fermentation	16 000	16 000	16 000	17 000	18 000	18 000	18 000	18 000
Manure Management	7 900	8 000	7 900	8 200	8 500	8 800	8 900	8 900
Agricultural Soils**	40 000	40 000	40 000	40 000	40 000	40 000	40 000	40 000
Agriculture Total	**62 000**	**61 000**	**60 000**	**61 000**	**63 000**	**63 000**	**64 000**	**63 000**
Land Use Change & Forestry*	**2 500**	**3 200**	**2 900**	**2 800**	**1 500**	**2 100**	**1 700**	**1 700**
Waste								
Solid Waste Disposal on Land	19 000	19 000	20 000	20 000	20 000	20 000	20 000	21 000
Wastewater Handling	1 200	1 200	1 300	1 300	1 300	1 300	1 300	1 300
Waste Incineration	320	320	330	330	330	340	340	340
Waste Total	**20 000**	**21 000**	**21 000**	**22 000**	**22 000**	**22 000**	**22 000**	**23 000**
TOTAL	**601 000**	**595 000**	**610 000**	**617 000**	**635 000**	**653 000**	**671 000**	**682 000**
CO_2 from Land Use Change & Forestry**	-40 000	-60 000	-50 000	-30 000	-30 000	-20 000	-30 000	-20 000

* CH_4 and N_2O emissions from prescribed and other fires.
** Only one significant figure is shown due to high uncertainty.
Note: Due to rounding, individual values may not add up to totals.

LONG-TERM GREENHOUSE GAS EMISSION TRENDS IN CANADA

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
	kt CO_2 eq	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*kt CO_2 eq*	*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	28 300	23 900	24 000	20 400	26 600	31 000	33 000	35 100	35 500	38 300	38 600	37 300	38 900	39 100	40 000	40 200	39 900	37 400
Electricity and Steam Generation	71 200	71 300	77 500	80 700	86 900	83 200	76 200	89 300	98 500	107 000	95 200	96 500	104 000	93 800	95 600	100 000	101 000	111 000
Mining	5 950	6 970	6 160	6 030	6 810	6 370	7 940	7 650	8 510	8 700	7 650	7 210	6 850	9 930	10 900	12 000	13 000	13 300
Manufacturing	63 400	55 600	48 500	44 000	46 100	46 000	48 200	50 900	56 800	57 800	54 400	51 100	50 400	49 300	50 500	53 700	53 300	53 400
Construction	830	749	626	620	565	419	366	303	724	627	730	829	844	496	448	739	1 120	973
Transportation**																		
Gasoline Total	94 800	91 700	84 400	81 800	81 100	80 600	80 900	81 800	84 100	85 700	84 100	81 600	83 300	85 500	88 300	88 700	89 600	91 700
Diesel Total	31 300	31 400	29 200	30 900	32 700	33 900	34 500	36 300	37 900	38 500	37 600	35 400	35 300	38 000	42 000	45 600	48 600	52 300
Propane and Natural Gas Vehicles	110	101	183	396	759	855	1 100	1 550	1 850	1 740	1 730	1 920	1 940	2 150	2 370	2 480	2 590	2 020
Domestic Air	10 400	10 400	9 700	9 000	9 600	10 000	10 100	10 700	11 300	11 200	10 600	9 580	9 720	9 030	10 100	10 900	12 000	13 000
Domestic Marine	6 620	8 130	5 870	4 870	4 800	4 430	4 540	4 820	5 740	6 030	6 070	6 490	6 450	5 620	5 940	5 700	5 560	6 160
Rail	7 010	6 800	6 120	5 780	6 450	6 360	5 620	5 680	6 350	6 810	7 110	6 590	6 890	6 860	7 100	6 430	6 290	6 380
Vehicles Subtotal	**150 000**	**149 000**	**135 000**	**133 000**	**135 000**	**136 000**	**137 000**	**141 000**	**147 000**	**150 000**	**147 000**	**142 000**	**144 000**	**147 000**	**156 000**	**160 000**	**165 000**	**172 000**
Pipelines	3 860	4 080	3 690	2 800	3 600	4 530	3 920	4 710	6 090	6 470	6 690	7 410	9 590	10 100	10 500	11 600	12 100	12 200
Transportation Subtotal	**154 000**	**153 000**	**139 000**	**135 000**	**139 000**	**141 000**	**141 000**	**146 000**	**153 000**	**156 000**	**154 000**	**149 000**	**153 000**	**157 000**	**166 000**	**171 000**	**177 000**	**184 000**
Residential	60 500	53 500	54 600	45 700	47 100	49 300	47 000	43 900	46 200	48 900	46 500	44 700	44 800	49 100	49 600	48 100	53 300	50 200
Commercial and Institutional	32 300	32 500	32 800	30 900	30 400	29 200	28 100	24 500	26 200	28 100	26 100	25 900	26 400	28 700	28 200	30 000	30 200	30 700
Other	1 210	1 280	1 370	4 860	2 760	2 740	2 500	2 270	2 450	2 900	3 150	3 170	5 440	3 370	2 710	2 620	2 870	2 940
Combustion Subtotal	**418 000**	**398 000**	**385 000**	**369 000**	**386 000**	**389 000**	**384 000**	**399 000**	**428 000**	**449 000**	**426 000**	**416 000**	**431 000**	**431 000**	**444 000**	**459 000**	**471 000**	**484 000**
Fugitive																		
Solid Fuels (i.e. Coal Mining)	1 000	1 000	1 100	1 100	1 300	1 500	1 500	1 600	2 000	1 600	1 900	2 100	1 800	1 800	1 800	1 700	1 800	1 600
Oil and Gas	26 000	26 000	26 000	26 000	28 000	29 000	29 000	31 000	33 000	35 000	36 000	38 000	41 000	43 000	45 000	48 000	51 000	51 000
Fugitive Subtotal	**27 000**	**27 000**	**27 000**	**27 000**	**29 000**	**31 000**	**31 000**	**32 000**	**35 000**	**37 000**	**38 000**	**40 000**	**42 000**	**44 000**	**47 000**	**50 000**	**53 000**	**53 000**
Energy Total	**445 000**	**425 000**	**411 000**	**395 000**	**415 000**	**420 000**	**415 000**	**432 000**	**464 000**	**485 000**	**464 000**	**455 000**	**473 000**	**475 000**	**491 000**	**509 000**	**524 000**	**537 000**
Industrial Processes																		
Non-Metallic Mineral Production	7 760	7 660	6 470	6 210	6 950	7 140	7 530	8 370	8 540	8 480	8 160	6 980	6 640	6 880	7 510	7 690	7 840	8 280
Ammonia, Adipic Acid & Nitric Acid Production	12 000	12 000	8 600	13 000	13 000	14 000	10 000	10 000	10 000	12 000	15 000	14 000	14 000	13 000	15 000	16 000	16 000	15 000
Ferrous Metal Production	12 300	10 900	9 500	10 600	11 600	11 600	10 600	10 700	11 000	10 500	7 590	8 900	9 080	8 760	8 050	8 500	8 290	8 110
Aluminum and Magnesium Production	7 000	7 100	6 800	6 700	7 600	7 800	8 400	9 500	9 300	9 300	11 000	13 000	12 000	13 000	13 000	11 000	11 000	11 000
Other & Undifferentiated Production	7 800	10 000	7 400	8 100	9 000	9 000	10 000	11 000	11 000	9 900	10 000	11 000	12 000	13 000	13 000	13 000	15 000	14 000
Industrial Processes Total	**47 000**	**48 000**	**39 000**	**45 000**	**48 000**	**50 000**	**47 000**	**49 000**	**50 000**	**50 000**	**52 000**	**54 000**	**54 000**	**55 000**	**57 000**	**56 000**	**59 000**	**56 000**
Solvent & Other Product Use	**370**	**380**	**380**	**380**	**390**	**390**	**390**	**400**	**410**	**410**	**400**	**400**	**400**	**400**	**400**	**900**	**900**	**900**
Agriculture*	**64 000**	**63 000**	**62 000**	**62 000**	**61 000**	**61 000**	**60 000**	**60 000**	**60 000**	**59 000**	**62 000**	**61 000**	**60 000**	**61 000**	**63 000**	**63 000**	**64 000**	**63 000**
Land-Use Change & Forestry	**370**	**280**	**650**	**740**	**890**	**1 200**	**1 100**	**1 800**	**1 700**	**1 300**	**2 500**	**3 200**	**2 900**	**2 800**	**1 500**	**2 100**	**1 700**	**1 700**
Waste																		
Solid Waste Disposal on Land	14 000	15 000	16 000	17 000	17 000	17 000	17 000	18 000	17 000	18 000	19 000	19 000	20 000	20 000	20 000	20 000	20 000	21 000
Wastewater Handling	1 100	1 100	1 100	1 100	1 100	1 100	1 200	1 200	1 200	1 200	1 200	1 200	1 300	1 300	1 300	1 300	1 300	1 300
Waste Incineration	280	280	290	290	290	290	300	300	300	310	320	320	330	330	330	340	340	340
Waste Total	**16 000**	**17 000**	**17 000**	**18 000**	**19 000**	**19 000**	**19 000**	**19 000**	**18 000**	**20 000**	**20 000**	**21 000**	**21 000**	**22 000**	**22 000**	**22 000**	**22 000**	**23 000**
NATIONAL TOTAL	**572 000**	**553 000**	**531 000**	**521 000**	**545 000**	**550 000**	**542 000**	**563 000**	**594 000**	**616 000**	**601 000**	**595 000**	**610 000**	**617 000**	**635 000**	**653 000**	**671 000**	**682 000**

A simplified methodology was used to estimate historical greenhouse gas emissions in Canada for 1980 to 1989 (resulting in higher uncertainties for the 1980 to 1989 estimates).

*Agriculture total includes greenhouse gas emissions from the following sources: enteric fermentation, manure management and agricultural soils. Data Source: Agriculture and Agri-Food Canada, *The Health of Our Air — Toward Sustainable Agriculture in Canada*, 1999.

**Transportation

Gasoline Total Includes: Gasoline Automobiles, Light-Duty Gasoline Trucks, Heavy-Duty Gasoline Vehicles, Motorcycles and Off-Road Gasoline Vehicles.

Diesel Total Includes: Diesel Automobiles, Light-Duty Diesel Trucks, Heavy-Duty Diesel Vehicles and Off-Road Diesel Vehicles.

Note: Due to rounding, individual values may not add up to totals.

Methodologies Used for Historical Greenhouse Gas Emissions Estimate

Historical greenhouse gas emissions between 1980 and 1989 were estimated using present methodologies. The methodologies were modified only if the activity data sources or emission factors were unavailable. In general, the uncertainties for the historical greenhouse gas emissions are higher than the uncertainties associated with the latest inventory.

Major deviations from the current methodologies (i.e. activity data sources, emission factors or computation methods) are discussed by the following sectors:

Energy

Current methodologies were used to estimate CO_2, CH_4 and N_2O emissions for the Energy sector with some minor modifications. Nineteen ninety emission factors were kept constant for historical greenhouse gas emissions estimates (only CO_2 emission factors for Natural Gas varied due to variances in heating values). Emission rates for Fugitive Oil & Gas were based on Ross & Picard (1998) 1990 emission and production data. Methane and nitrous oxide emission factors for gasoline and diesel vehicles were calculated based on 1990 Canadian totals. All gasoline and diesel vehicle types were grouped into a gasoline and diesel total. Fuel use activity data sources for the Energy sector were from Statistics Canada (CANSIM, 1996).

Industrial Process

The historical greenhouse gas emission methodologies used for the Industrial Process sector were comparable to current methodologies. The emission rates for SF_6 and PFCs were calculated based on 1990 aluminum and magnesium production and emission data. Calculated 1990 emission rates were kept constant for historical greenhouse gas emissions estimates. The aluminum and magnesium production activity data source were from P. Chevalier, Natural Resources Canada. The mineral, chemical and metal production activity data source were from Statistics Canada (CANSIM, 1996).

Solvent & Other Product Use

The methodologies used to estimate historical greenhouse gas emissions for the Solvent & Other Product Use sector were the same as current methodologies.

Agriculture

The historical greenhouse gas emission data source were based on Census data published in the report *The Health of Our Air - Toward Sustainable Agriculture in Canada*, Agriculture and Agri Food Canada (1999). Greenhouse gas emissions were extrapolated or interpolated from the above report.

Land Use Change & Forestry

The emission estimates were based on the prescribed burned data from the report *Selected Forestry Statistics Canada*, Forestry Canada (1992) and Weber & Taylor (1992).

Waste

The methodologies used to estimate historical greenhouse gas emissions for the waste sector were the same as current methodologies.

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CANADA'S 1990 GREENHOUSE GAS EMISSION SUMMARY

GHG Source and Sink Category	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	Total
	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*
Global Warming Potential Multiplier	1		21		310	140-11 700	6 500-9 200	23 900	
Energy									
Fuel Combustion									
Fossil Fuel Industries	38 500	0.7	15	0.4	110				38 600
Electricity and Steam Generation	94 500	0.9	18	2.3	720				95 200
Mining	7 600	0.2	3.7	0.1	41				7 650
Manufacturing	53 900	1.5	31	1.5	460				54 400
Construction	728	0.0	0.2	0.0	1.9				730
Transportation									
Gasoline Automobiles	51 600	9.0	190	6.4	2 000				53 800
Light-Duty Gasoline Trucks	20 400	4.0	83	4.2	1 300				21 800
Heavy-Duty Gasoline Vehicles	3 020	0.4	9.1	0.4	130				3 170
Motorcycles	225	0.2	3.8	0.0	1.4				230
Off-Road Gasoline Vehicles	4 910	6.2	130	0.1	39				5 080
Diesel Automobiles	657	0.0	0.4	0.0	7.5				664
Light-Duty Diesel Trucks	591	0.0	0.3	0.0	6.7				598
Heavy-Duty Diesel Vehicles	24 300	1.2	25	0.9	280				24 700
Off-Road Diesel Vehicles	10 300	0.5	11	4.2	1 300				11 600
Propane and Natural Gas Vehicles	1 690	2.2	47	0.0	1.3				1 730
Domestic Air	10 300	0.7	14	1.0	310				10 600
Domestic Marine	5 720	0.4	9.2	1.1	340				6 070
Rail	6 310	0.4	7.3	2.5	790				7 110
Vehicles Subtotal	**140 000**	**25**	**530**	**21**	**6 500**				**147 000**
Pipelines	6 670	0.2	3.2	0.1	22				6 690
Transportation Subtotal	**147 000**	**25**	**530**	**21**	**6 500**				**154 000**
Residential	40 700	230	4 800	2.9	910				46 500
Commercial and Institutional	26 000	0.5	11	0.3	79				26 100
Other	3 130	0.0	1.0	0.1	17				3 150
Combustion Subtotal	**412 000**	**260**	**5 400**	**29**	**8 800**				**426 000**
Fugitive									
Solid Fuels (i.e. Coal Mining)		91	1 900						1 900
Oil and Gas	9 800	1 200	26 000						36 000
Fugitive Subtotal	**9 800**	**1 300**	**28 000**	**0**	**0**				**38 000**
Energy Total	**422 000**	**1 600**	**34 000**	**29**	**8 800**				**464 000**
Industrial Processes									
Non-Metallic Mineral Production	8 160								8 160
Ammonia, Adipic Acid & Nitric Acid Production	3 130			37	11 000				15 000
Ferrous Metal Production	7 590								7 590
Aluminum and Magnesium Production	2 640						6 000	2 900	11 000
Other & Undifferentiated Production	10 000								10 000
Industrial Processes Total	**32 000**	**0**	**0**	**37**	**11 000**		**6 000**	**2 900**	**52 000**
Solvent & Other Product Use	**0**	**0**	**0**	**1**	**420**				**400**
Agriculture									
Enteric Fermentation		760	16 000						16 000
Manure Management		190	4 000	13	3 900				7 900
Agricultural Soils**	7 000			100	30 000				40 000
Agriculture Total	**7 000**	**950**	**20 000**	**110**	**34 000**				**62 000**
Land Use Change & Forestry*		**70**	**1 000**	**4**	**1 000**				**2 500**
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	53				320
Waste Total	**250**	**900**	**19 000**	**3.0**	**920**				**20 000**
TOTAL	**461 000**	**3 500**	**74 000**	**180**	**57 000**	**0**	**6 000**	**2 900**	**601 000**
CO_2 from Land Use Change & Forestry**	-40 000								

* CH_4 and N_2O emissions from prescribed and other fires.
** Only one significant figure is shown due to high uncertainty.
Note: Due to rounding, individual values may not add up to totals.

CANADA'S 1991 GREENHOUSE GAS EMISSION SUMMARY

GHG Source and Sink Category	CO_2 kt	CH_4 kt	CH_4 kt CO_2 eq	N_2O kt	N_2O kt CO_2 eq	HFCs kt CO_2 eq	PFCs kt CO_2 eq	SF_6 kt CO_2 eq	Total kt CO_2 eq
Global Warming Potential Multiplier	1		21		310	140-11 700	6 500-9 200	23 900	
Energy									
Fuel Combustion									
Fossil Fuel Industries	37 200	0.7	14	0.3	100				37 300
Electricity and Steam Generation	95 700	0.9	19	2.4	740				96 500
Mining	7 170	0.2	3.4	0.1	40				7 210
Manufacturing	50 600	1.4	30	1.5	460				51 100
Construction	825	0.0	0.3	0.0	3.6				829
Transportation									
Gasoline Automobiles	48 900	8.3	170	6.8	2 100				51 200
Light-Duty Gasoline Trucks	20 600	4.0	83	4.9	1 500				22 200
Heavy-Duty Gasoline Vehicles	3 230	0.5	9.7	0.5	140				3 380
Motorcycles	215	0.2	3.6	0.0	1.3				220
Off-Road Gasoline Vehicles	4 400	5.6	120	0.1	35				4 550
Diesel Automobiles	618	0.0	0.4	0.0	7.0				625
Light-Duty Diesel Trucks	515	0.0	0.3	0.0	5.9				522
Heavy-Duty Diesel Vehicles	23 600	1.2	24	0.9	270				23 900
Off-Road Diesel Vehicles	9 210	0.5	10	3.7	1 200				10 400
Propane and Natural Gas Vehicles	1 870	2.4	50	0.0	1.3				1 920
Domestic Air	9 280	0.6	12	0.9	280				9 580
Domestic Marine	6 150	0.5	11	1.1	340				6 490
Rail	5 850	0.3	6.7	2.4	730				6 590
Vehicles Subtotal	**134 000**	**24**	**500**	**21**	**6 600**				**142 000**
Pipelines	7 380	0.2	3.5	0.1	24				7 410
Transportation Subtotal	**142 000**	**24**	**500**	**21**	**6 600**				**149 000**
Residential	38 900	230	4 900	3.0	920				44 700
Commercial and Institutional	25 800	0.5	11	0.3	78				25 900
Other	3 160	0.0	1.0	0.0	14				3 170
Combustion Subtotal	**401 000**	**260**	**5 500**	**29**	**9 000**				**416 000**
Fugitive									
Solid Fuels (i.e. Coal Mining)		99	2 100						2 100
Oil and Gas	10 000	1 300	27 000						38 000
Fugitive Subtotal	**10 000**	**1 400**	**30 000**	**0**	**0**				**40 000**
Energy Total	**411 000**	**1 700**	**35 000**	**29**	**9 000**				**455 000**
Industrial Processes									
Non-Metallic Mineral Production	6 980								6 980
Ammonia, Adipic Acid & Nitric Acid Production	3 220			35	11 000				14 000
Ferrous Metal Production	8 900								8 900
Aluminum and Magnesium Production	3 010						6 000	3 300	13 000
Other & Undifferentiated Production	11 000								11 000
Industrial Processes Total	**34 000**	**0**	**0**	**35**	**11 000**		**6 000**	**3 300**	**54 000**
Solvent & Other Product Use	**0**	**0**	**0**	**1**	**420**				**400**
Agriculture									
Enteric Fermentation		770	16 000						16 000
Manure Management		190	4 000	13	3 900				8 000
Agricultural Soils**	7 000			100	30 000				40 000
Agriculture Total	**7 000**	**960**	**20 000**	**110**	**34 000**				**61 000**
Land Use Change & Forestry*		**90**	**2 000**	**5**	**1 000**				**3 200**
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	**452 000**	**3 600**	**76 000**	**180**	**57 000**	**0**	**6 000**	**3 300**	**595 000**
CO_2 from Land Use Change & Forestry**	-60 000								

* CH_4 and N_2O emissions from prescribed and other fires.

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

Note: Due to rounding, individual values may not add up to totals.

CANADA'S 1992 GREENHOUSE GAS EMISSION SUMMARY

GHG Source and Sink Category	CO_2 kt	CH_4 kt	CH_4 kt CO_2 eq	N_2O kt	N_2O kt CO_2 eq	HFCs kt CO_2 eq	PFCs kt CO_2 eq	SF_6 kt CO_2 eq	Total kt CO_2 eq
Global Warming Potential Multiplier	1		21		310	140-11 700	6 500-9 200	23 900	
Energy									
Fuel Combustion									
Fossil Fuel Industries	38 800	0.7	15	0.3	100				38 900
Electricity and Steam Generation	103 000	0.9	19	2.5	780				104 000
Mining	6 810	0.2	3.3	0.1	40				6 850
Manufacturing	49 900	1.4	30	1.5	460				50 400
Construction	839	0.0	0.3	0.0	4.0				844
Transportation									
Gasoline Automobiles	49 000	8.1	170	7.6	2 300				51 600
Light-Duty Gasoline Trucks	22 000	4.2	88	5.9	1 800				24 000
Heavy-Duty Gasoline Vehicles	3 650	0.5	11	0.5	160				3 820
Motorcycles	213	0.2	3.6	0.0	1.3				217
Off-Road Gasoline Vehicles	3 520	4.5	94	0.1	28				3 640
Diesel Automobiles	615	0.0	0.4	0.0	7.0				622
Light-Duty Diesel Trucks	474	0.0	0.3	0.0	5.4				480
Heavy-Duty Diesel Vehicles	24 100	1.2	25	0.9	270				24 400
Off-Road Diesel Vehicles	8 730	0.5	9	3.5	1 100				9 830
Propane and Natural Gas Vehicles	1 890	2.5	52	0.0	1.4				1 940
Domestic Air	9 420	0.5	11	0.9	290				9 720
Domestic Marine	6 100	0.5	11	1.1	340				6 450
Rail	6 120	0.3	7.1	2.5	760				6 890
Vehicles Subtotal	**136 000**	**23**	**480**	**23**	**7 100**				**144 000**
Pipelines	9 550	0.2	4.6	0.1	31				9 590
Transportation Subtotal	**145 000**	**23**	**490**	**23**	**7 200**				**153 000**
Residential	38 500	250	5 300	3.2	990				44 800
Commercial and Institutional	26 300	0.5	11	0.3	79				26 400
Other	5 410	0.1	1.5	0.1	20				5 440
Combustion Subtotal	**415 000**	**280**	**5 900**	**31**	**9 700**				**431 000**
Fugitive									
Solid Fuels (i.e. Coal Mining)		87	1 800						1 800
Oil and Gas	11 000	1 400	30 000						41 000
Fugitive Subtotal	**11 000**	**1 500**	**32 000**	**0**	**0**				**42 000**
Energy Total	**426 000**	**1 800**	**38 000**	**31**	**9 700**				**473 000**
Industrial Processes									
Non-Metallic Mineral Production	6 640								6 640
Ammonia, Adipic Acid & Nitric Acid Production	3 320			35	11 000				14 000
Ferrous Metal Production	9 080								9 080
Aluminum and Magnesium Production	3 210						7 000	2 200	12 000
Other & Undifferentiated Production	12 000								12 000
Industrial Processes Total	**34 000**	**0**	**0**	**35**	**11 000**		**7 000**	**2 200**	**54 000**
Solvent & Other Product Use	**0**	**0**	**0**	**1**	**430**				**400**
Agriculture									
Enteric Fermentation		760	16 000						16 000
Manure Management		190	3 900	13	4 000				7 900
Agricultural Soils**	6 000			100	30 000				40 000
Agriculture Total	**6 000**	**950**	**20 000**	**110**	**34 000**				**60 000**
Land Use Change & Forestry*		**80**	**2 000**	**4**	**1 000**				**2 900**
Waste									
Solid Waste Disposal on Land		930	20 000						20 000
Wastewater Handling		17	370	2.9	890				1 300
Waste Incineration	260	0.5	10	0.2	55				330
Waste Total	**260**	**950**	**20 000**	**3.1**	**950**				**21 000**
TOTAL	**466 000**	**3 800**	**79 000**	**180**	**57 000**	**0**	**7 000**	**2 200**	**610 000**
CO_2 from Land Use Change & Forestry**	-50 000								

* CH_4 and N_2O emissions from prescribed and other fires.

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

Note: Due to rounding, individual values may not add up to totals.

CANADA'S 1993 GREENHOUSE GAS EMISSION SUMMARY

GHG Source and Sink Category	CO_2 *kt*	CH_4 *kt*	CH_4 *kt CO_2 eq*	N_2O *kt*	N_2O *kt CO_2 eq*	HFCs *kt CO_2 eq*	PFCs *kt CO_2 eq*	SF_6 *kt CO_2 eq*	Total *kt CO_2 eq*
Global Warming Potential Multiplier	1		21		310	140-11 700	6 500-9 200	23 900	
Energy									
Fuel Combustion									
Fossil Fuel Industries	39 000	0.7	15	0.3	110				39 100
Electricity and Steam Generation	93 000	0.9	18	2.4	730				93 800
Mining	9 870	0.2	4.8	0.2	51				9 930
Manufacturing	48 800	1.4	29	1.4	450				49 300
Construction	494	0.0	0.2	0.0	2.0				496
Transportation									
Gasoline Automobiles	49 100	7.8	160	8.3	2 600				51 800
Light-Duty Gasoline Trucks	23 300	4.3	91	6.9	2 100				25 500
Heavy-Duty Gasoline Vehicles	4 010	0.6	12	0.6	180				4 200
Motorcycles	214	0.2	3.6	0.0	1.3				219
Off-Road Gasoline Vehicles	3 650	4.6	97	0.1	29				3 770
Diesel Automobiles	609	0.0	0.4	0.0	6.9				616
Light-Duty Diesel Trucks	457	0.0	0.3	0.0	5.2				462
Heavy-Duty Diesel Vehicles	25 400	1.2	26	0.9	290				25 800
Off-Road Diesel Vehicles	9 870	0.5	11	4.0	1 200				11 100
Propane and Natural Gas Vehicles	2 090	2.6	55	0.0	1.5				2 150
Domestic Air	8 750	0.5	11	0.9	270				9 030
Domestic Marine	5 300	0.5	9.4	1.0	320				5 620
Rail	6 090	0.3	7.0	2.5	760				6 860
Vehicles Subtotal	**139 000**	**23**	**490**	**25**	**7 800**				**147 000**
Pipelines	10 000	0.2	4.8	0.1	33				10 100
Transportation Subtotal	**149 000**	**23**	**490**	**25**	**7 800**				**157 000**
Residential	42 800	250	5 300	3.2	1 000				49 100
Commercial and Institutional	28 600	0.6	12	0.3	90				28 700
Other	3 350	0.1	1.2	0.1	17				3 370
Combustion Subtotal	**415 000**	**280**	**5 900**	**33**	**10 000**				**431 000**
Fugitive									
Solid Fuels (i.e. Coal Mining)		87	1 800						1 800
Oil and Gas	11 000	1 500	31 000						43 000
Fugitive Subtotal	**11 000**	**1 600**	**33 000**	**0**	**0**				**44 000**
Energy Total	**426 000**	**1 900**	**39 000**	**33**	**10 000**				**475 000**
Industrial Processes									
Non-Metallic Mineral Production	6 880								6 880
Ammonia, Adipic Acid & Nitric Acid Production	3 560			32	9 900				13 000
Ferrous Metal Production	8 760								8 760
Aluminum and Magnesium Production	3 770						7 000	2 000	13 000
Other & Undifferentiated Production	13 000								13 000
Industrial Processes Total	**36 000**	**0**	**0**	**32**	**9 900**		**7 000**	**2 000**	**55 000**
Solvent & Other Product Use	**0**	**0**	**0**	**1**	**440**				**400**
Agriculture									
Enteric Fermentation		800	17 000						17 000
Manure Management		190	4 000	13	4 100				8 200
Agricultural Soils**	5 000			100	30 000				40 000
Agriculture Total	**5 000**	**990**	**21 000**	**100**	**36 000**				**61 000**
Land Use Change & Forestry*		**70**	**2 000**	**4**	**1 000**				**2 800**
Waste									
Solid Waste Disposal on Land		950	20 000						20 000
Wastewater Handling		18	370	2.9	910				1 300
Waste Incineration	260	0.3	6.5	0.2	56				330
Waste Total	**260**	**970**	**20 000**	**3.1**	**960**				**22 000**
TOTAL	**467 000**	**3 900**	**82 000**	**190**	**58 000**	**0**	**7 000**	**2 000**	**617 000**
CO_2 from Land Use Change & Forestry**	-30 000								

* CH_4 and N_2O emissions from prescribed and other fires.
** Only one significant figure is shown due to high uncertainty.
Note: Due to rounding, individual values may not add up to totals.

CANADA'S 1994 GREENHOUSE GAS EMISSION SUMMARY

GHG Source and Sink Category	CO_2 kt	CH_4 kt	CH_4 kt CO_2 eq	N_2O kt	N_2O kt CO_2 eq	HFCs kt CO_2 eq	PFCs kt CO_2 eq	SF_6 kt CO_2 eq	Total kt CO_2 eq
Global Warming Potential Multiplier	1		21		310	140-11 700	6 500-9 200	23 900	
Energy									
Fuel Combustion									
Fossil Fuel Industries	39 900	0.7	15	0.4	110				40 000
Electricity and Steam Generation	94 800	0.9	18	2.5	760				95 600
Mining	10 900	0.3	5.3	0.2	58				10 900
Manufacturing	50 000	1.4	30	1.4	440				50 500
Construction	446	0.0	0.2	0.0	1.4				448
Transportation									
Gasoline Automobiles	49 300	7.6	160	8.9	2 800				52 200
Light-Duty Gasoline Trucks	24 800	4.5	95	7.9	2 400				27 300
Heavy-Duty Gasoline Vehicles	4 440	0.6	13	0.6	200				4 650
Motorcycles	216	0.2	3.6	0.0	1.3				220
Off-Road Gasoline Vehicles	3 800	4.8	100	0.1	30				3 930
Diesel Automobiles	600	0.0	0.4	0.0	6.8				607
Light-Duty Diesel Trucks	471	0.0	0.3	0.0	5.4				477
Heavy-Duty Diesel Vehicles	28 300	1.4	29	1.0	320				28 600
Off-Road Diesel Vehicles	11 000	0.6	12	4.4	1 400				12 300
Propane and Natural Gas Vehicles	2 290	3.9	82	0.0	2.5				2 370
Domestic Air	9 770	0.5	11	1.0	300				10 100
Domestic Marine	5 590	0.5	9.8	1.1	340				5 940
Rail	6 310	0.4	7.3	2.5	790				7 100
Vehicles Subtotal	**147 000**	**25**	**530**	**28**	**8 600**				**156 000**
Pipelines	10 400	0.2	5.0	0.1	34				10 500
Transportation Subtotal	**157 000**	**25**	**530**	**28**	**8 600**				**166 000**
Residential	43 400	250	5 200	3.2	990				49 600
Commercial and Institutional	28 100	0.6	12	0.3	90				28 200
Other	2 700	0.0	0.9	0.0	13				2 710
Combustion Subtotal	**427 000**	**280**	**5 900**	**36**	**11 000**				**444 000**
Fugitive									
Solid Fuels (i.e. Coal Mining)		84	1 800						1 800
Oil and Gas	12 000	1 600	33 000						45 000
Fugitive Subtotal	**12 000**	**1 700**	**35 000**	**0**	**0**				**47 000**
Energy Total	**439 000**	**1 900**	**41 000**	**36**	**11 000**				**491 000**
Industrial Processes									
Non-Metallic Mineral Production	7 510								7 510
Ammonia, Adipic Acid & Nitric Acid Production	3 700			38	12 000				15 000
Ferrous Metal Production	8 050								8 050
Aluminum and Magnesium Production	3 680						7 000	2 000	13 000
Other & Undifferentiated Production	13 000								13 000
Industrial Processes Total	**36 000**	**0**	**0**	**38**	**12 000**		**7 000**	**2 000**	**57 000**
Solvent & Other Product Use	**0**	**0**	**0**	**1**	**440**				**400**
Agriculture									
Enteric Fermentation		830	18 000						18 000
Manure Management		200	4 200	14	4 400				8 500
Agricultural Soils**	4 000			100	30 000				40 000
Agriculture Total	**4 000**	**1 000**	**22 000**	**120**	**37 000**				**63 000**
Land Use Change & Forestry*		**40**	**800**	**2**	**700**				**1 500**
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	6.5	0.2	56				330
Waste Total	**270**	**980**	**21 000**	**3.1**	**970**				**22 000**
TOTAL	**480 000**	**4 000**	**84 000**	**200**	**62 000**	**0**	**7 000**	**2 000**	**635 000**
CO_2 from Land Use Change & Forestry**	-30 000								

* CH_4 and N_2O emissions from prescribed and other fires.

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

Note: Due to rounding, individual values may not add up to totals.

CANADA'S 1995 GREENHOUSE GAS EMISSION SUMMARY

GHG Source and Sink Category	CO_2 kt	CH_4 kt	CH_4 kt CO_2 eq	N_2O kt	N_2O kt CO_2 eq	HFCs kt CO_2 eq	PFCs kt CO_2 eq	SF_6 kt CO_2 eq	Total kt CO_2 eq
Global Warming Potential Multiplier	1		21		310	140-11 700	6 500-9 200	23 900	
Energy									
Fuel Combustion									
Fossil Fuel Industries	40 100	0.7	15	0.4	110				40 200
Electricity and Steam Generation	99 500	0.9	19	2.5	790				100 000
Mining	11 900	0.3	6.0	0.2	69				12 000
Manufacturing	53 200	1.6	35	1.6	510				53 700
Construction	737	0.0	0.3	0.0	2.3				739
Transportation									
Gasoline Automobiles	48 300	7.3	150	8.9	2 800				51 200
Light-Duty Gasoline Trucks	25 700	4.5	94	8.4	2 600				28 400
Heavy-Duty Gasoline Vehicles	4 740	0.7	14	0.7	210				4 970
Motorcycles	209	0.2	3.5	0.0	1.3				214
Off-Road Gasoline Vehicles	3 770	4.8	100	0.1	30				3 900
Diesel Automobiles	578	0.0	0.3	0.0	6.6				585
Light-Duty Diesel Trucks	466	0.0	0.3	0.0	5.3				472
Heavy-Duty Diesel Vehicles	30 400	1.5	31	1.1	350				30 800
Off-Road Diesel Vehicles	12 200	0.6	13	4.9	1 500				13 700
Propane and Natural Gas Vehicles	2 370	5.4	110	0.0	3.8				2 480
Domestic Air	10 500	0.6	12	1.0	320				10 900
Domestic Marine	5 350	0.4	8.9	1.1	340				5 700
Rail	5 710	0.3	6.6	2.3	710				6 430
Vehicles Subtotal	**150 000**	**26**	**550**	**29**	**8 900**				**160 000**
Pipelines	11 600	0.3	5.5	0.1	38				11 600
Transportation Subtotal	**162 000**	**27**	**560**	**29**	**8 900**				**171 000**
Residential	42 000	250	5 200	3.2	980				48 100
Commercial and Institutional	29 900	0.6	12	0.3	95				30 000
Other	2 610	0.0	0.9	0.0	13				2 620
Combustion Subtotal	**442 000**	**280**	**5 800**	**37**	**11 000**				**459 000**
Fugitive									
Solid Fuels (i.e. Coal Mining)		82	1 700						1 700
Oil and Gas	13 000	1 700	35 000						48 000
Fugitive Subtotal	**13 000**	**1 800**	**37 000**	**0**	**0**				**50 000**
Energy Total	**455 000**	**2 000**	**43 000**	**37**	**11 000**				**509 000**
Industrial Processes									
Non-Metallic Mineral Production	7 690								7 690
Ammonia, Adipic Acid & Nitric Acid Production	4 050			37	12 000				16 000
Ferrous Metal Production	8 500								8 500
Aluminum and Magnesium Production	3 540						6 000	1 900	11 000
Other & Undifferentiated Production	13 000								13 000
Industrial Processes Total	**37 000**	**0**	**0**	**37**	**12 000**		**6 000**	**1 900**	**56 000**
Solvent & Other Product Use	**0**	**0**	**0**	**1**	**450**	**500**			**900**
Agriculture									
Enteric Fermentation		860	18 000						18 000
Manure Management		210	4 300	15	4 500				8 800
Agricultural Soils**	3 000			100	30 000				40 000
Agriculture Total	**3 000**	**1 100**	**22 000**	**120**	**38 000**				**63 000**
Land Use Change & Forestry*		**50**	**1 000**	**4**	**1 000**				**2 100**
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	7.2	0.2	57				340
Waste Total	**270**	**990**	**21 000**	**3.2**	**980**				**22 000**
TOTAL	**495 000**	**4 100**	**87 000**	**200**	**63 000**	**500**	**6 000**	**1 900**	**653 000**
CO_2 from Land Use Change & Forestry**	-20 000								

* CH_4 and N_2O emissions from prescribed and other fires.

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

Note: Due to rounding, individual values may not add up to totals.

CANADA'S 1996 GREENHOUSE GAS EMISSION SUMMARY

GHG Source and Sink Category	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	Total
	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*
Global Warming Potential Multiplier	1		21		310	140-11 700	6 500-9 200	23 900	
Energy									
Fuel Combustion									
Fossil Fuel Industries	39 800	0.7	16	0.4	110				39 900
Electricity and Steam Generation	100 000	0.9	20	2.6	800				101 000
Mining	12 900	0.3	6.8	0.3	76				13 000
Manufacturing	52 800	1.6	33	1.5	480				53 300
Construction	1 120	0.0	0.4	0.0	3.3				1 120
Transportation									
Gasoline Automobiles	47 300	6.9	150	8.4	2 600				50 100
Light-Duty Gasoline Trucks	26 900	4.5	94	8.5	2 600				29 600
Heavy-Duty Gasoline Vehicles	4 770	0.7	14	0.7	210				4 990
Motorcycles	206	0.2	3.5	0.0	1.2				210
Off-Road Gasoline Vehicles	4 540	5.8	120	0.1	36				4 690
Diesel Automobiles	596	0.0	0.4	0.0	6.8				604
Light-Duty Diesel Trucks	463	0.0	0.3	0.0	5.3				469
Heavy-Duty Diesel Vehicles	32 000	1.6	33	1.2	360				32 400
Off-Road Diesel Vehicles	13 400	0.7	14	5.4	1 700				15 100
Propane and Natural Gas Vehicles	2 470	5.5	110	0.0	3.8				2 590
Domestic Air	11 600	0.6	13	1.1	350				12 000
Domestic Marine	5 210	0.4	8.5	1.1	340				5 560
Rail	5 580	0.3	6.4	2.3	700				6 290
Vehicles Subtotal	**155 000**	**27**	**570**	**29**	**8 900**				**165 000**
Pipelines	12 100	0.3	5.7	0.1	39				12 100
Transportation Subtotal	**167 000**	**27**	**570**	**29**	**9 000**				**177 000**
Residential	46 900	260	5 400	3.3	1 000				53 300
Commercial and Institutional	30 100	0.6	13	0.3	95				30 200
Other	2 860	0.0	1.0	0.0	14				2 870
Combustion Subtotal	**454 000**	**290**	**6 000**	**37**	**12 000**				**471 000**
Fugitive									
Solid Fuels (i.e. Coal Mining)		84	1 800						1 800
Oil and Gas	13 000	1 800	37 000						51 000
Fugitive Subtotal	**13 000**	**1 900**	**39 000**	**0**	**0**				**53 000**
Energy Total	**467 000**	**2 200**	**45 000**	**37**	**12 000**				**524 000**
Industrial Processes									
Non-Metallic Mineral Production	7 840								7 840
Ammonia, Adipic Acid & Nitric Acid Production	4 130			40	12 000				16 000
Ferrous Metal Production	8 290								8 290
Aluminum and Magnesium Production	3 730						6 000	1 400	11 000
Other & Undifferentiated Production	15 000								15 000
Industrial Processes Total	**39 000**	**0**	**0**	**40**	**12 000**		**6 000**	**1 400**	**59 000**
Solvent & Other Product Use	**0**	**0**	**0**	**2**	**450**	**500**			**900**
Agriculture									
Enteric Fermentation		860	18 000						18 000
Manure Management		210	4 400	15	4 600				8 900
Agricultural Soils**	2 000			100	30 000				40 000
Agriculture Total	**2 000**	**1 100**	**23 000**	**130**	**40 000**				**64 000**
Land Use Change & Forestry*		**40**	**900**	**3**	**900**				**1 700**
Waste									
Solid Waste Disposal on Land		970	20 000						20 000
Wastewater Handling		18	390	3.0	940				1 300
Waste Incineration	270	0.3	6.9	0.2	58				340
Waste Total	**270**	**990**	**21 000**	**3.2**	**1 000**				**22 000**
TOTAL	**508 000**	**4 300**	**90 000**	**210**	**66 000**	**500**	**6 000**	**1 400**	**671 000**
CO_2 from Land Use Change & Forestry**	-30 000								

* CH_4 and N_2O emissions from prescribed and other fires.
** Only one significant figure is shown due to high uncertainty.
Note: Due to rounding, individual values may not add up to totals.

CANADA'S 1997 GREENHOUSE GAS EMISSION SUMMARY

GHG Source and Sink Category	CO_2 *kt*	CH_4 *kt*	CH_4 *kt CO_2 eq*	N_2O *kt*	N_2O *kt CO_2 eq*	HFCs *kt CO_2 eq*	PFCs *kt CO_2 eq*	SF_6 *kt CO_2 eq*	Total *kt CO_2 eq*
Global Warming Potential Multiplier	1		21		310	140-11 700	6 500-9 200	23 900	
Energy									
Fuel Combustion									
Fossil Fuel Industries	37 300	0.7	14	0.3	100				37 400
Electricity and Steam Generation	111 000	1.0	21	2.7	840				111 000
Mining	13 200	0.3	5.8	0.2	71				13 300
Manufacturing	52 900	1.5	32	1.5	460				53 400
Construction	970	0.0	0.3	0.0	2.8				973
Transportation									
Gasoline Automobiles	47 500	6.7	140	8.2	2 500				50 200
Light-Duty Gasoline Trucks	28 700	4.4	93	8.7	2 700				31 500
Heavy-Duty Gasoline Vehicles	5 220	0.8	16	0.8	230				5 470
Motorcycles	217	0.2	3.7	0.0	1.3				222
Off-Road Gasoline Vehicles	4 190	5.3	110	0.1	33				4 330
Diesel Automobiles	586	0.0	0.3	0.0	6.7				593
Light-Duty Diesel Trucks	487	0.0	0.3	0.0	5.5				493
Heavy-Duty Diesel Vehicles	35 500	1.7	37	1.3	400				35 900
Off-Road Diesel Vehicles	13 500	0.7	15	5.5	1 700				15 300
Propane and Natural Gas Vehicles	1 950	3.2	67	0.0	2.0				2 020
Domestic Air	12 600	0.6	13	1.2	380				13 000
Domestic Marine	5 810	0.5	9.8	1.1	340				6 160
Rail	5 660	0.3	6.5	2.3	710				6 380
Vehicles Subtotal	**162 000**	**24**	**510**	**29**	**9 000**				**172 000**
Pipelines	12 100	0.3	5.8	0.1	40				12 200
Transportation Subtotal	**174 000**	**25**	**520**	**29**	**9 100**				**184 000**
Residential	43 800	260	5 400	3.3	1 000				50 200
Commercial and Institutional	30 600	0.6	13	0.3	97				30 700
Other	2 920	0.1	1.1	0.1	17				2 940
Combustion Subtotal	**466 000**	**290**	**6 000**	**38**	**12 000**				**484 000**
Fugitive									
Solid Fuels (i.e. Coal Mining)		78	1 600						1 600
Oil and Gas	14 000	1 800	38 000						51 000
Fugitive Subtotal	**14 000**	**1 900**	**39 000**	**0**	**0**				**53 000**
Energy Total	**480 000**	**2 200**	**45 000**	**38**	**12 000**				**537 000**
Industrial Processes									
Non-Metallic Mineral Production	8 280								8 280
Ammonia, Adipic Acid & Nitric Acid Production	4 140			34	11 000				15 000
Ferrous Metal Production	8 110								8 110
Aluminum and Magnesium Production	3 790						6 000	1 400	11 000
Other & Undifferentiated Production	14 000								14 000
Industrial Processes Total	**38 000**	**0**	**0**	**34**	**11 000**		**6 000**	**1 400**	**56 000**
Solvent & Other Product Use	**0**	**0**	**0**	**2**	**460**	**500**			**900**
Agriculture									
Enteric Fermentation		870	18 000						18 000
Manure Management		200	4 200	15	4 600				8 900
Agricultural Soils**	1 000			100	30 000				40 000
Agriculture Total	**1 000**	**1 100**	**23 000**	**130**	**39 000**				**63 000**
Land Use Change & Forestry*		**40**	**900**	**3**	**900**				**1 700**
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**	**21 000**	**3.2**	**1 000**				**23 000**
TOTAL	**520 000**	**4 300**	**90 000**	**210**	**64 000**	**500**	**6 000**	**1 400**	**682 000**
CO_2 from Land Use Change & Forestry**	-20 000								

* CH_4 and N_2O emissions from prescribed and other fires.
** Only one significant figure is shown due to high uncertainty.
Note: Due to rounding, individual values may not add up to totals.

Biomass Methodologies

Residential Firewood

The calculation of greenhouse gas emissions from the combustion of residential firewood is based on a study commissioned by the National Emissions Inventory and Projection Task Group (Canadian Facts, 1997). The study collected firewood consumption data in terms of appliance type. The emission factors for different wood burning stoves are from the AP-42 supplement B. The wood consumed by various appliance types in the study were grouped into six categories roughly matching the emission factors. The six categories and the appliances that were included in each are shown below:

1) Conventional stoves
   - -non-air tight
   - -air tight, non-advanced technology
2) Stove/fireplace inserts with adv technology (no catalyst)
   - -non-catalytic fireplaces
   - -non-catalytic stove
3) Stoves/fireplaces with catalyst
   - -catalytic fireplaces
   - -catalytic stove
   - -non-air tight wood burning fireplaces with inserts
   - -air tight non-advanced technology wood burning fireplaces with inserts
4) Conventional fireplaces
   - -without glass doors
   - -with glass doors (non-air tight)
   - -with air tight glass doors
5) Furnaces
   - -wood burning fireplaces
6) Other equipment
   - -other wood burning equipment

The wood consumption data from the 1996 study was used to extrapolate the amount of wood burned in the years 1990 to 1995, and 1997. Statistics Canada and Natural Resources Canada data were not used in the estimate since they appear to greatly underestimate wood consumption. The method used to extrapolate data consisted of two steps. The first step was to develop a growth factor on a provincial level for each year. It was assumed that firewood use would change with heating degree days below 18.0 Celsius. Since the firewood data was from 1996, that was considered to be the base year. The growth factor for each year was then calculated by dividing the degree days of each year by the degree days of the base year.

The second step of the extrapolation was to multiply the tonnes of wood burned in 1996 in each of the categories by the appropriate growth factors. This provided an estimate of the amount of wood burned in the years 1990 to 1995, and 1997.

The amount of wood burned was then multiplied by the emission factors to calculate the greenhouse gas emissions. The emission factors for nitrous oxide and methane are from the AP-42 Supplement B, and the emission factor for carbon dioxide is from Ortech, 1994 (see Appendix C: Emission Factors).

Industrial Firewood and Spent Pulping Liquors

Data for industrial firewood and spent pulping liquor is available in the QRESD. The 1990 and 1991 data for the Atlantic provinces were grouped together and the data for the Prairie provinces were also grouped together. It was separated into individual provincial numbers using data from the 1992 QRESD. For that year, the data for Newfoundland and Nova Scotia was grouped together and entered into the spreadsheets under Nova Scotia because the data required to divide the numbers between the two provinces did not exist.

The emission factor for carbon dioxide from spent pulping liquor combustion was based on two assumptions — that the carbon content of spent pulping liquor was 41% by weight and that there was a 95% conversion of the carbon to carbon dioxide. The emission factor is therefore as follows:

$$EF\ CO_2 = 0.41 * 0.95 * (44\ g/mol / 12\ g/mol)$$
$$= 1.428\ tonne\ CO_2 / tonne\ spl \quad \text{(Jaques, 1992)}$$

The CH_4 and N_2O emission factors for industrial firewood are from Supplement D of the AP-42. Because emission factors were given for three different types of boilers, an average for the three was used. To calculate the emissions from industrial firewood, the amount burned was multiplied by the emission factors.

No estimates for CH_4 or N_2O have been made for spent pulping liquor since there are no available emission factors.

References

Canadian Facts (a division of CF Group Inc.), *Residential Fuelwood Combustion in Canada*, Toronto, April 1997.

EPA, *AP-42, 5th Edition, Volume 1, Stationary Point and Area Sources*, January 1995.

Jaques, A.P., *Canada's Greenhouse Gas Emissions: Estimates for 1990*, Report EPS 5/AP/2, Environment Canada, 1992.

ORTECH Corporation, I*nventory Methods Manual for Estimating Canadian Emissions of Greenhouse Gases*, unpublished document prepared for Environment Canada, 1994.

Statistics Canada, *Quarterly Report on Energy Supply and Demand*, 1990-1997,. Document No. 57-003.

Transportation Methodology

Mobile Sources

An electronic spreadsheet-based model has been developed by Environment Canada to estimate greenhouse gas emissions from mobile sources. The Mobile Greenhouse gas Emissions Model, or M-GEM, which Environment Canada's transportation emission inventory is now based on, represents an updated methodology for dis-aggregating vehicle data and calculating emissions more accurately than previously achievable. It estimates carbon dioxide, methane and nitrous oxide emissions from all mobile sources, but has been primarily designed for ground (non-rail) transportation.[1] The focus is on road vehicles, which accounted for 68% of Transportation emissions, or close to one fifth of the country's total in 1996.

Road and Off-Road (Ground, Non-Rail) Transport

Methodology

Since emissions are proportional to fuel consumption, it is essential to consider this data first. Currently, a portion of the fuel quantities sold for road transport can be obtained quite easily from retail pump sales and sales to commercial fleets (Statistics Canada, Catalogue No. 57-003). Although Statistics Canada also reports transport fuel use in the agricultural, commercial, industrial and institutional economic sectors, it is uncertain whether these fuels are used by vehicles on or off road. On-road fuel use, then, is a subset of all (non-rail) ground transportation consumption recorded by Statistics Canada in its *Quarterly Report on Energy Supply-Demand* (Statistics Canada, Catalogue No. 57-003). Four major fuels are utilized for ground transport in Canada: gasoline, diesel fuel oil, natural gas and propane. To evaluate emissions, each of these must be considered separately. Emissions are calculated on the basis of equation (1):

$$E = [EF_{Category}] \times [Fuel_{Category}] \tag{1}$$

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

As indicated above, on-road fuel use must be separated from off-road consumption and the two are related in the following way:

$$Fuel_{Ground\ (non\text{-}rail)} = Fuel_{Road} + Fuel_{Off\text{-}road} \tag{2}$$

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 has been assumed that transportation uses of natural gas and propane are by road vehicles only. Although not absolutely correct, this assumption introduces only a small degree of error and allows a separate, simplified analysis of these 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:

$$Fuel_{Road,\ Category} = [\text{Vehicle population}] \times [\text{Average distance driven/year}] \times [\text{Fuel Consumption Ratio}] \tag{3}$$

As these parameters are different for each vehicle type, the model has been designed to calculate fuel use by division into relevant categories. Vehicles are categorized into seven major types, identical to those utilized in the U.S. Environmental Protection Agency's *Mobile_* models. They are: light-duty gasoline automobiles (LDGA), light-duty gasoline trucks (LDGT), heavy-duty gasoline vehicles (HDGV), motorcycles, light-duty diesel automobiles (LDDA), light-duty diesel trucks (LDDT), and heavy-duty diesel trucks (HDDT). 'Light-duty' vehicles are classified as those weighing less than 8 500 lbs, while 'heavy-duty' vehicles cover all those greater than 8 500 lbs (3 855 kg).

Vehicle statistics were obtained from a number of sources. Within Environment Canada, a compendium listing quantities of all vehicle types has been assembled for the year 1989 (Environment Canada, 1996).

1 Note that pipeline transport emissions are not calculated by the model. A brief outline of the approach used for that subcategory is presented at the end of this discussion.

Information was obtained from a commercially available database of light-duty vehicle populations (DesRosiers, 1990) and other sources. To update this information, 1995 statistics were compiled from a more recent version of the same database (DesRosiers, 1996) and a similar one for heavy duty vehicles (Polk, 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 (Warbanski, 1998), which was extrapolated one further year to provide estimates for 1997.

The above information was sufficient for all vehicle types with the exception of motorcycles, for which data was obtained from Statistics Canada (Catalogue No. 53-219). This source was also utilized to provide statistics on populations of all vehicles in the Canadian Territories. (The 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 different pollution control devices have on emission rates. To account for the effects these technologies have on emissions of methane and nitrous oxide, estimates of the number and types of vehicles equipped with catalytic converters and other controls were developed.

Light-duty gasoline automobiles and trucks, together responsible for about 75% of on-road greenhouse gas emissions in Canada, were both further subdivided. Five types of pollution-control technology were defined. Splits by model year were obtained on the basis of Canadian sales (Environment Canada, 1996; DesRosiers, 1990), regulatory information (Government of Canada, 1997) and additional international reports (IPCC, 1997) covering information back to the 1970s. This was combined with data on the age distribution of vehicles by province (Philpott, 1993) and reported lifetimes (Gorely, 1997) and expected deterioration rates of catalytic converters. The final result is that the on-road mix of control devices for any given year can be determined by the 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 other vehicle categories. Fleet-average car and light-truck FCRs by model year were obtained from Transport Canada (1998) and the U.S. EPA (Heavenrich and Hellman, 1996). These consumption ratios are determined by standardized vehicle tests in the lab, but recent research has shown that real-world fuel use is consistently higher. Based on studies performed in the U.S., on-road vehicle fuel consumption figures in the M-GEM have been adjusted to 25% above 'nameplate' FCR ratings (Maples, 1993). Average FCRs for all operating vehicles within each sub-category of light-duty gasoline automobiles and trucks are calculated by apportioning the model-year consumption data according to the vehicle age and control technology distributions discussed earlier.

FCR estimates for classifications other than light-duty cars and trucks have been set to values recommended by the Intergovernmental Panel on Climate Change (IPCC, 1997).

Estimates for distances travelled by each class of vehicle were obtained within Environment Canada (Environment Canada, 1996). These figures are based on indirect Statistics Canada data and surveys performed in the late 1980s. Since the surveys included only personal-use vehicles and Canadian driving habits seem to have changed in the interim, the data is less reliable than most of the other statistics incorporated within the M-GEM.

The model estimates on- and off-road fuel use and emissions. In an effort to improve accuracy, a check has been incorporated which compares two estimates of off-road consumption. As indicated earlier, 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 by using statistics on the sales of diesel oil and gasoline upon which road taxes were paid (Catalogue No. 53-218). (Statistics Canada records data on the sales of fuel upon which road taxes were paid. The difference between total gasoline or diesel oil used for ground (non-rail) transport and this quantity constitutes a second estimate of off-road use.) Since the source of the sales data, provincial tax records, is considerably different than the surveys which Statistics Canada relies on for most other energy data (Catalogue No. 57-003), the two off-road estimates are not exactly comparable. However, it can be assumed that the values should agree within a certain window of accuracy.

The M-GEM is currently programmed to accept a plus or minus 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. A summary of 1990, 1995 and 1997 results, by vehicle classification, is shown in Tables B2-1, B2-2 and B2-3. Included in the table are emissions from natural gas and propane road vehicles. (Rail, marine and air sources are also included and are discussed below.)

The emission factors which have been utilized for vehicles originate from a variety of sources and are summarized in a table entitled “Emission Factors - Mobile Combustion Sources”, in M-GEM. CO_2 emission factors are fuel-dependent and are identical to those described in a previous report (Jaques, 1992). As indicated earlier, pollution-control devices have a strong effect on methane and nitrous oxide emissions, so emission factors associated with these gases vary with vehicle type. For example, there are five technology categories in the light-duty gasoline automobile and light-duty gasoline truck (LDGA and LDGT) classes, each with a unique emission factor. In these two classes, the categories are based solely on catalytic control technology. A short description of each type follows.

Uncontrolled vehicles were the norm in Canada in the 1960s. Non-catalyst-controlled vehicles were brought to market in the late ‘60s and early ‘70s, becoming prevalent until 1975. Emission-control technology on these included modifications to ignition timing and air-fuel ratios, exhaust-gas recirculation (EGR), and air injection into the exhaust manifold (IPCC, 1997). Note that no separate category exists in the inventory for vehicles with no emission control, since these have virtually the same greenhouse gas emission factors as those with non-catalytic control (IPCC, 1997).

Oxidation catalytic converters were first used on Canadian vehicles introduced in 1975 and their use continued on production vehicles until the 1987 model year (Philpott, 1993). These are two-way units which oxidize hydrocarbons.

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 (IPCC, 1997). Later (around the 1984 model year), vehicles began utilizing 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. The reason for this is discussed below.

‘Tier 1’, a more advanced emission control technology, was introduced to North American light-duty gasoline vehicles in 1994. It consists of an improved three-way catalytic converter under more sophisticated computer control.

Methane emission factors adopted for each of these vehicle types were those recommended by the IPCC for North American vehicles (IPCC, 1997). These factors originated with the EPA as a result of its work with the *Mobile5* vehicle emission model, and were reported in 1996. They are given as ranges within each vehicle type, with the actual value dependent upon the type of inspection and maintenance program in effect in the region within which they operate (Weaver, 1996). For the Canadian situation, the average value within each range was chosen. 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 (Dasch, 1992; Urban and Garbe, 1980; Prigent and De Soete, 1989; De Soete,1989; Prigent et al., 1991). The results of these studies are comparable for non-catalyst and oxidation-catalyst-equipped vehicles, but differ for Tier 0 three-way aged catalysts. The only consistent and systematic studies on the effect of aging on catalysts are De Soete (1989) and Prigent et al. (1991).

Uncontrolled engine exhaust emissions contain very little N_2O. Prigent and De Soete show that N_2O 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 NO and NH_3 react over the platinum in catalytic converters. The production of N_2O is highly temperature dependent. Prigent and De Soete (1989) 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 to 500°C). These authors observed a peak of N_2O formation close to the catalyst light-off temperature and found that the amount of N_2O emitted increased 2 to 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.

TABLE B2-1 DETAILS OF VEHICLE EMISSIONS IN CANADA FOR 1990

		Category Vehicle Population	Fuel Consumption Ratio *l/100 km*	Average Distance Travelled *km*	Total Fuel Consumed *Ml*	Emissions CO_2 *Mt*	CH_4 *Mt CO_2 eq*	N_2O *Mt CO_2 eq*	G.H.G. Total *Mt CO_2 eq*
GROUND (NON-RAIL) SOURCES									
On-Road Transport									
GASOLINE SOURCES									
Light-Duty Gasoline Automobiles	**Sum (*Avg*)**	**11 100 000**	***11.5***	***17 000***	**21 900**	**51.6**	**0.19**	**2.0**	**53.8**
Tier 1 Three-Way Catalyst		0	0.0	-	0	-	-	-	-
Tier 0 Three-Way Catalyst (new)		555 000	10.3	17 000	997	2.35	0.01	0.08	2.43
Tier 0 Three-Way Catalyst (aged)		4 430 000	10.4	17 000	7 920	18.7	0.05	1.4	20.2
Oxidation Catalyst		3 350 000	10.9	17 000	6 300	14.9	0.06	0.39	15.3
Non-Catalyst		2 740 000	14.3	17 000	6 630	15.6	0.07	0.10	15.8
Light-Duty Gasoline Trucks	**Sum (*Avg*)**	**3 450 000**	***15.4***	***16 000***	**8 630**	**20.4**	**0.08**	**1.3**	**21.8**
Tier 1 Three-Way Catalyst		0	0.0	-	0	-	-	-	-
Tier 0 Three-Way Catalyst (new)		208 000	14.3	16 000	483	1.14	+	0.07	1.21
Tier 0 Three-Way Catalyst (aged)		1 460 000	14.4	16 000	3 400	8.03	0.03	1.1	9.16
Oxidation Catalyst		1 040 000	14.6	16 000	2 460	5.79	0.02	0.15	5.96
Non-Catalyst		747 000	19.0	16 000	2 290	5.40	0.03	0.03	5.46
Heavy-Duty Gasoline Vehicles	**Sum (*Avg*)**	**219 000**	***47.5***	***12 000***	**1 280**	**3.02**	**0.01**	**0.13**	**3.17**
Three-Way Catalyst		73 000	43.5	12 000	391	0.92	+	0.12	1.04
Non-Catalytic Controlled		73 000	43.5	12 000	391	0.92	+	0.01	0.93
Uncontrolled		73 000	55.6	12 000	500	1.18	0.01	0.01	1.19
Motorcycles	**Sum (*Avg*)**	**331 000**	***10.3***	***2 800***	**96**	**0.23**	**+**	**+**	**0.23**
Non-Catalytic Controlled		165 000	9.3	2 800	43	0.10	+	+	0.10
Uncontrolled		165 000	11.2	2 800	52	0.12	+	+	0.13
DIESEL SOURCES									
Light-Duty Diesel Automobiles	**Sum (*Avg*)**	**124 000**	***11.2***	***17 000***	**241**	**0.66**	**+**	**0.01**	**0.66**
Advanced Control		41 400	10.0	17 000	71	0.20	+	+	0.20
Moderate Control		41 400	10.4	17 000	74	0.20	+	+	0.21
Uncontrolled		41 400	13.3	17 000	95	0.26	+	+	0.26
Light-Duty Diesel Trucks	**Sum (*Avg*)**	**77 200**	***15.1***	***19 000***	**216**	**0.59**	**+**	**0.01**	**0.60**
Advanced Control		25 700	13.9	19 000	66	0.18	+	+	0.18
Moderate Control		25 700	13.9	19 000	66	0.18	+	+	0.18
Uncontrolled		25 700	17.5	19 000	84	0.23	+	+	0.23
Heavy-Duty Diesel Vehicles	**Sum (*Avg*)**	**357 000**	***43.0***	***58 000***	**8 920**	**24.3**	**0.03**	**0.28**	**24.7**
Advanced Control		119 000	41.7	58 000	2 890	7.88	0.01	0.09	7.98
Moderate Control		119 000	41.7	58 000	2 890	7.88	0.01	0.09	7.98
Uncontrolled		119 000	45.5	58 000	3 150	8.60	0.01	0.10	8.71
NATURAL GAS VEHICLES		-	-	-	**69 700**	**0.13**	**0.03**	**+**	**0.17**
PROPANE VEHICLES		-	-	-	**1 020**	**1.55**	**0.02**	**-**	**1.57**
On-Road Transport Subtotal		-	-	-	-	**102**	**0.36**	**3.7**	**107**
Off-Road Sources									
Off-Road Gasoline		-	-	-	-	**4.91**	**0.13**	**0.04**	**5.08**
Off-Road Diesel		-	-	-	-	**10.3**	**0.01**	**1.3**	**11.6**
Off-Road Sources Subtotal		-	-	-	-	**15.2**	**0.14**	**1.3**	**16.7**
Total Ground (Non-Rail) Sources		-	-	-	-	**118**	**0.50**	**5.0**	**123**
RAIL, MARINE AND AIR SOURCES									
Rail Transport									
Total Rail (Diesel Fuel Oil)		-	-	-	-	**6.31**	**0.01**	**0.79**	**7.11**
Marine Transport									
Motor Gasoline		-	-	-	-	+	+	+	+
Diesel Fuel Oil		-	-	-	-	2.81	+	0.32	3.13
Light (Distillate) Fuel Oil		-	-	-	-	+	+	+	+
Heavy (Residual) Fuel Oil		-	-	-	-	2.91	0.01	0.02	2.94
Total Marine Transport	**Sum (Avg)**	-	-	-	-	**5.72**	**0.01**	**0.34**	**6.07**
Air Transport									
Aviation Gasoline		-	-	-	-	0.38	0.01	0.01	0.40
Aviation Turbo Fuel		-	-	-	-	9.90	0.01	0.30	10.2
Total Air Transport	**Sum (Avg)**	-	-	-	-	**10.3**	**0.01**	**0.31**	**10.6**
Total (All Mobile Sources)		-	-	-	-	**140**	**0.53**	**6.5**	**147**

Fuel-consumption data was arrived at by partitioning fuel from Statistics Canada Catalogue Number 57-003 (Quarterly) according to vehicle type and activity.
CH_4 and N_2O emissions data were arrived at by multiplying fuel quantity by percent of catalyst technology, emission factor and Global Warming Potential (GWP).
(GWP for CH_4 = 21; GWP for N_2O = 310)
\+ Non-zero values too small to display.

TABLE B2-2 DETAILS OF VEHICLE EMISSIONS IN CANADA FOR 1995

		Category Vehicle Population	Fuel Consumption Ratio *l/100 km*	Average Distance Travelled *km*	Total Fuel Consumed *Ml*	Emissions: CO_2 *Mt*	Emissions: CH_4 *Mt CO_2 eq*	Emissions: N_2O *Mt CO_2 eq*	Emissions: G.H.G. Total *Mt CO_2 eq*
GROUND (NON-RAIL) SOURCES									
On-Road Transport									
GASOLINE SOURCES									
Light-Duty Gasoline Automobiles	**Sum (*Avg*)**	**10 900 000**	***10.5***	***18 000***	**20 500**	**48.3**	**0.15**	**2.8**	**51.2**
Tier 1 Three-Way Catalyst		835 000	10.1	18 000	1 520	3.58	0.01	0.10	3.69
Tier 0 Three-Way Catalyst (new)		110 000	10.1	18 000	201	0.47	0.00	0.02	0.49
Tier 0 Three-Way Catalyst (aged)		7 740 000	10.2	18 000	14 100	33.4	0.10	2.5	36.0
Oxidation Catalyst		564 000	10.4	18 000	1 050	2.48	0.01	0.07	2.55
Non-Catalyst		1 620 000	12.1	18 000	3 550	8.38	0.04	0.05	8.47
Light-Duty Gasoline Trucks	**Sum (*Avg*)**	**4 420 000**	***14.3***	***17 000***	**10 900**	**25.7**	**0.09**	**2.6**	**28.4**
Tier 1 Three-Way Catalyst		390 000	14.4	17 000	957	2.26	+	0.12	2.38
Tier 0 Three-Way Catalyst (new)		53 800	14.4	17 000	132	0.31	+	0.02	0.33
Tier 0 Three-Way Catalyst (aged)		3 240 000	14.2	17 000	7 830	18.5	0.07	2.4	21.0
Oxidation Catalyst		209 000	14.1	17 000	509	1.20	+	0.03	1.24
Non-Catalyst		537 000	15.5	17 000	1 460	3.44	0.02	0.02	3.48
Heavy-Duty Gasoline Vehicles	**Sum (*Avg*)**	**318 000**	***47.5***	***13 000***	**2 010**	**4.74**	**0.01**	**0.21**	**4.97**
Three-Way Catalyst		106 000	43.5	13 000	613	1.45	+	0.19	1.64
Non-Catalytic Controlled		106 000	43.5	13 000	613	1.45	+	0.01	1.46
Uncontrolled		106 000	55.6	13 000	784	1.85	0.01	0.01	1.87
Motorcycles	**Sum (Avg)**	**295 000**	***10.3***	***2 900***	**89**	**0.21**	**+**	**+**	**0.21**
Non-Catalytic Controlled		148 000	9.3	2 900	40	0.09	+	+	0.10
Uncontrolled		148 000	11.2	2 900	48	0.11	+	+	0.12
DIESEL SOURCES									
Light-Duty Diesel Automobiles	**Sum (Avg)**	**105 000**	***11.2***	***18 000***	**212**	**0.58**	**+**	**0.01**	**0.59**
Advanced Control		34 900	10.0	18 000	63	0.17	+	+	0.17
Moderate Control		34 900	10.4	18 000	65	0.18	+	+	0.18
Uncontrolled		34 900	13.3	18 000	84	0.23	+	+	0.23
Light-Duty Diesel Trucks	**Sum (Avg)**	**88 600**	***15.1***	***13 000***	**171**	**0.47**	**+**	**0.01**	**0.47**
Advanced Control		29 500	13.9	13 000	52	0.14	+	+	0.14
Moderate Control		29 500	13.9	13 000	52	0.14	+	+	0.14
Uncontrolled		29 500	17.5	13 000	66	0.18	+	+	0.18
Heavy-Duty Diesel Vehicles	**Sum (Avg)**	**634 000**	***43.0***	***41 000***	**11 200**	**30.4**	**0.03**	**0.35**	**30.8**
Advanced Control		211 000	41.7	41 000	3 610	9.85	0.01	0.11	10.0
Moderate Control		211 000	41.7	41 000	3 610	9.85	0.01	0.11	9.97
Uncontrolled		211 000	45.5	41 000	3 940	10.7	0.01	0.12	10.8
NATURAL GAS VEHICLES		**-**	**-**	**-**	**204 000**	**0.38**	**0.09**	**+**	**0.48**
PROPANE VEHICLES		**-**	**-**	**-**	**1 300**	**1.98**	**0.02**	**-**	**2**
On-Road Transport Subtotal		**-**	**-**	**-**	**-**	**113**	**0.41**	**6**	**119**
Off-Road Sources									
Off-Road Gasoline		**-**	**-**	**-**	**-**	**3.77**	**0.10**	**0.03**	**3.90**
Off-Road Diesel		**-**	**-**	**-**	**-**	**12.2**	**0.01**	**1.5**	**13.7**
Off-Road Sources Subtotal		**-**	**-**	**-**	**-**	**16.0**	**0.11**	**1.6**	**17.6**
Total Ground (Non-Rail) Sources		**-**	**-**	**-**	**-**	**129**	**0.52**	**7.5**	**137**
RAIL, MARINE AND AIR SOURCES									
Rail Transport									
Total Rail (Diesel Fuel Oil)		**-**	**-**	**-**	**-**	**5.71**	**0.01**	**0.71**	**6.43**
Marine Transport									
Motor Gasoline		-	-	-	-	0.06	0.06	0.06	0.06
Diesel Fuel Oil		-	-	-	-	2.82	0.06	0.32	3.14
Light (Distillate) Fuel Oil		-	-	-	-	0.06	0.06	0.06	0.06
Heavy (Residual) Fuel Oil		-	-	-	-	2.45	0.01	0.02	2.48
Total Marine Transport	**Sum (Avg)**	**-**	**-**	**-**	**-**	**5.35**	**0.01**	**0.34**	**5.70**
Air Transport									
Aviation Gasoline		-	-	-	-	**0.29**	**0.01**	**0.01**	**0.30**
Aviation Turbo Fuel		-	-	-	-	**10.2**	**0.01**	**0.31**	**10.5**
Total Air Transport	**Sum (Avg)**	**-**	**-**	**-**	**-**	**10.5**	**0.01**	**0.32**	**10.9**
Total (All Mobile Sources)		**-**	**-**	**-**	**-**	**150**	**0.55**	**8.9**	**160**

Fuel-consumption data was arrived at by partitioning fuel from Statistics Canada Catalogue Number 57-003 (Quarterly) according to vehicle type and activity.
CH_4 and N_2O emissions data were arrived at by multiplying fuel quantity by percent of catalyst technology, emission factor and Global Warming Potential (GWP).
(GWP for CH_4 = 21; GWP for N_2O = 310)
+ Non-zero values too small to display.

TABLE B2-3 DETAILS OF VEHICLE EMISSIONS IN CANADA FOR 1997

		Category Vehicle Population	Fuel Consumption Ratio l/100 km	Average Distance Travelled km	Total Fuel Consumed Ml	Emissions CO_2 Mt	CH_4 Mt CO_2 eq	N_2O Mt CO_2 eq	G.H.G. Total Mt CO_2 eq
GROUND (NON-RAIL) SOURCES									
On-Road Transport									
GASOLINE SOURCES									
Light-Duty Gasoline Automobiles	**Sum (Avg)**	**10 600 000**	***10.3***	***18 000***	**20 100**	**47.5**	**0.14**	**2.5**	**50.2**
Tier 1 Three-Way Catalyst		2 730 000	10.0	18 000	5 030	11.9	0.03	0.33	12.3
Tier 0 Three-Way Catalyst (new)		0	0.0	-	0	-	-	-	-
Tier 0 Three-Way Catalyst (aged)		6 430 000	10.1	18 000	12 000	28.3	0.08	2.2	30.6
Oxidation Catalyst		91 600	10.1	18 000	170	0.40	0.00	0.01	0.41
Non-Catalyst		1 370 000	11.8	18 000	2 950	6.96	0.03	0.04	7.03
Light-Duty Gasoline Trucks	**Sum (Avg)**	**4 850 000**	***14.2***	***18 000***	**12 200**	**28.7**	**0.09**	**2.7**	**31.5**
Tier 1 Three-Way Catalyst		1 370 000	14.2	18 000	3 410	8.05	0.01	0.41	8.47
Tier 0 Three-Way Catalyst (new)		0	0.0	-	0	-	-	-	-
Tier 0 Three-Way Catalyst (aged)		2 940 000	14.1	18 000	7 310	17.3	0.06	2.3	19.7
Oxidation Catalyst		37 500	14.2	18 000	95	0.22	0.00	0.01	0.23
Non-Catalyst		501 000	15.0	18 000	1 350	3.18	0.02	0.02	3.22
Heavy-Duty Gasoline Vehicles	**Sum (Avg)**	**339 000**	***47.5***	***14 000***	**2 210**	**5.22**	**0.02**	**0.23**	**5.47**
Three-Way Catalyst		113 000	43.5	14 000	675	1.59	+	0.21	1.80
Non-Catalytic Controlled		113 000	43.5	14 000	675	1.59	+	0.01	1.60
Uncontrolled		113 000	55.6	14 000	863	2.04	0.01	0.01	2.06
Motorcycles	**Sum (Avg)**	**299 000**	***10.3***	***3 000***	**92**	**0.22**	**+**	**+**	**0.22**
Non-Catalytic Controlled		150 000	9.3	3 000	42	0.10	+	+	0.10
Uncontrolled		150 000	11.2	3 000	50	0.12	+	+	0.12
DIESEL SOURCES									
Light-Duty Diesel Automobiles	**Sum (Avg)**	**104 000**	***11.2***	***18 000***	**215**	**0.59**	**+**	**0.01**	**0.59**
Advanced Control		34 700	10.0	18 000	64	0.17	+	+	0.18
Moderate Control		34 700	10.4	18 000	66	0.18	+	+	0.18
Uncontrolled		34 700	13.3	18 000	85	0.23	+	+	0.23
Light-Duty Diesel Trucks	**Sum (Avg)**	**93 100**	***15.1***	***13 000***	**178**	**0.49**	**+**	**0.01**	**0.49**
Advanced Control		31 000	13.9	13 000	55	0.15	+	+	0.15
Moderate Control		31 000	13.9	13 000	55	0.15	+	+	0.15
Uncontrolled		31 000	17.5	13 000	69	0.19	+	+	0.19
Heavy-Duty Diesel Vehicles	**Sum (Avg)**	**744 000**	***43.0***	***41 000***	**13 000**	**35.5**	**0.04**	**0.40**	**35.9**
Advanced Control		248 000	41.7	41 000	4 210	11.5	0.01	0.13	11.6
Moderate Control		248 000	41.7	41 000	4 210	11.5	0.01	0.13	11.6
Uncontrolled		248 000	45.5	41 000	4 590	12.5	0.01	0.14	12.7
NATURAL GAS VEHICLES		**-**	**-**	**-**	**109 000**	**0.21**	**0.05**	**+**	**0.26**
PROPANE VEHICLES		**-**	**-**	**-**	**1 140**	**1.74**	**0.02**	**-**	**1.76**
On-Road Transport Subtotal		**-**	**-**	**-**	**-**	**120**	**0.36**	**5.9**	**126**
Off-Road Sources									
Off-Road Gasoline		**-**	**-**	**-**	**-**	**4.19**	**0.11**	**0.03**	**4.33**
Off-Road Diesel		**-**	**-**	**-**	**-**	**13.5**	**0.02**	**1.7**	**15.3**
Off-Road Sources Subtotal		**-**	**-**	**-**	**-**	**17.7**	**0.13**	**1.7**	**19.6**
Total Ground (Non-Rail) Sources		**-**	**-**	**-**	**-**	**138**	**0.48**	**7.6**	**146**
RAIL, MARINE AND AIR SOURCES									
Rail Transport									
Total Rail (Diesel Fuel Oil)		**-**	**-**	**-**	**-**	**5.66**	**0.01**	**0.71**	**6.38**
Marine Transport									
Motor Gasoline		-	-	-	-	0.04	0.04	0.04	0.04
Diesel Fuel Oil		-	-	-	-	2.80	0.04	0.32	3.12
Light (Distillate) Fuel Oil		-	-	-	-	0.04	0.04	0.04	0.04
Heavy (Residual) Fuel Oil		-	-	-	-	2.94	0.01	0.02	2.97
Total Marine Transport	**Sum (Avg)**	**-**	**-**	**-**	**-**	**5.81**	**0.01**	**0.34**	**6.16**
Air Transport									
Aviation Gasoline		**-**	**-**	**-**	**-**	**0.26**	**0.01**	**0.01**	**0.27**
Aviation Turbo Fuel		**-**	**-**	**-**	**-**	**12.3**	**0.01**	**0.38**	**12.7**
Total Air Transport	**Sum (Avg)**	**-**	**-**	**-**	**-**	**12.6**	**0.01**	**0.38**	**13.0**
Total (All Mobile Sources)		**-**	**-**	**-**	**-**	**162**	**0.51**	**9.0**	**172**

Fuel-consumption data was arrived at by partitioning fuel from Statistics Canada Catalogue Number 57-003 (Quarterly) according to vehicle type and activity.
CH_4 and N_2O emissions data were arrived at by multiplying fuel quantity by percent of catalyst technology, emission factor and Global Warming Potential (GWP).
(GWP for CH_4 = 21; GWP for N_2O = 310)
+ Non-zero values too small to display.

An unpublished Environment Canada study (Barton and Simpson, 1995) reports on the measurement of emissions from 14 typical pre-1994 Canadian automobiles under the standard Transport Canada driving cycle (Urban Dynamometer Driving Schedule). All vehicles were equipped with Tier 0 three-way converters. Average tailpipe emissions were about 0.7 g/l for the 10 vehicles with aged converters and 0.4 g/l for the 4 vehicles with the new units.

In order to account for the effect of aged Tier 0 catalysts on emissions of nitrous oxide, vehicles within that category have been divided. Separate classifications are utilized for light-duty gasoline Tier 0 vehicles equipped with aged and new three-way catalytic converters; vehicles 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 3-way catalyst-equipped Tier 0 automobiles, have been adopted on the basis of De Soete's (1989) and Barton and Simpson's work. These can be compared with factors of 0.046 g/l for non-catalytic conversion-control technology, and 0.20 g/l for oxidation catalysts. Note that these emission factors represent values which are lower than those reported in previous inventory publications. In addition to considering Barton and Simpson's (1995) research, results from a recent survey of N_2O emission studies issued by the U.S. EPA (Michaels, 1998), have been incorporated.

In the same report, Michaels also documented EPA tests which were conducted in 1998 on a small sample of typical North American vehicles. The 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). Emission rates of 0.21 g/l of fuel have been adopted for Tier 1 gasoline automobiles on the basis of these tests.

Research indicates that under standard test conditions, light-duty gasoline trucks show consistently higher emissions of nitrous oxide per unit of fuel consumed than light-duty gasoline automobiles.[2] As a result, higher emission factors have been adopted for light trucks. For example, the LDGT N_2O emission rates utilized by M-GEM are 0.39 g/l for Tier 1 types and 1.0 g/l for aged Tier 0 types. (For more details on emission factors, see Appendix C.)

To summarize, the methodology utilized to calculate road vehicle emissions is a full *IPCC Tier 3* type (see IPCC, 1997). On the other hand, estimates provided by the M-GEM for off-road greenhouse gases must be considered to be of a *Tier 1* nature, since they are based simply on calculated fuel consumption multiplied by appropriate emission factors. (The emission factors adopted for off-road vehicles are from IPCC, 1997; see Appendix C).

Rail, Marine and Air Transport

Road, marine and aircraft emissions are also estimated by M-GEM. Fuel consumption by each of these transportation modes is obtained from Statistics Canada (Catalogue No. 57-003) and multiplied by fuel-specific emission factors. As Statistics Canada lists quantities of each of the refined petroleum products used by marine vessels (i.e., heavy fuel oil, diesel oil, light fuel oil and gasoline) it has been possible to ascribe, in a rudimentary fashion, emission by vessel type. In the same manner, aircraft emissions can be roughly subdivided into conventional and jet aircraft, based on the two reported aviation fuel types (jet and gasoline).

Carbon dioxide emission factors utilized were (as for road vehicles) derived by Jaques, 1992. Emission factors for methane and nitrous oxide from rail and marine sources are from IPCC, 1997. Those for aviation sources have been obtained from the earlier work of De Soete (1989) and Prigent, et al., 1991. (See also Appendix C). The methodologies used to estimate emissions from rail, marine and aircraft transportation sources are considered to be modified *IPCC Tier 1* types (IPCC, 1997).

According to *IPCC Guidelines* (IPCC, 1997), international marine and air transportation emissions should not be included in National Inventory totals, but reported separately as "bunkers". In keeping with the *Guidelines*, any fuel recorded by Statistics Canada as having been sold to foreign-registered marine or aviation carriers is excluded from National Inventory emission calculations. (i.e., all tables in the text and in the appendices which 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 is used for international transport. Conversely, it has become apparent that not all of the fuels sold to domestically-registered carriers is consumed within the country. The IPCC is currently giving consideration to establishing clearer guidelines for bunker methodologies. In Canada, modified statistical procedures may be required in the future to more accurately track bunker fuels.

2 See for example, Barton and Simpson, 1995 or Michaels, 1998.

Pipeline Sources

Oil and gas pipelines utilize compressors and other equipment to transport fuels. The combustion greenhouse gas emissions associated with this equipment are not calculated by M-GEM, but are categorized by the *IPCC Guidelines* under Transportation (IPCC, 1997). The methodology employed by Environment Canada, a *Tier* 1 sectoral approach, is relatively straight forward. Fuel consumption by pipelines is recorded directly by Statistics Canada (in Catalogue No. 57-003). It consists primarily of natural gas, but some refined petroleum such as diesel oil is also utilized. Emissions are determined by multiplying these consumption figures by fuel-specific emission factors. (The emission factors are those for generic industrial energy consumption, as listed in Appendix C).

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Solid Waste Disposal on Land Methodology

The following is an explanation of factors that contribute to landfill gas generation and the Scholl Canyon model (used to estimate greenhouse gas emissions from landfills). Landfill gas, which is composed mainly of methane and carbon dioxide, is produced by the anaerobic decomposition of organic wastes. The first phase of this process typically begins after waste has been in a landfill for 10 to 50 days. Although the majority of methane and carbon dioxide 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. These factors include waste composition, moisture content, temperature, pH, buffer capacity, availability of nutrients, waste density and particle size. The factors and their contribution to landfill gas generation are discussed below.

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 dependant on the distribution and the types of organic matter in the landfill (Tchobanoglous, 1993).

Moisture Content

The amount of moisture within a landfill also significantly effects the gas generation rates, since water is required for anaerobic degradation of organic matter.

Temperature

Anaerobic digestion is an exothermic process. The growth rates of bacteria tend to increase with temperature until an optimum is reached (Tchobanoglous, 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 methane in landfills is greatest when neutral pH conditions exist. Methanogenic bacteria activity is inhibited in acidic environments. For gas generation to continue, the pH of the landfill must not drop below 6.2 (Tchobanoglous, 1993).

Availability of Nutrients

Certain nutrients are required for anaerobic digestion. These include carbon, hydrogen, nitrogen and phosphorus. In general, municipal solid waste (MSW) contains the necessary nutrients to support the required bacteria 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 effects the gas generation rate.

Methodology

Two methodologies to estimate emissions from landfills are presented in the IPCC guidelines (IPCC, 1997). They include a default method and a theoretical first order kinetics method, which is also know as the Scholl Canyon model. The default method estimates emissions based only on the waste landfilled in the year of interest, whereas the Scholl Canyon model estimates emissions based on the waste that has been landfilled in the past. During the last several decades, the composition and amount of waste landfilled (due primarily to population growth) in Canada has significantly changed. For this reason a static model such as the default method is not appropriate. The emissions from MSW landfills and wood waste landfills in Canada were, therefore, estimated using the Scholl Canyon model, which relies on the following first-order decay equation:

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

where:

G_i = emission rate from the i^{th} section (kg of CH_4/year)
k = methane generation rate (1/year)
L_o = methane generation potential (m^3 of CH_4/tonne of refuse)
M_i = mass of refuse in the i^{th} section (Mt)
t_i = age of the i^{th} section (years) (IPCC, 1997)

In Canada there are well over 10,000 landfill sites (Levelton, 1991). In order to estimate methane emissions from landfills, information on several of the factors described above are needed. In addition, information on the amount of methane 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 (M_i)

MSW Landfills

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

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 Natural Resources Canada (NRCan) Wood Residue Data Base (1997). The amount of wood residue landfilled in the years 1993 to 1996 has been estimated based on a study of Pulp and Paper Mill waste completed for Paprican (1997), a study of mill residue by SEAFOR (1990) and an internal Canadian Pulp and Paper Association (CPPA) document (1998).

Methane Generation Rate (k)

The methane kinetic rate constant (k) represents the first-order rate at which methane 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 the 1991 Levelton study which acknowledges the limited amount of data available to estimate these values. 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 US k values and precipitation data, the average annual precipitation and mean daily temperature at Canadian landfills has 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 by Levelton (1991) and are listed in Table B.1.

TABLE B3-1 VALUES OF k

Province	k
British Columbia	0.028
Alberta	0.006
Saskatchewan	0.006
Manitoba	0.006
Ontario	0.024
Quebec	0.024
New Brunswick	0.011
Prince Edward Island	0.011
Nova Scotia	0.011
Newfoundland	0.011
North West Territories	0.003
Yukon	0.003

Source: 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 these four provinces was 0.01yr-1 (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, 1993).

Methane Generation Potential (L_o)

MSW Landfills

The values of theoretical and measured L_o range from 4.4 to 194 kg CH_4 /tonne of waste (Pelt,1998). For the years 1941 through to 1989, a value for L_o of 165 kg of CH_4 /tonne of waste — as suggested by the U.S. EPA — has been used (Levelton, 1991). The following equation was utilized to calculate a value of L_o for use in the years 1990 through 1996 (Ortech, 1994).

$$L_0 = (M_c{*}F_b{*}S)/2$$

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, 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 greenhouse gas (GHG) generation. The biodegradable fraction (F_b) has been determined by dividing the biodegradable carbon by the total carbon. The stoichiometric factor in the equation above for methane is 16/12, the ratio of the molecular mass of methane to carbon. The product of the three variables is divided by two since it is assumed that 50% of the gas produced will be methane and the other 50% will be carbon dioxide (Pelt, 1998). Based on these considerations, a L_o of 117 kg CH_4 / tonne of waste was calculated. As waste disposal practices in Canada change, the L_o value will be adjusted again to reflect this.

Wood Waste Landfills

The equation above has been used to calculate an L_o value of 118 kg CH_4/tonne 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 the SEAFOR (1990) and Paprican (1997) studies, the NRCan (1997) wood residue data base and an internal CPPA (1998) document.

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Methodology for 1997 Fugitive Emissions from Conventional Upstream Oil and Gas Industries

The 1997 estimates for fugitive emissions from the conventional upstream oil and gas industries were made in a manner which was different than that utilized for the 1990 to 1996 period. Emission data for 1996 was extrapolated by the changes in production between 1996 and 1997. This method will be used on an interim basis until a new study similar to the Clearstone (Picard and Ross, 1998) work is undertaken again in the future. The data used as the basis for extrapolations are shown in table B4-1. Fugitive emissions from the recently developed Hybernia oil field have not been estimated, but are assumed to have been relatively small in 1997. The estimated emissions are shown in national and provincial tables under the heading Energy - Fugitive Oil and Gas. (Note that this category also includes a very small contribution from the non-conventional upstream oil and gas industries, which was estimated using the identical methodology as that used for the 1990 to 1996 period.)

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Picard D.J. and Ross B.D., *CH_4 and VOC Emissions from the Canadian Upstream Oil and Gas Industry, Vol 1 and 2*, Clearstone Engineering, Calgary, December 1998, DRAFT.

TABLE B4-1 DATA USED TO EXTRAPOLATE 1997 EMISSIONS

Activity	Extrapolation data
Flaring	Gross new production of Natural Gas (StatCan 26-006)
Raw CO_2	Net withdrawals of Natural Gas (StatCan 26-006)
Oil and Gas Well Drilling	Constant at 96 levels (2)
Oil and Gas Well Servicing	Constant at 96 levels (2)
Natural Gas Production	Gross New Production of Natural Gas (StatCan 26-006)
Light/Medium Oil Production	Total Production of Light and Medium Crude Oil (StatCan 26-006)
Heavy Oil Production	Total Production of Heavy Oil (StatCan 26-006)
Crude Bitumen Production	Total Production of Crude Bitumen (StatCan 26-006)
Natural Gas Processing	Net Withdrawals of Natural Gas (StatCan 26-006)
Natural Gas Transmissions	Natural Gas Transmission Pipeline length (StatCan 57-205)
Liquid Product Transport	Constant at 96 levels (2)
Accidents and Equipment Failures	Constant at 95 levels(1)
Surface Casing Vents Blows and Gas Migration	Constant at 96 levels (2)

(1) 1995 levels used because 1996 had two extraordinary incidents.
(2) Assumed constant since the source is relatively small and relevant data is not readily available.

Emission Factors

With the exclusion of emissions that have been estimated by individual companies, or by numerical models, a summary of all of the emission factors (and their sources) used to develop Canada's greenhouse gas emissions are summarized in the following 11 tables.

TABLE C1 ENERGY: STATIONARY COMBUSTION SOURCES - GASEOUS FUELS

Fuel	Use	CO_2 *g / m³ fuel*	CH_4 *g / m³ fuel*	N_2O *g / m³ fuel*
Natural Gas	Utility Boiler	1 880	0.0048	0.02
	Industrial Boiler	1 880	0.048	0.02
	Commercial Boiler	1 880	0.043	0.02
	Residential Boiler Heater	1 880	0.043	0.02
	Other	1 880	0.043	0.02
		g/l HFO* eq	**g/l HFO* eq**	**g/l HFO* eq**
Refinery Fuel (Still) Gas	Industrial Energy	2 000	-	0.00002

* HFO = Heavy Fuel Oil Equivalent (in energy terms).
References:
CO_2 Emission Factors: *Natural Gas* - Marland and Rotty, 1983. *Refinery Fuel Gas* - ibid.
CH_4 Emission Factors: *Natural Gas* - U.S. EPA, 1985.
N_2O Emission Factors: *All* - Canadian Electrical Association/CANMET, 19903; U.S. EPA, 1989.

TABLE C2 ENERGY: STATIONARY COMBUSTION SOURCES - LIQUID PETROLEUM FUELS

Fuel	Use	CO_2 *g / l fuel*	CH_4 *g / l fuel*	N_2O *g / l fuel*
Light (Distillate) Oil	Utility Boiler	2 830	0.006	0.013
	Industrial Boiler	2 830	0.006	0.013
	Commercial Boiler	2 830	0.026	0.013
	Residential Furnace	2 830	0.214	0.006
	Other	2 830	0.026	0.013
Heavy (Residual) Oil	Utility Boiler	3 090	0.03	0.013
	Industrial Boiler	3 090	0.12	0.013
	Commercial Boiler	3 090	0.06	0.013
	Other	3 090	0.06	0.013
Diesel	Prime Mover	2 730	0.26	0.40
Natural Gas Liquids	Propane: Energy	1 530	0.03	-
	Butane: Energy	1 760	0.03	-
	Ethane: Energy	1 110	0.03	-

TABLE C3 ENERGY: STATIONARY COMBUSTION SOURCES - SOLID PETROLEUM FUELS

Fuel	Use	CO_2 *g / l fuel*	CH_4 *g / l fuel*	N_2O *g / l fuel*
Petroleum Coke, Liquid Derived	Energy, Coking applications	4 200	0.12	-
Petroleum Coke from Catalytic Cracker	Energy, Coking applications	3 800	-	-

References:
CO_2 Emission Factors: *Light and Heavy Distillates, Diesel* - Jaques, 1992. *Natural Gas Liquids* - Derivation assuming pure fuels, 100% oxidation; density information, Institute of Petroleum, 1973, Perry & Chilton, 1973 as per Jaques, 1992.
CH_4 Emission Factors: *Light and Heavy Distillates, Natural Gas Liquids* - U.S. EPA, 1985 (roundoff applied to commercial boiler burning heavy oil). Diesel - U.S. EPA, 1985; NAPAP, 1987; OECD, 1991.
N_2O Emission Factors: *Diesel* - DeSoete, 1989; Prigent & DeSoete, 1989; Pringent et al., 1991. *Light and Heavy Distillates* - U.S. EPA, 1996.

TABLE C4 ENERGY: STATIONARY COMBUSTION SOURCES - COAL FUELS, PART 1

Location	Coal Type	Use(s)	CO_2 *g / kg fuel*
New Brunswick	High Volatile Bituminous	Energy, Electric Power Production	2 230
Nova Scotia	High Volatile Bituminous	Energy, Electric Power Production	2 300
Quebec	U.S. Medium Volatile Bituminous	Energy, Electric Power Production	2 500
	Anthracite	Energy, Electric Power Production	2 390
Ontario	Lignite	Energy, Electric Power Production	1 490
	Low Volatile Bituminous	Energy, Electric Power Production	2 520
	U.S. Medium Volatile Bituminous	Energy, Electric Power Production	2 500
	U.S. Medium Volatile Bituminous	Integrated Steel Plants	2 460
Manitoba	Lignite	Energy, Electric Power Production	1 520
	Low Volatile Bituminous	Energy, Electric Power Production	2 520
Saskatchewan	Lignite	Energy, Electric Power Production	1 340
Alberta	Sub-Bituminous	Energy, Electric Power Production	1 740
	Low Volatile Bituminous	Energy, Electric Power Production	1 700
British Columbia	Low Volatile Bituminous	Energy, Electric Power Production	1 700
Canada	Coke	General Combustion, Where Coke Production Occurs Off-site	2 480

TABLE C5 ENERGY: STATIONARY COMBUSTION SOURCES - COAL FUELS, PART 2

Use (All Coal Types, All Provinces)	CH_4 *g / kg fuel*	N_2O *g / kg fuel*
Conventional Utility Boilers	0.015	0.05
Fluidized Bed Combustion Systems	0.015	2.11
Conventional Industrial Boilers, Commercial and Other Heating Systems	0.015	0.11

References:
CO_2 Emission Factors: Jaques, 1992, Lauer, 1991.
CH_4 Emission Factors: U.S. EPA, 1985 (average).
N_2O Emission Factors: Canadian Electrical Association/CANMET, 1990; U.S. EPA, 1989.

TABLE C6a ENERGY: TRANSPORTATION - GROUND (NON- RAIL) SOURCES

Fuel	Use	CO_2 *g / l fuel*	CH_4 *g / l fuel*	N_2O *g / l fuel*
	On-Road Transport:			
Motor Gasoline	*Light-Duty Gasoline Automobiles (LDGA)*			
	- Tier 1 Three-Way Catalyst	2 360	0.25	0.21
	- Tier 0, New Three-Way Catalyst	2 360	0.32	0.25
	- Tier 0, Aged Three-Way Catalyst	2 360	0.32	0.58
	- Oxidation Catalyst	2 360	0.42	0.20
	- Non-Catalyst	2 360	0.52	0.046
	Light-Duty Gasoline Trucks (LDGT)			
	- Tier 1 Heavy-Duty Catalyst	2 360	0.19	0.39
	- Tier 0, New Heavy-Duty Catalyst	2 360	0.41	0.45
	- Tier 0, Aged Heavy-Duty Catalyst	2 360	0.41	1.00
	- Oxidation Catalyst	2 360	0.44	0.20
	- Non-Catalyst	2 360	0.56	0.046
	Heavy-Duty Gasoline Vehicles (HDGV)			
	- Three-way Catalyst	2 360	0.17	1.00
	- Non-Catalyst	2 360	0.29	0.046
	- Uncontrolled	2 360	0.49	0.046
	Motorcycles (MC)			
	- Non-Catalytic Controlled	2 360	1.4	0.046
	- Uncontrolled	2 360	2.3	0.046
Diesel Oil	*Light-Duty Diesel Autos (LDDA)*			
	- Advance Control	2 730	0.05	0.1
	- Moderate Control	2 730	0.07	0.1
	- Uncontrolled	2 730	0.10	0.1
	Light-Duty Diesel Trucks (LDDT)			
	- Advance Control	2 730	0.07	0.1
	- Moderate Control	2 730	0.07	0.1
	- Uncontrolled	2 730	0.07	0.1
	Heavy Duty Diesel Vehicles (HDDV)			
	- Advance Control	2 730	0.12	0.1
	- Moderate Control	2 730	0.13	0.1
	- Uncontrolled	2 730	0.15	0.1
Natural Gas	*Natural Gas Vehicles*	2	0.022	0.00006
Propane	*Other Diesel Vehicles*	1 530	0.70	0.09
	Off-Road Vehicles:			
Gasoline	*Other Gasoline Vehicles*	2 360	3	0.06
Diesel	*Other Diesel Vehicles*	2 730	0.14	1.1

TABLE C6b ENERGY: TRANSPORTATION - RAIL AND NON-GROUND SOURCES

Fuel	Use	CO_2 *g / l fuel*	CH_4 *g / l fuel*	N_2O *g / l fuel*
	Rail Transportation			
Diesel	Railroad Trains	2 730	0.15	1.1
	Marine Transportation			
Gasoline	Boats	2 360	1.3	0.06
Diesel	Ships	2 730	0.15	1.00
Light (Distillate) Oil	Ships	2 830	0.3	0.07
Heavy (Residual) Oil	Ships	3 090	0.3	0.08
	Air Transportation			
Aviation Gasoline	Conventional Aircraft	2 330	2.19	0.23
Aviation Turbo	Jet Aircraft	2 550	0.08	0.25

References:

CO_2 Emission Factors: Jaques, 1992. Propane: derivation assuming pure fuel, 100% oxidation.

CH_4 Emission Factors:

On-Road Vehicle: *Natural Gas, Propane - Based on U.S. uncontrolled vehicles*; *Gasoline and Diesel* - average values used; *All CH_4 values for road vehicles* - IPCC/OECD/IEA, 1997.

Off-Road, Ground (Non-Rail) Vehicles: Andrias, et al. (1994), as found in IPCC/OECD/IEA, 1997; *Fuel Densities* - Statistics Canada, 57-003.

Rail Transport (Diesel): Andrias, et al. (1994), as found in IPCC/OECD/IEA, 1997; *Fuel Densities* - Statistics Canada, 57-003.

Marine Transport: *Gasoline and Diesel* - Andrias, et al., 1994, as found in IPCC/OECD/IEA, 1997; Fuel Densities - Statistics Canada, 57-003. *Light and Heavy Fuel Oil* - Lloyd's Register, 1995, as found in IPCC/OECD/IEA,1997; Fuel Densities - Statistics Canada, 57-003; HHV to LHV conversion - IPCC/OECD/IEA, 1997.

Aviation Transport: U.S. EPA (1985), NAPAP (1987), OECD, 1991; *Density information* - Institute of Petroleum, 1973 & Perry and Chilton, 1973, as per Jaques, 1992.

N_2O Emission Factors

Gasoline On-Road Vehicles: *Tier 1 LDGA & LDGT* - H. Michaels, 1998. *Tier 0 LDGA & LDGT* - Barton & Simpson, 1994; Ratio aged to new - DeSoete, 1989. *Oxidation & Non-Catalyst LDGA and LDGT* - H. Michaels, 1998; *HDGV, Three-Way Catalyst* - Barton and Simpson, 1994; *HDGV, Non Catalytic and Uncontrolled* - H. Michaels, 1998; *Motorcycles* - H. Michaels, 1998.

Diesel On-Road Vehicles: *LDDT* - Dietzman et al., 1980 and DeSoete, 1989; Fuel efficiencies conversions - U.S. EPA, developed by Engine, Fuel and Emissions Engineering Inc, 1996. *LDDA, HDDV* - Same values as LDDT assumed.

Natural Gas, Propane On-Road Vehicles: Heath, et al., CERI, 1996.

Off-Road, Ground (Non-Rail) Vehicles: Andrias, et al., 1994, as found in IPCC/OECD/IEA, 1997; *Fuel Densities* - Statistics Canada, 57-003.

Rail Transport (Diesel): Andrias, et al., 1994, as found in IPCC/OECD/IEA, 1997; *Fuel Densities* - Statistics Canada, 57-003.

Marine Transport: *Gasoline and Diesel* - Andrias, et al., 1994, as found in IPCC/OECD/IEA, 1997; Fuel Densities - Statistics Canada, 57-003. *Light and Heavy Fuel Oil* - Lloyd's Register, 1995, as found in IPCC/OECD/IEA, 1997; Fuel Densities - Statistics Canada, 57-003; Fuel energy densities - Statistics Canada 57-003; HHV to LHV conversion - IPCC/OECD/IEA, 1997.

Aviation Transport: DeSoete, 1989; Prigent & DeSoete, 1989; Pringent et al., 1991; *Density information* - Institute of Petroleum, 1973 & Perry and Chilton, 1973, as per Jaques, 1992.

TABLE C7 INDUSTRIAL PROCESS SOURCES

Source	Description	CO_2	N_2O	CF_4	C_2F_6
		g / kg feed			
Mineral Use					
Limestone Use	In Iron and Steel, Glass, Non-Ferrous Metal Production	440	-	-	-
Soda Ash Use	In Glass Manufacture	415	-	-	-
		g / kg product			
Mineral Products					
Cement Production	Limestone Calcination	500	-	-	-
Lime Production	Limestone Calcination	790	-	-	-
Chemical Industry					
Ammonia Production	From Natural Gas	1 600	-	-	-
Metal Manufacture					
Primary Aluminum	Electrolysis Process	(1.54-1.83)	-	(0.3-1.1)	(0.02-0.1)

References:
CO_2 Emission Factors:
Limestone Use - ORTECH, 1994. *Soda Ash Use* - DOE/EIA, 1993. *Lime Production* - ORTECH, 1991, *Cement Production* - Orchard, 1973, Jaques 1992. *Ammonia Production* - Industrial Chemicals, 1980; Jaques 1992. *Primary Aluminum* - ORTECH, 1994 (emission factors vary with technology used).
CH_4 Emission Factors:
Adipic Acid Production - Thiemens and Trogler, 1991.
CF_4, C_2F_6 Emission Factors:
Primary Aluminum Production - Unisearch Associates, 1994, adapted by Environment Canada; emission factors vary with smelting technology.

TABLE C8 HYDROCARBON NON-ENERGY PRODUCTS

Description	CO_2 *g / l*
Ethane Use	222
Butane Use	352
Propane Use	306
Petrochemical Distillate Use for Feedstocks	500
Naptha Used for Various Products	625
Petroleums Used for Lubricants	1 410
Petroleums Used for Other Products	1 450
	t / m³
Natural Gas Use for Chemical Products	1 260

References:
CO_2 Emission Factors: IPCC/OECD/IEA, 1997.

TABLE C9 SOLVENT AND OTHER PRODUCT EMISSION SOURCES

Product	Application	CO_2 *g / capita*	CH_4 *g / capita*	N_2O *g / capita*
Nitrous Oxide Use	Anaesthetic Usage	-	-	46.2
	Propellant Usage	-	-	2.38

References:
N_2O Emission Factors: *Anaesthetic Usage* - Fettes, 1994.

TABLE C10 BIOMASS EMISSION AND SEQUESTRATION FACTORS

Source/Sink	Description	CO_2 *g / kg fuel*	CH_4 *g / kg fuel*	N_2O *g / kg fuel*
Wood Fuel / Wood Waste	Industrial Combustion	1 500	0.15	0.16
Accidental Forest Fires	Open Combustion	1 630	3.0	0.24
Prescribed Burns	Open Combustion	1 620	6.2	0.25
Spent Pulping Liquor	Industrial Combustion	1 500	-	-
Stoves and Fireplaces				
Conventional Stoves	Residential Combustion	1 500	15	0.16
Conventional Fireplaces	Residential Combustion	1 500	15	0.16
Fireplaces with inserts (non-catalytic controls)	Residential Combustion	1 500	8	0.16
Fireplaces with inserts (with catalytic controls)	Residential Combustion	1 500	5.8	0.16
Other Wood Burning Equipment	Residential Combustion	1 500	15	0.16

Note: CO_2 emission from biomass sources are not included in inventory totals. Emissions for CH_4 and N_2O are inventoried under Energy, except for accidental forest fires and prescribed burns, which are reported under Land Use Change and Forestry.

References:
CO_2 Emission Factors
Wood Fuel/Wood Waste - U.S. EPA (1996); Accidental Forest Fires and Prescribed Burns - Taylor (1996).
CH_4 Emission Factors
Wood Fuel/Wood Waste - U.S. EPA (1985); Accidental Forest Fires and Prescribed Burns - Taylor (1996).
N_2O Emission Factors
Wood Fuel/Wood Waste - Rosland & Steen (1990), Radke et al. (1991); Accidental Forest Fires and Prescribed Burns - Taylor (1996).

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Uncertainty

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 socio-economic 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.

In 1994, Environment Canada completed a study of the underlying uncertainties associated with Canada's greenhouse gas emissions 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 not warranted in this report and readers are referred to the original study for further details.[1] Overall uncertainties were developed based on a stochastic model and were estimated to be about 4% for carbon dioxide, 30% for methane and 40% for nitrous oxide. It should be noted that individual sector uncertainties can be even greater. In addition, as far as inventories go, the uncertainties associated with carbon dioxide (which dominates the greenhouse gas inventory) are very low.

Uncertainty Estimates - Methods and Results

While evaluating uncertainties it was determined that, while many estimates are likely to have *normal* (symetrical) distributions, some are non-symetrical. Individual uncertainty range estimates by industry experts were skewed in some cases (i.e, not symetrically distributed), necessitating the use of Monte Carlo stochastic computer simulation to develop group and then overall uncertainty estimates for each greenhouse gas. 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 earlier 1990 inventory, many data sources and emission rates have remained the same, as have the methods used to estimate emissions, so it is reasonable to assume that the uncertainty in the carbon dioxide and methane emissions are still of the same order.

Table D-1 provides a summary of the uncertainties as they are presumed to relate to the current 1996 estimates. It must be understood that these represent the reliability of the estimation methodologies in use. They cannot be construed as a complete evaluation of inventory accuracy, since the method of statistical uncertainties cannot account for unforseen emission sources. Furthermore, because uncertainty estimates have not been undated since 1994, some sources are now unaccounted for. For example, N_2O emissions from agriculture soils (a significant source) are currently estimated using new techniques and therefore this source has no uncertainty attached to it. In fact, the overwhelming quantity of newer methodologies now used for developing N_2O emissions has dictated that the total uncertainty previously calculated for this gas is no longer valid.

True statistical uncertainty estimates for PFC, SF_6 and HFC emissions have not been developed. Canadian researchers indicate that measured PFC emissions have a factor of uncertainty of about two (Schiff, 1996). Since total PFC emission estimates represent further extrapolations from the measured data, they are expected to be even less certain. Estimates for SF_6 emissions from magnesium manufacturing are based on consumption data supplied by industry and therefore their quality is assumed to be somewhat higher. HFC methodologies are based on highly aggregated consumption information, so emission estimates are presumed to be of about the same order of uncertainty as those for PFCs.

A few broad statements can be made about Table D-1. First, the quantity of emission sources for which numerical uncertainty estimates are not available (n/a) amounts to about 10% of the total Greenhouse Gas Inventory. In general, the least accurate estimates are those for N_2O. The uncertainty of these estimates generally fall in the 50% and above range. However, about two thirds of the current N_2O inventory (representing close to 7% of Canadian emissions) has not been statistically evaluated.

Of greatest concern are large sources of emissions with either significant or unknown uncertainty ranges. Two examples are immediately apparent. The Upstream Oil and Gas Industry's methane emissions represent about 6% of the Canadian inventory and have been experiencing rapid growth (more than 40% between

1 T.J. McCann & Associates, 1994.

TABLE D1 UNCERTAINTY OF CANADA'S GREENHOUSE GAS EMISSION ESTIMATES BY SOURCE

Source/Sink (Old Categories)	1996 Emission Estimates kt CO_2 eq	Uncertainty[1] +/- %	Quality of National Estimates[2]	Share of Canadian Emissions in Percent CO_2 equivalent %	Canadian Emission Trends
Carbon Dioxide (CO_2)					
Mobile Fuel Combustion	155 000	5-10	1	23	UP
Power and Steam Generation	100 000	5	1	15	UP
Industrial Energy Consumption	81 400	8	1	12	UP
Residential and Agriculture Energy Consumption	49 800	6-8	1	7	UP
Producer Consumption of Energy	37 200	20	2	6	UP
Commercial and Public Administration Energy Consumption	30 100	6-8	1	4	UP
Miscellaneous Non-Energy Petroleum Uses	28 700	30	2	4	UP
Pipelines, Fuel Combustion	12 100	10	1	2	UP
Cement and Lime Production (Non-Energy)	5 530	10-15	2	1	VARIABLE
Ammonia Production and Others (Non-Energy)	6 440	n/a	3	1	UP
Agricutural Soils (Non-Energy)*	2 000	n/a	3	0	DOWN
Municipal Solid Waste Incineration*	270	n/a	3	0	UP
Carbon Dioxide (CO_2) Total	**508 000**	**~4**	**1**	**76**	UP
Methane (CH_4)					
Upstream Oil and Gas Industry (Non-Combustion)**	37 000	~30	2	6	UP
Landfills (Non-Energy)	20 000	30	2	3	UP
Enteric Fermentation (Non-Energy)	18 000	~20	2	3	UP
Manure Management (Non-Energy)	4 400	+50/-30	3	1	UP
Fugitive Coal Mining**	1 800	+50/-30	3	0	DOWN
Mobile Fuel Combustion**	570	40	2	0	UP
Wastewater & Composting (Non-Energy)*	390	n/a	3	0	UP
Wood and Wood Waste Combustion*	5 400	n/a	3	1	UP
Prescribed Fires*	900	n/a	3	0	DOWN
Sectoral Stationary Fuel Combustion[3] **	64	40	2	0	UP
Power and Steam Generation**	20	~40	2	0	UP
Producer Consumption of Energy**	16	~40	2	0	UP
Municipal Solid Waste Incineration*	6.9	n/a	2	0	DOWN
Pipelines, Fuel Combustion**	5.7	~40	2	0	UP
Methane (CH_4) Total	**90 000**	**~30**	**2**	**13**	**UP**
Nitrous Oxide (N_2O)					
Agricultural Soils (Non-Energy)*	30 000	n/a	3	5	UP
Adipic Acid Production (Non-Energy)	11 000	15	2	2	DOWN
Mobile Fuel Combustion**	8 900	50	3	1	UP
Manure Management (Non-Energy)*	4 600	n/a	3	1	UP
Wood and Wood Waste Combustion*	1 500	n/a	3	0	UP
Sectoral Stationary Fuel Combustion**	1 100	50	3	0	UP
Prescribed Fire (Land Use Change and Forestry)*	900	n/a	3	0	DOWN
Wastewater Handling (Non-Energy)*	940	n/a	3	0	UP
Nitric Acid Production (Non-Energy)	1 000	60	3	0	FLAT
Anaesthetics & Propellants (Non-Energy)	450	+100/-50	3	0	UP
Municipal Solid Waste Incineration*	58	n/a	3	0	UP
Pipelines, Fuel Combustion**	39	~50	3	0	UP
Nitrous Oxide (N_2O) Total	**66 000**	**n/a**	**3**	**10**	**UP**
Perfluorocarbons (PFCs)					
Aluminum Manufacturing (Non-Energy)*	6 000	n/a	3	1	DOWN
Sulphur Hexaflouride (SF_6)					
Magnesium Manufacturing (Non-Energy)*	1 400	n/a	2	0	DOWN
Hydrofluorocarbon (HFCs)					
Refrigeration and Foam Uses (Non-Energy)*	500	n/a	3	0	FLAT
National Total (excluding CO_2 from Land Use Change and Forestry)	**671 000**	**n/a**	**1**	**100**	**UP**

1 Overall uncertainties have previously been estimated to be +/- 4% for CO_2, +/- 30% for CH_4 and +/- 40% for N_20.
2 Quality of National Estimates: Class 1 = Up to 10% Uncertainty, Class 2 = 10-50% Uncertainty, Class 3 = Above 50% Uncertainty.
3 Sectoral Stationary Fuel Combustion = Mining, Construction, Commercial and Institutional.
* Since uncertainty estimates were developed, a new methodology has been incorporated to evaluate greenhouse gas emissions from this source.
** The methodology has been revised and improved since the uncertainty study was performed. Therefore, the uncertainty associated with this source is assumed to be within the previous range.
n/a Numerical uncertainty not available; data quality has been estimated.
Note: Due to rounding, individual values may not add up to totals.

Conversion of Original to New Data Categories

Old Category		New Category
Carbon Dioxide (CO_2)		**Carbon Dioxide (CO_2)**
Mobile Fuel Combustion	=	Transportation (excluding Pipelines)
Power and Steam Generation	=	Electricity and Steam Generation
Industrial Energy Consumption	=	Petroleum Product from Natural Gas Portion of Fossil Fuel Industries, Manufacturing, Mining, Construction, Ferrous Metal Production, and CO_2 from Aluminum and Magnesium Production
Residential and Agriculture Energy Consumption	=	Residential and Other
Producer Consumption of Energy	=	Fossil Fuel Industries (excluding Petroleum Product from Natural Gas)
Commercial and Public Administration Energy Consumption	=	Commercial and Institutional
Miscellaneous Non-Energy Petroleum Uses	=	Fugitive Oil & Gas and Other & Undifferentiated Production
Pipelines, Fuel Combustion	=	Pipelines
Cement and Lime Production (Non-Energy)	=	Non-Metallic Mineral Production (excluding Soda Ash and Limestone Use)
Ammonia Production and Others (Non-Energy)	=	CO_2 from Ammonia/Adipic Acid & Nitric Acid Production, Soda Ash and Limestone Use portion of Non-Metallic Mineral Production
Agricutural Soils (Non-Energy)	=	Agricultural Soils
Municipal Solid Waste Incineration	=	Waste Incineration
Methane (CH_4)		**Methane (CH_4)**
Upstream Oil and Gas Industry (Non-Combustion)	=	Fugitive Oil & Gas
Landfills (Non-Energy)	=	Solid Waste Disposal on Land
Enteric Fermentation (Non-Energy)	=	Enteric Fermentation
Manure Management (Non-Energy)	=	Manure Management
Fugitive Coal Mining	=	Fugitive Solid Fuels (i.e. Coal Mining)
Mobile Fuel Combustion	=	Transportation (excluding Pipelines)
Wastewater & Composting (Non-Energy)	=	Wastewater Handling
Wood and Wood Waste Combustion	=	Wood combustion methane emissions portion of Residential and Manufacturing
Prescribed Fires	=	Land Use Change & Forestry
Sectoral Stationary Fuel Combustion	=	Residential, Manufacturing, Mining, Construction, Commercial and Institutional & Other
Power and Steam Generation	=	Electricity and Steam Generation
Producer Consumption of Energy	=	Fossil Fuel Industries
Municipal Solid Waste Incineration	=	Waste Incineration
Pipelines, Fuel Combustion	=	Pipelines
Nitrous Oxide (N_2O)		**Nitrous Oxide (N_2O)**
Agricultural Soils (Non-Energy)	=	Agricultural Soils
Adipic Acid Production (Non-Energy)	=	Adipic Acid portion of Ammonia/Adipic Acid & Nitric Acid Production
Mobile Fuel Combustion	=	Transportation (excluding Pipelines)
Manure Management (Non-Energy)	=	Manure Management
Wood and Wood Waste Combustion	=	Residential and Manufacturing
Sectoral Stationary Fuel Combustion	=	Fossil Fuel Industries, Electricity & Steam Generation, Mining, Construction and Other (Fuel Combustion)
Prescribed Fire (Land Use Change and Forestry)	=	Prescribed Fire portion of Land Use Change & Forestry
Wastewater Handling (Non-Energy)	=	Wastewater Handling
Nitric Acid Production (Non-Energy)	=	Nitric Acid portion of Ammonia/Adipic Acid & Nitric Acid Production
Anaesthetics & Propellants (Non-Energy)	=	Solvent & Other Product Use
Municipal Solid Waste Incineration	=	Waste Incineration
Pipelines, Fuel Combustion	=	Pipelines
Perfluorocarbons (PFCs)		**Perfluorocarbons (PFCs)**
Aluminum Manufacturing (Non-Energy)	=	Aluminum and Magnesium Production
Sulphur Hexaflouride (SF_6)		**Sulphur Hexaflouride (SF_6)**
Magnesium Manufacturing (Non-Energy)	=	Aluminum and Magnesium Production
Hydrofluorocarbon (HFCs)		**Hydrofluorocarbon (HFCs)**
Refrigeration and Foam Uses (Non-Energy)	=	Solvent & Other Product Use

1990 and 1996). With an estimated uncertainty of about 30%, this source could bear further study. A second example is the nitrous oxide emissions from agricultural soils. The statistical uncertainty associated with the estimate has not yet been determined, but indications are that it may have an accuracy of only about an order of magnitude. Considering that this source represents 5% of the inventory, further research in this area is warranted as well.

New Data Categories

In order to allow more accurate correspondence with the new 1996 IPCC Guidelines (IPCC/OECD/IEA, 1997), Canada has adopted a new presentation for its inventory tables (see, for example, Appendix A). This

TABLE D2 NUMBER OF SIGNIFICANT FIGURES APPLIED TO GREENHOUSE GAS SUMMARY TABLES
Based on the Uncertainty of Emission Estimates

GHG Source or Sink (New Categories)	CO_2	CH_4	N_2O	HFCs	PFCs	SF_6	Total
Energy							
Fuel Combustion							
Fossil Fuel Industries	3	2	2				3
Electricity and Steam Generation	3	2	2				3
Mining	3	2	2				3
Manufacturing	3	2	2				3
Construction	3	2	2				3
Transportation							
Gasoline Cars	3	2	2				3
Light-Duty Gasoline Trucks	3	2	2				3
Heavy-Duty Gasoline Trucks	3	2	2				3
Motorcycles	3	2	2				3
Off-Road Gasoline Vehicles	3	2	2				3
Diesel Cars	3	2	2				3
Light-Duty Diesel Trucks	3	2	2				3
Heavy-Duty Diesel Trucks	3	2	2				3
Off-Road Diesel Vehicles	3	2	2				3
Propane and Natural Gas Vehicles	3	2	2				3
Domestic Air	3	2	2				3
Domestic Marine	3	2	2				3
Rail	3	2	2				3
Vehicles Subtotal	**3**	**2**	**2**				**3**
Pipelines	3	2	2				3
Transportation Subtotal	**3**	**2**	**2**				**3**
Residential	3	2	2				3
Commercial and Institutional	3	2	2				3
Other	3	2	2				3
Combustion Subtotal	**3**	**2**	**2**				**3**
Fugitive							
Solid Fuels (i.e. Coal Mining)		2					2
Oil and Gas	2	2					2
Fugitive Subtotal	**2**	**2**					**2**
Energy Total	**3**	**2**	**2**				**3**
Industrial Processes							
Non-Metallic Mineral Production	3						3
Ammonia, Adipic Acid & Nitric Acid Production	3		2				3
Ferrous Metal Production	3						3
Aluminum and Magnesium Production	3				1	2	2
Other and Undifferentiated Production	2						2
Industrial Processes Total	**2**		**2**		**1**	**2**	**2**
Solvent & Other Product Use			**2**	**1**			**1**
Agriculture							
Enteric Fermentation		2					2
Manure Management		2	2				2
Agricultural Soils	1		1				1
Agriculture Total	**1**	**2**	**2**				**2**
Land Use Change & Forestry		**1**	**1**				**2**
Waste							
Solid Waste Disposal on Land		2					2
Wastewater Handling		2	2				2
Waste Incineration	2	2	2				2
Waste Total	**2**	**2**	**2**				**2**
TOTAL	**3**	**2**	**2**	**1**	**1**	**2**	**3**
CO_2 from Land Use Change & Forestry	**1**						

presentation reflects the sectors and categories which are now an integral part of the IPCC approach. Unfortunately, older data categories (as presented in earlier Canadian Inventories[2]) do not directly correspond with the line items in the new tables. To allow comparisons between the newer and older data categories, a set of conversions has been developed (see box above).

Since the uncertainty estimates were developed for an older version of the inventory, they can only be presented for the old data categories. The conversions described in the box can be applied to the emissions, but no attempt has been made to recalculate statistical uncertainties for the new categories. Thus, the uncertainty estimates provided can only be accurately applied to those emission categories for which a direct one-to-one relationship to the old data format exists.

Rounding Protocol

In order to provide some guidance as to the approximate level of uncertainty which each of the emission estimates represent, engineering approximations have been developed for the new categories. This data quality is reflected by presenting the emissions to an appropriate number of significant figures. The number of significant figures to which each source category has been rounded is shown in Table D2. These have 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:	greater than 50% uncertainty
Two significant figures:	10% to 50% uncertainty
Three significant figures:	less than 10% uncertainty

These uncertainty intervals were usually, but not always, followed. In some cases, emission estimates which have uncertainty marginally outside the specified interval, have been shown with a greater number of significant figures than the intervals listed would dictate. This has been done to maintain consistency between categories within a sector. It should be noted that emissions from agricultural soils, carbon dioxide from LUCF, PFC and HFC emissions have a very high uncertainty (IPCC, 1997; Schiff, 1996) and as a result only one significant figure has been shown for these estimates.

All calculations, including summing of emission totals, have been made using unrounded data.

References

International Panel on Climate Change /OECD/IEA, *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, IPCC, Bracknell, UK, 1997.

Schiff, H., Personal communication with researcher who performed measurements of PFC emissions from aluminum smelters in Canada, 1996. Note that a factor of uncertainty of two is equivalent to a statistical uncertainty of about 30%.

T.J. McCann and Associates, *Uncertainties in Canada's 1990 Greenhouse Gas Emission Estimates*. Report prepared for Environment Canada, Pollution Data Branch, Hull, March, 1994.

2 See, for example, Jaques, A.P., F. Neitzert, P. Boileau, *Trends in Canada's Greenhouse Gas Emissions 1990-1995*, Environment Canada, Pollution Data Branch; Ottawa, 1997.

1997 Standard IPCC Tables - Brief Version

The following tables conform to the standard Intergovernmental Panel on Climate Change (IPCC) structure, as required for reporting greenhouse gas emissions in a consistent international format to the United Nations Framework Convention on Climate Change (UNFCCC). Though the categorizations conform with those utilized in the tables elsewhere in this document, there are some differences. In general, the IPCC tables are more detailed than the one-page national summaries shown in Appendix A, but in some cases emissions are also grouped slightly differently. These differences in reporting structure have no effect on the estimates themselves, however. Total national emissions and sector sums are identical in all table formats.

1997 STANDARD IPCC TABLES - BRIEF VERSION

TABLE 1 - SECTORAL REPORT FOR ENERGY

(Gg)

Greenhouse Gas Source and Sink Categories	CO_2	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
Total Energy	**480 000**	**2 200**	**38**				
A. Fuel Combustion Activities (Sectoral Approach)	**466 000**	**290**	**38**				
1. Energy Industries	**161 000**	**1.7**	**3.1**				
a. Public Electricity and Heat Production	111 000	1.0	2.7				
b. Petroleum Refining	21 600	0.1	0.1				
c. Manufacture of Solid Fuels and Other Energy Industries	28 900	0.6	0.3				
2. Manufacturing Industries and Construction	**53 900**	**1.8**	**1.7**				
a. Iron and Steel	7 120	0.2	0.4				
b. Non-Ferrous Metals	2 850	0.0	0.1				
c. Chemicals	8 600	0.3	0.1				
d. Pulp Paper and Print	10 900	0.6	0.6				
e. Food Processing Beverages and Tobacco	IE	IE	IE				
f. Other (please specify)	34 400	0.8	0.6				
3. Transport	**174 000**	**25**	**29**				
a. Civil Aviation	12 600	0.6	1.2				
b. Road Transportation	120 000	17	19				
c. Railways	5 660	0.3	2.3				
d. Navigation	5 810	0.5	1.1				
e. Other Transport	17 700	6.0	5.6				
f. Pipeline Transport	12 100	0.3	0.1				
4. Other Sectors	**77 200**	**260**	**3.7**				
a. Commercial/Institutional	30 600	0.6	0.3				
b. Residential	43 800	260	3.3				
c. Agriculture/Forestry/Fishing	2 920	0.1	0.1				
5. Other (please specify)							
B. Fugitive Emissions from Fuels	**14 000**	**1 900**	**NE**				
1. Solid Fuels	**NE**	**78**	**NA**				
a. Coal Mining	NE	78	NA				
b. Solid Fuel Transformation	NE	NE	NA				
c. Other (please specify)							
2. Oil and Natural Gas	**14 000**	**1 800**	**NE**				
a. Oil	36	690	NA				
b. Natural Gas	27	1 100	NA				
c. Venting and Flaring	14 000	29	NE				
Memo Items (1)							
International Bunkers	**3 970**	**0.1**	**1.9**				
Aviation	2 450	0.1	1.1				
Marine	1 520	0.0	0.8				
CO_2 Emissions from Biomass	**71 000**						

(1) Not included in energy totals.

Precursor gas estimates are not yet available.

IE = Inventoried elsewhere
NA = Not applicable
NE = Not estimated
NO = Not known to be occurring

1997 STANDARD IPCC TABLES - BRIEF VERSION

TABLE 2 - SECTORAL REPORT FOR INDUSTRIAL PROCESSES

Greenhouse Gas Source and Sink Categories	CO_2 (Gg)	CH_4 (Gg)	N_2O (Gg)	NO_x (Gg)	CO (Gg)	NMVOC (Gg)	SO_2 (Gg)	HFCs (Gg CO_2 Equivalent)		PFCs (Gg CO_2 Equivalent)		SF_6 (Gg CO_2 Equivalent)	
								P	A	P	A	P	A
Total Industrial Processes	**38 000**	**NE**	**34**							**NE**	**6 000**	**1 400**	**1 400**
A. Mineral Products	**8 280**		**NA**										
1. Cement Production	6 010												
2. Lime Production	1 930												
3. Limestone and Dolomite Use	279												
4. Soda Ash Production and Use	64												
5. Asphalt Roofing	NA												
6. Road Paving with Asphalt	NA												
7. Other (please specify)													
B. Chemical Industry	**4 140**		**34**										
1. Ammonia Production	4 140		NA										
2. Nitric Acid Production	NA		2.5										
3. Adipic Acid Production	NA		32										
4. Carbide Production	IE		NA										
5. Other (please specify)													
C. Metal Production	**11 900**		**NE**								**6 000**	**1 400**	**1 400**
1. Iron and Steel Production	8 110												
2. Ferroalloys Production	IE												
3. Aluminium Production	3 790										6 000		
4. SF_6 Used in Aluminium and Magnesium Foundries	NA											1 400	1 400
5. Other (please specify)													
D. Other Production	**NA**	**NA**	**NA**										
1. Pulp and Paper													
2. Food and Drink													
E. Production of Halocarbons and Sulphur Hexafluoride	**NA**	**NA**	**NA**					**NO**	**NO**	**NO**	**NO**	**NO**	**NO**
1. By-product Emissions													
2. Fugitive Emissions													
3. Other (please specify)													
F. Other (Undifferentiated Processes)	**14 000**	**NE**	**NE**										

P = Potential emissions based on Tier 1 Approach. A = Actual emissions based on Tier 2 Approach.

Precursor gas estimates are not yet available.

IE = Inventoried elsewhere
NA = Not applicable
NE = Not estimated
NO = Not known to be occuring

1997 STANDARD IPCC TABLES - BRIEF VERSION

TABLE 3 - SECTORAL REPORT FOR SOLVENT AND OTHER PRODUCT USE

Greenhouse Gas Source and Sink Categories	(Gg) CO_2	CH_4	N_2O	NO_x	CO	NMVOC	SO_2	(Gg CO_2 Equivalent) HFCs P	HFCs A	PFCs P	PFCs A	SF_6 P	SF_6 A
Total Solvent and Other Product Use	**NE**	**NA**	**2**					**5 000**	**500**				
A. Paint Application			NA										
B. Degreasing and Dry Cleaning			NA										
C. Chemical Products, Manufacture and Processing			NA										
D. Anaesthetic and Propellant use			**2**										
E. Consumption of Halocarbons and Sulphur Hexafluoride	**NA**	**NA**	**NA**					**5 000**	**500**	**NE**	**NE**	**NE**	**NE**
1. Refrigeration and Air Conditioning Equipment								5 000	400				
2. Foam Blowing								10	10				
3. Fire Extinguishers								NE	NE				
4. Aerosols								20	20				
5. Solvents								NE	NE				
6. Other (please specify)													

P = Potential emissions based on Tier 1 Approach. A = Actual emissions based on Tier 2 Approach.

Precursor gas estimates are not yet available.

IE = Inventoried elsewhere
NA = Not applicable
NE = Not estimated
NO = Not known to be occuring

1997 STANDARD IPCC TABLES - BRIEF VERSION

TABLE 4 - SECTORAL REPORT FOR AGRICULTURE

(Gg)

Greenhouse Gas Source and Sink Categories	CO_2	CH_4	N_2O	NO_x	CO	NMVOC
Total Agriculture	**1 000**	**1 100**	**130**			
A. Enteric Fermentation	**NA**	**870**	**NE**			
1. Cattle		840				
2. Buffalo		NE				
3. Sheep		5.8				
4. Goats		0.1				
5. Camels and Llamas		NE				
6. Horses		6.4				
7. Mules and Asses		0.0				
8. Swine		17				
9. Poultry		0.0				
10. Other (please specify)						
B. Manure Management	**NA**	**200**	**15**			
1. Cattle		76	IE			
2. Buffalo		NE	NE			
3. Sheep		0.1	IE			
4. Goats		0.0	IE			
5. Camels and Llamas		NE	NE			
6. Horses		0.0	IE			
7. Mules and Asses		0.0	IE			
8. Swine		120	IE			
9. Poultry		10	IE			
10. Anaerobic		IE	0.0			
11. Liquid Systems		IE	0.4			
12. Solid Storage and Dry Lot		IE	14			
13. Other		IE	0.5			
C. Rice Cultivation	**NO**	**NO**	**NO**			
1. Irrigated						
2. Rainfed						
3. Deep Water						
4. Other (please specify)						
D. Agricultural Soils	**1 000**	**NA**	**100**			
E. Prescribed Burning of Savannas	**NO**	**NO**	**NO**			
F. Field Burning of Agricultural Residues	**NO**	**NO**	**NO**			
1. Cereals						
2. Pulse						
3. Tuber and Root						
4. Sugar Cane						
5. Other (please specify)						
G. Other (please specify)						

Precursor gas estimates are not yet available.

IE = Inventoried elsewhere
NA = Not applicable
NE = Not estimated
NO = Not known to be occurring

1997 STANDARD IPCC TABLES - BRIEF VERSION

TABLE 5 - SECTORAL REPORT FOR LAND-USE CHANGE AND FORESTRY

(Gg)

Greenhouse Gas Source and Sink Categories	CO_2 Emissions	CO_2 Removal	CH_4	N_2O	NO_x	CO
Total Land-Use Change and Forestry	**10 000**	**-40 000**	**40**	**3**		
A. Changes in Forest and Other Woody Biomass Stocks (1)	**0**	**-30 000**	**NA**	**NA**		
1. Tropical Forests	NA	NA				
2. Temperate Forests						
3. Boreal Forests						
4. Grasslands/Tundra	NA	NA				
5. Other (please specify)						
B. Forest and Grassland Conversion	**4 000**	**NO**	**NA**	**NA**		
1. Tropical Forests	NA					
2. Temperate Forests	3 000					
3. Boreal Forests	800					
4. Grasslands/Tundra	100					
5. Other (urban)	200					
C. Abandonment of Managed Lands	**0**	**-4 000**	**NA**	**NA**		
1. Tropical Forests		NA				
2. Temperate Forests		-4 000				
3. Boreal Forests		-100				
4. Grasslands/Tundra		0				
5. Other (please specify)		0				
D. CO_2 Emissions and Removals from Soil (2)	**5 000**		**NA**	**NA**		
E. Other (fires caused by human activities)	**6 000**	**NA**	**40**	**3**		
1. Prescribed Burning (CO_2 included in A)	NE		10	1		
2. Other Fires in Wood Production Forest (CO_2 included in A)	NE		20	1		
3. Fires (Outside of Wood Production Forest)	6 000		10	1		

(1) Using the currently approved IPCC methodology.
(2) Emissions from agricultural soils and liming are included in Section 4.

IE = Inventoried elsewhere
NA = Not applicable
NE = Not estimated
NO = Not known to be occurring

1997 STANDARD IPCC TABLES - BRIEF VERSION

TABLE 6 - SECTORAL REPORT FOR WASTE

(Gg)

Greenhouse Gas Source and Sink Categories	CO_2	CH_4	N_2O	NO_x	CO	NMVOC
Total Waste	**280**	**1 000**	**3.2**			
A. Solid Waste Disposal on Land	**NA**	**1 000**	**NA**			
1. Managed Waste Disposal on Land		1 000				
2. Unmanaged Waste Disposal Sites		NE				
3. Other (please specify)						
B. Wastewater Handling	**NE**	**19**	**3.1**			
1. Industrial Wastewater		NE	NE			
2. Domestic and Commercial Wastewater		19	3.1			
3. Other (please specify)						
C. Waste Incineration	**280**	**0.3**	**0.2**			
D. Other (please specify)						

Precursor gas estimates are not yet available.

IE = Inventoried elsewhere
NA = Not applicable
NE = Not estimated
NO = Not known to be occurring

1997 STANDARD IPCC TABLES - BRIEF VERSION

TABLE 7A - SUMMARY REPORT FOR NATIONAL GREENHOUSE GAS INVENTORIES

Greenhouse Gas Source and Sink Categories	CO_2 Emissions (Gg)	CO_2 Removals (Gg)	CH_4 (Gg)	N_2O (Gg)	NO_x (Gg)	CO (Gg)	NMVOC (Gg)	SO_2 (Gg)	HFCs (Gg CO_2 Equivalent)		PFCs (Gg CO_2 Equivalent)		SF_6 (Gg CO_2 Equivalent)	
									P	A	P	A	P	A
Total CO_2 Emissions (not including LUCF)	**520 000**	NA	NA	NA										
Total National Emissions and Removals	**535 000**	**-40 000**	**4 300**	**210**					**5 000**	**500**	**NE**	**6 000**	**1 400**	**1 400**
1. Energy	**480 000**	**NA**	**2 200**	**38**										
A. Fuel Combustion (Sectoral Approach)	466 000		290	38										
1. Energy Industries	161 000		1.7	3.1										
2. Manufacturing Industries and Construction	53 900		1.8	1.7										
3. Transport	174 000		25	29										
4. Other Sectors	77 200		260	3.7										
5. Other (please specify)														
B. Fugitive Emissions from Fuels	14 000		1 900	NE										
1. Solid Fuels	NE		78	NA										
2. Oil and Natural Gas	14 000		1 800	NE										
2. Industrial Processes	**38 000**	**NA**	**NE**	**34**							**NE**	**6 000**	**1 400**	**1 400**
A. Mineral Products	8 280			NA										
B. Chemical Industry	4 140			34										
C. Metal Production	11 900			NE								6 000	1 400	1 400
D. Other Production														
E. Production of Halocarbons and Sulphur Hexafluoride									NO	NO			NO	NO
F. Other (Undifferentiated Processes)	14 000		NE											
3. Solvent and Other Product Use	**NE**	**NA**	**NE**	**2**					**5 000**	**500**				
4. Agriculture	**1 000**	**IE**	**1 100**	**130**										
A. Enteric Fermentation	NA	NA	870	NA										
B. Manure Management	NA	NA	200	15										
C. Rice Cultivation	NO	NO	NO	NO										
D. Agricultural Soils	1 000	IE	NE	100										
E. Prescribed Burning of Savannas	NO	NO	NO	NO										
F. Field Burning of Agricultural Residues	NO	NO	NO	NO										
G. Other (please specify)														
5. Land-Use Change & Forestry	**10 000**	**-40 000**	**40**	**3**										
A. Changes in Forest and Other Woody Biomass Stocks	0	-30 000	NA	NA										
B. Forest and Grassland Conversion	4 000	NO	NA	NA										
C. Abandonment of Managed Lands	0	-4 000	NA	NA										
D. CO_2 Emissions and Removals from Soil (1)	5 000		NA	NA										
E. Other (fires caused by human activities)	6 000	NA	40	3										

P = Potential emissions based on Tier 1 Approach. A = Actual emissions based on Tier 2 Approach.

(1) Emissions from agricultural soils and liming are included in Section 4.

Precursor gas estimates are not yet available.

IE = Inventoried elsewhere
NA = Not applicable
NE = Not estimated
NO = Not known to be occurring

1997 STANDARD IPCC TABLES - BRIEF VERSION

TABLE 7A (continued) - SUMMARY REPORT FOR NATIONAL GREENHOUSE GAS INVENTORIES

Greenhouse Gas Source and Sink Categories	(Gg)								(Gg CO_2 Equivalent)					
	CO_2 Emissions	CO_2 Removals	CH_4	N_2O	NO_x	CO	NMVOC	SO_2	HFCs		PFCs		SF_6	
									P	A	P	A	P	A
6. Waste	**280**	**NA**	**1 000**	**3.2**										
A. Solid Waste Disposal on Land	NA		1 000	NA										
B. Wastewater Handling	NE		19	3.1										
C. Waste Incineration	280		0.3	0.2										
D. Other														
7. Other (please specify)														
Memo Items														
International Bunkers	**3 970**	**NA**	**0.1**	**1.9**										
Aviation	2 450		0.1	1.1										
Marine	1 520		0.0	0.8										
CO_2 Emissions from Biomass	**71 000**													

P = Potential emissions based on Tier 1 Approach. A = Actual emissions based on Tier 2 Approach.

(1) Emissions from agricultural soils and liming are included in Section 4.

Precursor gas estimates are not yet available.

IE = Inventoried elsewhere
NA = Not applicable
NE = Not estimated
NO = Not known to be occurring

1997 STANDARD IPCC TABLES - BRIEF VERSION

TABLE 7B - SHORT SUMMARY REPORT FOR NATIONAL GREENHOUSE GAS INVENTORIES

	(Gg)								(Gg CO_2 Equivalent)					
Greenhouse Gas Source and Sink Categories	CO_2 Emissions	CO_2 Removals	CH_4	N_2O	NO_x	CO	NMVOC	SO_2	HFCs P	HFCs A	PFCs P	PFCs A	SF_6 P	SF_6 A
Total CO_2 Emissions (not including LUCF)	**520 000**	NA	NA	NA										
Total National Emissions and Removals	**535 000**	**-40 000**	**4 300**	**210**					**5 000**	**500**	**NE**	**6 000**	**1 400**	**1 400**
1. Energy Reference Approach[1]														
Sectoral Approach	**480 000**	**NA**	**2 200**	**38**										
A. Fuel Combustion	466 000	NA	290	38										
B. Fugitive Emissions from Fuels	14 000	NA	1 900	NA										
2. Industrial Processes	**38 000**	**NA**	**NE**	**34**							**NE**	**6 000**	**1 400**	**1 400**
3. Solvent and Other Product Use		**NA**	**NA**	**2**					**5 000**	**500**				
4. Agriculture	**1 000**	**IE**	**1 100**	**130**										
5. Land Use Change & Forestry[2]	**10 000**	**-40 000**	**40**	**3**										
6. Waste	**280**	**NA**	**1 000**	**3.2**										
7. Other (please specify)														
Memo Items														
International Bunkers	**3 970**	**NA**	**0.1**	**1.9**										
Aviation	2 450		0.1	1.1										
Marine	1 520		0.0	0.8										
CO_2 Emissions from Biomass	**71 000**													
TOTALS (EXCLUDING LUCF) - Gg CO_2 eq	**520 000**		**90 000**	**64 000**						**500**		**6 000**		**1 400**

NATIONAL TOTAL, ALL GASES 682 000 Gg CO_2 eq

P = Potential emissions based on Tier 1 Approach. A = Actual emissions based on Tier 2 Approach.

(1) Reference approach covered elsewhere.
(2) Emissions from agricultural soils and liming are included in Section 4.

Precursor gas estimates are not yet available.

IE = Inventoried elsewhere
NA = Not applicable
NE = Not estimated
NO = Not known to be occuring

Provincial and Territorial Emissions, 1990 to 1996

Summary tables of emissions by province and territory are included in Appendix F. Although the Intergovernmental Panel on Climate Change (IPCC) reporting guidelines only require that national-level detail be reported under the United Nations Framework Convention on Climate Change (UNFCCC), it is considered important to provide these details due to the distinct regional differences which exist within Canada. At the date of publication, 1997 provincial and territorial emission data was not yet available, so details have been provided for the 1990 to 1996 period only.

With respect to territorial tables, note that 1990 and 1991 emission estimates are not available individually for the Yukon and Northwest Territories. Unfortunately, energy data have been compiled collectively for the territories in those two years, so the emissions must be presented as a sum. This data limitation was removed starting with the 1992 collection year, so emission estimates are presented individually for both territories from that year onwards.

Finally, it must be noted that provincial and territorial emission estimates do not sum exactly to the national totals. The differences are due to two factors — rounding and a lack of certain provincial activity data. The former requires no further explanation, but the latter results in the omission of certain estimates associated with the *Solvent and Other Product Use and Industrial Processes* sectors. More specifically, tabled provincial and territorial emissions do not include HFCs (from refrigeration and other equipment); nor do they include CO_2 from Limestone and Soda Ash Use (which are included nationally under *Non-Metallic Mineral Production*). National totals for these sources amounted to about 0.8 Mt CO_2 eq in 1996. In the future, it is hoped that such difficulties will be overcome and that it will be possible to present these emissions by province.

NEWFOUNDLAND'S GREENHOUSE GAS EMISSION ESTIMATES FROM 1990 TO 1996

GHG Source and Sink Category	1990 All Gases kt CO_2 eq	1991 All Gases kt CO_2 eq	1992 All Gases kt CO_2 eq	1993 All Gases kt CO_2 eq	1994 All Gases kt CO_2 eq	1995 All Gases kt CO_2 eq	1996 All Gases kt CO_2 eq
Energy							
Fuel Combustion							
Fossil Fuel Industries	1 040	1 010	862	1 050	469	937	1 070
Electricity and Steam Generation	1 640	1 280	1 500	1 350	660	1 250	1 150
Mining	519	733	579	675	790	817	853
Manufacturing	473	423	441	316	348	317	271
Construction	32	22	26	22	18	17	15
Transportation							
Gasoline Automobiles	772	738	743	749	750	722	701
Light-Duty Gasoline Trucks	568	565	590	615	639	634	630
Heavy-Duty Gasoline Vehicles	73	71	72	73	74	72	74
Motorcycles	7	6	6	5	5	5	5
Off-Road Gasoline Vehicles	70	70	72	64	35	41	43
Diesel Automobiles	4	3	3	3	3	2	2
Light-Duty Diesel Trucks	13	12	9	7	6	4	3
Heavy-Duty Diesel Vehicles	460	490	420	440	470	440	450
Off-Road Diesel Vehicles	290	150	160	280	250	250	300
Propane and Natural Gas Vehicles	1	1	1	5	4	5	3
Domestic Air	510	390	450	380	370	400	410
Domestic Marine	710	680	620	550	480	570	610
Rail	0	0	0	0	0	0	0
Vehicles Subtotal	**3 500**	**3 200**	**3 100**	**3 200**	**3 100**	**3 100**	**3 200**
Pipelines	0	0	0	0	0	0	0
Transportation Subtotal	**3 500**	**3 200**	**3 100**	**3 200**	**3 100**	**3 100**	**3 200**
Residential	970	910	860	930	860	820	780
Commercial and Institutional	320	290	390	320	310	280	290
Other	25	42	140	56	55	77	76
Combustion Subtotal	**8 500**	**7 900**	**7 900**	**7 900**	**6 600**	**7 700**	**7 800**
Fugitive							
Solid Fuels (i.e. Coal Mining)	0	0	0	0	0	0	0
Oil and Gas	0	0	0	0	0	0	0
Fugitive Subtotal	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Energy Total	**8 500**	**7 900**	**7 900**	**7 900**	**6 600**	**7 700**	**7 800**
Industrial Processes							
Non-Metallic Mineral Production	59	54	49	65	63	63	67
Adipic Acid & Nitric Acid Production	0	0	0	0	0	0	0
Ferrous Metal Production	0	0	0	0	0	0	0
Aluminum and Magnesium Production	0	0	0	0	0	0	0
Other & Undifferentiated Production	337	59	14	14	14	15	14
Industrial Processes Total	**400**	**110**	**63**	**79**	**77**	**77**	**82**
Solvent & Other Product Use	**9**	**9**	**9**	**9**	**9**	**9**	**9**
Agriculture							
Enteric Fermentation	17	17	17	17	16	17	17
Manure Management	14	14	14	13	12	12	12
Agricultural Soils**	46	48	47	45	42	49	47
Agriculture Total	**77**	**79**	**79**	**75**	**70**	**77**	**75**
Land Use Change & Forestry*	**18**	**50**	**30**	**32**	**34**	**29**	**29**
Waste							
Solid Waste Disposal on Land	340	350	360	360	370	380	380
Wastewater Handling	19	19	19	19	19	19	19
Waste Incineration	8	8	9	9	8	8	8
Waste Total	**360**	**370**	**380**	**390**	**400**	**410**	**410**
TOTAL	**9 360**	**8 510**	**8 510**	**8 470**	**7 180**	**8 250**	**8 360**

* CH_4 and N_2O emissions from prescribed and other fires.
** Only one significant figure is shown due to high uncertainty.
Note: Due to rounding, individual values may not add up to totals.
Ammonia production emissions are included under undifferentiated production at the provincial level.

NEWFOUNDLAND'S 1996 GREENHOUSE GAS EMISSION SUMMARY

GHG Source and Sink Category	CO_2 kt	CH_4 kt	CH_4 kt CO_2 eq	N_2O kt	N_2O kt CO_2 eq	HFCs kt CO_2 eq	PFCs kt CO_2 eq	SF_6 kt CO_2 eq	Total kt CO_2 eq
Global Warming Potential Multiplier	1		21		310	140-11 700	6 500-9 200	23 900	
Energy									
Fuel Combustion									
Fossil Fuel Industries	1 070	0.0	0.0	0.0	0.0				1 070
Electricity and Steam Generation	1 150	0.0	0.3	0.0	2.6				1 150
Mining	849	0.0	0.0	0.0	4.4				853
Manufacturing	270	0.0	0.0	0.0	0.1				271
Construction	15	0.0	0.0	0.0	0.0				15
Transportation									
Gasoline Automobiles	659	0.1	1.9	0.1	40				701
Light-Duty Gasoline Trucks	570	0.1	2.0	0.2	58				630
Heavy-Duty Gasoline Vehicles	71	0.0	0.2	0.0	3				74
Motorcycles	4	0.0	0.1	0.0	0				5
Off-Road Gasoline Vehicles	41	0.1	1.1	0.0	0				43
Diesel Automobiles	2	0.0	0.0	0.0	0				2
Light-Duty Diesel Trucks	3	0.0	0.0	0.0	0				3
Heavy-Duty Diesel Vehicles	449	0.0	0.5	0.0	5				450
Off-Road Diesel Vehicles	269	0.0	0.3	0.1	34				300
Propane and Natural Gas Vehicles	3	0.0	0.0	0.0	0				3
Domestic Air	396	0.0	0.4	0.0	12				410
Domestic Marine	551	0.0	0.7	0.2	62				610
Rail	0	0.0	0.0	0.0	0				0
Vehicles Subtotal	**3 020**	**0.3**	**7.1**	**0.7**	**210**				**3 200**
Pipelines	0	0.0	0.0	0.0	0				0
Transportation Subtotal	**3 020**	**0.3**	**7.1**	**0.7**	**210**				**3 200**
Residential	513	11	230	0.1	38				780
Commercial and Institutional	293	0.0	0.0	0.0	0.4				290
Other	76	0.0	0.0	0.0	0.1				76
Combustion Subtotal	**7 260**	**11**	**240**	**0.8**	**260**				**7 800**
Fugitive									
Solid Fuels (i.e. Coal Mining)		0.0	0.0						0
Oil and Gas	0	0.0	0.0						0
Fugitive Subtotal	**0**	**0.0**	**0.0**						**0**
Energy Total	**7 260**	**11**	**240**	**0.8**	**260**				**7 800**
Industrial Processes									
Non-Metallic Mineral Production	67								67
Adipic Acid & Nitric Acid Production	0			0.0	0.0				0
Ferrous Metal Production	0								0
Aluminum and Magnesium Production	0						0	0	0
Other & Undifferentiated Production	14								14
Industrial Processes Total	**82**	**0**	**0**	**0.0**	**0.0**		**0**	**0**	**82**
Solvent & Other Product Use	**0**	**0**	**0**	**0.0**	**8.6**				**9**
Agriculture									
Enteric Fermentation		0.8	17						17
Manure Management		0.4	8.0	0.0	4.1				12
Agricultural Soils**	3			0.1	40				47
Agriculture Total	**3**	**1**	**25**	**0.2**	**48**				**75**
Land Use Change & Forestry*		**1**	**13**	**0.1**	**16**				**29**
Waste									
Solid Waste Disposal on Land		18	380						380
Wastewater Handling		0.0	1.0	0.1	18				19
Waste Incineration	7	0.0	0	0.0	2				8
Waste Total	**7**	**18**	**390**	**0.1**	**19**				**410**
TOTAL	**7 350**	**31**	**660**	**1.1**	**350**		**0**	**0**	**8 360**

* CH_4 and N_2O emissions from prescribed and other fires.
** Only one significant figure is shown due to high uncertainty.
Note: Due to rounding, individual values may not add up to totals.
Ammonia production emissions are included under undifferentiated production at the provincial level.
Limestone and soda ash use are not included in provincial totals.

PRINCE EDWARD ISLAND'S GREENHOUSE GAS EMISSION ESTIMATES FROM 1990 TO 1996

GHG Source and Sink Category	1990 All Gases kt CO_2 eq	1991 All Gases kt CO_2 eq	1992 All Gases kt CO_2 eq	1993 All Gases kt CO_2 eq	1994 All Gases kt CO_2 eq	1995 All Gases kt CO_2 eq	1996 All Gases kt CO_2 eq
Energy							
Fuel Combustion							
Fossil Fuel Industries	1	1	1	2	3	2	2
Electricity and Steam Generation	105	95	51	80	65	32	28
Mining	0	0	0	0	0	0	1
Manufacturing	26	31	29	93	63	76	70
Construction	10	11	11	9	9	7	7
Transportation							
Gasoline Automobiles	287	274	265	258	257	255	248
Light-Duty Gasoline Trucks	146	149	155	161	170	181	192
Heavy-Duty Gasoline Vehicles	20	23	26	29	33	37	42
Motorcycles	1	1	1	1	1	1	1
Off-Road Gasoline Vehicles	14	9	8	10	17	11	15
Diesel Automobiles	3	3	3	3	3	3	3
Light-Duty Diesel Trucks	2	2	2	1	1	1	1
Heavy-Duty Diesel Vehicles	80	85	85	90	101	100	106
Off-Road Diesel Vehicles	57	52	32	33	49	57	52
Propane and Natural Gas Vehicles	1	1	1	2	2	1	2
Domestic Air	15	12	9	9	9	8	11
Domestic Marine	90	116	129	112	92	63	113
Rail	0	0	0	0	0	0	0
Vehicles Subtotal	**717**	**725**	**715**	**710**	**735**	**718**	**786**
Pipelines	0	0	0	0	0	0	0
Transportation Subtotal	**717**	**725**	**715**	**710**	**735**	**718**	**786**
Residential	394	362	363	362	343	309	334
Commercial and Institutional	170	163	164	155	153	164	172
Other	20	20	51	28	27	40	47
Combustion Subtotal	**1 440**	**1 410**	**1 380**	**1 440**	**1 400**	**1 350**	**1 450**
Fugitive							
Solid Fuels (i.e. Coal Mining)	0	0	0	0	0	0	0
Oil and Gas	0	0	0	0	0	0	0
Fugitive Subtotal	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Energy Total	**1 440**	**1 410**	**1 380**	**1 440**	**1 400**	**1 350**	**1 450**
Industrial Processes							
Non-Metallic Mineral Production	0	0	0	0	0	0	0
Adipic Acid & Nitric Acid Production	0	0	0	0	0	0	0
Ferrous Metal Production	0	0	0	0	0	0	0
Aluminum and Magnesium Production	0	0	0	0	0	0	0
Other & Undifferentiated Production	3	3	3	3	4	3	3
Industrial Processes Total	**3**	**3**	**3**	**3**	**4**	**3**	**3**
Solvent & Other Product Use	**2**	**2**	**2**	**2**	**2**	**2**	**2**
Agriculture							
Enteric Fermentation	130	130	130	130	130	130	130
Manure Management	76	75	73	72	74	76	76
Agricultural Soils**	210	230	260	220	180	220	240
Agriculture Total	**420**	**430**	**460**	**420**	**380**	**430**	**440**
Land Use Change & Forestry*	**4**	**11**	**7**	**4**	**4**	**4**	**7**
Waste							
Solid Waste Disposal on Land	61	62	64	65	67	68	69
Wastewater Handling	7	7	7	7	7	7	7
Waste Incineration	8	8	9	9	9	9	9
Waste Total	**77**	**78**	**79**	**81**	**83**	**84**	**86**
TOTAL	**1 950**	**1 930**	**1 940**	**1 950**	**1 870**	**1 870**	**1 990**

* CH_4 and N_2O emissions from prescribed and other fires.
** Only one significant figure is shown due to high uncertainty.
Note: Due to rounding, individual values may not add up to totals.
Ammonia production emissions are included under undifferentiated production at the provincial level.

PRINCE EDWARD ISLAND'S 1996 GREENHOUSE GAS EMISSION SUMMARY

GHG Source and Sink Category	CO_2 kt	CH_4 kt	CH_4 kt CO_2 eq	N_2O kt	N_2O kt CO_2 eq	HFCs kt CO_2 eq	PFCs kt CO_2 eq	SF_6 kt CO_2 eq	Total kt CO_2 eq
Global Warming Potential Multiplier	1		21		310	140-11 700	6 500-9 200	23 900	
Energy									
Fuel Combustion									
Fossil Fuel Industries	2	0.0	0.0	0.0	0.0				2
Electricity and Steam Generation	27	0.1	1.1	0.0	0.3				28
Mining	1	0.0	0.0	0.0	0.0				1
Manufacturing	70	0.0	0.0	0.0	0.0				70
Construction	7	0.0	0.0	0.0	0.0				7
Transportation									
Gasoline Automobiles	234	0.0	0.7	0.0	13				248
Light-Duty Gasoline Trucks	174	0.0	0.6	0.1	17				192
Heavy-Duty Gasoline Vehicles	40	0.0	0.1	0.0	2				42
Motorcycles	1	0.0	0.0	0.0	0				1
Off-Road Gasoline Vehicles	15	0.0	0.4	0.0	0				15
Diesel Automobiles	3	0.0	0.0	0.0	0				3
Light-Duty Diesel Trucks	1	0.0	0.0	0.0	0				1
Heavy-Duty Diesel Vehicles	105	0.0	0.1	0.0	1				106
Off-Road Diesel Vehicles	46	0.0	0.0	0.0	6				52
Propane and Natural Gas Vehicles	2	0.0	0.0	0.0	0				2
Domestic Air	10	0.0	0.0	0.0	0				11
Domestic Marine	102	0.0	0.1	0.0	11				113
Rail	0	0.0	0.0	0.0	0				0
Vehicles Subtotal	**733**	**0.1**	**2.2**	**0.2**	**51**				**786**
Pipelines	0	0.0	0.0	0.0	0				0
Transportation Subtotal	**733**	**0.1**	**2.2**	**0.2**	**51**				**786**
Residential	294	1.6	34	0.0	6				334
Commercial and Institutional	172	0.0	0.0	0.0	0				172
Other	47	0.0	0.0	0.0	0				47
Combustion Subtotal	**1 350**	**1.8**	**37**	**0.2**	**58**				**1 450**
Fugitive									
Solid Fuels (i.e. Coal Mining)		0.0	0.0						0
Oil and Gas	0	0.0	0.0						0
Fugitive Subtotal	**0**	**0.0**	**0.0**						**0**
Energy Total	**1 350**	**1.8**	**37**	**0.2**	**58**				**1 450**
Industrial Processes									
Non-Metallic Mineral Production	0								0
Adipic Acid & Nitric Acid Production	0			0	0				0
Ferrous Metal Production	0								0
Aluminum and Magnesium Production	0						0	0	0
Other & Undifferentiated Production	3								3
Industrial Processes Total	**3**	**0**	**0**	**0.0**	**0.0**		**0**	**0**	**3**
Solvent & Other Product Use	**0**	**0**	**0**	**0.0**	**2.1**				**2**
Agriculture									
Enteric Fermentation		6.1	130						130
Manure Management		2.2	47	0.1	29				76
Agricultural Soils**	40			0.6	200				240
Agriculture Total	**40**	**8.4**	**180**	**0.7**	**230**				**440**
Land Use Change & Forestry*		**0.2**	**3.3**	**0.0**	**3.9**				**7**
Waste									
Solid Waste Disposal on Land		3.3	69						69
Wastewater Handling		0.2	3	0.0	4.3				7
Waste Incineration	7	0.0	0	0.0	1				9
Waste Total	**7**	**3.4**	**72**	**0.0**	**5.7**				**86**
TOTAL	**1 400**	**14**	**290**	**1.0**	**300**		**0**	**0**	**1 990**

* CH_4 and N_2O emissions from prescribed and other fires.
** Only one significant figure is shown due to high uncertainty.
Note: Due to rounding, individual values may not add up to totals.
Ammonia production emissions are included under undifferentiated production at the provincial level.
Limestone and soda ash use are not included in provincial totals.

NOVA SCOTIA'S GREENHOUSE GAS EMISSION ESTIMATES FROM 1990 TO 1996

GHG Source and Sink Category	1990 All Gases kt CO_2 eq	1991 All Gases kt CO_2 eq	1992 All Gases kt CO_2 eq	1993 All Gases kt CO_2 eq	1994 All Gases kt CO_2 eq	1995 All Gases kt CO_2 eq	1996 All Gases kt CO_2 eq
Energy							
Fuel Combustion							
Fossil Fuel Industries	675	727	775	910	585	654	659
Electricity and Steam Generation	6 920	7 070	7 470	7 390	7 220	6 980	7 280
Mining	23	21	25	21	16	4	12
Manufacturing	642	520	597	695	792	898	776
Construction	60	36	32	25	31	35	31
Transportation							
Gasoline Automobiles	1 680	1 550	1 570	1 600	1 540	1 650	1 580
Light-Duty Gasoline Trucks	940	908	956	1 010	1 010	1 120	1 140
Heavy-Duty Gasoline Vehicles	135	127	130	134	128	139	141
Motorcycles	12	12	11	11	10	10	12
Off-Road Gasoline Vehicles	73	56	54	51	211	51	45
Diesel Automobiles	26	25	26	27	26	28	28
Light-Duty Diesel Trucks	21	17	16	14	13	12	11
Heavy-Duty Diesel Vehicles	790	758	798	801	826	854	895
Off-Road Diesel Vehicles	335	306	316	363	382	401	279
Propane and Natural Gas Vehicles	6	6	6	7	9	9	9
Domestic Air	496	492	455	498	483	491	472
Domestic Marine	615	702	616	608	641	575	573
Rail	67	50	58	57	60	46	34
Vehicles Subtotal	**5 200**	**5 000**	**5 000**	**5 200**	**5 300**	**5 400**	**5 200**
Pipelines	0	0	0	0	0	0	0
Transportation Subtotal	**5 200**	**5 000**	**5 000**	**5 200**	**5 300**	**5 400**	**5 200**
Residential	2 300	2 100	1 900	2 300	2 100	1 800	2 000
Commercial and Institutional	811	780	932	779	724	755	786
Other	107	191	547	153	148	202	228
Combustion Subtotal	**16 700**	**16 400**	**17 300**	**17 400**	**17 000**	**16 700**	**17 000**
Fugitive	0	0	0	0	0	0	0
Solid Fuels (i.e. Coal Mining)	1 200	1 300	1 200	1 100	970	830	830
Oil and Gas	0	0	3	5	6	6	5
Fugitive Subtotal	**1 200**	**1 300**	**1 200**	**1 100**	**970**	**830**	**830**
Energy Total	**17 900**	**17 800**	**18 500**	**18 500**	**17 900**	**17 600**	**17 800**
Industrial Processes							
Non-Metallic Mineral Production	199	182	166	228	219	217	239
Adipic Acid & Nitric Acid Production	0	0	0	0	0	0	0
Ferrous Metal Production	0	0	0	0	0	0	0
Aluminum and Magnesium Production	0	0	0	0	0	0	0
Other & Undifferentiated Production	100	80	69	64	55	70	70
Industrial Processes Total	**300**	**260**	**240**	**290**	**270**	**290**	**310**
Solvent & Other Product Use	**14**	**14**	**14**	**14**	**14**	**14**	**14**
Agriculture							
Enteric Fermentation	190	190	190	180	180	180	180
Manure Management	110	110	110	110	110	110	110
Agricultural Soils**	280	320	290	270	260	290	300
Agriculture Total	**580**	**610**	**580**	**560**	**550**	**580**	**600**
Land Use Change & Forestry*	**33**	**18**	**25**	**7**	**7**	**7**	**15**
Waste							
Solid Waste Disposal on Land	540	550	560	580	560	570	590
Wastewater Handling	39	39	39	40	40	40	40
Waste Incineration	16	16	16	16	16	16	16
Waste Total	590	610	620	630	610	630	650
TOTAL	**19 400**	**19 300**	**20 000**	**20 000**	**19 400**	**19 100**	**19 400**

* CH_4 and N_2O emissions from prescribed and other fires.
** Only one significant figure is shown due to high uncertainty.
Note: Due to rounding, individual values may not add up to totals.
Ammonia production emissions are included under undifferentiated production at the provincial level.

NOVA SCOTIA'S 1996 GREENHOUSE GAS EMISSION SUMMARY

GHG Source and Sink Category	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	Total
	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*
Global Warming Potential Multiplier	1		21		310	140-11 700	6 500-9 200	23 900	
Energy									
Fuel Combustion									
Fossil Fuel Industries	657	0.0	0.1	0.0	1.7				659
Electricity and Steam Generation	7 240	0.1	1.1	0.2	46				7 280
Mining	11	0.0	0.0	0.0	0.0				12
Manufacturing	765	0.0	0.6	0.0	9.9				776
Construction	31	0.0	0.0	0.0	0.0				31
Transportation									
Gasoline Automobiles	1 490	0.2	4.4	0.3	88				1 580
Light-Duty Gasoline Trucks	1 030	0.2	3.5	0.4	110				1 140
Heavy-Duty Gasoline Vehicles	134	0.0	0.4	0.0	5.9				141
Motorcycles	12	0.0	0.2	0.0	0.1				12
Off-Road Gasoline Vehicles	44	0.1	1.2	0.0	0.3				45
Diesel Automobiles	28	0.0	0.0	0.0	0.3				28
Light-Duty Diesel Trucks	11	0.0	0.0	0.0	0.1				11
Heavy-Duty Diesel Vehicles	884	0.0	0.9	0.0	10				895
Off-Road Diesel Vehicles	248	0.0	0.3	0.1	31				279
Propane and Natural Gas Vehicles	9	0.0	0.1	0.0	0.0				9
Domestic Air	458	0.0	0.3	0.0	14				472
Domestic Marine	534	0.0	0.8	0.1	39				573
Rail	31	0.0	0.0	0.0	3.8				34
Vehicles Subtotal	**4 920**	**0.6**	**12**	**1.0**	**300**				**5 200**
Pipelines	0	0.0	0.0	0.0	0.0				0
Transportation Subtotal	**4 920**	**0.6**	**12**	**1.0**	**300**				**5 200**
Residential	1 620	14	290	0.2	50				2 000
Commercial and Institutional	784	0.0	0	0.0	1.1				786
Other	227	0.0	0	0.0	0.4				228
Combustion Subtotal	**16 200**	**14**	**300**	**1.3**	**410**				**17 000**
Fugitive									
Solid Fuels (i.e. Coal Mining)		40	830						830
Oil and Gas	0	0.2	4.9						5
Fugitive Subtotal	**0**	**40**	**830**						**830**
Energy Total	**16 200**	**54**	**1 100**	**1.3**	**410**				**17 800**
Industrial Processes									
Non-Metallic Mineral Production	239								239
Adipic Acid & Nitric Acid Production	0			0	0				0
Ferrous Metal Production	0								0
Aluminum and Magnesium Production	0						0	0	0
Other & Undifferentiated Production	70								70
Industrial Processes Total	**310**	**0**	**0**	**0**	**0**		**0**	**0**	**310**
Solvent & Other Product Use	**0**	**0**	**0**	**0**	**14**				**14**
Agriculture									
Enteric Fermentation		8.7	180						180
Manure Management		3.2	67	0.1	42				110
Agricultural Soils**	40			0.9	300				300
Agriculture Total	**40**	**12**	**250**	**1.0**	**300**				**600**
Land Use Change & Forestry*		**0.3**	**7**	**0.0**	**8**				**15**
Waste									
Solid Waste Disposal on Land		28	590						590
Wastewater Handling		0.5	11	0.1	30				40
Waste Incineration	14	0.0	0	0.0	3				16
Waste Total	**14**	**29**	**600**	**0.1**	**32**				**650**
TOTAL	**16 600**	**95**	**2 000**	**2.5**	**770**		**0**	**0**	**19 400**

* CH_4 and N_2O emissions from prescribed and other fires.
** Only one significant figure is shown due to high uncertainty.
Note: Due to rounding, individual values may not add up to totals.
Ammonia production emissions are included under undifferentiated production at the provincial level.
Limestone and soda ash use are not included in provincial totals.

NEW BRUNSWICK'S GREENHOUSE GAS EMISSION ESTIMATES FROM 1990 TO 1996

GHG Source and Sink Category	1990 All Gases kt CO_2 eq	1991 All Gases kt CO_2 eq	1992 All Gases kt CO_2 eq	1993 All Gases kt CO_2 eq	1994 All Gases kt CO_2 eq	1995 All Gases kt CO_2 eq	1996 All Gases kt CO_2 eq
Energy							
Fuel Combustion							
Fossil Fuel Industries	891	932	901	948	1 100	897	1 030
Electricity and Steam Generation	6 040	5 580	6 180	5 230	5 890	7 040	6 230
Mining	88	77	57	81	118	129	175
Manufacturing	1 270	1 230	1 350	1 390	1 340	1 610	1 450
Construction	65	55	55	34	42	40	43
Transportation							
Gasoline Automobiles	1 570	1 500	1 490	1 490	1 510	1 440	1 450
Light-Duty Gasoline Trucks	706	712	760	798	849	857	909
Heavy-Duty Gasoline Vehicles	100	101	108	113	119	119	136
Motorcycles	7	6	6	6	7	7	7
Off-Road Gasoline Vehicles	14	15	13	16	13	7	11
Diesel Automobiles	19	18	18	18	19	18	19
Light-Duty Diesel Trucks	22	18	16	15	15	15	13
Heavy-Duty Diesel Vehicles	848	837	850	909	1 010	1 080	1 100
Off-Road Diesel Vehicles	330	380	406	426	487	442	497
Propane and Natural Gas Vehicles	6	6	6	8	11	15	11
Domestic Air	94	92	97	92	108	117	121
Domestic Marine	465	423	413	470	488	479	497
Rail	132	134	142	131	121	115	113
Vehicles Subtotal	**4 320**	**4 240**	**4 330**	**4 490**	**4 750**	**4 710**	**4 890**
Pipelines	0	0	0	0	0	0	0
Transportation Subtotal	**4 320**	**4 240**	**4 330**	**4 490**	**4 750**	**4 710**	**4 890**
Residential	1 230	1 240	1 200	1 220	1 140	977	1 010
Commercial and Institutional	733	640	501	433	477	506	462
Other	54	68	167	87	88	130	111
Combustion Subtotal	**14 700**	**14 100**	**14 700**	**13 900**	**14 900**	**16 000**	**15 400**
Fugitive							
Solid Fuels (i.e. Coal Mining)	2	1	0	1	1	1	1
Oil and Gas	0	0	0	0	0	0	0
Fugitive Subtotal	**2**	**1**	**0**	**1**	**1**	**1**	**1**
Energy Total	**14 700**	**14 100**	**14 700**	**13 900**	**14 900**	**16 000**	**15 400**
Industrial Processes							
Non-Metallic Mineral Production	78	76	81	88	93	97	111
Adipic Acid & Nitric Acid Production	0	0	0	0	0	0	0
Ferrous Metal Production	0	0	0	0	0	0	0
Aluminum and Magnesium Production	0	0	0	0	0	0	0
Other & Undifferentiated Production	48	40	40	43	44	110	51
Industrial Processes Total	**130**	**120**	**121**	**130**	**140**	**210**	**160**
Solvent & Other Product Use	**11**	**11**	**11**	**11**	**11**	**11**	**11**
Agriculture							
Enteric Fermentation	150	150	150	150	150	150	150
Manure Management	81	81	80	80	82	82	83
Agricultural Soils**	240	240	250	240	190	240	250
Agriculture Total	**470**	**470**	**480**	**470**	**420**	**470**	**480**
Land Use Change & Forestry*	**170**	**380**	**250**	**230**	**230**	**400**	**290**
Waste							
Solid Waste Disposal on Land	450	460	470	480	490	500	510
Wastewater Handling	51	51	51	51	52	52	52
Waste Incineration	0	0	0	0	0	0	0
Waste Total	**500**	**510**	**520**	**530**	**540**	**550**	**570**
TOTAL	**16 000**	**15 500**	**16 100**	**15 300**	**16 300**	**17 700**	**16 800**

* CH_4 and N_2O emissions from prescribed and other fires.
** Only one significant figure is shown due to high uncertainty.
Note: Due to rounding, individual values may not add up to totals.
Ammonia production emissions are included under undifferentiated production at the provincial level.

NEW BRUNSWICK'S 1996 GREENHOUSE GAS EMISSION SUMMARY

GHG Source and Sink Category	CO_2 kt	CH_4 kt	CH_4 kt CO_2 eq	N_2O kt	N_2O kt CO_2 eq	HFCs kt CO_2 eq	PFCs kt CO_2 eq	SF_6 kt CO_2 eq	Total kt CO_2 eq
Global Warming Potential Multiplier	1		21		310	140-11 700	6 500-9 200	23 900	
Energy									
Fuel Combustion									
Fossil Fuel Industries	1 030	0.0	0.1	0.0	1.4				1 030
Electricity and Steam Generation	6 210	0.1	1.1	0.1	26				6 230
Mining	175	0.0	0.0	0.0	0.2				175
Manufacturing	1 430	0.0	0.8	0.0	13				1 450
Construction	42	0.0	0.0	0.0	0.0				43
Transportation									
Gasoline Automobiles	1 370	0.2	4.2	0.3	77				1 450
Light-Duty Gasoline Trucks	824	0.1	2.8	0.3	82				909
Heavy-Duty Gasoline Vehicles	130	0.0	0.4	0.0	6				136
Motorcycles	7	0.0	0.1	0.0	0				7
Off-Road Gasoline Vehicles	11	0.0	0.3	0.0	0				11
Diesel Automobiles	18	0.0	0.0	0.0	0				19
Light-Duty Diesel Trucks	13	0.0	0.0	0.0	0				13
Heavy-Duty Diesel Vehicles	1 090	0.1	1.1	0.0	12				1 100
Off-Road Diesel Vehicles	442	0.0	0.5	0.2	55				497
Propane and Natural Gas Vehicles	11	0.0	0.1	0.0	0				11
Domestic Air	117	0.0	0.2	0.0	4				121
Domestic Marine	467	0.0	0.7	0.1	29				497
Rail	101	0.0	0.1	0.0	13				113
Vehicles Subtotal	**4 600**	**0.5**	**11**	**0.9**	**280**				**4 890**
Pipelines	0	0.0	0.0	0.0	0				0
Transportation Subtotal	**4 600**	**0.5**	**11**	**0.9**	**280**				**4 890**
Residential	709	12	260	0.1	43				1 010
Commercial and Institutional	461	0.0	0.1	0.0	0.8				462
Other	110	0.0	0.0	0.0	0.3				111
Combustion Subtotal	**14 800**	**13**	**270**	**1.2**	**360**				**15 400**
Fugitive									
Solid Fuels (i.e. Coal Mining)		0.0	0.7						1
Oil and Gas	0	0.0	0.0						0
Fugitive Subtotal	**0**	**0.0**	**0.7**						**1**
Energy Total	**14 800**	**13**	**270**	**1.2**	**360**				**15 400**
Industrial Processes									
Non-Metallic Mineral Production	111								111
Adipic Acid & Nitric Acid Production	0			0.0	0.0				0
Ferrous Metal Production	0								0
Aluminum and Magnesium Production	0						0	0	0
Other & Undifferentiated Production	51								51
Industrial Processes Total	**160**	**0**	**0**	**0.0**	**0.0**		**0**	**0**	**160**
Solvent & Other Product Use	**0**	**0**	**0**	**0.0**	**11**				**11**
Agriculture									
Enteric Fermentation		7.0	150						150
Manure Management		2.4	50	0.1	33				83
Agricultural Soils**	40			0.7	200				250
Agriculture Total	**40**	**9**	**200**	**0.8**	**200**				**480**
Land Use Change & Forestry*		**6**	**130**	**0.5**	**200**				**290**
Waste									
Solid Waste Disposal on Land		24	510						510
Wastewater Handling		1.3	28	0.1	24				52
Waste Incineration	0	0.0	0	0.0	0				0
Waste Total	**0**	**26**	**540**	**0.1**	**24**				**570**
TOTAL	**15 000**	**49**	**1 000**	**2.6**	**790**		**0**	**0**	**16 800**

* CH_4 and N_2O emissions from prescribed and other fires.
** Only one significant figure is shown due to high uncertainty.
Note: Due to rounding, individual values may not add up to totals.
Ammonia production emissions are included under undifferentiated production at the provincial level.
Limestone and soda ash use are not included in provincial totals.

QUEBEC'S GREENHOUSE GAS EMISSION ESTIMATES FROM 1990 TO 1996

GHG Source and Sink Category	1990 All Gases kt CO_2 eq	1991 All Gases kt CO_2 eq	1992 All Gases kt CO_2 eq	1993 All Gases kt CO_2 eq	1994 All Gases kt CO_2 eq	1995 All Gases kt CO_2 eq	1996 All Gases kt CO_2 eq
Energy							
Fuel Combustion							
Fossil Fuel Industries	2 840	2 460	2 630	2 770	3 030	3 100	3 010
Electricity and Steam Generation	1 440	478	947	293	322	123	260
Mining	845	772	620	757	928	988	910
Manufacturing	12 100	10 900	11 100	10 800	10 900	11 500	12 000
Construction	133	138	149	113	108	191	190
Transportation							
Gasoline Automobiles	13 800	12 800	13 100	13 400	13 500	13 400	13 400
Light-Duty Gasoline Trucks	3 310	3 360	3 720	4 090	4 430	4 660	4 910
Heavy-Duty Gasoline Vehicles	552	569	635	703	767	814	841
Motorcycles	45	41	41	43	45	47	49
Off-Road Gasoline Vehicles	362	429	294	263	310	211	244
Diesel Automobiles	244	228	233	238	240	238	239
Light-Duty Diesel Trucks	101	97	94	92	97	102	103
Heavy-Duty Diesel Vehicles	5 890	5 980	6 060	6 100	6 560	7 080	7 260
Off-Road Diesel Vehicles	937	453	459	860	1 220	1 020	646
Propane and Natural Gas Vehicles	77	89	90	178	179	174	125
Domestic Air	1 870	1 450	1 720	1 550	1 740	1 670	1 800
Domestic Marine	1 400	1 470	1 420	1 120	1 290	910	931
Rail	583	618	628	612	611	556	445
Vehicles Subtotal	**29 200**	**27 600**	**28 500**	**29 200**	**31 000**	**30 900**	**31 000**
Pipelines	25	27	30	26	27	24	18
Transportation Subtotal	**29 200**	**27 600**	**28 500**	**29 300**	**31 000**	**31 000**	**31 000**
Residential	8 800	8 200	8 200	9 000	8 900	8 400	8 800
Commercial and Institutional	4 270	4 020	4 330	4 540	4 490	5 010	5 000
Other	472	433	1 180	325	261	208	220
Combustion Subtotal	**60 100**	**55 000**	**57 600**	**57 800**	**59 900**	**60 500**	**61 400**
Fugitive							
Solid Fuels (i.e. Coal Mining)	0	0	0	0	0	0	0
Oil and Gas	280	320	320	330	380	400	400
Fugitive Subtotal	**280**	**320**	**320**	**330**	**380**	**400**	**400**
Energy Total	**60 400**	**55 300**	**57 900**	**58 200**	**60 300**	**60 900**	**61 800**
Industrial Processes							
Non-Metallic Mineral Production	1 710	1 410	1 220	1 410	1 670	1 720	1 540
Adipic Acid & Nitric Acid Production	15	14	15	15	1	1	14
Ferrous Metal Production	0	1	8	9	8	7	9
Aluminum and Magnesium Production	10 000	10 000	10 000	10 000	10 000	10 000	9 000
Other & Undifferentiated Production	0	350	300	260	92	0	130
Industrial Processes Total	**11 000**	**13 000**	**12 000**	**13 000**	**13 000**	**11 000**	**11 000**
Solvent & Other Product Use	**110**	**110**	**110**	**110**	**110**	**110**	**110**
Agriculture							
Enteric Fermentation	2 400	2 400	1 700	2 400	2 400	2 400	2 500
Manure Management	1 700	1 700	1 400	1 700	1 700	1 800	1 800
Agricultural Soils**	3 800	3 500	3 100	3 600	3 400	3 700	3 700
Agriculture Total	**7 900**	**7 500**	**6 200**	**7 700**	**7 500**	**7 900**	**7 900**
Land Use Change & Forestry*	**160**	**280**	**240**	**170**	**150**	**310**	**160**
Waste							
Solid Waste Disposal on Land	5 400	4 900	5 100	5 300	5 200	5 400	5 500
Wastewater Handling	251	253	256	259	261	263	264
Waste Incineration	137	139	141	142	144	145	146
Waste Total	**5 800**	**5 300**	**5 500**	**5 700**	**5 600**	**5 800**	**5 900**
TOTAL	**85 500**	**81 100**	**81 800**	**84 800**	**86 300**	**86 400**	**87 000**

* CH_4 and N_2O emissions from prescribed and other fires.
** Only one significant figure is shown due to high uncertainty.
Note: Due to rounding, individual values may not add up to totals.
Ammonia production emissions are included under undifferentiated production at the provincial level.

QUEBEC'S 1996 GREENHOUSE GAS EMISSION SUMMARY

GHG Source and Sink Category	CO_2 kt	CH_4 kt	CH_4 kt CO_2 eq	N_2O kt	N_2O kt CO_2 eq	HFCs kt CO_2 eq	PFCs kt CO_2 eq	SF_6 kt CO_2 eq	Total kt CO_2 eq
Global Warming Potential Multiplier	1		21		310	140-11 700	6 500-9 200	23 900	
Energy									
Fuel Combustion									
Fossil Fuel Industries	3 010	0.0	0.4	0.0	3.4				3 010
Electricity and Steam Generation	258	0.0	0.2	0.0	2.7				260
Mining	906	0.0	0.1	0.0	3.7				910
Manufacturing	11 900	0.3	5.9	0.3	77				12 000
Construction	190	0.0	0.1	0.0	0.4				190
Transportation									
Gasoline Automobiles	12 700	1.8	37	2.4	740				13 400
Light-Duty Gasoline Trucks	4 420	0.7	14	1.5	470				4 910
Heavy-Duty Gasoline Vehicles	803	0.1	2.4	0.1	36				841
Motorcycles	48	0.0	0.8	0.0	0				49
Off-Road Gasoline Vehicles	236	0.3	6.3	0.0	2				244
Diesel Automobiles	236	0.0	0.1	0.0	3				239
Light-Duty Diesel Trucks	102	0.0	0.1	0.0	1				103
Heavy-Duty Diesel Vehicles	7 170	0.4	7.4	0.3	81				7 260
Off-Road Diesel Vehicles	574	0.0	0.6	0.2	72				646
Propane and Natural Gas Vehicles	124	0.1	1.5	0.0	0				125
Domestic Air	1 750	0.1	2.0	0.2	53				1 800
Domestic Marine	881	0.1	1.4	0.2	49				931
Rail	396	0.0	0.5	0.2	49				445
Vehicles Subtotal	**29 400**	**3.6**	**75**	**5.0**	**1 600**				**31 000**
Pipelines	18	0.0	0.0	0.0	0				18
Transportation Subtotal	**29 400**	**3.6**	**75**	**5.0**	**1 600**				**31 000**
Residential	5 900	120	2 400	1.4	420				8 800
Commercial and Institutional	4 990	0.1	1.9	0.0	14				5 000
Other	218	0.0	0.1	0.0	2				220
Combustion Subtotal	**56 800**	**120**	**2 500**	**6.7**	**2 100**				**61 400**
Fugitive									
Solid Fuels (i.e. Coal Mining)		0.0	0.0						0
Oil and Gas	0	19	400						400
Fugitive Subtotal	**0**	**19**	**400**						**400**
Energy Total	**56 800**	**140**	**2 900**	**6.7**	**2 100**				**61 800**
Industrial Processes									
Non-Metallic Mineral Production	1 540								1 540
Adipic Acid & Nitric Acid Production	0			0.0	14				14
Ferrous Metal Production	9								9
Aluminum and Magnesium Production	3 230						5 000	840	9 000
Other & Undifferentiated Production	130								130
Industrial Processes Total	**4 910**	**0**	**0**	**0.0**	**14**		**5 000**	**840**	**11 000**
Solvent & Other Product Use	**0**	**0**	**0**	**0.4**	**110**				**110**
Agriculture									
Enteric Fermentation		120	2 500						2 500
Manure Management		63	1 300	1.6	490				1 800
Agricultural Soils**	200			10	3 000				3 700
Agriculture Total	**200**	**180**	**3 800**	**10**	**4 000**				**7 900**
Land Use Change & Forestry*		**4**	**75**	**0**	**90**				**160**
Waste									
Solid Waste Disposal on Land		260	5 500						5 500
Wastewater Handling		1.6	33	0.8	230				264
Waste Incineration	120	0.2	3	0.1	26				146
Waste Total	**120**	**260**	**5 500**	**0.8**	**260**				**5 900**
TOTAL	**62 100**	**590**	**12 000**	**21**	**6 500**		**5 000**	**840**	**87 000**

* CH_4 and N_2O emissions from prescribed and other fires.
** Only one significant figure is shown due to high uncertainty.
Note: Due to rounding, individual values may not add up to totals.
Ammonia production emissions are included under undifferentiated production at the provincial level.
Limestone and soda ash use are not included in provincial totals.

ONTARIO'S GREENHOUSE GAS EMISSION ESTIMATES FROM 1990 TO 1996

GHG Source and Sink Category	1990 All Gases kt CO_2 eq	1991 All Gases kt CO_2 eq	1992 All Gases kt CO_2 eq	1993 All Gases kt CO_2 eq	1994 All Gases kt CO_2 eq	1995 All Gases kt CO_2 eq	1996 All Gases kt CO_2 eq
Energy							
Fuel Combustion							
Fossil Fuel Industries	6 200	6 510	7 000	7 100	6 560	6 170	6 370
Electricity and Steam Generation	26 500	27 900	28 600	18 800	16 500	18 900	21 300
Mining	456	555	709	910	1 230	545	685
Manufacturing	24 200	22 500	21 100	20 700	21 300	22 400	21 900
Construction	150	261	275	92	67	77	191
Transportation							
Gasoline Automobiles	21 000	20 200	20 100	20 300	20 500	20 000	19 500
Light-Duty Gasoline Trucks	7 710	7 960	8 470	9 110	9 720	10 100	10 700
Heavy-Duty Gasoline Vehicles	892	930	994	1 070	1 140	1 190	1 200
Motorcycles	85	82	80	81	78	73	69
Off-Road Gasoline Vehicles	1 190	1 100	943	770	803	1 000	1 070
Diesel Automobiles	208	198	192	189	183	174	182
Light-Duty Diesel Trucks	159	120	105	96	87	79	64
Heavy-Duty Diesel Vehicles	7 380	6 620	6 940	7 600	8 300	9 250	9 430
Off-Road Diesel Vehicles	2 430	2 230	2 160	2 240	2 330	2 480	2 630
Propane and Natural Gas Vehicles	702	736	755	811	773	804	924
Domestic Air	3 210	2 890	2 660	2 720	2 780	3 070	3 440
Domestic Marine	939	1 050	941	738	759	671	725
Rail	1 830	1 970	1 940	1 930	1 910	1 690	1 820
Vehicles Subtotal	**47 700**	**46 100**	**46 300**	**47 700**	**49 300**	**50 500**	**51 800**
Pipelines	2 200	2 330	3 150	3 310	3 350	3 920	4 230
Transportation Subtotal	**49 900**	**48 400**	**49 500**	**51 000**	**52 700**	**54 500**	**56 000**
Residential	17 800	17 300	18 100	20 100	20 800	19 900	22 300
Commercial and Institutional	9 050	9 350	9 940	10 600	10 200	10 700	11 300
Other	852	923	1 760	999	907	1 070	1 080
Combustion Subtotal	**135 000**	**134 000**	**137 000**	**130 000**	**130 000**	**134 000**	**141 000**
Fugitive							
Solid Fuels (i.e. Coal Mining)	0	0	0	0	0	0	0
Oil and Gas	1 400	1 400	1 400	1 500	1 500	1 500	1 500
Fugitive Subtotal	**1 400**	**1 400**	**1 400**	**1 500**	**1 500**	**1 500**	**1 500**
Energy Total	**136 000**	**135 000**	**138 000**	**132 000**	**132 000**	**136 000**	**143 000**
Industrial Processes							
Non-Metallic Mineral Production	3 690	3 020	3 040	2 850	3 190	3 230	3 320
Adipic Acid & Nitric Acid Production	11 000	10 000	10 000	9 200	11 000	11 000	12 000
Ferrous Metal Production	7 590	8 900	9 070	8 740	8 040	8 480	8 280
Aluminum and Magnesium Production	500	500	500	500	500	540	530
Other & Undifferentiated Production	3 900	4 100	4 300	4 600	4 200	4 400	5 300
Industrial Processes Total	**26 000**	**27 000**	**27 000**	**26 000**	**27 000**	**27 000**	**29 000**
Solvent & Other Product Use	**160**	**160**	**160**	**160**	**160**	**170**	**170**
Agriculture							
Enteric Fermentation	3 300	3 300	3 200	3 000	3 100	3 100	3 000
Manure Management	2 000	2 000	2 000	1 900	1 900	2 000	2 000
Agricultural Soils**	7 000	6 000	6 000	7 000	6 000	7 000	6 000
Agriculture Total	**12 000**	**12 000**	**11 000**	**11 000**	**11 000**	**12 000**	**11 000**
Land Use Change & Forestry*	**250**	**280**	**140**	**650**	**120**	**180**	**180**
Waste							
Solid Waste Disposal on Land	6 700	7 400	7 600	7 800	7 900	7 600	7 200
Wastewater Handling	380	390	390	400	410	410	420
Waste Incineration	80	81	82	80	79	81	82
Waste Total	**7 200**	**7 800**	**8 000**	**8 200**	**8 400**	**8 100**	**7 700**
TOTAL	**182 000**	**181 000**	**185 000**	**178 000**	**179 000**	**183 000**	**191 000**

* CH_4 and N_2O emissions from prescribed and other fires.
** Only one significant figure is shown due to high uncertainty.
Note: Due to rounding, individual values may not add up to totals.
Ammonia production emissions are included under undifferentiated production at the provincial level.

ONTARIO'S 1996 GREENHOUSE GAS EMISSION SUMMARY

GHG Source and Sink Category	CO_2 kt	CH_4 kt	CH_4 kt CO_2 eq	N_2O kt	N_2O kt CO_2 eq	HFCs kt CO_2 eq	PFCs kt CO_2 eq	SF_6 kt CO_2 eq	Total kt CO_2 eq
Global Warming Potential Multiplier	1		21		310	140-11 700	6 500-9 200	23 900	
Energy									
Fuel Combustion									
Fossil Fuel Industries	6 360	0.0	1.0	0.0	11				6 370
Electricity and Steam Generation	21 200	0.2	3.3	0.4	130				21 300
Mining	681	0.0	0.3	0.0	3.0				685
Manufacturing	21 600	0.6	12	0.7	230				21 900
Construction	190	0.0	0.1	0.0	0.8				191
Transportation									
Gasoline Automobiles	18 400	2.7	56	3.4	1000				19 500
Light-Duty Gasoline Trucks	9 740	1.6	34	3.1	950				10 700
Heavy-Duty Gasoline Vehicles	1 140	0.2	3.4	0.2	51				1 200
Motorcycles	67	0.1	1.1	0.0	0				69
Off-Road Gasoline Vehicles	1 030	1.3	28	0.0	8				1 070
Diesel Automobiles	180	0.0	0.1	0.0	2				182
Light-Duty Diesel Trucks	64	0.0	0.0	0.0	1				64
Heavy-Duty Diesel Vehicles	9 320	0.5	9.6	0.3	110				9 430
Off-Road Diesel Vehicles	2 340	0.1	2.5	0.9	290				2 630
Propane and Natural Gas Vehicles	875	2.3	47	0.0	2				924
Domestic Air	3 340	0.2	3.4	0.3	100				3 440
Domestic Marine	696	0.1	1.2	0.1	28				725
Rail	1 620	0.1	1.9	0.7	200				1 820
Vehicles Subtotal	**48 800**	**9.0**	**190**	**9.0**	**2 800**				**51 800**
Pipelines	4 210	0.1	2.0	0.0	13				4 230
Transportation Subtotal	**53 100**	**9.1**	**190**	**9.0**	**2 800**				**56 000**
Residential	20 600	67	1 400	0.9	290				22 300
Commercial and Institutional	11 200	0.2	4.9	0.1	37				11 300
Other	1 080	0.0	0.4	0.0	6				1 080
Combustion Subtotal	**136 000**	**77**	**1 600**	**11**	**3 500**				**141 000**
Fugitive									
Solid Fuels (i.e. Coal Mining)		0.0	0.0						0
Oil and Gas	10	71	1 500						1 500
Fugitive Subtotal	**10**	**71**	**1 500**						**1 500**
Energy Total	**136 000**	**150**	**3 100**	**11**	**3 500**				**143 000**
Industrial Processes									
Non-Metallic Mineral Production	3 320								3 320
Adipic Acid & Nitric Acid Production	0			37	12 000				12 000
Ferrous Metal Production	8 280								8 280
Aluminum and Magnesium Production	0						0	530	530
Other & Undifferentiated Production	5 300								5 300
Industrial Processes Total	**17 000**	**0**	**0**	**37**	**12 000**		**0**	**530**	**29 000**
Solvent & Other Product Use	**0**	**0**	**0**	**0.6**	**170**				**170**
Agriculture									
Enteric Fermentation		150	3 000						3 000
Manure Management		60	1 300	2.3	710				2 000
Agricultural Soils**	300			20	6 000				6 000
Agriculture Total	**300**	**200**	**4 300**	**20**	**7 000**				**11 000**
Land Use Change & Forestry*		**4**	**85**	**0**	**100**				**180**
Waste									
Solid Waste Disposal on Land		340	7 200						7 200
Wastewater Handling		3.1	65	1.1	350				420
Waste Incineration	65	0.2	4	0.0	13				82
Waste Total	**65**	**350**	**7 300**	**1.2**	**370**				**7 700**
TOTAL	**153 000**	**700**	**15 000**	**72**	**22 000**		**0**	**530**	**191 000**

* CH_4 and N_2O emissions from prescribed and other fires.
** Only one significant figure is shown due to high uncertainty.
Note: Due to rounding, individual values may not add up to totals.
Ammonia production emissions are included under undifferentiated production at the provincial level.
Limestone and soda ash use are not included in provincial totals.

MANITOBA'S GREENHOUSE GAS EMISSION ESTIMATES FROM 1990 TO 1996

GHG Source and Sink Category	1990 All Gases kt CO_2 eq	1991 All Gases kt CO_2 eq	1992 All Gases kt CO_2 eq	1993 All Gases kt CO_2 eq	1994 All Gases kt CO_2 eq	1995 All Gases kt CO_2 eq	1996 All Gases kt CO_2 eq
Energy							
Fuel Combustion							
Fossil Fuel Industries	8	2	3	2	0	1	0
Electricity and Steam Generation	544	397	402	315	327	248	409
Mining	67	58	69	63	47	55	43
Manufacturing	1 240	1 140	1 030	1 060	1 110	1 090	931
Construction	14	18	12	5	3	48	137
Transportation							
Gasoline Automobiles	1 990	1 980	1 920	1 830	1 820	1 780	1 650
Light-Duty Gasoline Trucks	871	937	994	1 020	1 100	1 150	1 230
Heavy-Duty Gasoline Vehicles	185	194	199	198	205	209	206
Motorcycles	7	8	7	7	7	6	4
Off-Road Gasoline Vehicles	348	334	358	403	389	452	438
Diesel Automobiles	20	20	19	18	18	17	17
Light-Duty Diesel Trucks	30	29	30	31	32	34	36
Heavy-Duty Diesel Vehicles	996	992	1 030	1 090	1 170	1 250	1 330
Off-Road Diesel Vehicles	874	653	562	614	646	817	798
Propane and Natural Gas Vehicles	43	49	49	46	34	55	47
Domestic Air	477	444	410	27	510	543	581
Domestic Marine	0	0	0	0	0	0	0
Rail	622	537	545	535	572	565	524
Vehicles Subtotal	**6 500**	**6 200**	**6 100**	**5 800**	**6 500**	**6 900**	**6 900**
Pipelines	821	947	1 190	1 220	1 160	1 260	1 260
Transportation Subtotal	**7 290**	**7 120**	**7 320**	**7 040**	**7 650**	**8 150**	**8 120**
Residential	1 710	1 600	1 480	1 520	1 490	1 560	1 680
Commercial and Institutional	1 440	1 440	1 470	1 520	1 430	1 530	1 660
Other	54	51	65	108	85	71	120
Combustion Subtotal	**12 400**	**11 800**	**11 800**	**11 600**	**12 100**	**12 700**	**13 100**
Fugitive							
Solid Fuels (i.e. Coal Mining)	0	0	0	0	0	0	0
Oil and Gas	420	420	430	440	440	460	490
Fugitive Subtotal	**420**	**420**	**430**	**440**	**440**	**460**	**490**
Energy Total	**12 800**	**12 200**	**12 300**	**12 100**	**12 600**	**13 200**	**13 600**
Industrial Processes							
Non-Metallic Mineral Production	191	179	62	67	71	74	85
Adipic Acid & Nitric Acid Production	21	20	21	21	26	29	30
Ferrous Metal Production	0	0	0	0	0	0	0
Aluminum and Magnesium Production	0	0	0	0	0	0	0
Other & Undifferentiated Production	55	41	45	82	77	42	45
Industrial Processes Total	**270**	**240**	**130**	**170**	**170**	**140**	**160**
Solvent & Other Product Use	**17**	**17**	**17**	**17**	**17**	**17**	**17**
Agriculture							
Enteric Fermentation	1 300	1 300	1 400	1 500	1 600	1 700	1 800
Manure Management	690	710	760	780	850	930	970
Agricultural Soils**	5 000	5 000	5 000	5 000	5 000	5 000	5 000
Agriculture Total	**7 200**	**7 300**	**7 400**	**7 400**	**7 100**	**7 400**	**7 900**
Land Use Change & Forestry*	**36**	**120**	**400**	**40**	**56**	**69**	**120**
Waste							
Solid Waste Disposal on Land	370	420	430	450	460	470	490
Wastewater Handling	57	57	57	58	58	58	59
Waste Incineration	0	0	0	0	0	0	0
Waste Total	420	470	490	500	520	530	550
TOTAL	**20 700**	**20 400**	**20 700**	**20 200**	**20 500**	**21 400**	**22 300**

* CH_4 and N_2O emissions from prescribed and other fires.

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

Note: Due to rounding, individual values may not add up to totals.
Ammonia production emissions are included under undifferentiated production at the provincial level.

MANITOBA'S 1996 GREENHOUSE GAS EMISSION SUMMARY

GHG Source and Sink Category	CO_2 kt	CH_4 kt	CH_4 kt CO_2 eq	N_2O kt	N_2O kt CO_2 eq	HFCs kt CO_2 eq	PFCs kt CO_2 eq	SF_6 kt CO_2 eq	Total kt CO_2 eq
Global Warming Potential Multiplier	1		21		310	140-11 700	6 500-9 200	23 900	
Energy									
Fuel Combustion									
Fossil Fuel Industries	0	0.0	0.0	0.0	0.0				0
Electricity and Steam Generation	405	0.0	0.2	0.0	4.4				409
Mining	43	0.0	0.0	0.0	0.2				43
Manufacturing	927	0.0	0.2	0.0	3.6				931
Construction	136	0.0	0.1	0.0	0.5				137
Transportation									
Gasoline Automobiles	1 560	0.2	5.0	0.3	82				1 650
Light-Duty Gasoline Trucks	1 120	0.2	3.9	0.4	110				1 230
Heavy-Duty Gasoline Vehicles	197	0.0	0.6	0.0	9				206
Motorcycles	4	0.0	0.1	0.0	0				4
Off-Road Gasoline Vehicles	423	0.5	11	0.0	3				438
Diesel Automobiles	17	0.0	0.0	0.0	0				17
Light-Duty Diesel Trucks	35	0.0	0.0	0.0	0				36
Heavy-Duty Diesel Vehicles	1 310	0.1	1.4	0.0	15				1 330
Off-Road Diesel Vehicles	709	0.0	0.8	0.3	89				798
Propane and Natural Gas Vehicles	46	0.0	0.5	0.0	0				47
Domestic Air	563	0.0	0.8	0.1	17				581
Domestic Marine	0	0.0	0.0	0.0	0				0
Rail	465	0.0	0.5	0.2	58				524
Vehicles Subtotal	**6 450**	**1.2**	**25**	**1.2**	**390**				**6 900**
Pipelines	1 260	0.0	0.6	0.0	4				1 260
Transportation Subtotal	**7 710**	**1.2**	**26**	**1.3**	**390**				**8 120**
Residential	1 560	4.6	97	0.1	21				1 680
Commercial and Institutional	1 660	0.0	0.8	0.0	5.5				1 660
Other	118	0.0	0.1	0.0	1.5				120
Combustion Subtotal	**12 600**	**5.9**	**120**	**1.4**	**430**				**13 100**
Fugitive									
Solid Fuels (i.e. Coal Mining)		0.0	0.0						0
Oil and Gas	1	23	490						490
Fugitive Subtotal	**1**	**23**	**490**						**490**
Energy Total	**12 600**	**29**	**610**	**1.4**	**430**				**13 600**
Industrial Processes									
Non-Metallic Mineral Production	85								85
Adipic Acid & Nitric Acid Production	0			0.1	30				30
Ferrous Metal Production	0								0
Aluminum and Magnesium Production	0						0	0	0
Other & Undifferentiated Production	45								45
Industrial Processes Total	**130**	**0**	**0**	**0.1**	**30**		**0**	**0**	**160**
Solvent & Other Product Use	**0**	**0**	**0**	**0.1**	**17**				**17**
Agriculture									
Enteric Fermentation		84	1800						1 800
Manure Management		24	500	1.5	470				970
Agricultural Soils**	60			20	5 000				5 000
Agriculture Total	**60**	**110**	**2 300**	**20**	**6 000**				**7 900**
Land Use Change & Forestry*		**3**	**55**	**0**	**60**				**120**
Waste									
Solid Waste Disposal on Land		23	490						490
Wastewater Handling		1.1	23	0.1	36				59
Waste Incineration	0	0.0	0	0.0	0				0
Waste Total	**0**	**24**	**510**	**0.1**	**36**				**550**
TOTAL	**12 700**	**160**	**3 500**	**20**	**6 100**		**0**	**0**	**22 300**

* CH_4 and N_2O emissions from prescribed and other fires.
** Only one significant figure is shown due to high uncertainty.
Note: Due to rounding, individual values may not add up to totals.
Ammonia production emissions are included under undifferentiated production at the provincial level.
Limestone and soda ash use are not included in provincial totals.

SASKATCHEWAN'S GREENHOUSE GAS EMISSION ESTIMATES FROM 1990 TO 1996

GHG Source and Sink Category	1990 All Gases kt CO_2 eq	1991 All Gases kt CO_2 eq	1992 All Gases kt CO_2 eq	1993 All Gases kt CO_2 eq	1994 All Gases kt CO_2 eq	1995 All Gases kt CO_2 eq	1996 All Gases kt CO_2 eq
Energy							
Fuel Combustion							
Fossil Fuel Industries	2 330	1 010	2 400	1 220	2 200	2 740	2 210
Electricity and Steam Generation	10 400	10 500	11 800	12 100	13 000	13 400	13 700
Mining	960	925	985	1 730	1 860	1 900	1 380
Manufacturing	1 140	1 890	2 540	2 280	2 340	2 040	2 310
Construction	33	23	27	22	15	44	88
Transportation							
Gasoline Automobiles	1 590	1 600	1 890	1 750	1 620	1 480	1 450
Light-Duty Gasoline Trucks	1 030	1 100	1 390	1 390	1 400	1 400	1 550
Heavy-Duty Gasoline Vehicles	197	252	375	432	493	554	513
Motorcycles	2	2	3	3	3	3	3
Off-Road Gasoline Vehicles	1 190	1 110	436	563	813	804	810
Diesel Automobiles	14	14	16	15	13	11	13
Light-Duty Diesel Trucks	73	80	75	76	87	86	93
Heavy-Duty Diesel Vehicles	1 450	1 650	1 610	1 680	1 950	1 950	2 150
Off-Road Diesel Vehicles	1 400	1 460	1 400	1 570	1 710	1 790	1 870
Propane and Natural Gas Vehicles	37	49	49	59	65	63	60
Domestic Air	260	224	222	184	179	221	235
Domestic Marine	0	0	0	0	0	0	0
Rail	600	304	372	369	524	527	579
Vehicles Subtotal	**7 840**	**7 830**	**7 840**	**8 100**	**8 860**	**8 890**	**9 330**
Pipelines	1 590	1 730	2 360	2 380	2 200	2 520	2 490
Transportation Subtotal	**9 430**	**9 560**	**10 200**	**10 500**	**11 100**	**11 400**	**11 800**
Residential	2 150	2 140	2 060	2 170	2 100	2 130	2 450
Commercial and Institutional	1 050	996	904	1 480	1 300	1 250	1 450
Other	303	261	307	329	329	331	382
Combustion Subtotal	**27 800**	**27 300**	**31 300**	**31 800**	**34 200**	**35 300**	**35 800**
Fugitive							
Solid Fuels (i.e. Coal Mining)	12	11	13	13	13	14	14
Oil and Gas	6 100	6 300	6 700	7 400	7 900	8 800	9 600
Fugitive Subtotal	**6 100**	**6 300**	**6 700**	**7 400**	**7 900**	**8 800**	**9 600**
Energy Total	**34 000**	**34 000**	**38 000**	**39 000**	**42 000**	**44 000**	**45 000**
Industrial Processes							
Non-Metallic Mineral Production	82	75	0	0	0	0	0
Adipic Acid & Nitric Acid Production	0	0	0	0	0	0	0
Ferrous Metal Production	0	0	0	0	0	0	0
Aluminum and Magnesium Production	0	0	0	0	0	0	0
Other & Undifferentiated Production	240	270	600	780	780	840	1 100
Industrial Processes Total	**320**	**350**	**600**	**780**	**780**	**840**	**1 100**
Solvent & Other Product Use	**15**	**15**	**15**	**15**	**15**	**15**	**15**
Agriculture							
Enteric Fermentation	2 500	2 500	2 700	2 800	2 900	3 100	3 200
Manure Management	900	930	990	1 000	1 100	1 100	1 100
Agricultural Soils**	8 000	8 000	8 000	7 000	8 000	7 000	8 000
Agriculture Total	**12 000**	**12 000**	**11 000**	**11 000**	**12 000**	**11 000**	**12 000**
Land Use Change & Forestry*	**74**	**180**	**150**	**140**	**200**	**390**	**130**
Waste							
Solid Waste Disposal on Land	420	430	450	460	470	480	490
Wastewater Handling	87	87	87	87	87	88	88
Waste Incineration	0	0	0	0	0	0	0
Waste Total	500	520	530	550	560	570	580
TOTAL	**46 500**	**46 500**	**50 700**	**51 600**	**55 200**	**57 300**	**59 300**

* CH_4 and N_2O emissions from prescribed and other fires.
** Only one significant figure is shown due to high uncertainty.
Note: Due to rounding, individual values may not add up to totals.
Ammonia production emissions are included under undifferentiated production at the provincial level.

SASKATCHEWAN'S 1996 GREENHOUSE GAS EMISSION SUMMARY

GHG Source and Sink Category	CO_2 kt	CH_4 kt	CH_4 kt CO_2 eq	N_2O kt	N_2O kt CO_2 eq	HFCs kt CO_2 eq	PFCs kt CO_2 eq	SF_6 kt CO_2 eq	Total kt CO_2 eq
Global Warming Potential Multiplier	1		21		310	140-11 700	6 500-9 200	23 900	
Energy									
Fuel Combustion									
Fossil Fuel Industries	2 200	0.1	1.5	0.0	9.0				2 210
Electricity and Steam Generation	13 600	0.2	3.2	0.5	150				13 700
Mining	1 380	0.0	0.7	0.0	4.7				1 380
Manufacturing	2 310	0.0	0.4	0.0	3.2				2 310
Construction	87	0.0	0.0	0.0	0.3				88
Transportation									
Gasoline Automobiles	1 390	0.2	4.8	0.2	62				1 450
Light-Duty Gasoline Trucks	1 420	0.3	5.3	0.4	130				1 550
Heavy-Duty Gasoline Vehicles	490	0.1	1.5	0.1	22				513
Motorcycles	3	0.0	0.0	0.0	0				3
Off-Road Gasoline Vehicles	783	1.0	21	0.0	6				810
Diesel Automobiles	13	0.0	0.0	0.0	0				13
Light-Duty Diesel Trucks	92	0.0	0.1	0.0	1				93
Heavy-Duty Diesel Vehicles	2 130	0.1	2.2	0.1	24				2 150
Off-Road Diesel Vehicles	1 660	0.1	1.8	0.7	210				1 870
Propane and Natural Gas Vehicles	60	0.0	0.6	0.0	0				60
Domestic Air	227	0.0	0.5	0.0	7				235
Domestic Marine	0	0.0	0.0	0.0	0				0
Rail	514	0.0	0.6	0.2	64				579
Vehicles Subtotal	**8 770**	**1.8**	**38**	**1.7**	**520**				**9 330**
Pipelines	2 480	0.1	1.2	0.0	8				2 490
Transportation Subtotal	**11 300**	**1.9**	**39**	**1.7**	**530**				**11 800**
Residential	2 350	3.8	80	0.1	21				2 450
Commercial and Institutional	1 450	0.0	0.7	0.0	4.8				1 450
Other	381	0.0	0.2	0.0	1.4				382
Combustion Subtotal	**35 000**	**6.0**	**130**	**2.3**	**730**				**35 800**
Fugitive									
Solid Fuels (i.e. Coal Mining)		0.7	14						14
Oil and Gas	1 700	370	7 800						9 600
Fugitive Subtotal	**1 700**	**370**	**7 800**						**9 600**
Energy Total	**36 700**	**380**	**8 000**	**2.3**	**730**				**45 000**
Industrial Processes									
Non-Metallic Mineral Production	0								0
Adipic Acid & Nitric Acid Production	0			0.0	0.0				0
Ferrous Metal Production	0								0
Aluminum and Magnesium Production	0						0	0	0
Other & Undifferentiated Production	1 100								1 100
Industrial Processes Total	**1 100**	**0**	**0**	**0.0**	**0**		**0**	**0**	**1 100**
Solvent & Other Product Use	**0**	**0**	**0**	**0.1**	**15**				**15**
Agriculture									
Enteric Fermentation		150	3 200						3 200
Manure Management		14	300	2.7	840				1 100
Agricultural Soils**	-1 000			30	9 000				8 000
Agriculture Total	**-1 000**	**170**	**3 500**	**30**	**10 000**				**12 000**
Land Use Change & Forestry*		**3**	**58**	**0**	**70**				**130**
Waste									
Solid Waste Disposal on Land		23	490						490
Wastewater Handling		2.7	56	0.1	32				88
Waste Incineration	0	0.0	0	0.0	0				0
Waste Total	**0**	**26**	**550**	**0.1**	**32**				**580**
TOTAL	**36 600**	**570**	**12 000**	**34**	**11 000**		**0**	**0**	**59 300**

* CH_4 and N_2O emissions from prescribed and other fires.
** Only one significant figure is shown due to high uncertainty.
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Ammonia production emissions are included under undifferentiated production at the provincial level.
Limestone and soda ash use are not included in provincial totals.

ALBERTA'S GREENHOUSE GAS EMISSION ESTIMATES FROM 1990 TO 1996

GHG Source and Sink Category	1990 All Gases kt CO_2 eq	1991 All Gases kt CO_2 eq	1992 All Gases kt CO_2 eq	1993 All Gases kt CO_2 eq	1994 All Gases kt CO_2 eq	1995 All Gases kt CO_2 eq	1996 All Gases kt CO_2 eq
Energy							
Fuel Combustion							
Fossil Fuel Industries	21 200	21 900	22 300	23 400	23 800	22 400	21 500
Electricity and Steam Generation	40 100	42 100	45 100	45 500	48 900	49 000	48 900
Mining	4 340	3 730	3 340	5 270	5 540	7 330	8 760
Manufacturing	8 500	7 460	7 790	7 170	7 350	8 440	8 180
Construction	85	170	179	89	87	165	216
Transportation							
Gasoline Automobiles	5 630	5 150	5 070	4 940	5 200	5 040	4 660
Light-Duty Gasoline Trucks	3 650	3 520	3 670	3 760	4 170	4 250	4 210
Heavy-Duty Gasoline Vehicles	651	697	796	881	1 040	1 120	1 090
Motorcycles	25	24	23	24	26	23	22
Off-Road Gasoline Vehicles	1 380	1 000	1 040	1 020	695	644	1 310
Diesel Automobiles	51	46	43	40	40	36	34
Light-Duty Diesel Trucks	93	81	76	76	87	87	93
Heavy-Duty Diesel Vehicles	3 710	3 560	3 650	3 950	4 790	5 080	5 740
Off-Road Diesel Vehicles	2 910	2 730	2 320	2 700	3 110	4 040	5 060
Propane and Natural Gas Vehicles	491	538	542	473	576	639	747
Domestic Air	1 550	1 390	1 450	1 530	1 580	1 660	1 850
Domestic Marine	0	0	1	1	0	1	0
Rail	1 800	1 540	1 560	1 560	1 620	1 240	1 150
Vehicles Subtotal	**21 900**	**20 300**	**20 200**	**21 000**	**22 900**	**23 900**	**26 000**
Pipelines	1 230	1 320	1 860	2 040	2 520	2 580	2 690
Transportation Subtotal	**23 200**	**21 600**	**22 100**	**23 000**	**25 400**	**26 500**	**28 700**
Residential	6 590	6 460	6 400	6 620	7 250	7 550	8 700
Commercial and Institutional	5 050	4 630	4 340	5 010	5 370	6 020	5 250
Other	525	434	537	571	348	327	406
Combustion Subtotal	**110 000**	**108 000**	**112 000**	**117 000**	**124 000**	**128 000**	**131 000**
Fugitive							
Solid Fuels (i.e. Coal Mining)	240	250	270	270	270	300	290
Oil and Gas	25 000	26 000	28 000	29 000	30 000	32 000	34 000
Fugitive Subtotal	**25 000**	**26 000**	**28 000**	**29 000**	**31 000**	**32 000**	**34 000**
Energy Total	**135 000**	**135 000**	**140 000**	**146 000**	**155 000**	**160 000**	**165 000**
Industrial Processes							
Non-Metallic Mineral Production	869	793	718	914	889	894	991
Adipic Acid & Nitric Acid Production	660	650	660	660	650	660	670
Ferrous Metal Production	0	5	6	10	3	9	2
Aluminum and Magnesium Production	0	0	0	0	0	0	0
Other & Undifferentiated Production	7 900	8 700	8 800	9 900	11 000	10 000	11 000
Industrial Processes Total	**9 400**	**10 000**	**10 000**	**12 000**	**12 000**	**12 000**	**13 000**
Solvent & Other Product Use	**39**	**39**	**40**	**40**	**41**	**41**	**42**
Agriculture							
Enteric Fermentation	5 100	5 300	5 500	5 600	6 000	6 200	6 200
Manure Management	1 900	2 000	2 100	2 100	2 200	2 300	2 300
Agricultural Soils**	10 000	10 000	10 000	10 000	9 000	10 000	10 000
Agriculture Total	**19 000**	**19 000**	**19 000**	**19 000**	**18 000**	**21 000**	**21 000**
Land Use Change & Forestry*	**1 600**	**1 900**	**1 500**	**1 300**	**560**	**240**	**570**
Waste							
Solid Waste Disposal on Land	870	930	780	820	860	890	850
Wastewater Handling	140	140	140	140	150	150	150
Waste Incineration	0	0	0	0	0	0	0
Waste Total	**1 000**	**1 100**	**920**	**960**	**1 000**	**1 000**	**990**
TOTAL	**166 000**	**167 000**	**172 000**	**179 000**	**186 000**	**194 000**	**199 000**

* CH_4 and N_2O emissions from prescribed and other fires.
** Only one significant figure is shown due to high uncertainty.
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ALBERTA'S 1996 GREENHOUSE GAS EMISSION SUMMARY

GHG Source and Sink Category	CO_2 kt	CH_4 kt	CH_4 kt CO_2 eq	N_2O kt	N_2O kt CO_2 eq	HFCs kt CO_2 eq	PFCs kt CO_2 eq	SF_6 kt CO_2 eq	Total kt CO_2 eq
Global Warming Potential Multiplier	1		21		310	140-11 700	6 500-9 200	23 900	
Energy									
Fuel Combustion									
Fossil Fuel Industries	21 400	0.5	10	0.2	67				21 500
Electricity and Steam Generation	48 500	0.4	9.2	1.3	420				48 900
Mining	8 700	0.2	4.6	0.2	52				8 760
Manufacturing	8 130	0.3	5.3	0.2	46				8 180
Construction	215	0.0	0.1	0.0	0.6				216
Transportation									
Gasoline Automobiles	4 420	0.7	14	0.7	220				4 660
Light-Duty Gasoline Trucks	3 840	0.7	14	1.2	360				4 210
Heavy-Duty Gasoline Vehicles	1 040	0.2	3.1	0.2	46				1 090
Motorcycles	21	0.0	0.4	0.0	0				22
Off-Road Gasoline Vehicles	1 260	1.6	34	0.0	10				1 310
Diesel Automobiles	34	0.0	0.0	0.0	0				34
Light-Duty Diesel Trucks	92	0.0	0.1	0.0	1				93
Heavy-Duty Diesel Vehicles	5 670	0.3	5.8	0.2	64				5 740
Off-Road Diesel Vehicles	4 500	0.2	4.8	1.8	560				5 060
Propane and Natural Gas Vehicles	731	0.8	16	0.0	0				747
Domestic Air	1 790	0.1	1.8	0.2	54				1 850
Domestic Marine	0	0.0	0.0	0.0	0				0
Rail	1 020	0.1	1.2	0.4	130				1 150
Vehicles Subtotal	**24 400**	**4.5**	**95**	**4.7**	**1 400**				**26 000**
Pipelines	2 680	0.1	1.3	0.0	9				2 690
Transportation Subtotal	**27 100**	**4.6**	**96**	**4.7**	**1 500**				**28 700**
Residential	8 480	7.8	160	0.2	56				8 700
Commercial and Institutional	5 230	0.1	2.4	0.1	19.0				5 250
Other	404	0.0	0.2	0.0	1.6				406
Combustion Subtotal	**128 000**	**14**	**290**	**6.8**	**2 100**				**131 000**
Fugitive									
Solid Fuels (i.e. Coal Mining)		14	290						290
Oil and Gas	8 600	1200	25 000						34 000
Fugitive Subtotal	**8 600**	**1200**	**25 000**						**34 000**
Energy Total	**137 000**	**1200**	**26 000**	**6.8**	**2 100**				**165 000**
Industrial Processes									
Non-Metallic Mineral Production	991								991
Adipic Acid & Nitric Acid Production	0			2.2	670				670
Ferrous Metal Production	2								2
Aluminum and Magnesium Production	0						0	0	0
Other & Undifferentiated Production	11 000								11 000
Industrial Processes Total	**12 000**	**0**	**0**	**2.2**	**670**		**0**	**0**	**13 000**
Solvent & Other Product Use	**0**	**0**	**0**	**0.1**	**42**				**42**
Agriculture									
Enteric Fermentation		290	6 200						6 200
Manure Management		31	650	5.4	1 700				2 300
Agricultural Soils**	2 000			30	10 000				10 000
Agriculture Total	**2 000**	**330**	**6 800**	**40**	**10 000**				**21 000**
Land Use Change & Forestry*		**16**	**330**	**1**	**200**				**570**
Waste									
Solid Waste Disposal on Land		40	850						850
Wastewater Handling		2.9	62	0.3	87				150
Waste Incineration	0	0.0	0	0.0	0				0
Waste Total	**0**	**43**	**910**	**0.3**	**87**				**990**
TOTAL	**151 000**	**1600**	**34 000**	**47**	**15 000**		**0**	**0**	**199 000**

* CH_4 and N_2O emissions from prescribed and other fires.
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Limestone and soda ash use are not included in provincial totals.

BRITISH COLUMBIA'S GREENHOUSE GAS EMISSION ESTIMATES FROM 1990 TO 1996

GHG Source and Sink Category	1990 All Gases kt CO_2 eq	1991 All Gases kt CO_2 eq	1992 All Gases kt CO_2 eq	1993 All Gases kt CO_2 eq	1994 All Gases kt CO_2 eq	1995 All Gases kt CO_2 eq	1996 All Gases kt CO_2 eq
Energy							
Fuel Combustion							
Fossil Fuel Industries	3 100	2 610	1 820	1 380	1 980	3 000	3 700
Electricity and Steam Generation	1 240	887	1 300	2 440	2 410	2 840	1 280
Mining	294	276	330	359	279	150	149
Manufacturing	6 320	6 410	5 860	6 460	5 970	6 770	7 090
Construction	139	89	68	78	59	88	203
Transportation							
Gasoline Automobiles	5 380	5 300	5 270	5 340	5 390	5 300	5 260
Light-Duty Gasoline Trucks	2 770	2 970	3 200	3 470	3 760	3 970	4 060
Heavy-Duty Gasoline Vehicles	354	410	477	554	635	701	734
Motorcycles	39	38	39	38	39	39	38
Off-Road Gasoline Vehicles	362	361	376	528	564	606	629
Diesel Automobiles	74	70	67	65	62	58	65
Light-Duty Diesel Trucks	80	64	56	51	51	50	49
Heavy-Duty Diesel Vehicles	2 930	2 830	2 880	3 010	3 290	3 510	3 690
Off-Road Diesel Vehicles	1 760	1 750	1 810	1 750	1 870	2 250	2 500
Propane and Natural Gas Vehicles	369	439	440	553	714	709	659
Domestic Air	1 910	1 970	2 010	1 780	2 030	2 430	2 700
Domestic Marine	1 850	2 060	2 310	2 030	2 200	2 360	2 020
Rail	1 470	1 430	1 640	1 670	1 680	1 690	1 620
Vehicles Subtotal	**19 300**	**19 700**	**20 600**	**20 800**	**22 300**	**23 700**	**24 000**
Pipelines	820	1 060	1 000	1 080	1 200	1 330	1 450
Transportation Subtotal	**20 200**	**20 800**	**21 600**	**21 900**	**23 500**	**25 000**	**25 500**
Residential	4 390	4 290	4 060	4 740	4 440	4 490	5 090
Commercial and Institutional	2 920	3 150	3 050	3 470	3 250	3 270	3 380
Other	733	737	663	704	458	158	195
Combustion Subtotal	**39 300**	**39 200**	**38 700**	**41 500**	**42 300**	**45 800**	**46 600**
Fugitive							
Solid Fuels (i.e. Coal Mining)	490	480	360	470	510	570	630
Oil and Gas	3 000	3 100	3 500	3 600	4 300	4 900	5 100
Fugitive Subtotal	**3 500**	**3 600**	**3 800**	**4 100**	**4 800**	**5 400**	**5 800**
Energy Total	**43 000**	**43 000**	**43 000**	**46 000**	**47 000**	**51 000**	**52 000**
Industrial Processes							
Non-Metallic Mineral Production	843	781	839	947	1 020	1 060	1 140
Adipic Acid & Nitric Acid Production	0	0	0	0	0	0	0
Ferrous Metal Production	0	0	0	0	0	0	0
Aluminum and Magnesium Production	1 000	1 000	1 000	1 000	1 000	1 000	1 000
Other & Undifferentiated Production	100	57	0	0	120	64	90
Industrial Processes Total	**2 200**	**2 100**	**2 100**	**2 200**	**2 400**	**2 300**	**2 400**
Solvent & Other Product Use	**50**	**51**	**52**	**54**	**55**	**57**	**58**
Agriculture							
Enteric Fermentation	910	930	950	940	1 000	1 000	1 000
Manure Management	380	390	390	390	420	430	420
Agricultural Soils**	1 000	1 000	1 000	1 000	1 000	1 000	1 000
Agriculture Total	**2 500**	**2 400**	**2 400**	**2 500**	**2 500**	**2 600**	**2 700**
Land Use Change & Forestry*	**36**	**51**	**51**	**51**	**51**	**54**	**51**
Waste							
Solid Waste Disposal on Land	3 400	3 700	3 800	3 800	3 900	4 000	4 300
Wastewater Handling	190	190	200	200	210	210	220
Waste Incineration	67	68	70	72	74	76	78
Waste Total	**3 600**	**3 900**	**4 000**	**4 100**	**4 200**	**4 300**	**4 600**
TOTAL	**51 200**	**51 400**	**51 300**	**54 500**	**56 300**	**60 500**	**62 400**

* CH_4 and N_2O emissions from prescribed and other fires.
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Note: Due to rounding, individual values may not add up to totals.
Ammonia production emissions are included under undifferentiated production at the provincial level.

BRITISH COLUMBIA'S 1996 GREENHOUSE GAS EMISSION SUMMARY

GHG Source and Sink Category	CO_2 kt	CH_4 kt	CH_4 kt CO_2 eq	N_2O kt	N_2O kt CO_2 eq	HFCs kt CO_2 eq	PFCs kt CO_2 eq	SF_6 kt CO_2 eq	Total kt CO_2 eq
Global Warming Potential Multiplier	1		21		310	140-11 700	6 500-9 200	23 900	
Energy									
Fuel Combustion									
Fossil Fuel Industries	3 680	0.0	0.0	0.1	17				3 700
Electricity and Steam Generation	1 270	0.0	0.7	0.0	6.8				1 280
Mining	148	0.0	0.0	0.0	0.6				149
Manufacturing	7 020	0.3	5.8	0.2	68				7 090
Construction	203	0.0	0.1	0.0	0.6				203
Transportation									
Gasoline Automobiles	5 000	0.8	17	0.8	240				5 260
Light-Duty Gasoline Trucks	3 710	0.6	13	1.1	340				4 060
Heavy-Duty Gasoline Vehicles	700	0.1	2.1	0.1	31				734
Motorcycles	38	0.0	0.6	0.0	0				38
Off-Road Gasoline Vehicles	608	0.8	16	0.0	5				629
Diesel Automobiles	64	0.0	0.0	0.0	1				65
Light-Duty Diesel Trucks	48	0.0	0.0	0.0	1				49
Heavy-Duty Diesel Vehicles	3 650	0.2	3.8	0.1	41				3 690
Off-Road Diesel Vehicles	2 220	0.1	2.4	0.9	280				2 500
Propane and Natural Gas Vehicles	608	2.3	49	0.0	2				659
Domestic Air	2 620	0.1	2.7	0.3	80				2 700
Domestic Marine	1 900	0.2	3.4	0.4	110				2 020
Rail	1 440	0.1	1.7	0.6	180				1 620
Vehicles Subtotal	**22 600**	**5.3**	**110**	**4.3**	**1 300**				**24 000**
Pipelines	1 440	0.0	0.7	0.0	5				1 450
Transportation Subtotal	**24 000**	**5.3**	**110**	**4.3**	**1 300**				**25 500**
Residential	4 660	17	360	0.2	73				5 090
Commercial and Institutional	3 370	0.1	1.5	0.0	11				3 380
Other	195	0.0	0.0	0.0	0.5				195
Combustion Subtotal	**44 600**	**23**	**480**	**4.8**	**1 500**				**46 600**
Fugitive									
Solid Fuels (i.e. Coal Mining)		30	630						630
Oil and Gas	3 200	95	2 000						5 100
Fugitive Subtotal	**3 200**	**120**	**2 600**						**5 800**
Energy Total	**47 800**	**150**	**3 100**	**4.8**	**1 500**				**52 000**
Industrial Processes									
Non-Metallic Mineral Production	1 140								1 140
Adipic Acid & Nitric Acid Production	0			0.0	0				0
Ferrous Metal Production	0								0
Aluminum and Magnesium Production	497						600	0	1 000
Other & Undifferentiated Production	90								90
Industrial Processes Total	**1 730**	**0**	**0**	**0.0**	**0**		**600**	**0**	**2 400**
Solvent & Other Product Use	**0**	**0**	**0**	**0.2**	**58**				**58**
Agriculture									
Enteric Fermentation		50	1 000						1 000
Manure Management		7.8	160	0.8	260				420
Agricultural Soils**	30			4	1 000				1 000
Agriculture Total	30	57	1 200	5	1 000				2 700
Land Use Change & Forestry*		**1**	**23**	**0**	**30**				**51**
Waste									
Solid Waste Disposal on Land		210	4 300						4 300
Wastewater Handling		4.6	96	0.4	120				220
Waste Incineration	65	0.0	0	0.0	13				78
Waste Total	**65**	**210**	**4 400**	**0.4**	**130**				**4 600**
TOTAL	**49 600**	**430**	**9 100**	**10**	**3 100**		**600**	**0**	**62 400**

* CH_4 and N_2O emissions from prescribed and other fires.
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Ammonia production emissions are included under undifferentiated production at the provincial level.
Limestone and soda ash use are not included in provincial totals.

YUKON AND NORTHWEST TERRITORIES' GREENHOUSE GAS EMISSION ESTIMATES FROM 1990 TO 1996

GHG Source and Sink Category	1990 All Gases kt CO_2 eq	1991 All Gases kt CO_2 eq	1992 All Gases kt CO_2 eq	1993 All Gases kt CO_2 eq	1994 All Gases kt CO_2 eq	1995 All Gases kt CO_2 eq	1996 All Gases kt CO_2 eq
Energy							
Fuel Combustion							
Fossil Fuel Industries	143	83	84	68	63	93	67
Electricity and Steam Generation	319	325	332	328	365	407	343
Mining	53	60	138	45	116	91	31
Manufacturing	43	19	24	11	28	34	25
Construction	7	6	8	7	7	26	4
Transportation							
Gasoline Automobiles	108	108	117	118	109	107	100
Light-Duty Gasoline Trucks	46	49	57	61	60	63	63
Heavy-Duty Gasoline Vehicles	8	9	11	12	12	13	12
Motorcycles	1	1	1	1	1	1	0
Off-Road Gasoline Vehicles	81	66	52	86	84	66	82
Diesel Automobiles	1	1	1	1	1	1	1
Light-Duty Diesel Trucks	3	2	2	1	2	3	3
Heavy-Duty Diesel Vehicles	134	117	116	93	151	210	204
Off-Road Diesel Vehicles	283	210	200	270	286	174	438
Propane and Natural Gas Vehicles	1	3	0	5	6	11	3
Domestic Air	214	226	240	264	289	257	353
Domestic Marine	0	0	1	1	0	71	90
Rail	2	2	2	2	2	2	1
Vehicles Subtotal	**881**	**794**	**799**	**915**	**1 000**	**978**	**1 350**
Pipelines	0	0	0	0	2	0	0
Transportation Subtotal	**881**	**794**	**799**	**915**	**1 010**	**978**	**1 350**
Residential	163	190	208	261	257	148	222
Commercial and Institutional	334	405	395	433	423	518	436
Other	3	13	21	7	6	8	6
Combustion Subtotal	**1 950**	**1 890**	**2 010**	**2 070**	**2 270**	**2 300**	**2 490**
Fugitive							
Solid Fuels (i.e. Coal Mining)	0	0	0	0	0	0	0
Oil and Gas	58	81	110	110	98	96	90
Fugitive Subtotal	**58**	**81**	**110**	**110**	**98**	**96**	**90**
Energy Total	**2 000**	**2 000**	**2 100**	**2 200**	**2 400**	**2 400**	**2 600**
Industrial Processes							
Non-Metallic Mineral Production	0	0	0	0	0	0	0
Adipic Acid & Nitric Acid Production	0	0	0	0	0	0	0
Ferrous Metal Production	0	0	0	0	0	0	0
Aluminum and Magnesium Production	0	0	0	0	0	0	0
Other & Undifferentiated Production	4	12	2	3	100	86	66
Industrial Processes Total	**4**	**12**	**2**	**3**	**100**	**86**	**66**
Solvent & Other Product Use	**1**	**1**	**1**	**1**	**1**	**1**	**2**
Agriculture							
Enteric Fermentation	0	0	0	0	0	0	0
Manure Management	0	0	0	0	0	0	0
Agricultural Soils**	0	0	0	0	0	0	0
Agriculture Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Land Use Change & Forestry*	**4**	**13**	**30**	**49**	**27**	**230**	**47**
Waste							
Solid Waste Disposal on Land	11	11	11	12	12	13	13
Wastewater Handling	10	10	11	11	11	11	11
Waste Incineration	0	0	0	0	0	0	0
Waste Total	**21**	**21**	**22**	**23**	**23**	**24**	**25**
TOTAL	**2 040**	**2 040**	**2 210**	**2 330**	**2 550**	**2 930**	**2 740**

* CH_4 and N_2O emissions from prescribed and other fires.
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YUKON AND NORTHWEST TERRITORIES' 1996 GREENHOUSE GAS EMISSION SUMMARY

GHG Source and Sink Category	CO_2 kt	CH_4 kt	CH_4 kt CO_2 eq	N_2O kt	N_2O kt CO_2 eq	HFCs kt CO_2 eq	PFCs kt CO_2 eq	SF_6 kt CO_2 eq	Total kt CO_2 eq
Global Warming Potential Multiplier	1		21		310	140-11 700	6 500-9 200	23 900	
Energy									
Fuel Combustion									
Fossil Fuel Industries	67	0.0	0.0	0.0	0.2				67
Electricity and Steam Generation	330	0.0	0.6	0.0	12				343
Mining	31	0.0	0.0	0.0	0.1				31
Manufacturing	25	0.0	0.0	0.0	0.0				25
Construction	4	0.0	0.0	0.0	0.0				4
Transportation									
Gasoline Automobiles	95	0.0	0.3	0.0	5				100
Light-Duty Gasoline Trucks	58	0.0	0.2	0.0	5				63
Heavy-Duty Gasoline Vehicles	12	0.0	0.0	0.0	1				12
Motorcycles	0	0.0	0.0	0.0	0				0
Off-Road Gasoline Vehicles	79	0.1	2.1	0.0	1				82
Diesel Automobiles	1	0.0	0.0	0.0	0				1
Light-Duty Diesel Trucks	3	0.0	0.0	0.0	0				3
Heavy-Duty Diesel Vehicles	202	0.0	0.2	0.0	2				204
Off-Road Diesel Vehicles	389	0.0	0.4	0.2	49				438
Propane and Natural Gas Vehicles	3	0.0	0.0	0.0	0				3
Domestic Air	342	0.0	0.7	0.0	10				353
Domestic Marine	81	0.0	0.1	0.0	9				90
Rail	1	0.0	0.0	0.0	0				1
Vehicles Subtotal	**1 270**	**0.2**	**4.1**	**0.3**	**82**				**1 350**
Pipelines	0	0.0	0.0	0.0	0				0
Transportation Subtotal	**1 270**	**0.2**	**4.1**	**0.3**	**82**				**1 350**
Residential	204	0.7	15	0.0	3				222
Commercial and Institutional	436	0.0	0.1	0.0	0.7				436
Other	6	0.0	0.0	0.0	0.0				6
Combustion Subtotal	**2 370**	**0.9**	**20**	**0.3**	**98**				**2 490**
Fugitive									
Solid Fuels (i.e. Coal Mining)		0.0	0.0						0
Oil and Gas	5	4.0	85						90
Fugitive Subtotal	**5**	**4.0**	**85**						**90**
Energy Total	**2 370**	**5.0**	**100**	**0.3**	**98**				**2 600**
Industrial Processes									
Non-Metallic Mineral Production	0								0
Adipic Acid & Nitric Acid Production	0			0.0	0.0				0
Ferrous Metal Production	0								0
Aluminum and Magnesium Production	0						0	0	0
Other & Undifferentiated Production	66								66
Industrial Processes Total	**66**	**0**	**0**	**0.0**	**0**		**0**	**0**	**66**
Solvent & Other Product Use	**0**	**0**	**0**	**0.0**	**2**				**2**
Agriculture									
Enteric Fermentation		0.0	0						0
Manure Management		0.0	0.0	0.0	0.0				0
Agricultural Soils**	0			0	0				0
Agriculture Total	**0**	**0**	**0**	**0**	**0**				**0**
Land Use Change & Forestry*		**0**	**0**	**0.2**	**50**				**47**
Waste									
Solid Waste Disposal on Land		1	13						13
Wastewater Handling		0.4	8.2	0.0	3.1				11
Waste Incineration	0	0	0	0.0	0				0
Waste Total	**0**	**1**	**22**	**0.0**	**3.1**				**25**
TOTAL	**2 440**	**7**	**150**	**0.5**	**150**		**0**	**0**	**2 740**

* CH_4 and N_2O emissions from prescribed and other fires.
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YUKON'S GREENHOUSE GAS EMISSION ESTIMATES FROM 1992 TO 1996

GHG Source and Sink Category	1992 All Gases kt CO_2 eq	1993 All Gases kt CO_2 eq	1994 All Gases kt CO_2 eq	1995 All Gases kt CO_2 eq	1996 All Gases kt CO_2 eq
Energy					
Fuel Combustion					
Fossil Fuel Industries	68	44	37	68	56
Electricity and Steam Generation	58	44	30	34	10
Mining	0	2	2	9	12
Manufacturing	1	2	1	1	0
Construction	1	0	2	4	4
Transportation					
Gasoline Automobiles	84	84	76	74	68
Light-Duty Gasoline Trucks	41	44	42	43	43
Heavy-Duty Gasoline Vehicles	8	8	8	9	8
Motorcycles	0	0	0	0	0
Off-Road Gasoline Vehicles	8	9	8	11	10
Diesel Automobiles	1	1	1	1	1
Light-Duty Diesel Trucks	1	1	1	1	1
Heavy-Duty Diesel Vehicles	57	53	105	113	107
Off-Road Diesel Vehicles	127	65	14	25	120
Propane and Natural Gas Vehicles	0	2	3	5	2
Domestic Air	18	19	22	25	31
Domestic Marine	0	0	0	0	0
Rail	0	0	0	0	0
Vehicles Subtotal	**345**	**288**	**279**	**308**	**391**
Pipelines	0	0	0	0	0
Transportation Subtotal	**345**	**288**	**279**	**308**	**391**
Residential	9	24	29	20	25
Commercial and Institutional	66	56	49	51	37
Other	8	5	6	8	6
Combustion Subtotal	**557**	**464**	**435**	**503**	**540**
Fugitive					
Solid Fuels (i.e. Coal Mining)	0	0	0	0	0
Oil and Gas	47	48	45	42	40
Fugitive Subtotal	**47**	**48**	**45**	**42**	**40**
Energy Total	**600**	**510**	**480**	**550**	**580**
Industrial Processes					
Non-Metallic Mineral Production	0	0	0	0	0
Adipic Acid & Nitric Acid Production	0	0	0	0	0
Ferrous Metal Production	0	0	0	0	0
Aluminum and Magnesium Production	0	0	0	0	0
Other & Undifferentiated Production	1	0	0	2	2
Industrial Processes Total	**1**	**0**	**0**	**2**	**2**
Solvent & Other Product Use	**0**	**0**	**0**	**0**	**0**
Agriculture					
Enteric Fermentation	0	0	0	0	0
Manure Management	0	0	0	0	0
Agricultural Soils**	0	0	0	0	0
Agriculture Total	**0**	**0**	**0**	**0**	**0**
Land Use Change & Forestry*	**70**	**120**	**47**	**420**	**83**
Waste					
Solid Waste Disposal on Land	4	4	4	4	4
Wastewater Handling	4	4	3	4	4
Waste Incineration	0	0	0	0	0
Waste Total	**7**	**7**	**8**	**8**	**8**
TOTAL	**683**	**641**	**536**	**973**	**638**

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YUKON'S 1996 GREENHOUSE GAS EMISSION SUMMARY

GHG Source and Sink Category	CO_2 kt	CH_4 kt	CH_4 kt CO_2 eq	N_2O kt	N_2O kt CO_2 eq	HFCs kt CO_2 eq	PFCs kt CO_2 eq	SF_6 kt CO_2 eq	Total kt CO_2 eq
Global Warming Potential Multiplier	1		21		310	140-11 700	6 500-9 200	23 900	
Energy									
Fuel Combustion									
Fossil Fuel Industries	56	0.0	0.0	0.0	0.2				56
Electricity and Steam Generation	9	0.0	0.0	0.0	0.4				10
Mining	12	0.0	0.0	0.0	0.0				12
Manufacturing	0	0.0	0.0	0.0	0.0				0
Construction	4	0.0	0.0	0.0	0.0				4
Transportation									
Gasoline Automobiles	64	0.0	0.2	0.0	3				68
Light-Duty Gasoline Trucks	39	0.0	0.1	0.0	4				43
Heavy-Duty Gasoline Vehicles	8	0.0	0.0	0.0	0				8
Motorcycles	0	0.0	0.0	0.0	0				0
Off-Road Gasoline Vehicles	10	0.0	0.3	0.0	0				10
Diesel Automobiles	1	0.0	0.0	0.0	0				1
Light-Duty Diesel Trucks	1	0.0	0.0	0.0	0				1
Heavy-Duty Diesel Vehicles	106	0.0	0.1	0.0	1				107
Off-Road Diesel Vehicles	107	0.0	0.1	0.0	13				120
Propane and Natural Gas Vehicles	2	0.0	0.0	0.0	0				2
Domestic Air	29	0.0	0.2	0.0	1				31
Domestic Marine	0	0.0	0.0	0.0	0				0
Rail	0	0.0	0.0	0.0	0				0
Vehicles Subtotal	**367**	**0.0**	**1.0**	**0.1**	**23**				**391**
Pipelines	0	0.0	0.0	0.0	0				0
Transportation Subtotal	367	0.0	1.0	0.1	23				391
Residential	19	0.2	4.7	0.0	1				25
Commercial and Institutional	37	0.0	0.0	0.0	0.0				37
Other	6	0.0	0.0	0.0	0.0				6
Combustion Subtotal	**510**	**0.3**	**6**	**0.1**	**24**				**540**
Fugitive									
Solid Fuels (i.e. Coal Mining)		0.0	0.0						0
Oil and Gas	2	1.9	39						40
Fugitive Subtotal	**2**	**1.9**	**39**						**40**
Energy Total	**512**	**2.1**	**45**	**0.1**	**24**				**580**
Industrial Processes									
Non-Metallic Mineral Production	0								0
Adipic Acid & Nitric Acid Production	0			0.0	0.0				0
Ferrous Metal Production	0								0
Aluminum and Magnesium Production	0						0	0	0
Other & Undifferentiated Production	2								2
Industrial Processes Total	**2**	**0**	**0**	**0.0**	**0**		**0**	**0**	**2**
Solvent & Other Product Use	**0**	**0**	**0**	**0.0**	**0**				**0**
Agriculture									
Enteric Fermentation		0.0	0						0
Manure Management		0.0	0.0	0.0	0.0				0
Agricultural Soils**	0			0	0				0
Agriculture Total	**0**	**0**	**0**	**0**	**0**				**0**
Land Use Change & Forestry*		**2**	**38**	**0.1**	**50**				**83**
Waste									
Solid Waste Disposal on Land		0	4						4
Wastewater Handling		0.1	2.6	0.0	1.0				4
Waste Incineration	0	0.0	0	0.0	0				0
Waste Total	**0**	**0**	**7**	**0.0**	**1.0**				**8**
TOTAL	**514**	**3**	**53**	**0.2**	**71**		**0**	**0**	**638**

* CH_4 and N_2O emissions from prescribed and other fires.
** Only one significant figure is shown due to high uncertainty.
Note: Due to rounding, individual values may not add up to totals.
Ammonia production emissions are included under undifferentiated production at the provincial level.
Limestone and soda ash use are not included in provincial totals.

NORTHWEST TERRITORIES' GREENHOUSE GAS EMISSION ESTIMATES FROM 1992 TO 1996

GHG Source and Sink Category	1992 All Gases *kt CO_2 eq*	1993 All Gases *kt CO_2 eq*	1994 All Gases *kt CO_2 eq*	1995 All Gases *kt CO_2 eq*	1996 All Gases *kt CO_2 eq*
Energy					
Fuel Combustion					
Fossil Fuel Industries	16	24	26	25	11
Electricity and Steam Generation	274	284	335	373	333
Mining	138	44	114	83	19
Manufacturing	23	9	28	33	25
Construction	8	7	5	22	1
Transportation					
Gasoline Automobiles	33	33	33	33	32
Light-Duty Gasoline Trucks	16	17	18	19	21
Heavy-Duty Gasoline Vehicles	3	3	4	4	4
Motorcycles	0	0	0	0	0
Off-Road Gasoline Vehicles	44	76	76	55	72
Diesel Automobiles	0	0	0	0	0
Light-Duty Diesel Trucks	1	1	1	1	1
Heavy-Duty Diesel Vehicles	59	41	46	98	97
Off-Road Diesel Vehicles	73	205	272	148	318
Propane and Natural Gas Vehicles	0	2	3	5	2
Domestic Air	222	245	268	232	323
Domestic Marine	1	1	0	71	90
Rail	2	2	2	2	1
Vehicles Subtotal	**454**	**627**	**723**	**670**	**961**
Pipelines	0	0	2	0	0
Transportation Subtotal	**454**	**627**	**726**	**670**	**961**
Residential	199	237	228	128	197
Commercial and Institutional	328	377	373	466	399
Other	12	2	0	0	0
Combustion Subtotal	**1 450**	**1 610**	**1 830**	**1 800**	**1 950**
Fugitive					
Solid Fuels (i.e. Coal Mining)	0	0	0	0	0
Oil and Gas	59	61	53	53	50
Fugitive Subtotal	**59**	**61**	**53**	**53**	**50**
Energy Total	**1 500**	**1 700**	**1 900**	**1 900**	**2 000**
Industrial Processes					
Non-Metallic Mineral Production	0	0	0	0	0
Adipic Acid & Nitric Acid Production	0	0	0	0	0
Ferrous Metal Production	0	0	0	0	0
Aluminum and Magnesium Production	0	0	0	0	0
Other & Undifferentiated Production	2	2	100	84	64
Industrial Processes Total	**2**	**2**	**100**	**84**	**64**
Solvent & Other Product Use	**1**	**1**	**1**	**1**	**1**
Agriculture					
Enteric Fermentation	0	0	0	0	0
Manure Management	0	0	0	0	0
Agricultural Soils**	0	0	0	0	0
Agriculture Total	**0**	**0**	**0**	**0**	**0**
Land Use Change & Forestry*	**4**	**4**	**4**	**4**	**4**
Waste					
Solid Waste Disposal on Land	8	8	8	9	9
Wastewater Handling	7	7	8	8	8
Waste Incineration	0	0	0	0	0
Waste Total	**15**	**15**	**16**	**16**	**17**
TOTAL	**1 530**	**1 690**	**2 010**	**1 960**	**2 100**

* CH_4 and N_2O emissions from prescribed and other fires.
** Only one significant figure is shown due to high uncertainty.
Note: Due to rounding, individual values may not add up to totals.
Ammonia production emissions are included under undifferentiated production at the provincial level.

NORTHWEST TERRITORIES' 1996 GREENHOUSE GAS EMISSION SUMMARY

GHG Source and Sink Category	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs	PFCs	SF_6	Total
	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*
Global Warming Potential Multiplier	1		21		310	140-11 700	6 500-9 200	23 900	
Energy									
Fuel Combustion									
Fossil Fuel Industries	11	0.0	0.0	0.0	0.0				11
Electricity and Steam Generation	321	0.0	0.5	0.0	11				333
Mining	19	0.0	0.0	0.0	0.1				19
Manufacturing	25	0.0	0.0	0.0	0.0				25
Construction	1	0.0	0.0	0.0	0.0				1
Transportation									
Gasoline Automobiles	31	0.0	0.1	0.0	2				32
Light-Duty Gasoline Trucks	19	0.0	0.1	0.0	2				21
Heavy-Duty Gasoline Vehicles	4	0.0	0.0	0.0	0				4
Motorcycles	0	0.0	0.0	0.0	0				0
Off-Road Gasoline Vehicles	69	0.1	1.9	0.0	1				72
Diesel Automobiles	0	0.0	0.0	0.0	0				0
Light-Duty Diesel Trucks	1	0.0	0.0	0.0	0				1
Heavy-Duty Diesel Vehicles	96	0.0	0.1	0.0	1				97
Off-Road Diesel Vehicles	282	0.0	0.3	0.1	35				318
Propane and Natural Gas Vehicles	2	0.0	0.0	0.0	0				2
Domestic Air	313	0.0	0.6	0.0	10				323
Domestic Marine	81	0.0	0.1	0.0	9				90
Rail	1	0.0	0.0	0.0	0				1
Vehicles Subtotal	**898**	**0.2**	**3.1**	**0.2**	**59**				**961**
Pipelines	0	0.0	0.0	0.0	0				0
Transportation Subtotal	**898**	**0.2**	**3.1**	**0.2**	**59**				**961**
Residential	185	0.5	10	0.0	2				197
Commercial and Institutional	398	0.0	0.1	0.0	0.7				399
Other	0	0.0	0.0	0.0	0.0				0
Combustion Subtotal	**1 860**	**0.7**	**14**	**0.2**	**73**				**1 950**
Fugitive									
Solid Fuels (i.e. Coal Mining)		0.0	0.0						0
Oil and Gas	4	2.2	46						50
Fugitive Subtotal	**4**	**2.2**	**46**						**50**
Energy Total	**1 860**	**2.8**	**60**	**0.2**	**73**				**2 000**
Industrial Processes									
Non-Metallic Mineral Production	0								0
Adipic Acid & Nitric Acid Production	0			0.0	0.0				0
Ferrous Metal Production	0								0
Aluminum and Magnesium Production	0						0	0	0
Other & Undifferentiated Production	64								64
Industrial Processes Total	**64**	**0**	**0**	**0.0**	**0**		**0**	**0**	**64**
Solvent & Other Product Use	**0**	**0**	**0**	**0.0**	**1**				**1**
Agriculture									
Enteric Fermentation		0.0	0						0
Manure Management		0.0	0.0	0.0	0.0				0
Agricultural Soils**	0			0	0				0
Agriculture Total	**0**	**0**	**0**	**0**	**0**				**0**
Land Use Change & Forestry*		**0**	**2**	**0.0**	**2**				**4**
Waste									
Solid Waste Disposal on Land		0	9						9
Wastewater Handling		0.3	5.6	0.0	2.1				8
Waste Incineration	0	0.0	0	0.0	0				0
Waste Total	**0**	**1**	**15**	**0.0**	**2.1**				**17**
TOTAL	**1 930**	**5**	**97**	**0.3**	**79**		**0**	**0**	**2 100**

* CH_4 and N_2O emissions from prescribed and other fires.
** Only one significant figure is shown due to high uncertainty.
Note: Due to rounding, individual values may not add up to totals.
Ammonia production emissions are included under undifferentiated production at the provincial level.
Limestone and soda ash use are not included in provincial totals.

TABLE G GLOBAL WARMING POTENTIALS

Greenhouse Gas	Chemical Formula	Global Warming Potential[1] 100 Years
Carbon Dioxide	CO_2	1
Methane	CH_4	21
Nitrous Oxide	N_2O	310
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	$C_2H_2F_4$	1 000
HFC-134a	CH_2FCF_3	1 300
HFC-143	$C_2H_3F_3$	300
HFC-143a	$C_2H_3F_3$	3 800
HFC-152a	$C_2H_4F_2$	140
HFC-227ea	C_3HF_7	2 900
HFC-236fa	$C_3H_2F_6$	6 300
HFC-245ca	$C_3H_3F_5$	560
Perfluorocarbons (PFCs)		
Carbon Tetrafluoride	CF_4	6 500
Carbon Hexafluoride	C_2F_6	9 200
Perfluoropropane	C_3F_8	7 000
Perfluorbutane	C_4F_{10}	7 000
Perfluorocyclobutane	$c\text{-}C_4F_8$	8 700
Perfluoropentane	C_5F_{12}	7 500
Perfluorohexane	C_6F_{14}	7 400
Sulphur Hexafluoride	SF_6	23 900

[1] Intergovernmental Panel on Climate Change (IPCC) Working Group I, 1995 Summary for Policy Makers, WMO/UNEP, 1996.

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