

Canada's Greenhouse Gas Inventory

1990 -1999

Emission and
Removal Estimation
Practices and Methods

April 2001



Environment
Canada

Environnement
Canada

Canada

National Library of Canada cataloguing in publication data

Main entry under title :

Canada's greenhouse gas inventory, 1990-1999 : emission and removal estimation practices and methods

Issued also in French under title : Inventaire canadien des gaz à effet de serre 1990-1999, pratiques et méthodes d'estimation des émissions et de l'absorption.

Issued also on the Internet.

"April 2001"

ISBN 0-662-30815-8

Cat. No. En49-5/5-9-1-1999E

1. Greenhouse gases – Canada – Measurement.
2. Methane – Environmental aspects – Canada.
3. Nitrous oxide – Environmental aspects – Canada.
4. Carbon dioxide – Environmental aspects – Canada.
5. Pollution – Canada – Measurement.
- I. Canada. Air Pollution Prevention Directorate. Pollution Data Branch.

TD885.G73C32 2001

363.738'74'0971

C2001-980231-5



Printed in Canada using recycled paper and vegetable-based inks.

Canada's Greenhouse Gas Inventory 1990 - 1999

**Emission and Removal
Estimation Practices
and Methods**

Environment Canada

April 2001

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, Parties included in Annex I are now required to submit and publish, on an annual basis, a national inventory report of emissions of greenhouse gases by sources and removals by sinks. Canada's Greenhouse Gas Inventory 1990-1999, and its companion document, Trends in Canada's Greenhouse Gas Emissions 1990-1999, have been prepared by the staff of the Greenhouse Gas Division of Environment Canada in consultation with a wide range of stakeholders. This document, along with the Common Reporting Format, constitutes Canada's official greenhouse gas inventory submission to the UNFCCC for 2001.

In December of 1997, at the 3rd Conference of the Parties in Kyoto, Japan, Annex I 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 to 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. While additional monitoring and reporting guidelines remain to be agreed upon, the emission estimates contained within these reports, 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 estimates for Canada. The methods outlined are similar in many respects to those developed by the Intergovernmental Panel on Climate Change (IPCC) and follow the recently agreed to UNFCCC Common Reporting Format (CRF). While many areas still remain for which estimates can be improved, given current resources as well as the level of detail and types of information available, the estimates in this report are thought to be as accurate a representation of emissions and removals in Canada as is currently possible.



A. Jaques, April 2001

Readers' Comments

Comments regarding the contents of this report should be addressed to:

Art Jaques, P. Eng.

Chief – Greenhouse Gas Division

Pollution Data Branch

Environment Canada

Hull, Quebec, K1A 0H3

Acknowledgements

The Greenhouse Gas Division wishes to acknowledge the support and effort of a number of individuals who helped to produce the 1999 national greenhouse gas inventory. First and foremost, we would like to acknowledge the financial support provided by the National Climate Change Secretariat, and in particular David Oulton, Ian McGregor and Don Strange, without whom this report and supporting studies would not have been possible. Of the many individuals and organizations that provided advice and information, the Greenhouse Gas Division is especially indebted to Ron Rasia, Gary Smalldridge and Serge Grenier of Statistics Canada for their help in interpreting Canada's energy supply and demand data. In addition, a special note of thanks should go to Maria Wellisch of MWA, Werner Kurz of ESSA, Dave Boulter, Darcie Booth and Tony Lempriere of the Canadian Forestry Service, Wayne Lindwall, Marie Boehm, Henry Janzen and Ward Smith of Agriculture Canada, and Neil McIlveen, Hertsel Labib and Rejean Casaubon of Natural Resources Canada.

We would be remiss were we not to thank Stephen Graham, and Steve Lapp of SGA Energy Limited for augmenting the work of Ken Olsen and other members of the Division to produce the Key Source analysis.

A final note of thanks should be given to the many individuals in various industries, industry associations and engineering consulting firms whose past support, advice and information on emissions continues to be the basis for many of the methods and emission factors used in developing the greenhouse gas inventory to date.

Ken Olsen managed the development of the inventory and the inventory report. The inventory estimates for 1999 were developed by Chia Ha and Scott McKibbin. Pascale Collas, along with Dominique Blain and Chang Liang, developed emission estimates and analysis for the forestry and agriculture sectors.

Table of Contents

Foreword	iii
Acknowledgements	iv
1.0 Introduction	1
1.1 Recalculations of Estimates	1
2.0 Methodology	3
2.1 Energy	4
2.1.A Fuel Combustion Activities	4
2.1.A.1 Energy Industries	6
2.1.A.1.a Public Electricity and Heat Production	6
2.1.A.1.a.1 Electricity Production	6
2.1.A.1.a.2 Heat Production	7
2.1.A.1.b Petroleum Refining	7
2.1.A.1.c Manufacture of Solid Fuels & Other Energy Industries	7
2.1.A.2 Manufacturing Industries & Construction	7
2.1.A.2.a Iron and Steel	8
2.1.A.2.b Non-Ferrous Metals	8
2.1.A.2.c Chemicals	8
2.1.A.2.d Pulp, Paper and Print	8
2.1.A.2.e Food Processing, Beverages and Tobacco	8
2.1.A.2.f Other: Manufacturing Industries and Construction	8
2.1.A.3 Transport	9
2.1.A.3.a Civil Aviation	9
2.1.A.3.b Road Transport	9
2.1.A.3.c Railways	13
2.1.A.3.d Navigation	14
2.1.A.3.e Other: Transport	14
2.1.A.3.e.1 Off-Road Transport	14
2.1.A.3.e.2 Pipeline Transport	14
2.1.A.4 Other Sectors	15
2.1.A.4.a Commercial/Institutional	15
2.1.A.4.b Residential	16
2.1.A.4.c Agriculture/Forestry/Fisheries	16
2.1.A.5 Other: Energy – Fuel Combustion Activities	16
2.1.B Fugitive Emissions from Fuels	16
2.1.B.1 Solid Fuels	16
2.1.B.1.a Coal Mining	16
2.1.B.1.b Solid Fuel Transformation	17
2.1.B.1.c Other: Solid Fuels	17
2.1.B.2 Oil and Natural Gas	17
2.1.B.2.a Oil	20
2.1.B.2.b Natural Gas	20
2.1.B.2.c Venting and Flaring	20
2.1.B.2.c.1 Venting	20
2.1.B.2.c.2 Flaring	21
2.1.B.2.d Other: Oil and Natural Gas	21

2.1.C Memo Items	21
2.1.C.1 International Bunkers	21
2.1.C.1.a Aviation	21
2.1.C.1.b Marine	21
2.1.C.2 Multilateral Operations	21
2.1.C.3 CO ₂ Emissions from Biomass	22
2.2 Industrial Processes	23
2.2.A Mineral Products	23
2.2.A.1 Cement Production	23
2.2.A.2 Lime Production	24
2.2.A.3 Limestone and Dolomite Use	24
2.2.A.4 Soda Ash Production and Use	25
2.2.A.5 Asphalt Roofing	25
2.2.A.6 Road Paving with Asphalt	25
2.2.A.7 Other: Mineral Products	25
2.2.B Chemical Industry	25
2.2.B.1 Ammonia Production	25
2.2.B.2 Nitric Acid Production	26
2.2.B.3 Adipic Acid Production	26
2.2.B.4 Carbide Production	27
2.2.B.5 Other: Chemical Industry	27
2.2.C Metal Production	27
2.2.C.1 Iron and Steel Production	27
2.2.C.2 Ferroalloys Production	27
2.2.C.3 Aluminum Production	27
2.2.C.4 SF ₆ Used in Aluminum and Magnesium Foundries	28
2.2.C.5 Other: Metal and Miscellaneous Chemical Production	29
2.2.D Other: Production	29
2.2.D.1 Pulp and Paper	29
2.2.D.2 Food and Drink	29
2.2.E Production of Halocarbons and SF ₆	29
2.2.F Consumption of Halocarbons and SF ₆	29
2.2.F.1 Refrigeration and Air Conditioning Equipment	30
2.2.F.2 Foam Blowing	32
2.2.F.3 Fire Extinguishers	33
2.2.F.4 Aerosols/Metered Dose Inhalers	33
2.2.F.5 Solvents	34
2.2.F.6 Semiconductor Manufacture	34
2.2.F.7 Electrical Equipment	35
2.2.F.8 Other: Consumption of Halocarbons and SF ₆	35
2.2.G Other: Industrial Processes	35
2.3 Solvent and Other Product Use	36
2.3.A Paint Application	36
2.3.B Degreasing and Dry Cleaning	36
2.3.C Chemical Products, Manufacture and Processing	36

2.3.D Other: Solvent and Other Product Use	36
2.3.D.1 Use of N ₂ O for Anaesthesia	36
2.3.D.2 N ₂ O from Fire Extinguishers	36
2.3.D.3 N ₂ O from Aerosol Cans	36
2.3.D.4 Other: Use of N ₂ O	37
2.4 Agriculture	37
2.4.A Enteric Fermentation	37
2.4.B Manure Management	38
2.4.C Rice Cultivation	40
2.4.D Agricultural Soils	40
2.4.D.1 Direct Soil Emissions	41
2.4.D.2 Animal Production	42
2.4.D.3 Indirect Emissions	42
2.4.D.3.a Volatilization and Subsequent Redeposition	42
2.4.D.4 Other: Agricultural Soils	43
2.4.E Prescribed Burning of Savannas	43
2.4.F Field Burning of Agricultural Residues	43
2.4.G Other: Agriculture	43
2.5 Land-Use Change and Forestry	44
2.5.A Changes in Forest & Other Woody Biomass Stocks	45
2.5.A.1 Tropical Forests	47
2.5.A.2 Temperate Forests	47
2.5.A.3 Boreal Forests	47
2.5.A.4 Grasslands/Tundra	47
2.5.A.5 Other: Changes in Forest & Other Woody Biomass Stocks	47
2.5.A.5.a Harvested Wood	47
2.5.B Forest and Grassland Conversion	47
2.5.B.1 Tropical Forests	48
2.5.B.2 Temperate Forests	48
2.5.B.3 Boreal Forests	48
2.5.B.4 Grasslands/Tundra	48
2.5.B.5 Other: Forest and Grassland Conversion	48
2.5.C Abandonment of Managed Lands	48
2.5.C.1 Tropical Forests	49
2.5.C.2 Temperate Forests	49
2.5.C.3 Boreal Forests	49
2.5.C.4 Grasslands/Tundra	49
2.5.C.5 Other: Abandonment of Managed Lands	49
2.5.D CO ₂ Emissions and Removals from Soil	49
2.5.D.1 Cultivation of Mineral Soils	50
2.5.D.2 Cultivation of Organic Soils	50
2.5.D.3 Liming of Agricultural Soils	50
2.5.D.4 Forest Soils	50
2.5.D.5 Other: CO ₂ Emissions and Removals from Soil	50

2.5.E Other: Land-Use Change and Forestry	50
2.5.E.1 Prescribed Burning	50
2.5.E.2 Other Fires in the Wood Production Forest	50
2.5.E.3 Other: Fires Caused by Human Activities Outside the Wood Production Forest	51
2.5.E.4 Wildfires	51
2.6 Waste	52
2.6.A Solid Waste Disposal on Land	52
2.6.A.1 Managed Waste Disposal on Land	53
2.6.A.2 Unmanaged Waste Disposal Sites	55
2.6.A.3 Other: Solid Waste Disposal on Land	55
2.6.B Wastewater Handling	55
2.6.B.1 Industrial Wastewater	55
2.6.B.2 Domestic and Commercial Wastewater	55
2.6.B.3 Other: Wastewater Handling	56
2.6.C Waste Incineration	56
2.6.D Other: Waste	57
3.0 Verification and QA/QC	59
3.1 Reference Approach	59
3.1.A Reference Approach Methodology	60
3.2 Inventory Review	60
3.3 Key Sources	61
3.3.A Level Assessment	64
3.3.B Trend Assessment	66
3.3.C Qualitative Assessment	67
3.3.C.1 Mitigation Techniques and Technologies	67
3.3.C.2 High Emission Growth	68
3.3.C.3 High Uncertainty	69
3.3.D Summary Assessment	69
4.0 Uncertainty Associated with Emission and Removal Estimates	73
5.0 Criteria Air Contaminants	77
Appendix I Emission Factors	79
Appendix II Canada's Emission Summary Tables 1990 - 1999	87

List of Tables

2.1	Activities and Extrapolation Data	.20
2.2	Equipment Categories and k Values	.31
2.3	Annual Leakage Rate (x)	.32
2.4	PFC Emission Rate	.34
2.5	Sources for Methane Emission Calculations (Exceptions)	.37
2.6	Sources for Manure Nitrogen Emission Calculations (Exceptions)	.39
3.1	Source Category Analysis Summary	.63
3.2	Key Source Categories Level Assessment	.64
3.3	Key Source by Trend Assessment	.66
3.4	Key Sources Identified Using Mitigation Techniques and Technologies	.68
3.5	Key Sources Identified From Anticipated High Emission Growth	.69
3.6	Key Sources With a High Composite Uncertainty	.70
3.7	Categorization of Source Tables	.70
4.1	Number of Significant Figures Applied to Greenhouse Gas Summary Tables (Based on the Uncertainty of Emission Estimates)	.75

List of Figures

3.1	Contributions of Key Source Categories to Level Assessment	.65
3.2	Contributions of Key Source Categories to Trend Assessment	.67

Section 1

Introduction

This report has been prepared in response to the Framework Convention on Climate Change (FCCC), and particularly Decision 3/C.P. 5 which states Annex 1 parties should annually submit by April 15 national inventories in accordance with the UNFCCC Guidelines on annual inventories (FCCC/CP/1999/7). These guidelines require an inventory report describing inventory methods and practices as well as emission data reported in the UNFCCC Common Reporting Format.

This volume contains a description of inventory methodologies, quality control and verification procedures, and the uncertainty associated with the greenhouse gas emission estimates. A separate volume, entitled Common Reporting Format (CRF), contains comprehensive emissions data, including a full set of tables and notes in the new format which has been developed by the UNFCCC secretariat to simplify analysis and comparability of Parties inventory data.

1.1 Recalculations of Estimates

The current estimates for 1990 have been revised downward from 612 Mt to 607 Mt of carbon dioxide equivalent (eCO₂), a decline of about 1%. The revision is primarily due to updated methods and data that affect emissions of nitrous oxide from agricultural soils and new combustion-related emission factors for methane and nitrous oxide. Details of relevant changes are discussed below in the Energy, Industries, Agriculture and Land-Use Change and Forestry sections of this report.

The changes in emission data are the result of improved or new data and better scientific understanding of emission sources in Canada. The revisions have been implemented consistent with the recalculation procedures outlined in the IPCC *Good Practice and Uncertainty Management in National Greenhouse Gas Inventories* and have no impact on the overall emission trend.

Energy Sector

Most of the fuel combustion estimates were recalculated due to revised fuel combustion emission factors and residential fuelwood use data.

Previous methane and nitrous oxide emission factors for fuel combustion were developed in the early 1990s. A review of literature was made for new data on emission factors in Canada to ensure that the most up-to-date factors are used.

Carbon dioxide emission factors were revised for natural gas and natural gas liquids. The updated factors are based on typical chemical properties of the fuels, and take into account the unique characteristics of natural gas consumed in the upstream oil and gas industry. Previous factors for natural gas were based on theoretical estimates of carbon content based on the energy content of marketable fuels. Those for natural gas liquids (NGLs) were based on the assumption of pure fuels.

A new set of coal carbon dioxide emission factors was developed for the years 1995 to present to take into account the current supply patterns of coal to major consumers. Previous factors were developed in the early 1990s.

The activity data previously used to calculate residential fuelwood combustion was an overestimate. The previous estimates were developed based on data from a survey of firewood consumption. During subsequent reviews of the data, it became apparent that there was confusion in the reporting of volumes of residential wood use between face cords and full cords. The survey data was reviewed and adjusted to account for this discrepancy.

Industrial Processes

The emissions from limestone use, Perfluorocarbon (PFC) consumption and feedstock use were recalculated due to new data and improved emission factors.

Activity data for the use of limestone was revised to reflect a new estimate published in the *Canada Minerals Yearbook*. In addition, new data was collected on the use of PFCs in Canada. This allowed for an estimate of this source which was not possible in previous inventories.

As part of the review of fuel properties in the Energy section, the carbon content of feedstocks and fossil fuels used for non-energy purposes was updated to

account for impurities in the feeds. These estimates were previously based on the assumption of 100% pure fuels.

Agriculture

The estimates of nitrous oxide emissions from manure and soils were revised due to revised activity data and emission factors.

The nitrogen loss rates from leaching and runoff was revised to 15% applied nitrogen from the Intergovernmental Panel on Climate Change (IPCC) default of 30%. This takes into account that the fact that the majority of nitrogen applied in Canada is in semi-arid conditions where leaching and runoff is minimal. The IPCC default factor is based on research from the European low countries which have high precipitation rates.

The area of histosols under cultivation was revised downward based on consultation with experts to reflect a more representative data source.

Previously included in the nitrous oxide from crop residue calculations, alfalfa crop residues are no longer counted because they are perennial crops which generate negligible amounts of residue.

Livestock nitrogen excretion rates were also revised to account for new published data which is more representative of Canadian conditions.

Land-Use Change and Forestry

Modifications were implemented to the method used to estimate the areas burned due to human activities in and outside of the wood production forest. Recent data indicate that overall fire occurrence and the area burned annually have substantially increased over the last two decades. Consequently, the methodology was revised in order to base estimates on actual area burned in Canada, and to better reflect both the increase in area burned and its annual variability. In this inventory, the total area burned annually in the wood production forest is calculated as a fixed proportion (approximately 15%) of the total area of forest land burned, which is reported annually by the Canadian Council of Forest Ministers.

Section 2 Methodology

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

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

- Energy
- Industrial Processes
- Solvent and Other Products
- Agriculture
- Land-Use Change and Forestry
- Waste

Each of these categories is further subdivided within the inventory. The methods described below have been grouped, as closely as possible, by UNFCCC sector and sub-sector. Differences between UNFCCC and CGHGI sector designations have been noted.

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

- Carbon Dioxide (CO₂)
- Methane (CH₄)
- Nitrous Oxide (N₂O)
- Hydrofluorocarbons (HFCs)
- Perfluorocarbons (PFCs)
- Sulphur Hexafluoride (SF₆)

The UNFCCC also requires emissions estimates for the following indirect greenhouse gases:

- Sulphur dioxide (SO₂)
- Nitrogen Oxides (NO_x)
- Carbon Monoxide (CO)
- Non-methane Volatile Organic Compounds (NMVOCs)

These gases (referred to as the *Criteria Air Contaminants*) are inventoried separately and estimated using different methodologies from the direct GHGs. The general methods that were employed are discussed in Chapter 5.

In general, an emission inventory can be defined as:

A comprehensive account of air-pollutant emissions and associated data from sources within the inventory area over a specified time frame.

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

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

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

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

For large area sources, carbon budgets – to account for source/sink balances – and 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). Other large-scale regional or national emission estimates under averaged conditions have been compiled to date for collective sources such as transportation.

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

- **Direct Measurement:** with few exceptions, GHG emission or removal measurements apply to point sources. At present, a very limited number of sources have measured and reported GHG emissions.
- **Mass-balance:** This approach determines atmospheric 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 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 method.
- **Technology Specific Emission Factor Calculations:** Company-specific emission factors (EFs) can be used to estimate the rate at which a pollutant is released (or captured) into the atmosphere as a result of some process activity or unit throughput. Although emissions or removals may not be measured, individual facilities may have measured rate data for various parameters for their plant. This can be combined with other plant specific information such as throughput, activity data and the number of such sources to derive plant specific emissions or removals for a point source or 'bottom-up' inventory.
- **Average or General Emission Factor Calculations:** Where plant specific data are not available, average or general EFs can be used for a given source or sector. These can be combined with company specific, sector specific, process specific or general activity and population data to calculate emissions for a top-down inventory. Average or general EFs for most of the sectors in the inventory have been developed by Environment Canada, in consultation with other government departments, industry associations, and other agencies and organizations. These values reflect the most accurate methodologies based on currently available data, and include information currently being developed by the IPCC for the UNFCCC. In general, CO₂ emission factors are well developed for many sources, CH₄ factors are less well defined and N₂O, PFC, HFC and SF₆ factors are often limited and less certain.

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

References

United Nations Framework Convention on Climate Change (UNFCCC), FCCC/CP/1999/7, January 2000.

2.1 Energy

Energy-related activities are by far the largest source of greenhouse gas emissions in Canada. The Energy section includes emissions of all greenhouse gases from the production of fuels and their combustion for the primary purpose of delivering energy.

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

Fuel combustion includes all combustion activities for the purpose of generating heat or work. Fugitive emissions comprise activity such as the escape or leakage and venting of methane (CH₄) and carbon dioxide (CO₂) during the extraction, processing and delivery of fossil fuels.

For all energy sources, CO₂, CH₄ and N₂O are the only GHGs inventoried.

2.1.A Fuel Combustion Activities

To estimate emissions from fuel combustion, the following methodology has been adopted. It applies, generally, to all source sectors, although additional refinements and more detailed procedures are often used:

Equation 2.1

$$\text{Quantity of Fuel Combusted} \times \text{EF per physical unit of Fuel} = \text{Emissions}$$

For each sector and sub-sector, the appropriate quantity of each fuel combusted is multiplied by a fuel and technology-specific emission factor.

The EFs employed in estimating the emissions for the current GHG inventory are listed in the emission factor section (see Appendix I):

- **Natural Gas Fuels:** The EFs vary by fuel type and combustion technology.

- **Refined Petroleum Product Fuels:** The EFs vary by fuel type and combustion technology.
- **Coal Fuels:** The EFs for CO₂ vary with the properties of the coal. Therefore, EFs are assigned for different provinces based upon the origins of the coal used. The EFs for CH₄ and N₂O vary with the combustion technology.

This is consistent with an IPCC Tier 2 type methodology, as described in the IPCC *Reference Manual* (IPCC, 1997).

CO₂ Emissions

Fuel combustion CO₂ emissions depend upon the amount of fuel consumed, the carbon content of the fuel and the fraction of the fuel oxidized (Jaques, 1992). The basis of the CO₂ emission factor derivations has been discussed in previous publications (Jaques, 1992). The factors have been obtained and developed from a number of studies conducted by Environment Canada, the United States Environmental Protection Agency (EPA) and other organizations, both domestic and international. The methods used to derive the factors are based on the carbon contents of the fuels and the typical fraction of carbon oxidized. Both the hydrocarbons (HCs) and particulate formed during combustion are accounted for to some extent, but emissions of carbon monoxide (CO) are included in the estimates of CO₂ emissions. It is assumed that CO in the atmosphere undergoes complete oxidation to CO₂ shortly after combustion (within 5 to 20 weeks of emission). EFs based upon the physical quantity of fuel combusted, rather than energy basis, provide a more accurate estimate of emissions since it minimizes the number of conversions required to derive the estimate as fuels are – initially – commonly reported in physical units. It is important to note that these Canadian specific EFs differ from those of the IPCC in that they relate emissions to the quantity of fuel consumed and not to the energy content of the fuel. The emission factors employed to estimate emissions are sub-divided by the type of fuel used.

Emission factors for all non-CO₂ GHGs from combustion activities vary to a lesser or greater degree with:

- fuel type;
- technology;
- operating conditions; and
- maintenance and vintage of technology.

CH₄ Emissions

During combustion of carbon based fuels a small portion of the fuel remains unoxidized as methane. Additional research is necessary to better establish CH₄ emission factors for many combustion processes. Overall factors are developed for sectors based on typical technology splits and available emission factors for the sector. In several sectors, methane EFs are not known.

N₂O Emissions

During combustion some of the nitrogen in the fuel or air is converted to nitrous oxide. The production of nitrous oxide is dependent upon the temperature in the boiler/stove and the control technology employed. Additional research is necessary to better establish N₂O emission factors for many combustion processes. Overall factors are developed for sectors based on typical technologies and available emission factors for the sector. In several sectors, nitrous oxide EFs are not known.

Biomass Combustion

There are emissions of CO₂ from the combustion of biomass used to produce energy. However, as per UNFCCC requirements, CO₂ emissions from biomass fuels are *not* included in the Energy section totals nor in the sectors or sub-sectors. They are accounted for in the Land-Use Change and Forestry (LUCF) section as a loss of biomass (forest) stocks. Carbon dioxide from biomass combustion for energy purposes are reported as a Memo item for information only. Methane and Nitrous Oxide emissions from biomass fuel combustion are reported in the Energy section in their appropriate sub-sectors and included in inventory totals.

Statistics Canada Energy-Use Data – the QRES

The fossil fuel energy-use data used to estimate combustion emissions are from the *Quarterly Report on Energy Supply-Demand* (QRES) compiled by Statistics Canada, Canada's national statistics agency. It is the principal source of energy-use data (Statistics Canada, #57-003).

This report uses a top-down approach to estimate the supply and demand of energy in Canada. The production of fuels in Canada is balanced with the use of fuels in broad categories such as import/export, producer consumption, industry, residential, etc. Industrial energy-use data are divided into broad sectors based on Standard Industrial Classification (SIC) or North American Industrial Classification System (NAICS) codes.

While the QRES D 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 QRES D by surveying the suppliers of energy, provincial energy ministries and some users of energy. The accuracy of the sectoral end-use data is less than the total energy supply data. As a result, the total emission estimates for Canada are known with more certainty than the emissions from specific categories. Since 1995, Statistics Canada has been collecting energy-use statistics from end users through the *Industrial Consumers of Energy* (ICE) survey. This bottom-up approach to estimating fuel use by industry (as opposed to the top-down approach used in the QRES D) may be capable of providing more accurate information at the sector level for future inventories.

References

Intergovernmental Panel on Climate Change (IPCC), *Greenhouse Gas Inventory Reporting Instructions*, Vol. 1; and *Greenhouse Gas Inventory Reference Manual*, Vol. 3, Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, 1997.

Jaques, A.P., *Canada's Greenhouse Gas Emissions: Estimates for 1990*, Environment Canada, Report EPS5/AP/4, 1992.

Statistics Canada, *Quarterly Report on Energy Supply-Demand in Canada* (QRES D), Catalogue #57-003.

2.1.A.1 Energy Industries

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

Mobile source fuel combustion emissions are included in the Transportation sector. Fugitive and flaring emissions are included under Fugitive Emissions.

2.1.A.1.a Public Electricity and Heat Production

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

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

The UNFCCC Reporting Guidelines require the Electricity and Heat Production sector to include only emissions generated by public utilities. Emissions associated with industrial generation should be reported for the industry that produces the energy under the appropriate industrial sector in the Energy section, regardless if the energy is for sale or internal use. The

rational for this is that it is very difficult to disaggregate emissions in cogeneration facilities (i.e. to separate the electricity component from the heat component). This also reduces uncertainty and simplifies the calculation. Statistics Canada does distinguish industrial electricity generation data, but aggregates it into one category called Industrial Electricity Generation. As a result, we are unable to reallocate industrial electricity generation emissions to specific industrial sub-sectors. Emissions associated with all electricity and heat production are therefore lumped together and reported in this sector.

Very few public heat systems exist in Canada and 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 electricity and heat plants.

2.1.A.1.a.1 Electricity Production

For electricity production, the supply grid in Canada includes hydropower, thermal combustion-derived electricity, nuclear, wind and tidal power. The total generation of wind, tidal and solar power is very small. Nuclear, hydropower, wind, solar and tidal generation are not considered to be direct emitters of greenhouse gases, therefore emissions estimates are only made for thermal combustion-derived electricity.

Two systems are used to generate electricity using thermal combustion:

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

Steam-turbine boilers are fired with coal, heavy fuel oil, natural gas or biomass. (Initial heat may be produced by light fuel oil, natural gas, kerosene or diesel oil.) Reciprocating engines use light oil, diesel, natural gas and/or a combination of all. Gas turbines are fired with natural gas or refined petroleum products.

Emission Calculations

The emissions associated with the Electricity Production sector are calculated using Equation 2.1. Greenhouse gas emissions are estimated based upon the quantities of fossil fuels consumed and, to some extent, the technology used to produce electricity. As noted, all of the fossil fuel energy-use data employed to estimate combustion emissions were derived from the *Quarterly Report on Energy Supply-Demand* (Statistics Canada, #57-003).

2.1.A.1.a.2 Heat Production

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

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

Emission Calculations

Emissions associated with the Heat Production sector are calculated using Equation 2.1. The fuel data are from the steam generation line in the QRES D.

References

Intergovernmental Panel on Climate Change (IPCC), *Greenhouse Gas Inventory Reporting Instructions*, Vol. 1; and *Greenhouse Gas Inventory Reference Manual*, Vol. 3, Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, 1997.

Statistics Canada, *Quarterly Report on Energy Supply-Demand in Canada* (QRES D), Catalogue #57-003.

2.1.A.1.b Petroleum Refining

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

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

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

Emission Calculations

The fuel combustion emissions associated with the Petroleum Refining sector are calculated using Equation 2.1.

2.1.A.1.c Manufacture of Solid Fuels & Other Energy Industries

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

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

The Other Energy Industries (or Other Fossil Fuel Industries) sector includes all emissions resulting from the combustion of producer-consumed fuels reported in the QRES D, with the exception of refined petroleum products, which are included under Petroleum Refining.

The producer consumption fuel-use data from the QRES D includes natural gas flared in the upstream oil and gas industry.

To avoid double-counting, the flaring emissions (estimated under 2.1.B) are subtracted from the total calculated for the Other Energy Industries sector.

Emissions from transportation fuels are allocated to the Transportation sector.

Emission Calculations

The emissions associated with the Manufacture of Solid Fuels & Other Energy Industries sector are calculated using Equation 2.1. The fuel-use data are all producer consumption of fossil fuels with the exception of refined petroleum products, reported in the QRES D.

2.1.A.2 Manufacturing Industries & Construction

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

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

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

Emissions of CH₄ and N₂O from the combustion of biomass are included in the pulp and paper industrial sub-sector. CO₂ emissions from biomass are not included but are listed separately (see Section 2.1.C.3).

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

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

2.1.A.2.a Iron and Steel

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

Emission Calculations

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

The fuel combustion emissions for each sub-sector within the Manufacturing Industries and Construction sector are calculated using Equation 2.1. Emissions associated with the use of metallurgical coke have been allocated to the Industrial Process sector.

2.1.A.2.b Non-Ferrous Metals

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

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

Emission Calculations

All fuel-use data for this sector were obtained from the QRES (Statistics Canada, #57-0035) reported as Smelting and Refining.

The fuel combustion emissions for each sub-sector within the Manufacturing Industries and Construction sector are calculated using Equation 2.1.

2.1.A.2.c Chemicals

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

Emission Calculations

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

The fuel combustion emissions for each sub-sector within the Manufacturing Industries and Construction sector are calculated using Equation 2.1.

2.1.A.2.d Pulp, Paper and Print

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

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

The common industrial grouping in Canada is pulp and paper and this is reflected in the QRES. Therefore, the sub-sector title was changed to Pulp and Paper in the CGHGI.

Emission Calculations

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

The fuel combustion emissions for each sub-sector within the Manufacturing Industries and Construction sector are calculated using Equation 2.1. Emission of methane and nitrous oxide from the combustion of biomass are also included.

2.1.A.2.e Food Processing, Beverages and Tobacco

[This sector is not listed in the CGHGI.]

This industrial subcategory is a small energy user and is not disaggregated in the QRES. Emissions from the Food Processing, Beverage and Tobacco sector included in Section 2.1.A.2.f.

2.1.A.2.f Other: Manufacturing Industries and Construction

[Titled *Other Manufacturing* in the CGHGI.]

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

Emission Calculations

All fuel-use data for this sector were obtained from the QRES (Statistics Canada, #57-003) as reported under Cement, Construction, Mining and Other Manufacturing.

The fuel combustion emissions for each sub-sector within the Manufacturing Industries and Construction sector are calculated using Equation 2.1.

References

Statistics Canada, *Quarterly Report on Energy Supply-Demand in Canada* (QRES), Catalogue #57-003.

2.1.A.3 Transport

[Titled *Transport* in the CGHI.]

This sector comprises the combustion of fuel by all forms of transportation in Canada. The sector has been divided into five distinct sub-sectors, as compared to six in the CGHI (IPCC, 1997; UNFCCC, 1999), as shown below.

UNFCCC	CGHI
a) civil aviation	civil aviation
b) road transportation	road transport
c) railways	railways
d) navigation	navigation
e) other transportation	off-road (non-rail, ground) transport pipeline transport

Emission Calculations

The fuel combustion emissions associated with the Transport sector are calculated using various adaptations of Equation 2.1. However, because of the many different types of vehicles, activities and fuels, the emission factors are numerous and complex.

In order to cope with the complexity, transport emissions are calculated using Canada's Mobile Greenhouse Gas Emission Model (**M-GEM**) (Jaques et al, 1997). This model incorporates a version of the IPCC recommended methodology for vehicle modeling (IPCC, 1997). M-GEM is used to calculate all transport emissions with the exception of those associated with the motive energy for propelling fuels in pipelines.

M-GEM was thoroughly updated in 2001 to include new findings on CH₄ and N₂O emissions. Additional data on vehicle populations were also incorporated.

The emission factors used by the model have been adopted from many sources. However, emphasis has been on North American research and Canadian studies, in particular. All emissions factors used are listed in the Transport EF table located in the Appendices.

2.1.A.3.a Civil Aviation

[Titled *Civil Aviation* in the CGHI.]

This sub-sector includes all emissions from domestic air transport (commercial, private, military, agricultural, etc.). Although the IPCC Guidelines call for military air transportation emissions to be reported elsewhere, they have been included here.

Excluded are emissions from fuel used at airports for ground transport (reported under Other Transport) and fuel used in stationary combustion applications at airports. As noted, emissions arising from fuel sold to foreign airlines are considered to be international bunkers and are reported separately.

Emission Calculations

Methodologies follow a modified IPCC Tier 1 sectoral approach. Emissions are based upon the quantities of aircraft fuels consumed (IPCC, 1997).

Emissions are estimated using the M-GEM model.

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

2.1.A.3.b Road Transport

[Titled *Road Transport* in the CGHI.]

M-GEM uses a far more detailed procedure for calculating emissions from Road Transport. For this sub-sector, data on fuel consumption, vehicle type, vehicle control technology, technology age, age distribution of the fleet, fuel efficiency and average distance traveled per year are all considered.

Emissions are calculated and assigned in accord with the IPCC reporting procedure (IPCC, 1997). The exception being that evaporative emissions are not listed separately, but are included with the corresponding combustion sources.

In order to improve accuracy, it is necessary to subdivide Road Transport into numerous sub-sectors as emissions are related to vehicle type. Light-Duty

Vehicles (LDVs) comprise automobiles and light trucks. The IPCC Road Transport sub-sectors are (IPCC, 1997, VI):

Cars: Automobiles designated primarily for transport of persons and having a capacity of up to 12 passengers. The gross vehicle weight rating is 3900 kg or less.

Light-Duty Trucks: Vehicles with a gross vehicle weight rating of 3900 kg or less which are designated primarily for transportation of light-weight cargo or that are equipped with special features such as four-wheel drive for off-road operation.

Heavy-Duty Trucks and Buses: Any vehicle rated at more than 3900 kg gross vehicle weight or designed to carry more than 12 persons at a time.

Motorcycles: Any motor vehicle designed to travel with not more than three wheels in contact with the ground and weighing less than 680 kg.

It is important to note that there are no universally accepted names or weight limits for the various Road Transport sub-sectors. However, for environmental emissions purposes, Canada, the United States and Mexico use designations that are closely aligned to those employed for use with the U.S. EPA Mobile emissions factor model. While similar to the above, there are slight differences. For example, the gross vehicle weight rating cutoff between light and heavy vehicles is 8500 lbs. or 3855.6 kg. Canada's emissions estimates for CO, NMVOCs and NO_x are calculated using the EPA designations. The EPA designations are:

- light-duty gasoline vehicles-automobiles (LDGV)
- light-duty gasoline trucks (LDGT)
- heavy-duty gasoline vehicles (HDGV)
- motorcycles
- light-duty diesel vehicles-automobiles (LDDV)
- light-duty diesel trucks (LDDT)
- heavy-duty diesel trucks (HDDT)

Both the UNFCCC and the EPA insert fuel type descriptors (e.g. gasoline, diesel, natural gas or propane) into their various vehicle sub-sectors where appropriate.

While CO₂ releases from vehicles are not considered to be technology dependent, CH₄ and N₂O emission levels are affected by changes in emission control equipment. For CH₄ emissions, vehicles equipped with more sophisticated controls tend to have lower emission rates. The effect of pollution-limiting equipment on N₂O emissions is a more complex matter. Catalytic converters became the primary means to control

hydrocarbon and, subsequently, NO_x emissions from gasoline vehicles in the late 1970s and early 1980s. Oxidation catalysts appeared first, followed later by '3-way catalysts'. The earlier generations of 3-way catalysts were part of emission-control packages that are now labeled Tier 0 controls. Tier 1, a more advanced technology, was introduced to LDVs in North America in 1994. However, to date, research indicates that all catalytic control units increase N₂O emissions, as compared to uncontrolled vehicles (DeSoete, 1989; Barton, 1995). However, after their introduction, Tier 0 catalytic control units were also shown to have deteriorating capacity to effectively reduce N₂O emission as they aged (DeSoete, 1989; Prigent, 1991). The full effects of aging were noted to occur after approximately one year of use. Note that the emission factors used for LDVs equipped with 'aged' Tier 0 controls are approximately one order of magnitude higher (on a per unit of fuel basis) than those from uncontrolled vehicles (DeSoete, 1989; Barton, 1995).

(Note: It is important not to confuse the Tier 0 and Tier 1 vehicle emissions control system designators mentioned above with the IPCC use of Tier to differentiate levels of sophistication for estimating emissions.)

Natural Gas and Propane Fuels - No breakdown by vehicle classification is available for natural gas and propane vehicles. Therefore, it was assumed that virtually all such vehicles are light duty and the vast majority are automobiles.

Emission Calculations

The methodology used to evaluate road transport greenhouse gas emissions follows a detailed IPCC Tier 3 method, as outlined by the IPCC (IPCC, 1997).

The M-GEM model disaggregates vehicle data and calculates emissions of carbon dioxide, methane and nitrous oxide from all mobile sources. However, the model was developed principally to handle the complex emissions calculations for road transport.

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

The QRESO lists data on four fuels for ground transport in Canada: gasoline, diesel fuel oil, natural gas and propane. Emissions are calculated separately for each fuel.

Emissions are calculated on the basis of Equation 2.2:

Equation 2.2

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

where:

E	=	the total emissions in a given vehicle category
$EF_{Category}$	=	the emission factor for the category
$Fuel_{Category}$	=	the amount of fuel consumed in a given category

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

Equation 2.3

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

where:

$Fuel_{Ground (non-rail)}$	=	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.
$Fuel_{Off-road}$	=	the quantity of fuel used for off-road transport (<i>including: agricultural, industrial and construction vehicles, as well as snow-mobiles, recreational vehicles, etc.</i>)

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

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

Equation 2.4

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

These parameters are different for each vehicle type. Therefore, M-GEM calculates fuel use by division into relevant types. On-road vehicles are separated into seven major types, identical to those used by the U.S. EPA in its Mobile Model.

Vehicle population and distribution data were obtained from a number of sources. Within Environment Canada, a compendium listing populations by vehicle type was assembled for the year 1989 (Environment Canada, 1996). Data for 1995 was also obtained from a commercially available database of light-duty and heavy-duty vehicle populations (DesRosiers, 1996). Interpolation between 1989 and 1995 allowed an estimate of on-road vehicle populations for the intervening years. This has been supplemented by additional data for 1996 through 1998, which was extrapolated to provide estimates for 1999. The above information was sufficient for all vehicle types with the exception of motorcycles. Motorcycle data was obtained from Statistics Canada (Statistics Canada, #53-219). This source provided population data for all vehicles in the Canadian territories. (Territories are not covered by the commercial databases.)

While a simple division of fuel consumption by vehicle type enables the allocation of emissions of carbon, it does not take into account the effect 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 were both further subdivided. Five types of pollution-control technology were defined:

- Tier 1 3-way catalyst
- Tier 0 3-way catalyst (new)
- Tier 0 3-way catalyst (aged)
- Oxidation catalyst
- Non-catalyst

Vehicles without emissions controls were the norm in Canada in the 1960s. Non-catalyst-controlled vehicles were brought to market in the late 1960s. Emission-control technology on these included modifications to

ignition timing and air-fuel ratios, exhaust-gas recirculation (EGR) and air injection into the exhaust manifold. (Note that no separate category was used for vehicles without emission control, since these have virtually the same greenhouse emissions as those with non-catalytic control. Oxidation (2-way) catalytic converters were first used on Canadian vehicles introduced in 1975 and their use continued on production vehicles until the 1987 model year. These so-called two-way converters oxidized hydrocarbons. The 3-way (oxidation-reduction) catalytic emission-control technology was introduced in Canada in 1980 (Philpott, 1993). Typical ancillary equipment included carburetors with simple electronic ignition. Later, for the 1984 model year, a portion of the fleet was equipped with electronic computer-controlled fuel injection, which became an integral part of the emission control system. By 1990, such computer systems were standard equipment on all gasoline vehicles. The broad category of control technologies produced from the time 3-way catalytic converters were introduced, up until 1993, has become known in North America as Tier 0 emission control. Tier 0 catalytic converter technology is further subdivided into 'new' and 'aged' types – the 'new' subcategory representing units less than one year old. Tier 1, a more advanced emission control technology, was introduced to North American light-duty gasoline vehicles in 1994. It consists of an improved 3-way catalytic converter under more sophisticated computer control.

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

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

fuel per hundred kilometres, are also available in more detail for light-duty gasoline transport than for the other vehicle categories. Fleet-average car and light-truck FCRs by model year were obtained from Transport Canada (Transport Canada, 2001) and the U.S. EPA (Heavenrich, 1996). FCRs are determined by standard vehicle laboratory tests. However, recent research has shown that real-world fuel use is consistently higher than laboratory generated data. Based on studies performed in the United States, on-road vehicle fuel consumption figures in the M-GEM have been adjusted to 25% above the laboratory FCR ratings (Maples, 1993). Average FCRs for all operating vehicles within each subcategory of light-duty gasoline automobiles and trucks are calculated by apportioning the model-year consumption data according to the vehicle age and control technology distribution. FCR estimates for classifications other than light-duty cars and trucks have been set to values recommended by the IPCC (IPCC, 1997).

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

In an effort to improve the accuracy of M-GEM, a check was incorporated into the model. This check compares two estimates of off-road consumption. As indicated earlier, using Statistics Canada data, off-road use can be calculated as the difference between total and on-road fuel use. The primary computation of off-road consumption is made on the basis of internally calculated on-road fuel use. The other estimate is obtained using on-road vehicle road tax sales data for diesel oil and gasoline (Statistics Canada, #53-218). Statistics Canada records data on the sales of fuel upon which road taxes are paid. The difference between total gasoline or diesel oil used for ground (non-rail) transport and road tax data constitutes a second estimate of off-road use. Sales data from provincial tax records is gathered in a much different manner than the surveys Statistics Canada uses for most other energy data as published in the QRES. Consequently, the two off-road fuel use estimates differ. However, it is assumed that the values agree within a certain window of accuracy. M-GEM is currently programmed to accept a 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 traveled is corrected by the ratio required to bring calculated off-road consumption within the desired range. All diesel and gasoline vehicle sub-categories 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 traveled.

Road transport CO₂ emission factors are fuel dependent (Jaques, 1992) and are listed in Appendix I.

Pollution-control devices have a strong effect on methane and nitrous oxide emissions. Emission factors associated with these gases vary with vehicle type. As noted, five technology categories were assigned in the light-duty gasoline automobile and light-duty gasoline truck classes, each with a unique emission factor. In these two classes, the categories are based solely on catalytic control technology. All emissions factors used are listed in the Transport EF table located within the appendices. For example, the emission rate for older automobiles equipped only with non-catalytic emission control is 0.52 g CH₄ /l of gasoline. For vehicles having advanced Tier 1 technology the rate is 0.25 g CH₄ /l.

Several studies report emissions of N₂O from cars equipped with and without catalytic converters (Dasch, 1992; Urban, 1980; Prigent, 1989; De Soete, 1989; Prigent, 1991). The results of these studies are comparable for non-catalyst and oxidation catalyst-equipped vehicles, but differ for Tier 0 3-way aged catalysts. Consistent and systematic studies on the effect of aging on catalysts are limited (De Soete, 1989 and Prigent, 1991). Uncontrolled engine exhaust emissions contain very little N₂O. Studies show that N₂O likely represents less than 1% (between 0.4 and 0.75%) of the over-all NO_x emissions from either gasoline or diesel engines without catalytic converters. However, N₂O is produced when NO and NH₃ react over the platinum in catalytic converters. The production of N₂O is highly temperature dependent. It was found that platinum-rhodium 3-way catalysts, that decrease NO_x emissions, could increase the N₂O concentration in the exhaust during catalyst light off, yet still produce very little N₂O at medium temperatures (400 to 500°C). A peak of N₂O formation was observed close to the catalyst light-off temperature and found that the amount of N₂O emitted increased 2 to 4.5 times after aging. The increase in N₂O 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 N₂O formation (De Soete, 1989 and Prigent, 1991). An unpublished Environment Canada study (Barton, 1995) reports on the measurement of emissions from 14 typical pre-1994 Canadian automobiles using the

standard Federal Test Procedures. All vehicles were equipped with Tier 0 3-way converters. Average tailpipe emissions were approximately 0.7 g/l for the ten vehicles with aged converters and 0.4 g/l for the four vehicles with the new systems. Therefore, in M-GEM, 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 used for light-duty gasoline Tier 0 vehicles equipped with aged converters and for those with new 3-way catalytic converters. Vehicles of model year greater than one year old are assumed to have aged units. N₂O 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 used in the model. These EFs can be compared with factors of 0.046 g/l for non-catalytic conversion-control technology, and 0.20 g/l for vehicles with oxidation catalysts. Note that these emission factors represent values that are lower than those reported in previous inventory publications. In addition, to prepare emission factors, results from a recent survey of N₂O emission studies issued by the U.S. EPA (Michaels, 1998) have been incorporated. The same study also documented EPA tests conducted in 1998 on a small sample of newer technology North American vehicles. These vehicles were equipped with Tier 1, aged catalytic converters. Average measured N₂O emission rates were about 50% lower, under standard conditions, than those reported for Tier 0 vehicles (Barton and Simpson, 1995). On the basis of these tests, EFs of 0.21 g/l of fuel have been adopted for Tier 1 gasoline automobiles. Research indicates that, under standard test conditions, light-duty gasoline trucks show consistently higher emissions of nitrous oxide per unit of fuel consumed than light-duty gasoline automobiles. As a result, higher emission factors have been adopted for light trucks. For example, the LDGT N₂O emission rates used in M-GEM are 0.39 g/l for Tier 1 types and 1.0 g/l for aged Tier 0 types.

2.1.A.3.c Railways

[Titled *Railways* in the CGHGI.]

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

Emission Calculations

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

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

2.1.A.3.d Navigation

[Titled *Navigation* in the CGHI.]

The UNFCCC uses the title *Navigation* for this, but lists emissions related to international bunkers under *Marine*.

Emission calculations are based on estimates of fuel use reported by registered Canadian vessels. Inadvertently, some international travel may be included in the domestic inventory since some domestic registered vessels do international travel. Data that would allow an accurate disaggregation of shipping activity by shipping route are not currently available.

Emission Calculations

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

Emissions are estimated using the M-GEM model.

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

2.1.A.3.e Other: Transport

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

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

2.1.A.3.e.1 Off-Road Transport

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

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

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

Emission Calculations

Off-road vehicles are handled by a simpler IPCC Tier 1 approach. For these, emissions are based on fuel type, fuel emission factors and total consumption only. Fuel consumption data is generated by M-GEM. Country-specific emission factors have been used (see Appendix I).

2.1.A.3.e.2 Pipeline Transport

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

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

The fuel used is primarily natural gas in the case of natural gas pipelines, but some refined petroleum such as diesel fuel is also used. Oil pipelines tend to use electrical motors to operate pumping equipment.

Emission Calculations

The combustion greenhouse gas emissions associated with this equipment are not calculated by M-GEM.

The methodology employed is considered an IPCC Tier 1 sectoral approach.

Fuel consumption data from the QRES (Statistics Canada, #57-003), reported as pipelines, are multiplied by fuel-specific emission factors.

References

Intergovernmental Panel on Climate Change (IPCC), *Greenhouse Gas Inventory Reporting Instructions*, Vol. 1; and *Greenhouse Gas Inventory Reference Manual*, Vol. 3, Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, 1997.

United Nations Framework Convention on Climate Change (UNFCCC), *Common Reporting Format*, SBSTA – UNFCCC, Tenth Session, Item 4(a), Addendum, FCCC/SBSTA/1999/L.5/Add.1, 8 Jun 99; and *Common Reporting Format*, Microsoft Excel Draft, November 1999.

Jaques, A.P., F. Neitzert, and P. Boileau, *Trends in Canada's Greenhouse Gas Emissions 1990-1995*, Environment Canada, En49-5/5-8E, April 1997.

Statistics Canada, *Quarterly Report on Energy Supply-Demand in Canada* (QRES), Catalogue #57-003.

Jaques, A.P., *Canada's Greenhouse Gas Emissions: Estimates for 1990*, Environment Canada, Report EPS5/AP/4, 1992.

Prigent, M., and G. De Soete, *Nitrous Oxide (N₂O) in Engines Exhaust Gases — A First Appraisal of Catalyst Impact*, Society of Automotive Engineers, Technical Paper Series 890492, 1989.

Prigent, M., G. De Soete, and R. Doziere, "The Effect of Aging On Nitrous Oxide (N₂O) Formation by Automotive Three-Way Catalysts," *Catalysts and Automotive Pollution Control*, Volume II; Elsevier Science Publishers, Amsterdam, 1991.

Neitzert, F., K. Olsen, and P. Collas, *Canada's Greenhouse Gas Inventory, 1997 Emissions and Removals with Trends*, Environment Canada, En49-8/5-9E, April 1999.

Barton, P., and J. Simpson, *The Effects of Aged Catalysts and Cold Ambient Temperatures on N₂O Emissions*, Environment Canada, MSED report #94-21 (unpublished), 1995.

Environment Canada, *Vehicle Population Data*, Transportation Systems Division, unpublished information, 1996.

DesRosiers, Automotive Consultants, *Year/Make Reports — Canada and 10 Provinces*, Reports prepared for Environment Canada in conjunction with Blackburn/Polk Marketing Services Inc., 1990 and 1996.

Statistics Canada, *Road Motor Vehicles — Registrations, 1990-1999*, Catalogue #53-219.

Warbanski, B., Office of Energy Efficiency, Natural Resources Canada, Written communication regarding Canadian vehicle populations, September 1998.

Statistics Canada, *Road Motor Vehicles — Fuel Sales, 1990-1999*, Catalogue #53-218.

Government of Canada, Transport Canada, "New Emission Standards," *Canada Gazette* Part II, SOR 97-376, August 20, 1997.

Dasch, J.M., "Nitrous Oxide Emissions from Vehicles," *Journal of Air and Waste Management Association*, 63-67, Vol. 42, January 1992.

De Soete, G., *Updated Evaluation of Nitrous Oxide Emissions from Industrial Fossil Fuel Combustion*, Draft Final Report, Prepared for the European Atomic Energy Community by Institut français du petrole, Ref. 37-559, 1989.

Gourley, D., Greater Vancouver Regional District, BC Air Care (Test) Program, Personal communication, 1997.

Heavenrich, R. M., and K. H. Hellman, *Light Duty Automotive Technology and Fuel Economy Trends Through 1996*, United States Environmental Protection Agency (U.S. EPA), Ann Arbor, Michigan, EPA/AA/TDSG/96-01, 1996.

Maples, J.D., *The Light-Duty Vehicle MPG Gap: Its Size Today and Potential Impacts in the Future*, University of Tennessee Transportation Centre, Knoxville, May 1993.

Michaels, H., *Emissions of Nitrous Oxide from Highway Mobile Sources — Comments on the Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990-1996 (March 1998)*, U.S. EPA, Office of Mobile Sources, EPA420-R-98-009, August 1998.

Philpott, S., *Mobile5c User Guide*, Unpublished report prepared for Environment Canada, 1993.

Polk Consultants, *Heavy Duty Vehicles*, Report prepared for Environment Canada in conjunction with Blackburn/Polk Marketing Services Inc., 1996.

Transport Canada, *Company Average Fuel Consumption for Canadian New Vehicles*, Road Vehicle Safety Division, 2001.

Urban, Charles M., and Robert J. Garbe, *Exhaust Emissions from Malfunctioning Three-Way Catalyst-Equipped Automobiles*, SAE paper 820783, 1980.

Weaver, Christopher S., and Lit-Mian Chan, *Mobile Source Emission Factors for Global Warming Gases*, Draft Final Report, Submitted to ICF, Inc. by Engine, Fuel and Emissions Engineering, Inc., Sacramento, June 24, 1996.

2.1.A.4 Other Sectors

There are emissions of CO₂ from the combustion of biomass used to produce energy. However, as per UNFCCC requirements, CO₂ emissions from biomass fuels are not included in the Energy section totals nor in the sectors or sub-sectors. Carbon dioxide is accounted for in the Land-Use Change and Forestry (LUCF) section as a loss of biomass (forest) stocks.

2.1.A.4.a Commercial/Institutional

[Commercial/Institutional in the CGHGI.]

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

Emission Calculations

The fuel combustion emissions associated with the Commercial/Institutional sector are calculated using Equation 2.1.

Fuel use information is from the Commercial and the Public Administration data in the QRES (Statistics Canada, #57-003).

All transportation fuels are reallocated to the Transport category.

2.1.A.4.b Residential

The emissions in this sub-sector arise, primarily, from the combustion of fuel to heat residential buildings. Methane and nitrous oxide emissions from firewood combustion are significant for this sub-sector. In general, these emissions are a result of the incomplete combustion of biomass in wood stoves and fireplaces.

Emission Calculations

The fuel combustion emissions associated with the Residential sector are calculated using Equation 2.1.

The EFs that were employed in estimating the GHG emissions from gaseous and liquid fuels for the current GHG inventory are those as specified for the Residential sector in Appendix I.

The methodology for biomass combustion is detailed in Section 2.1.C.3, though the CH₄ and N₂O emissions are reported here.

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

2.1.A.4.c Agriculture/Forestry/Fisheries

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

This IPCC category includes emissions from stationary fuel combustion in the agricultural, forestry and fisheries industries. However, emissions estimates are included for the agriculture and forestry portion of the sub-sector only. Fishery emissions are reported under either Transportation or Other Manufacturing (i.e. food processing). Mobile emissions associated with this sub-sector were not disaggregated and are included as off-road or marine emissions reported under Transport.

Emission Calculations

The fuel combustion emissions associated with the Agriculture and Forestry sub-sector are calculated using Equation 2.1.

Fuel-use information is extracted from the Agriculture and Forestry data in the QRESO (Statistics Canada, #57-003). Transportation fuels are reallocated to the Transport category.

References

Statistics Canada, *Quarterly Report on Energy Supply-Demand in Canada* (QRESO), Catalogue #57-003.

2.1.A.5 Other: Energy – Fuel Combustion Activities

[This sub-sector is not used to report emissions in the CGHGI.]

The UNFCCC Guidelines assign military fuel combustion to this sub-sector. However, emissions related to military vehicles have been included in the Transport category, while stationary military use has been included under the Institutional category due to data limitations in the QRESO.

2.1.B Fugitive Emissions from Fuels

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

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

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

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

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

2.1.B.1 Solid Fuels

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

2.1.B.1.a Coal Mining

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

Coal in its natural state contains varying amounts of methane. 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 seam. During coal mining, post-mining activities and coal handling, 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 until the methane in the coal has reached equilibrium with the surrounding atmospheric conditions.

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

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

Emission Calculations

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

The method used to estimate emission rates from coal mining (emission factors in Appendix I) was based on a modified procedure from the Coal Industry Advisory Board. It consists of a hybrid of IPCC Tier 3 and IPCC Tier 2 type methodologies, depending on availability of mine-specific data (King, 1994).

Underground Mines

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

Emissions from the mine shaft ventilation system were estimated (if measured data was not available) using Equation 2.5:

Equation 2.5

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

where:

X	=	depth of mine in metres
Y	=	m ³ of methane per tonne coal mined

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

Surface Mines

For surface mines, it was assumed that the average gas content of surface-mined bituminous or sub bituminous coals was 0.4 m³/tonne (based on U.S. measured data). Of this, it was assumed that 60% is released to

the atmosphere before combustion (King, 1994). For lignite, gas content values were estimated in 1990 (Hollingshead, 1990).

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

Post-Mining Activity

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 mined coal is not known, then it is assumed that the methane content was 1.5m³/tonne (the world average methane content of coals).

2.1.B.1.b Solid Fuel Transformation

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

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

2.1.B.1.c Other: Solid Fuels

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

2.1.B.2 Oil and Natural Gas

The Oil and Natural Gas sector includes fugitive emissions from conventional upstream oil and gas, synthetic oil production and natural gas distribution. Fuel combustion emissions in the oil and gas industry (when used for energy) are included under the Manufacture of Solid Fuels & Other Energy Industries sector (or *Fossil Fuel Industries* and *Mining* in the CGHGI).

For Canada, the comprehensive title Conventional Upstream Oil and Gas is used rather than using the split between Oil and Natural Gas. This sector title conforms more to the industry norm as gas is usually produced along with oil.

Emissions are also reported for unconventional crude oil production.

Conventional Upstream Oil and Gas

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

The Conventional Upstream Oil and Gas sub-sector is vast and complex. Therefore, the sources have been divided into major categories:

Oil and Gas Well Drilling

Oil and gas well drilling is a minor emission source. The emissions are from drill stem tests, release of entrained gas in drilling fluids and volatilization of invert drilling fluids.

Oil and Gas Well Servicing

Well servicing is also a minor emission source. The emissions are mainly from blow down treatments for shallow gas wells. Emissions from venting of mud tanks and depressurization of piping, wells and vessels could also be a source; however there is limited available data and the source is considered negligible.

Natural Gas Production

Natural gas is produced exclusively at gas wells or in combination with conventional oil, heavy oil and crude bitumen production wells with gas conservation schemes. The emission sources associated with natural gas production are wells, gathering systems, field facilities and gas batteries. The majority of emissions result from equipment leaks such as leaks from seals; however venting from the use of fuel gas to operate pneumatic equipment and line cleaning operations are also significant sources.

Light/Medium Oil Production

This type of production is defined by wells producing light- or medium-density crude oils (i.e. density $<900\text{kg/m}^3$). The emissions are from the wells, flow lines, and batteries (single, satellite, and central). The largest sources of emissions are the venting of solution gas and evaporative losses from storage facilities.

Heavy Oil Production

Heavy oil is defined as having a density $>900\text{kg/m}^3$. This viscous liquid requires a special infrastructure to produce. There are generally two types of heavy oil

production systems: primary and thermal. The emission sources from both types are from wells, flow lines, batteries (single and satellite) and cleaning plants. The largest source is venting of casing and solution gas.

Crude Bitumen Production

Crude bitumen is a highly viscous, dense liquid that cannot be removed from a well using primary production means. Enhanced in-situ recovery is required to recover the hydrocarbon from the formation. The sources of emissions are from wells, flow lines, satellite batteries and cleaning plants. The main source of emissions is from the venting of casing gas.

Gas Processing

Natural gas is processed before entering transmission pipelines to remove contaminants and condensable hydrocarbons. There are four different types of plants: sweet plants, sour plants 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 of the natural gas produced in Canada is transported from the processing plants to the gate of the local distribution systems by pipelines. The volumes transported by truck are insignificant and assumed negligible. The gas transmission system emission sources are from equipment leaks and process vents. Process vents include activities such as compressor start up and purging of lines during maintenance. The largest source of emissions is equipment leaks.

Liquid Product Transfer

The transport of liquid products from field processing facilities to refineries or distributors produces emissions due to loading and unloading of tankers, storage losses, equipment leaks and process vents. The transport systems included are LPG (both surface transport, and high-vapour-pressure pipeline systems), pentane plus systems (both by surface transport and low-vapour-pressure pipelines), and crude-oil pipeline systems.

Accidents and Equipment Failures

Fugitive emissions can result from human error or extraordinary equipment failures in all segments of the conventional upstream oil and gas industry. The major sources are emissions from pipeline ruptures, well blowouts and spills. Emissions from the disposal and land treatment of spills are not included due to insufficient data.

Surface Casing Vent Blows and Gas Migration

At some wells, fluids will flow into the surface casing from the surrounding formation. Depending on the well, the fluids will be collected, sealed in the casing, flared or vented. The vented emissions are estimated in this section. At some wells, particularly in the Lloydminster region, gas may migrate outside of the well, either from a leak in the production string or from a gas-bearing zone which was penetrated but not produced. The emissions from the gas flowing to the surface through the surrounding strata have been estimated.

Emission Calculations

Fugitive emission estimates from the conventional upstream oil and gas industries for 1990 to 1996 are based on a recent study (Picard, 1999). Details of the methods are available in the report. The emission estimates result from a rigorous engineering study based on the various products, processes and infrastructure used in the Canadian conventional upstream oil and gas industry.

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

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

The method used by Picard is considered a rigorous IPCC Tier 3 type method.

After 1996, the estimates for fugitive emissions from the conventional upstream oil and gas industries were made in a manner which was different than that utilized for the 1990 to 1996 period (which are based directly from the Picard study). Emission data for 1996 was extrapolated by the changes in relevant production data for the following years. This method was used on an interim basis until new data becomes available from a rigorous study. (The data used for the extrapolations can be found in Table 2.1 on the following page.)

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

Unconventional Crude Oil Production

This sub-sector includes emissions from oil sand open pit mining operations and 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.

Emissions related to methanogenic bacteria in the tailings ponds are a newly discovered phenomenon which 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 streams of the current processes will be reduced and the emissions will be correspondingly lowered.

Emission Calculations

The emission data reported are estimates made by the operators of the unconventional crude oil production facilities at Suncor, Syncrude and Husky. These data were compiled in a study for the Canadian Association of Petroleum Producers (CAPP) and Environment Canada (McCann, 1999). Descriptions of the methods are available in the full report.

Natural Gas Distribution

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

Emission Calculations

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

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

The activity data in the study were obtained from published sources and from specialized surveys of gas distribution system companies. The surveys obtained

Table 2.1 Activities and Extrapolation Data

Activity	Extrapolation Data
Flaring	Gross new production of Natural Gas (Statistics Canada, #26-006)
Raw CO ₂	Net withdrawals of Natural Gas (Statistics Canada, #26-006)
Oil and Gas Well Drilling	Constant at 1996 levels
Oil and Gas Well Servicing	Constant at 1996 levels
Natural Gas Production	Gross New Production of Natural Gas (Statistics Canada, #26-006)
Light/Medium Oil Production	Total Production of Light & Medium Crude Oil (Statistics Canada, #26-006)
Heavy Oil Production	Total Production of Heavy Oil (Statistics Canada, #26-006)
Crude Bitumen Production	Total Production of Crude Bitumen (Statistics Canada, #26-006)
Natural Gas Processing	Net Withdrawals of Natural Gas (Statistics Canada, #26-006)
Natural Gas Transmissions	Natural Gas Transmission Pipeline Length (Statistics Canada, #57-205)
Liquid Product Transport	Constant at 1996 levels
Accidents & Equipment Failures	Constant at 1995 levels (1996 was an anomalous year)
Surface Casing, Vent Blows and Gas Migration	Constant at 1996 levels

information on schedules of equipment, operation parameters of equipment, pipeline lengths used in the Canadian distribution system, etc.

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

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

2.1.B.2.a Oil

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

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

2.1.B.2.b Natural Gas

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

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

2.1.B.2.c Venting and Flaring

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

Venting and flaring emissions are the sum of flaring emissions from all activities, as well as the 'raw carbon dioxide' releases from the stripping of natural gas.

2.1.B.2.c.1 Venting

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

Raw natural gas contains carbon dioxide; this is removed and vented to the atmosphere at processing facilities. These are titled *Raw CO₂ Releases* and categorized as venting in the Common Reporting Format (CRF).

Emission Calculations

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

2.1.B.2.c.2 Flaring

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

Emissions for flaring waste gases are included under Fugitive Emissions and not in the Waste or Fuel Combustion categories.

The following sub-sector is included in the CGHGI:

Natural Gas Flaring

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

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

Emission Calculations

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

2.1.B.2.d Other: Oil and Natural Gas

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

References

Statistics Canada, *Coal and Coke Statistics*, 1990–1998 annual editions, Catalogue #45-002.

King, B., *Management of Methane Emissions from Coal Mines: Environmental, Engineering, Economic and Institutional Implications of Options*, Neill and Gunter Ltd., Halifax, March 1994.

Hollingshead, B., *Methane Emissions from Canadian Coal Operations: A Quantitative Estimate*, Coal Mining Research Company, March 1990.

Picard D.J. and Ross B.D., *CH₄ and VOC Emissions from the Canadian Upstream Oil and Gas Industry*, Vol. 1 and 2, Clearstone Engineering, Calgary, 1999.

Radian International, LLC, *1995 Air Emissions Inventory of the Canadian Natural Gas Industry*, Calgary, September 1997.

McCann, T.J., *CH₄ and VOC Emissions from the Canadian Upstream Oil and Gas Industry*, Vol. 3, T.J. McCann and Associates Ltd., Calgary, 1999.

Statistics Canada, *Gas Utilities, Transport and Distribution Systems*, 1990–1998 annual editions, Catalogue #57-205.

Statistics Canada, *Crude Petroleum and Natural Gas Production*, 1990–1998 annual editions, Catalogue #26-006.

Statistics Canada, *Gas Utilities, Transport and Distribution Systems*, 1990–1998 annual editions, Catalogue #57-205.

2.1.C Memo Items

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

2.1.C.1 International Bunkers

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

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

2.1.C.1.a Aviation

Emissions have been calculated using the same methods listed under Civil Aviation. Fuel-use data is reported as foreign airlines in the QRES.

2.1.C.1.b Marine

Emissions have been calculated using the same methods listed under Navigation. Fuel-use data is reported as foreign marine in the QRES.

2.1.C.2 Multilateral Operations

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

2.1.C.3 CO₂ Emissions from Biomass

As per the IPCC Guidelines, carbon dioxide emissions from the combustion of biomass used to produce energy are *not* included in the Energy section totals. They are accounted for in the Land-Use Change and Forestry section, and are recorded as a loss of biomass (forest) stocks. Methane and nitrous oxide emissions from biomass fuel combustion were reported in this Energy section in the appropriate sectors.

Biomass emissions have been grouped into two main sources: Residential Firewood, and Industrial Firewood and Spent Pulping Liquors.

Residential Firewood

Firewood is used as a primary or supplementary heating source for many Canadian homes. The combustion of the firewood results in carbon dioxide, methane and nitrous oxide emissions.

Emission Calculations

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

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

- 1) Conventional stoves
 - non-air tight
 - air tight, non-advanced technology
 - masonry heaters
- 2) Stove/fireplace inserts with advanced technology or catalyst control
 - advanced technology fireplaces
 - advanced technology stove
 - catalytic fireplaces
 - catalytic stoves

- 3) Conventional fireplaces
 - without glass doors
 - with glass doors (non-air tight)
 - with airtight glass doors
- 4) Furnaces
 - wood burning fireplaces
- 5) Other equipment
 - other wood burning equipment

The firewood consumption data for the other years were extrapolated based on the number of houses in each province using wood as principal or supplementary heat source from Statistics Canada #64-202 in relation to 1995.

The nitrous oxide and methane emission factors for different wood burning appliances are from the U.S. EPA's AP-42, supplement – (EPA, 1996). These emissions are included in the Fuel Combustion sector of the inventory.

The emission factors for carbon dioxide are from an Environment Canada study (ORTECH, 1994). These emissions are not included in the national inventory but are reported as memo items.

Emissions were calculated using Equation 2.1. The amount of wood burned in each appliance was then multiplied by the emission factors to calculate the greenhouse gas emissions.

Industrial Firewood and Spent Pulping Liquors

A limited amount of data for Industrial Firewood and Spent Pulping Liquor are available in the QRES (Statistics Canada, #57-003). The Statistics Canada data for 1990 and 1991 were combined for the Atlantic provinces, as were the data for the Prairie provinces. Individual provincial data were delineated by employing a data comparison with the 1992 QRES data. Unfortunately, for 1992, the data for Newfoundland and Nova Scotia was also combined and there were no comparable data to allow separation. Emissions are listed under Nova Scotia.

Emission Calculations

Data for Industrial Firewood and Spent Pulping Liquor are available in the QRES (Statistics Canada, #57-003).

Industrial Firewood CO₂ and CH₄ emission factors are those assigned by the U.S. EPA to Wood Fuel/Wood Waste (EPA, 1996). For methane, emission factors were given for three different types of boilers; the EF is an average for the three.

Industrial Firewood N₂O emission factors are those assigned to Wood Fuel/Wood Waste, (Rosland, 1990; Radke, 1991) see Appendix I.

The emission factor for carbon dioxide from Spent Pulping Liquor combustion was developed based on two assumptions:

1. The carbon content of Spent Pulping Liquor was 41% by weight.
2. There was a 95% conversion of the carbon to carbon dioxide.

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

$$\begin{aligned} \text{EF CO}_2 &= 0.41 * 0.95 * (44 \text{ g/mol} / 12 \text{ g/mol}) \\ &= 1.428 \text{ tonne CO}_2 / \text{tonne spl} \end{aligned}$$

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

Emissions are calculated using Equation 2.1, by applying emission factors to quantities of biomass combusted. The CH₄ and N₂O emissions are included in the manufacturing sector of the inventory.

References

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

Environment Canada, CAC Division 1995 *Criteria Contaminants Emissions Inventory Guidebook*, Version 1, Section 2.4, March 1999.

United States Environmental Protection Agency (U.S. EPA), *Compilation of Air Pollutant Emission Factors, Volume 1, Stationary Point and Area Sources*, U.S. EPA AP-42, Fifth Edition, Supplementary B, January 1996.

ORTECH Corporation, *Inventory 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, Catalogue #57-003.

Taylor, S.W., and K.L. Sherman, *Biomass Consumption and Smoke Emissions from Contemporary and Prehistoric Wildland Fires in British Columbia*, Prepared by the Pacific Forestry Centre, Canadian Forest Service, Natural Resources Canada, FRDA Report 249, March 1996.

Radke, L.F., D.A. Hegg, P.V. Hobbs, J.D. Nance, J.H. Lyons, K.K. Laursen, R.E. Weiss, P.J. Riggan, and D.E. Ward, "Particulate and Trace Gas Emissions from Large Biomass Fires in North America," in *Global Biomass Burning: Atmospheric Climatic and Biospheric Implications*, J.S. Levine (ed.), Massachusetts Institute of Technology, Cambridge, Massachusetts, 1991.

Rosland, A., and M. Steen, *Klimgass-Regnskap For Norge*, Statens Forurensningstilsyn, Oslo, Norway, 1990.

Jaques, A.P., *Canada's Greenhouse Gas Emissions: Estimates for 1990*, Environment Canada, Report EPS5/AP/4, 1992.

2.2 Industrial Processes

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

2.2.A Mineral Products

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

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

2.2.A.1 Cement Production

Carbon dioxide is generated during the production of clinker, an intermediate product from which cement is made. Calcium carbonate (CaCO₃) from limestone, chalk or other calcium-rich materials is heated in a high-temperature kiln, forming lime (CaO) and carbon dioxide in a process called calcination or calcining:



The lime is then combined with silica-containing materials to produce clinker (grayish-black pellets about the size of 12 mm 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 specialty cements are lower in lime, but are typically used in small quantities.

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

Emission Calculations

The emission factor for CO₂ emissions from cement production is based on the lime content of clinker. It was assumed that the clinker produced in Canada has an average lime content of 63.5% (Jaques, 1992) and that all the cement produced in Canada is of the Portland type (see Appendix I).

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

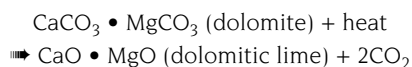
CO₂ emissions are estimated by applying an emission factor of 500g CO₂ /kg cement to the yearly national cement production.

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

2.2.A.2 Lime Production

Calcined limestone (quicklime or CaO) is formed by heating limestone to decompose carbonates. As with cement production, this is usually done at high temperatures in a rotary kiln and the process releases 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 for in Section 2.2.A.1.

Dolomitic limestone (or magnesite) may also be processed at high temperature to obtain dolomitic lime (and release CO₂) in accordance with the following reaction:



Emissions from the regeneration of lime from spent pulping liquors at pulp mills are not included in the inventory. Since this CO₂ is biogenic in origin, it is recorded as a change in forest stock in the Land-Use Change and Forestry section.

Emission Calculations

The mass of CO₂ produced per unit of lime manufactured may be estimated from a consideration of the molecular weights and the lime content of products (ORTECH, 1991).

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

The emissions are estimated by applying an emission factor of 790g CO₂ /kg quicklime produced in Canada.

2.2.A.3 Limestone and Dolomite Use

[Titled *Limestone Use* in the CGHGI.]

Limestone is used in a number of industries. In addition to its consumption in the production of cement and lime for resale, there are two other processes requiring significant amounts of the material: metallurgical smelting and glass making.

These industries use limestone at high temperatures. Therefore, the limestone is calcined to lime, producing CO₂ by the same reaction described in Section 2.2.A.1.

No data are available on the fraction of limestone used that is dolomitic. As noted in Section 2.2.A.2, lime production, and hence all limestone use, was assumed to be high calcium.

Emission Calculations

Data on the consumption of raw limestone by the glass and metallurgical smelting industries was obtained from the *Canada Minerals Yearbook* (NRCan, 2000). The data for 1999 was over ten times higher than previous data. This data was omitted and 1998 data was used for 1999.

The limestone use (non-dolomitic lime production) emission factor was developed by ORTECH (ORTECH, 1994).

Emissions are calculated by applying the EF to the Limestone Use data.

This technique is considered to be the IPCC default method.

2.2.A.4 Soda Ash Production and Use

Soda ash (sodium carbonate, Na_2CO_3) is a white crystalline solid that is used as a raw material in a large number of industries including glass manufacture, soap and detergents, pulp and paper manufacture, and water treatment (EIA, 1994). In Canada its use appears to be restricted to the glass industry.

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

EF	=	44.01 g/mole CO_2 /105.99 g/mole Na_2CO_3
	=	415 kg/tonne Na_2CO_3

Only limited production data have been published by Statistics Canada since 1993 due to confidentiality data suppression. Therefore, emissions have been assumed to be constant since 1993.

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

Emission Calculations

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

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

2.2.A.5 Asphalt Roofing

Not estimated.

2.2.A.6 Road Paving with Asphalt

Not estimated.

2.2.A.7 Other: Mineral Products

Not estimated.

References

ORTECH Corporation, *Inventory Methods Manual for Estimating Canadian Emissions of Greenhouse Gases*, Report to Environment Canada, April 1994.

Jaques, A.P., *Canada's Greenhouse Gas Emissions: Estimates for 1990*, Environment Canada, Report EPS5/AP/4, 1992.

Natural Resources Canada, *Canadian Minerals Yearbook*, Natural Resources Mining Sector, 1990–2000 annual editions.

Intergovernmental Panel on Climate Change (IPCC), *Greenhouse Gas Inventory Reporting Instructions*, Vol. 1; and *Greenhouse Gas Inventory Reference Manual*, Vol. 3, Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, 1997.

ORTECH Corporation, *Compilation of an Ontario Gridded Carbon Dioxide and Nitrous Oxide Emissions Inventory*, Prepared for the Ontario Ministry of the Environment, P-91-50-6436/OG, 1991.

United States Energy Information Administration (U.S. EIA), *Emissions of Greenhouse Gases in the United States 1987-1992*, Department of Energy, Washington, 1994.

Statistics Canada, *Non-Metallic Mineral Product Industries*, 1990-1993, Catalogue #44-250.

General Chemical Canada, Inc., Telephone communication, November 1995.

2.2.B Chemical Industry

[Titled *Chemical Production* in the CGHGI.]

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

2.2.B.1 Ammonia Production

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

One of the main uses for ammonia is in the manufacture of fertilizer. A large proportion of the manufactured ammonia is produced at plants that also produce urea. Urea production consumes much of the carbon dioxide that would otherwise be released to the atmosphere during ammonia manufacture. The carbon in urea may either become sequestered in plants or released to the atmosphere after its application to soils.

However, since this process is an agricultural application, it is accounted for under CO₂ emissions from soils in the Agriculture section. The carbon used in urea production is deducted from the total carbon dioxide produced from ammonia production. Although contrary to IPCC recommended procedure, this adjustment is necessary since it prevents double counting of agricultural soil emissions.

This methodology is used for the sole purpose of allocating the quantity of CO₂ 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 Section 2.2.G. Other: Industrial Processes).

Some of the hydrogen produced for ammonia production is from other chemical process by-products (Jaques, 1992). The gross ammonia production figure was reduced accordingly.

Emission Calculations

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

An emission factor of 1.56 t CO₂/t NH₃ produced was developed using typical material requirements for ammonia production in Canada (Jaques, 1992). (Note: this was rounded to 1600 g/kg in Appendix I.)

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

2.2.B.2 Nitric Acid Production

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

As nitric acid (HNO₃) is produced from ammonia (NH₃), nitrous oxide (N₂O) is emitted. Nitrous oxide emissions are in proportion to the amount of ammonia used and the concentration of N₂O in the exhaust gases depends on the type of plant and its emission controls. Canada-specific emission factors were developed, based on the type of abatement technology that is employed at individual plants.

One of the first attempts to estimate emissions of N₂O for this sector used information provided by global industry, which in turn, were based on company-specific measurements and calculations (ICI, 1991; Norsk Hydro, 1991). These estimates reported emissions ranging from 2 to 20 kg of N₂O/t of ammonia consumed

in the production of HNO₃. However, subsequent investigations indicated that emissions from Canadian plants were at the low end of this range (Collis, 1992).

Emission factors were developed for:

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

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

Emission Calculations

For Alberta it has been assumed that 175 kt HNO₃ are produced by plants with extended type 1 and 30 kt HNO₃ are produced by plants with extended type 2. The remainder were from catalytic converter type plants.

Emission factors are listed in Appendix I.

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

2.2.B.3 Adipic Acid Production

Adipic acid is used primarily for the manufacture of nylon. During its production, significant quantities of N₂O are produced and are usually vented to the atmosphere.

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

Emission Calculations

The emissions factor is listed in Appendix I. This factor is only valid for pre-1997 production when no emission controls were in place.

The emission estimates for adipic acid production are provided by the Dupont Maitland plant, Canada's only producer of adipic acid. The emissions were estimated based upon their production of adipic acid for the period 1990 to 1996 and based on monitoring from 1997 to the present.

2.2.B.4 Carbide Production

[This title is not used in the CGHGI.]

Emissions from this source are believed to be reported under Section 2.2.G.

2.2.B.5 Other: Chemical Industry

[This title is not used in the CGHGI.]

References

Farrel, J., Canadian Fertilizer Institute, Ammonia and Fertilizer Production data, 1990-1994, Unpublished report, January 1996.

Statistics Canada, *Industrial Chemicals and Synthetic Resins*, December 1999, Catalogue #46-006.

Jaques, A.P., Canada's Greenhouse Gas Emissions: Estimates for 1990, Environment Canada, Report EPS5/AP/4, 1992.

McCulloch, A., Letter from ICI Chemicals and Polymers Ltd., Runcorn, U.K., 1991.

Norsk Hydro, Information supplied to SFT (Statens Forurensningstilsyn), Oslo, May 1991.

Collis, G.A., Letter from Canadian Fertilizer Institute, March 1992.

Intergovernmental Panel on Climate Change (IPCC), *Greenhouse Gas Inventory Reporting Instructions*, Vol. 1; and *Greenhouse Gas Inventory Reference Manual*, Vol. 3, Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, 1997.

2.2.C Metal Production

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

2.2.C.1 Iron and Steel Production

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

Iron is produced through the reduction of iron oxide (ore) with metallurgical coke (as the reducing agent) in a blast furnace to produce pig iron. The metallurgical coke used in the furnace is oxidized in the process to CO₂ and emitted to the atmosphere. Some carbon is stored in the pig iron. However, this is mostly released to the atmosphere during the steel production process. Steel is made from pig iron and/or scrap steel using electric arc, basic oxygen or cupola furnaces.

The emissions estimates in this sub-sector do not include emissions from the production of steel in electric arc or basic oxygen type furnaces. The emissions

resulting from the oxidation of fossil fuel carbon based anodes in these furnaces are believed to be included in Section 2.2.G.

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

Emission Calculations

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

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

CO₂ emissions were estimated by applying the combustion emission factor for metallurgical coke to the amount of metallurgical coke used in the iron and steel industry.

2.2.C.2 Ferroalloys Production

[This title is not used in the CGHGI.]

Emissions are assumed to be included under Section 2.2.G.

2.2.C.3 Aluminum Production

[The UNFCCC uses the spelling Aluminium.]

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 (Al₂O₃) is dissolved in a fluorine bath consisting primarily of cryolite (Na₃AlF₆). 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 tetrafluoride (CF₄) and carbon hexafluoride (C₂F₆), are known to be emitted during the reduction process. The latter two, CF₄ and C₂F₆, are classified as perfluorocarbons (PFCs). PFCs are extremely inert, and are potent greenhouse gases. CF₄ has a 100-year Global Warming Potential (GWP) of 6500 while C₂F₆ has a GWP of 9200.

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

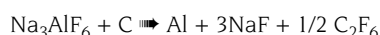


Most of the CO_2 forms from the reaction of the carbon anode with alumina, but some is formed as the anode reacts with other sources of oxygen (especially air). This occurs during cell operation and, in the case of pre-baked electrodes, during anode production and manufacture. Carbon dioxide emissions from this source are subtracted from the totals listed under Section 2.2.G.

Aluminum plants are characterized by the type of anode technology employed. In general, older plants with Söderberg technology have higher emissions than newer plants, which usually use pre-baked anodes. The trend in the Canadian 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.

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. 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 fluorine salts in the cell to chemically combine with the carbon anode (Laval University, 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:



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

Perfluorocarbon emissions can be controlled by computerized alumina feeders. Sensors detect alumina concentration and automatically feed more to the pot when levels become low. In this way, anode events can be controlled. The computers can be programmed to detect the onset of 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, 1990).

Although aluminum production consumes extremely large quantities of electrical energy, currently estimated to be 13.5 kWh per kg of aluminum (AIA, 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.

Emission Calculations

Carbon dioxide production-based emission factors for Canadian aluminum smelting were calculated (ORTECH, 1994) (see Appendix I).

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

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

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

2.2.C.4 SF_6 Used in Aluminum and Magnesium Foundries

[Titled *Magnesium Production* in the CGHGI.]

Sulphur hexafluoride (SF_6) is emitted during magnesium production. Sulphur hexafluoride is used in magnesium production as a cover gas to prevent oxidation of the molten metal. It is vented to the atmosphere immediately after use. Although emitted in relatively small quantities, SF_6 is an extremely potent greenhouse gas, with a 100-year GWP of 23 900.

SF_6 is not manufactured in Canada. All SF_6 is imported; therefore there are no SF_6 production-related emissions in Canada.

There are two magnesium producers in Canada, Norsk Hydro and Timminco Metals. Norsk Hydro has improved their production technologies to minimize the consumption of SF_6 while production has increased over the same period.

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

Some carbon dioxide emissions are associated with magnesium production. The CO₂ originates from carbonates in the raw magnesium-bearing ore. However, these emissions are estimated to be very small and are not included in the inventory.

Emission Calculations

Sulphur hexafluoride emission data were reported directly by the magnesium producers to the National Pollutant Release Inventory (NPRI) for 1999. For other years, the data were collected directly from the producers.

2.2.C.5 Other: Metal and Miscellaneous Chemical Production

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

Emissions of CO₂ from the oxidation of fossil-fuel based reducing agents in the production of other metals are included in the national inventory. These emissions are included in Section 2.2.G.

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

References

Statistics Canada, *Quarterly Report on Energy Supply-Demand in Canada* (QRES), Catalogue #57-003.

Intergovernmental Panel on Climate Change (IPCC), *Greenhouse Gas Inventory Reporting Instructions*, Vol. 1; and *Greenhouse Gas Inventory Reference Manual*, Vol. 3, Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, 1997.

Jacobs, C., *Preliminary Method for Estimating Country Emissions of CF₄ and C₂F₆*, United States Environmental Protection Agency, Washington, July 1994.

Laval University, Analytical Chemistry Group, *Polyfluorocarbons and the Environment (Their Effect on Atmospheric Equilibrium)*, Study for Environment Canada, March 1994.

Unisearch Associates, *Measurements of CF₄ and C₂F₆ in the Emissions from Canadian Aluminum Smelters by Tunable Diode Absorption Laser Spectroscopy*, Report to the Canadian Aluminum Association, April 1994.

ORTECH Corporation, *Inventory Methods Manual for Estimating Canadian Emissions of Greenhouse Gases*, Report to Environment Canada, April 1994.

Natural Resources Canada, *Canadian Minerals Yearbook*, Aluminum, Natural Resources Mining Sector, 1990–2000 annual editions.

Øye, H.P and R. Huglen, *Managing Aluminum Reduction Technology — Extracting the Most from Hall-Héroult*, J.O.M., November 1990.

Association de l'Industrie d'Aluminium du Québec (AIA), *The Aluminum Industry Today for the Needs of Tomorrow*, Montreal, 1993.

The following sectors and sub-sectors are not listed in the CGHGI.

2.2.D Other: Production

2.2.D.1 Pulp and Paper

Not estimated.

2.2.D.2 Food and Drink

Not estimated.

2.2.E Production of Halocarbons and SF₆

Not occurring.

2.2.F Consumption of Halocarbons and SF₆

[Note: The reporting for *Consumption of Halocarbons and SF₆* was originally listed in the *Solvent and Other Product Use* section, but the UNFCCC now requires these emissions to be reported in the *Industrial Processes* section.]

The major source of emissions from consumption of Halocarbons and SF₆ are due to the use of hydrofluorocarbons (HFCs) as replacements for chlorofluorocarbons (CFCs). HFCs were not used to any significant degree in Canada before 1995. CFCs are greenhouse gases, but are not included under the UNFCCC, since they are already controlled under the Montreal Protocol, and as a result are not inventoried herein.

Emissions from consumption of perfluorocarbons (PFCs) are minor relative to emissions from HFCs and PFC by-products from aluminum production. Recent PFC usage patterns show an increasing use of PFCs in the semiconductor manufacturing and electronic industries.

- Semiconductor Manufacturing
 - Plasma etching
 - Plasma cleaning of chemical vapour deposition chamber

- Electronic industries
 - Dielectric fluids
 - Electrical testing
 - Electronic cleaners (solvents)

There is no known production of HFCs/PFCs in Canada. The by-product emissions of PFCs from aluminum production are discussed in the Aluminum Production section (Section 2.2.C.3). All HFCs/PFCs consumed are imported in bulk or in product. No data are available for quantities of HFCs contained in imported equipment for the 1995 HFC estimate, so this source is not included, but it is assumed to be small, relative to others.

HFC emission estimates for 1995 were based on data from an initial HFC survey conducted by the Use Patterns and Controls Implementation Section of Environment Canada and used a modified IPCC Tier 1 methodology. The Use Patterns and Controls Implementation Section has since revised their HFC survey to obtain more detailed HFC activity data. IPCC Tier 2 methodology was used to estimate 1996 to 1998 HFC emissions based on detailed HFC activity data provided by the HFC survey. HFC activity data for 1999 are presently unavailable, therefore, the activity data used to estimate 1999 HFC emissions were based on available 1998 HFC data.

Detailed 1995 HFC data were not available to apply an IPCC Tier 2 estimate. Instead, where applicable, the IPCC Tier 1 methodology was adapted to make a more representative estimate of actual 1995 HFC emissions for the following groups: Aerosols; Foams; AC OEM; AC Service; Refrigeration; and Total Flooding System. PFC emission estimates for 1995 to 1999 were based on consumption data from the 1998 PFC survey conducted by the Use Patterns and Controls Implementation Section and used the 1996 Revised IPCC Guideline (Tier 2 methodology) or methodology provided by the IPCC Good Practice Guidance. Only 1995 to 1997 PFC consumption data were collected. PFC consumption data used to estimate 1998 and 1999 emissions were based on 1997 data.

Consumption of SF₆ from magnesium producers are discussed in Section 2.2.C.

Note that HFC and PFC consumption data provided by the Use Patterns and Controls Implementation Section are confidential (national HFC and PFC emissions are reported in an aggregated format).

References

1998 HFC and 1998 PFC Internal Survey, Use Patterns and Controls Implementation Section, National Office of Pollution Prevention, Environment Canada.

IPCC/OECD/IEA, *IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, Japan, 2000.

Intergovernmental Panel on Climate Change (IPCC), *Greenhouse Gas Inventory Reporting Instructions*, Vol. 1; and *Greenhouse Gas Inventory Reference Manual*, Vol. 3, Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, 1997.

2.2.F.1 Refrigeration and Air Conditioning Equipment

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

The major source of hydrofluorocarbons (HFCs) emissions is air conditioning (AC) equipment. From 1990 to 1994, the emissions from this source were considered negligible since HFCs were not widely used before the ban on production and use of CFCs came into effect in 1996 (as a result of the Montreal Protocol). Emissions from the consumption of PFCs for 1990 to 1994 were also assumed negligible.

Emission Calculations

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

HFC Estimate for 1995 – Emission Factors and Assumptions

AC Original Equipment Manufacture – Only original charging losses were estimated using the EFs for this sector. Other losses were accounted for under AC Service. The IPCC Guidelines employ a 2 to 5% loss rate. For Canada, a rate of 4% was assumed.

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

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

Equation 2.6

$$\text{HFC (refrig)} = \text{Charge} + \text{Operating Loss}$$

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

$$\begin{aligned}\text{HFC (refrig)} &= 0.17 \text{ Charge} + \text{Charge} \\ &= 1.17 \text{ Charge}\end{aligned}$$

or

$$\text{Charge} = \text{HFC (refrig)} / 1.17$$

Assuming assembly leakage is minimal:

$$\begin{aligned}\text{Emission} &= \text{operating loss} \\ &= 0.17 \text{ Charge}\end{aligned}$$

thus,

Equation 2.7

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

HFC emission estimates for 1996 to 1999 and PFC emission estimates for 1995 to 1999 in relation to refrigerators, freezers and air conditioning from system assembly – during system operation and at disposal – used the IPCC Tier 2 methodology presented in the revised IPCC Guidelines (IPCC, 1997).

System Assembly

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

Equation 2.8

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

where:

$$\begin{aligned}E_{\text{assembly, t}} &= \text{Emissions during system manufacture and assembly in year t} \\ E_{\text{charged, t}} &= \text{Quantity of refrigerant charged into new system in year t} \\ k &= \text{Assembly losses in percent of the quantity charged}\end{aligned}$$

The k value was chosen from a range of values that were provided for each equipment category in the revised IPCC Guidelines (see Table 2.2: Equipment Categories and k Values) (IPCC, 1997). The HFC and the PFC survey provided quantity of refrigerant charged.

Table 2.2 Equipment Categories and k Values

Equipment Category	k Values
Residential Refrigeration	2.0%
Commercial Refrigeration	3.5%
Stationary Air Conditioning	3.5%
Mobile Air Conditioning	4.5%

Annual Leakage

The same four categories from System Assembly were used to calculate emissions due to annual leakage. The equation given in the revised IPCC Guidelines was used to calculate HFC emissions for 1996 to 1999 and PFC emissions for 1995 to 1999 due to annual leakage (IPCC, 1997):

Equation 2.9

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

where:

$E_{\text{operation}, t}$	=	Quantity of HFC/PFC emitted during system operations in year t
$E_{\text{stock}, t}$	=	Quantity of HFC/PFC stocked in existing systems in year t
x	=	annual leakage rate in percent of total HFC/PFC charge in the stock

The amount of HFC/PFC stocked in existing systems includes the HFC/PFC in equipment manufactured in Canada, the amount of HFC/PFC in imported equipment, the amount of HFC in converted CFC equipment and excludes the amount of HFC/PFC in exported equipment. The amount of HFC used in converted CFC equipment was estimated based on the amount of HFC used for servicing equipment. It was assumed that no leakage occurs in the year of manufacturing or conversion. HFC/PFC consumption data were provided by the Use Patterns and Controls Implementation Section.

The IPCC Guidelines give a range of values for the annual leakage rate (x) for each of the different equipment categories. The annual leakage rate chosen for each category is shown in Table 2.3: Annual Leakage Rate (IPCC, 1997).

Table 2.3 Annual Leakage Rate (x)

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

System Disposal

HFC emissions for 1996 to 1999 from system disposal were not estimated, since HFC use only began in 1995 and was assumed to be negligible.

PFC emissions for 1995 to 1999 from system disposal were not estimated, due to lack of data. (PFC emissions from systems that have been disposed are assumed to be insignificant due to their limited use for specialized cooling systems prior to 1995.)

References

1998 HFC and 1998 PFC Internal Survey, Use Patterns and Controls Implementation Section, National Office of Pollution Prevention, Environment Canada.

Intergovernmental Panel on Climate Change (IPCC), *Greenhouse Gas Inventory Reporting Instructions*, Vol. 1; and *Greenhouse Gas Inventory Reference Manual*, Vol. 3, Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, 1997.

2.2.F.2 Foam Blowing

[Titled *Foams* in the CGHGI.]

Emission Calculations

HFC emission estimates for 1995 used an adaptation of the IPCC Tier 1 default method (IPCC, 1997). For that year, it was assumed that all foams produced were open cell foams. Emission factors for 1995 were developed based on loss rates adapted from the IPCC methodology (IPCC, 1997).

HFC Emissions from Foam Blowing

The IPCC Tier 2 methodology presented in the revised IPCC Guidelines was used to estimate 1996 to 1999 HFC and 1995 to 1999 PFC emissions from foam blowing (IPCC, 1997). Foams are grouped into two main categories: open cell and closed cell.

Open Cell Foam Blowing

In the production of open cell foam, 100% of the HFCs used are emitted (IPCC, 1997). Presently there is no known PFC use in open cell foam blowing. The Use Patterns and Controls Implementation Section provides data on the following open cell foam production categories that release HFC emissions:

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

Closed Cell Foam Blowing

During the production of closed cell foam, approximately 10% of the HFCs/PFCs used are emitted (IPCC, 1997). The remaining quantity of HFCs/PFCs are trapped in the foam and are emitted slowly over a period of approximately 20 years. The IPCC Tier 2 equation was used to calculate emissions from closed cell foam:

Equation 2.10

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

where:

$$\begin{aligned} E_{\text{foam}, t} &= \text{Emissions from closed cell foam in year } t \\ E_{\text{manufacturing}, t} &= \text{Quantity of HFCs/PFCs used in manufacturing closed cell foam in year } t \\ E_{\text{foam_stock}, t} &= \text{Quantity of HFCs/PFCs in stock (excluding exports) in year } t \end{aligned}$$

The Use Patterns and Controls Implementation Section provided quantities of HFCs/PFCs used in manufacturing and in stock of closed cell foam. The following are closed cell foam production categories that produce HFC emissions:

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

References

1998 HFC and 1998 PFC Internal Survey, Use Patterns and Controls Implementation Section, National Office of Pollution Prevention, Environment Canada.

Intergovernmental Panel on Climate Change (IPCC), *Greenhouse Gas Inventory Reporting Instructions*, Vol. 1; and *Greenhouse Gas Inventory Reference Manual*, Vol. 3, Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, 1997.

2.2.F.3 Fire Extinguishers

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

Emission Calculations

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

HFC/PFC Emissions from Fire Extinguishing

There are two types of fire extinguishing equipment considered: portable fire extinguishers and total flooding systems. The IPCC Tier 2 methodology of the revised IPCC Guidelines was used to calculate 1996 to 1999 HFC

emissions from portable fire extinguishers and total flooding systems (IPCC, 1997). Presently there is no known PFC use in fire extinguishing equipment.

Portable Fire Extinguishing Equipment

The IPCC Tier 2 methodology in the revised IPCC Guidelines estimated emissions as 60% of HFCs used in newly installed equipment (IPCC, 1997). The quantity of each type of HFCs was provided by the Use Patterns and Controls Implementation Section's HFC database.

Total Flooding Systems

The IPCC Tier 2 methodology provided in the revised IPCC Guidelines estimated emissions from total flooding systems as 35% of the HFCs used in new fire extinguishing systems installed (IPCC, 1997). The amount of each type of HFC used in new systems was provided by the Use Patterns and Controls Implementation Section's HFC database.

References

1998 HFC Internal Survey, Use Patterns and Controls Implementation Section, Environment Canada.

Intergovernmental Panel on Climate Change (IPCC), *Greenhouse Gas Inventory Reporting Instructions*, Vol. 1; and *Greenhouse Gas Inventory Reference Manual*, Vol. 3, Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, 1997.

2.2.F.4 Aerosols/Metered Dose Inhalers

[Titled *Aerosols* in the CGHGI.]

Emission Calculations

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

HFC Emissions from Use in Aerosols

The IPCC Tier 2 methodology presented in the revised IPCC Guidelines was used to calculate 1996 to 1999 HFC emissions from aerosols (IPCC, 1997). The emissions estimate for the current year is equal to half of the HFCs used in aerosols in the current year plus half of the HFCs used in aerosols in the previous year. The amount of HFCs used each year is equal to the amount of HFCs used to produce aerosols, the amount of HFCs in imported aerosol products and excludes the amount of HFCs in exported aerosol products. To calculate the amount of each type of HFC used in aerosol produced,

imported and exported, each year's activity data were provided by the Use Patterns and Controls Implementation Section's HFC database.

PFC consumption data shows product imported into Canada in aerosol cans contain solvents used as flux remover and precision cleaners for the electronic industry. PFC emissions are therefore reported in Section 2.2.F.5.

References

1998 HFC and 1998 PFC Internal Survey, Use Patterns and Controls Implementation Section, National Office of Pollution Prevention, Environment Canada.

Intergovernmental Panel on Climate Change (IPCC), *Greenhouse Gas Inventory Reporting Instructions*, Vol. 1; and *Greenhouse Gas Inventory Reference Manual*, Vol. 3, Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, 1997.

2.2.F.5 Solvents

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

Emissions from HFC/PFC used as Solvents

The IPCC Tier 2 methodology presented in the revised IPCC Guidelines was used to estimate 1996 to 1999 HFC and 1995 to 1999 PFC emissions from solvents (IPCC, 1997). The emission estimate for the current year is equal to half of the HFCs/PFCs used as solvents in the current year plus half of the HFCs/PFCs used as solvents in the previous year. The amount of HFCs/PFCs used each year is equal to the amount of HFCs/PFCs produced and imported as solvents, and excludes the amount of HFCs/PFCs exported as solvents. To calculate the amount of each type of HFC/PFC used as solvents, each year's activity data were provided by the Use Patterns and Controls Implementation Section. HFC/PFC used as solvents includes the following categories:

- Electronic industries
- Laboratory solvents
- General cleaning

References

1998 HFC and 1998 PFC Internal Survey, Use Patterns and Controls Implementation Section, National Office of Pollution Prevention, Environment Canada.

Intergovernmental Panel on Climate Change (IPCC), *Greenhouse Gas Inventory Reporting Instructions*, Vol. 1; and *Greenhouse Gas Inventory Reference Manual*, Vol. 3, Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, 1997.

2.2.F.6 Semiconductor Manufacture

HFC emissions are inventoried in Section 2.2.F.5.

IPCC Tier 2b methodology provided by the IPCC Good Practice Guidance was used to estimate 1995 to 1999 PFC emissions from the semiconductor manufacturing industry.

Two main uses of PFC in the semiconductor manufacturing industry are for plasma etching of silicon wafers and plasma cleaning of chemical vapour deposition chambers.

Bulk PFC consumption data were provided by the Use Patterns and Controls Implementation Section's PFC survey and emission rates chosen for each process are shown in Table 2.4: PFC Emission Rate, provided by the IPCC Good Practice Guidance (Tier 2b). Currently, there is no information on emission control technologies, therefore it was assumed 100% of PFCs were released (IPCC, 2000).

Table 2.4 PFC Emission Rate*

Tier 2b	CF ₄	C ₂ F ₆	C ₃ F ₈	c-C ₄ F ₈
Plasma Etching	0.7	0.4	0.4	0.3
Chemical Vapour Desposition Chamber	0.8	0.7	0.4	ND

ND - no data available

*IPCC Good Practice Guidance

References

1998 PFC Internal Survey, Use Patterns and Controls Implementation Section, National Office of Pollution Prevention, Environment Canada.

Intergovernmental Panel on Climate Change (IPCC)/Organization for Economic Co-operation and Development (OECD)/IEA, *IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, Japan, 2000

2.2.F.7 Electrical Equipment

HFC emissions are inventoried in Section 2.2.F.5.

The Tier 2 methodology and default emission factors presented in the IPCC Good Practice Guidance were used to estimate 1995 to 1999 PFC emissions. PFC consumption data were provided by the PFC survey. The data were categorized into emissive and contained PFC emission sources. Unidentified and miscellaneous PFC uses were also categorized under emissive emission sources.

Emissive sources include the following:

- Electrical Environmental Testing
- Gross Leak Testing
- Thermal Shock Testing

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

PFC emissions for contained sources are associated with its use as an electronic insulator and a dielectric coolant for heat transfer in the electronics industry. PFC consumption data were provided by the Use Patterns and Controls Implementation Section. The Tier 2 methodology and emission factors provided by the IPCC Good Practice Guidance were used to estimate 1995 to 1999 PFC emissions from contained sources, represented by the following equation:

Equation 2.11

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

where:

$E_{\text{contained}, t}$	=	Emissions from contained sources
$E_{\text{consumed}, t}$	=	quantity of PFCs sale for use or manufacturing of contained sources in year t
$E_{\text{stock}, t}$	=	quantity of PFCs in stock in year t
k	=	manufacturing emission rate = 1% of annual sales
x	=	leakage rate = 2% of stock
d	=	disposal emission factor = 5% of annual sales

References

1998 PFC Internal Survey, Use Patterns and Controls Implementation Section, National Office of Pollution Prevention, Environment Canada.

Intergovernmental Panel on Climate Change (IPCC)/Organization for Economic Co-operation and Development (OECD)/IEA, *IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, Japan, 2000.

2.2.F.8 Other: Consumption of Halocarbons and SF₆

2.2.G Other: Industrial Processes

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

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

A number of fossil fuels are used for purposes that are considered non-energy uses. These include the use of natural gas to produce hydrogen in the oil upgrading and refining industries, the use of petroleum coke for anodes in metal production, the use of Natural Gas Liquids (NGLs) and feedstocks in the chemicals industry, and the use of lubricants. These non-energy uses of fossil fuels result in varying degrees of oxidation of the fuel, producing CO₂ emissions.

The use of petroleum coke, in anodes for the production of aluminum, is reported 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 natural gas used to produce hydrogen for ammonia production is recorded by Statistics Canada with all other non-energy uses of natural gas. The emissions from ammonia production are also subtracted from the total non-energy emissions to avoid double counting.

Emission Calculations

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

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

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

For certain cases industry- and process-specific data were available. For example, the use of natural gas to produce hydrogen in the oil upgrading and refining industries. Reported as natural gas transformed to refined products and natural gas inter-product transfer by Statistics Canada (Statistics Canada, #57-003). In these instances, the natural gas is assumed to undergo 100% oxidation and the appropriate combustion emission factor is used.

References

Intergovernmental Panel on Climate Change (IPCC), *Greenhouse Gas Inventory Reporting Instructions*, Vol. 1; and *Greenhouse Gas Inventory Reference Manual*, Vol. 3, Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, 1997.

Statistics Canada, *Quarterly Report on Energy Supply-Demand in Canada* (QRES), Catalogue #57-003.

2.3 Solvent and Other Product Use

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

The majority of emissions in this section are also related to the use of nitrous oxide (N₂O) as an anaesthetic and a propellant.

Note: Hydrofluorocarbons (HFCs) as replacements for Chlorofluorocarbons (CFCs) was originally reported in this section, but the UNFCCC now requires these emissions to be reported in the Industrial Processes section (see Section 2.2.F). Emissions related to HFC consumption are not point sources and would be more appropriately categorized as product use emissions.

2.3.A Paint Application

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

Not estimated.

2.3.B Degreasing and Dry Cleaning

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

Not estimated.

2.3.C Chemical Products, Manufacture and Processing

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

Not estimated.

2.3.D Other: Solvent and Other Product Use

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

Not estimated.

2.3.D.1 Use of N₂O for Anaesthesia

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

Nitrous oxide is used in medical applications, primarily as a carrier gas but also as an anaesthetic in various dental and veterinary applications.

It has been assumed that all of the nitrous oxide used for anaesthetics will eventually be released to the atmosphere.

Emission Calculations

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

The population data used for the emissions calculations was obtained from Statistics Canada (Statistics Canada, #91-213).

2.3.D.2 N₂O from Fire Extinguishers

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

Not known to occur.

2.3.D.3 N₂O from Aerosol Cans

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

Nitrous oxide is used as a propellant for pressure and aerosol products, primarily in the food industry. The largest application is for pressure-packaged whipped cream, along with other dairy products. Applications outside of the food industry include the cosmetic industry and the use as a substitute for freon or hydrocarbons, such as butane and isobutane.

It was assumed that all the N₂O used in propellants were emitted to the atmosphere during the year of sale.

Emission Calculations

An emission factor was developed for N₂O used in propellants based upon consumption patterns in Canada in 1990 (see Appendix I).

The population data used for the emissions calculations was obtained from Statistics Canada (Statistics Canada, #91-213).

2.3.D.4 Other: Use of N₂O

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

References

Fettes, W., Communication between Senes Consultants and Puitan Bennet, February 1994.

Statistics Canada, *Annual Demographic Statistics*, 1990–1999 annual editions, Catalogue #91-213.

2.4 Agriculture

2.4.A Enteric Fermentation

Large quantities of methane (CH₄) are produced from herbivores through a process called enteric fermentation. During the normal digestive process, microorganisms break down carbohydrates into simple molecules for absorption into the bloodstream, where methane is produced as a by-product. This process results in methane in the rumen that is emitted by eructation and exhalation. Some methane is released later in the digestive process by flatulation. The animals that generate the most methane are ruminant animals such as cattle.

The IPCC emission factors are based on research conducted in the United States. 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 accuracy of using the IPCC cool climate emission factors for Canadian conditions.

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

Emission Calculations

Methane (CH₄) emissions from enteric fermentation were estimated by multiplying the populations of vari-

ous animals by average emission rates for each type of domestic animal.

The methodology used is considered IPCC Tier 1.

Generally, the IPCC default emission factors for cool climate were used for all regions of Canada (IPCC, 1997). In some cases, factors from other sources were used (Cassada and Safley, 1990).

In general, domestic animal population data were obtained from Statistics Canada (Statistics Canada, #26-603). Semi-annual or quarterly data were averaged to obtain annual populations. Some exceptions have been noted by appropriate classifications in Table 2.5 below.

Table 2.5 Sources for Methane Emission Calculations (Exceptions)

Source

Cattle

- Dairy Cattle - Includes dairy cows and dairy heifers only

Non-Dairy Cattle

- All other cattle

Buffalo

- Considered a negligible source in Canada

Sheep

Listed under *Other* in the CGHGI

- Includes lambs

Goats

Listed under *Other* in the CGHGI

- Data were not available on an annual basis from Statistics Canada #26-603. Therefore, for goats, data from the 1991 and 1996 farm census (Statistics Canada #93-350 and #93-356) have been used.

Camels and Llamas

- Considered a negligible source in Canada

Horses

Listed under *Other* in the CGHGI

- Data were not available from Statistics Canada #26-603. Therefore, for horses, data from the 1991 and 1996 farm census (Statistics Canada #93-350 and #93-356) have been used.

Mules and Asses

- Considered a negligible source in Canada

Swine – All pigs

Poultry

- Yearly population data are available from *Production of Poultry and Eggs* (Statistics Canada, #23-202)

References

Cassada, M. E. and C. M. Safley Jr., *Global Methane Emissions from Livestock and Poultry Manure*, 1990.

Intergovernmental Panel on Climate Change (IPCC), *Greenhouse Gas Inventory Reporting Instructions*, Vol. 1; and *Greenhouse Gas Inventory Reference Manual*, Vol. 3, Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, 1997.

Statistics Canada, *Livestock Statistics*, Agriculture Division, 1990-1999, Catalogue #23-603.

Statistics Canada, *Agricultural Profile of Canada in 1991*, Census of Agriculture, 1992, Catalogue #93-350.

Statistics Canada, *Agricultural Profile of Canada in 1996*, Census of Agriculture, 1997, Catalogue #93-356.

Statistics Canada, *Production of Poultry and Eggs*, Agriculture Division, 1990-1999 annual editions, Catalogue #23-202.

2.4.B Manure Management

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

Typically, poorly aerated manure handling systems generate large quantities of methane but smaller amounts of nitrous oxide, while well-aerated systems generate little methane but more nitrous oxide.

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.

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

Nitrous Oxide Emissions

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

Nitrification is the oxidation of NH_4^+ to NO_3^- and denitrification is the reduction of NO_3^- to N_2 .

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

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

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

Methane emissions have been reported based on animal type, while nitrous oxide emissions have been calculated based on manure management systems.

Emission Calculations

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

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

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

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

- Pasture and Paddock

- Liquid Systems
- Solid Storage or Dry Lot
- Other Systems

Table 2.6 Sources for Manure Nitrogen Emission Calculations (Exceptions)

Source
Cattle
Dairy Cattle
<ul style="list-style-type: none"> • Includes dairy cows and dairy heifers only
Non-Dairy Cattle
<ul style="list-style-type: none"> • In general, beef production uses the dry-lot type of manure management system
Buffalo
<ul style="list-style-type: none"> • Considered a negligible source in Canada
Sheep
Listed under Other in the CGHGI
<ul style="list-style-type: none"> • Includes lambs
Goats
Listed under Other in the CGHGI
<ul style="list-style-type: none"> • Data were not available from Statistics Canada #26-603. Therefore, for goats, data from the 1991 and 1996 farm census (Statistics Canada #93-350 and #93-356) have been used
Camels and Llamas
<ul style="list-style-type: none"> • Considered a negligible source in Canada
Horses
Listed under Other in the CGHGI
<ul style="list-style-type: none"> • Data were not available from Statistics Canada #26-603. Therefore, for horses, data from the 1991 and 1996 farm census (Statistics Canada #93-350 and #93-356) have been used
Mules and Asses
<ul style="list-style-type: none"> • Considered a negligible source in Canada
Swine – All pigs
Poultry
<ul style="list-style-type: none"> • Production data from Production of Poultry and Eggs (Statistics Canada, #23-202) have been used
Anaerobic Lagoons
Not used as a sector title in the CGHGI
Liquid Systems
Solid Storage and Dry Lot

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

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 for the other manure management systems.

The animal population data used to estimate the total manure nitrogen (N) excreted were the same as that used to calculate enteric fermentation emissions. In general, domestic animal population data were obtained from Statistics Canada (Statistics Canada, #26-603). Semi-annual or quarterly data were averaged to obtain annual populations. Some exceptions have been noted by appropriate sectors (see Table 2.6).

References

American Society of Agricultural Engineers (ASAE), *Manure Production and Characteristics in ASAE Standards* 1999. 46th Edition, Standards Engineering Practices Data, The Society for Engineering in Agricultural, Food, and Biological Systems, 1999, p. 663-665.

Intergovernmental Panel on Climate Change (IPCC), *Greenhouse Gas Inventory Reporting Instructions*, Vol. 1; and *Greenhouse Gas Inventory Reference Manual*, Vol. 3, Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, 1997.

Statistics Canada, *Livestock Statistics*, Agriculture Division, 1990-1999, Catalogue #23-603.

Statistics Canada, *Agricultural Profile of Canada in 1991*, Census of Agriculture, 1992, Catalogue #93-350.

Statistics Canada, *Agricultural Profile of Canada in 1996*, Census of Agriculture, 1997, Catalogue #93-356.

Statistics Canada, *Production of Poultry and Eggs*, Agriculture Division, 1990-1999 annual editions, Catalogue #23-202.

2.4.C Rice Cultivation

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

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

2.4.D 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 (CO₂) and nitrous oxide (N₂O).

Carbon Dioxide Emissions

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

Net CO₂ emissions have decreased since 1990 due to changes in farming practices. The primary reason for the reduced net emissions from soils is believed to be the increasingly common practice of conservation tillage. No-till farming was being practiced on over 16% of Canada's croplands in 1996 as opposed to 7% in 1991 (Statistics Canada, #93-350 and #93-356). No-till farming reduces the oxidation of soil organic carbon and therefore increases the carbon stored in soils.

As noted, a change in soil organic carbon is influenced by the conversion of land to agriculture, management practices, soil characteristics and climate. A key issue around the certainty of estimating carbon in soils is the relatively small annual increment of carbon change to an already large carbon pool. In order to develop an estimate of CO₂ emissions that reflects the diverse and myriad complexities that affect carbon fluxes in agricultural soils, the CENTURY computer model was employed (Parton, 1987).

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

There is a large degree of uncertainty associated with the estimates provided by the CENTURY model. Comparisons of CENTURY outputs with field measurements suggest that further refinements are required to improve the reliability of the model in predicting soil carbon change in response to no-till practices in the prairies (McConkey, 1998). In fact, the rate of carbon gain under carbon-conserving practices determined by Smith et al. (1997) using the CENTURY model was lower than that observed on the prairies, but higher than that observed in Eastern Canada. There has been a growing

awareness of limitations of the CENTURY model among soil scientists in Canada, and of the need for new models with measurable C pools. This concern has led to the change in the methodology in estimating agricultural soil carbon sink due to the adoption of carbon-conserving practices for Canada's Land Use, Land-Use Change and Forestry (LULUCF) August 1, 2000 Submission to the UNFCCC (Government of Canada, 2000).

Nitrous Oxide Emissions

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

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

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

Emission Calculations

Carbon Dioxide Emissions

The CENTURY model was used to estimate emissions. The emission estimates (as prepared by Smith) aggregates emissions from each of the Western provinces and the Eastern provinces. Emissions were divided among the Eastern provinces by prorating against the agricultural land area in each province (Smith, 1997 and Sellers, 1998). The CENTURY model, as run by Smith, didn't provide 1999 estimates. This data was estimated by interpolating between 1996 data and a forecasted 2000 estimate by Smith.

Since the CENTURY model does not estimate emissions from the liming of soils, liming emissions were estimated according to the IPCC default methodology (IPCC, 1997). The liming emissions were added to the results from the CENTURY model (Sellers, 1998).

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

Nitrous Oxide Emissions

The methodology used is based on the IPCC default and is divided by sources, direct and indirect (see Sections 2.4.D.1 to 2.4.D.4).

2.4.D.1 Direct Soil Emissions

[Titled *Direct Sources* in the CGHGI.]

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

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

Synthetic fertilizers

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

Emission Calculations

The methodology used to estimate N₂O emissions is the IPCC Tier 1 methodology.

The emission factor of 1.25% N₂O-N/kg N for all types of fertilizer combined with the amount of fertilizer nitrogen applied annually were used to estimate N₂O emissions from synthetic fertilizers (IPCC, 1997).

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

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

Animal Wastes Applied as Fertilizer

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

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

Emission Calculations

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

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

The amount of manure nitrogen excreted was reduced by the IPCC default value, 20%, to account for the volatilization of NH₃ and NO_x (IPCC, 1997).

In general, domestic animal population data were obtained from Statistics Canada (Statistics Canada, #26-603). Semi-annual or quarterly data were averaged to obtain annual populations. Some exceptions have been noted by appropriate sectors (see Section 2.4.A).

Plant Biological Nitrogen Fixation

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

Emission Calculations

The methodology used to estimate emissions was the IPCC default.

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

The amount of nitrogen in the nitrogen-fixing plants was estimated from production data, assuming that the crop mass is twice the mass of the edible portion and assuming it contains 0.03 kg N/kg dry mass (IPCC, 1997).

Estimates of the dry mass used the IPCC values for the average dry matter fractions of 86% for crops such as wheat, barley, corn, oats, rye, peas, beans, soya, lentils and tame hay (IPCC, 1997). Silage corn, potatoes and sugar beets were assumed to contain 30, 25 and 20% of dry mass, respectively. There were no explicit annual statistics available for alfalfa production. That information is combined with tame hay production. Therefore, alfalfa quantities have been estimated by assuming that 60% of tame hay production is alfalfa. In addition, the crop mass of alfalfa and tame hay was assumed to be equal to the reported production.

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

Crop Residue Decomposition

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

Emission Calculations

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

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

The emission rate of 1.25% N₂O-N/kg N was also IPCC default (IPCC, 1997).

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

Cultivation of Histosols

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

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

Emission Calculations

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

An emission factor of 5 kg N₂O-N/ha/yr (IPCC, 1997) was used.

2.4.D.2 Animal Production

[This title is not used in the CGHGI, it is referred to as grazing animals.]

This source of emissions is those associated with the application of manure to soils through grazing animals.

Emission Calculations

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

The excretion rates (ASAE, 1999) plus pasture and paddock system emission factors from the IPCC were used (IPCC, 1997). Animal population data is the same as that used in the manure management section (see Section 2.4.B).

2.4.D.3 Indirect Emissions

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 to produce N₂O.

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

2.4.D.3.a Volatilization and Subsequent Redeposition

Emission Calculations

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

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

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

Leaching and Runoff

Emission Calculations

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

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

2.4.D.4 Other: Agricultural Soils

[This title is not used in the CGHGI.]

References

Statistics Canada, *Agricultural Profile of Canada in 1991*, Census of Agriculture, 1992, Catalogue #93-350.

Statistics Canada, *Agricultural Profile of Canada in 1996*, Census of Agriculture, 1997, Catalogue #93-356.

Government of Canada, Proposals related to Kyoto Protocol Articles 3.3 and 3.4, Canadian Submission to the United Nations Framework Convention on Climate Change, August 1, 2000.

American Society of Agricultural Engineers (ASAE), 1999. *Manure Production and Characteristics in ASAE Standards 1999*. 46th Edition, Standards Engineering Practices Data, The Society for Engineering in Agricultural, Food, and Biological Systems, p. 663-665.

Neitzert, F., K. Olsen, and P. Collas, *Canada's Greenhouse Gas Inventory: 1997 Emissions and Removals with Trends*, Greenhouse Gas Division, Pollution Data Branch, Air Pollution Prevention Directorate, Environment Canada, April 1999.

Parton, W.J., D.S. Schimel, C.V. Cole, and D.S. Ojima, *Analysis of Factors Controlling Soil Organic Matter Levels in Great Plains Grasslands*, 1987.

Smith, W.N., R.L. Desjardins, E. Pattey, and A. Jaques, *Estimated Rates of Carbon Change in Agricultural Soils in Canada from 1970 to 2010*, Final report submitted to Art Jaques (unpublished), 1997.

Smith W.N., P. Rochette, C. Monreal, R. Desjardins, E. Pattey, and A. Jaques, "The Rate of Carbon Change in Agricultural Soils in Canada at the Landscape Level," *Canadian Journal of Soil Science*, 77:219-229, 1997.

McConkey, B. *Report on Prairie CENTURY Research Workshop*, Prepared for GEMC, Vancouver, August 27, 1998.

Seller, P., and M. Wellisch, MWA Consultants, *Greenhouse Gas Contribution of Canada's Forest Products Sector 1990-2010*, 1998.

Intergovernmental Panel on Climate Change (IPCC), *Greenhouse Gas Inventory Reporting Instructions*, Vol. 1; and *Greenhouse Gas Inventory Reference Manual*, Vol. 3, Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, 1997.

Korol, M., and G. Rattray, *Canadian Fertilizer Consumption, Shipments and Trade*, 1991–2000 annual editions, Agriculture and Agri-Food Canada.

Monteverde, C.A., R.L. Desjardins, and E. Pattey, *Estimates of Nitrous Oxide Emissions from Agroecosystems in Canada for 1981, 1986, 1991, and 1996 using the Revised 1996 IPCC/OECD Methodology*, March 1998.

Statistics Canada, *Field Crop Reporting Series No. 8*, Vol. 69-76, Agriculture Division, 1991–2000 annual editions, Catalogue #22-002.

Natural Resources Canada, *Canada Minerals Yearbook*, Mining Sector, Peat Chapter, 1995.

2.4.E Prescribed Burning of Savannas

[This title is not used in the CGHGI.]

This sector does not apply in Canada.

2.4.F Field Burning of Agricultural Residues

[This title is not used in the CGHGI.]

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

2.4.G Other: Agriculture

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

Many agricultural activities result in emissions of greenhouse gases. The processes that produce emissions are enteric fermentation related to 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 section rather than under Agriculture.

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

2.5 Land-Use Change and Forestry

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

Emissions from all anthropogenic activities related to the Land-Use Change and Forestry (LUCF) section are covered with the exception of non-CO₂ gases from energy-related activities, which are addressed in the Energy section. Carbon dioxide emissions from agricultural soils are reported in the Agriculture section.

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 CO₂-C per year). In the absence of significant human disturbance, this large flux of CO₂ from the atmosphere to the terrestrial biosphere is balanced by the return respiration fluxes. Globally, ecosystems are in a state of dynamic equilibrium.

Humans interact with land in many different ways. Certain land uses and land-use changes can directly alter the size and rate of natural exchanges of greenhouse gases (GHG) among terrestrial ecosystems, the atmosphere and the ocean. Changes in land use practices today affect both present and future CO₂ fluxes associated with that specific land use, a fact that distinguishes land use from fossil fuel consumption for purposes of CO₂ emissions analysis.

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

The 1996 CGHGI was 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 IPCC Guidelines (IPCC, 1997). 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 per-

spective. In Canada's case, this assessment involves the estimation of small changes cumulated over 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 practices and land-use change activities, as is required by the UNFCCC, is a complex task.

The results are presented under the following headings:

1. Changes in Forest and Other Woody Biomass Stocks;
2. Forest and Grassland Conversion - loosely defined as deforestation;
3. Abandonment of Managed Lands croplands, pastures or other managed lands;
4. CO₂ Emissions and Removals from Soil - associated with items 2 and 3 (not required by the IPCC); and
5. Other, which includes:
 - Emissions from human-induced fires; and
 - 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 (items 1, 3 and part of 4) currently remove CO₂ from the atmosphere, whereas forest and grassland conversion (item 2 and part of 4) and biomass burning (item 5) all release emissions.

All estimates in this section are drawn from a recent study performed for Environment Canada (Sellers and Wellisch, 1998). It is important to note that emissions and removals of CO₂ from LUCF reported in this section are not included in the sector or national totals in the CGHGI as per the IPCC Reporting Guidelines (IPCC, 1997).

LUCF activities can have an impact on three different carbon (C) reservoirs:

- above-ground biomass;
- below-ground biomass; and
- soil carbon.

The IPCC methodology currently omits below-ground biomass and soil carbon in forest stocks. Current data on these pools for the wood production forest in

Canada are inadequate. Changes in soil C resulting from land-use change activities (see Sections 2.5.B. and 2.5.C), while not required by the IPCC, are nevertheless reported here in Section 2.5.D.

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-CFS¹), 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), takes into account the carbon stored in below-ground biomass and dead organic matter, and incorporates 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 the methodology

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

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

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

The following general notes apply to the LUCF estimates:

- CO₂ from LUCF is classified separately and is not included in inventory sums.
- Removals (i.e. uptake by vegetation and soils) are shown as negative values.
- Individual sector estimates are given to two significant figures.
- For CO₂, totals have been rounded to one significant figure, to reflect the relatively high level of uncertainty associated with this category.
- Emissions estimates greatly depend on the way wood products are treated in the methodology (see Section 2.5.A).
- The information on human induced fires are for outside the wood production forest (WPF). Carbon dioxide emissions from fires in the WPF are included in net change in forest stocks. Note that the net CO₂ flux includes emissions from human-induced fires outside the WPF.

2.5.A Changes in Forest & 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 (i.e. forests of different ages and species, exposed to various climates and disturbances). For the purposes of defining the area of forest affected by human activity, a decision had to be made regarding the area of forestland that should be considered in this assessment. Approximately 58% of the Canadian forest area is classified as timber productive forest. The portion of the timber productive forest that is non-reserved and accessible is known as Canada's wood production forest and is generally available for commercial harvest (148 Mha). The wood production forest represents 35% of Canada's total forestlands

(Lowe et al., 1996). 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 CO₂ removals, represents 122.8 Mha, once the non-stocked portion and over-mature forests have been excluded (Sellers and Wellisch, 1998).

The 1994 update of the 1991 *Canadian Forest Inventory* (Lowe et al., 1994, 1996), 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.

Virtually all of the CO₂ removals in this sector 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.

Some double counting is likely to occur between the estimates in the Changes in Forest and Other Woody Biomass Stocks sector and those reported in the Energy and Waste sections (i.e. methane from landfill 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 in the methodology.

The method used to produce estimates for this sector 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. These methods, while promising, have yet to be approved for inclusion in the IPCC Guidelines. An overview of these two approaches is available in the IPCC *Special Report on Land-use, Land-use Change and Forestry* (IPCC, 2000).

Emission Calculations

With the current IPCC method (used to produce the results presented here) the net impact of a removal or emission is calculated as the difference between CO₂ uptake through forest growth and CO₂ 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. unused slash) are assumed to be released in the year of harvest.

The accumulation of above-ground biomass (annual biomass increment) by the wood production forest has been estimated by multiplying the forest area by the mean annual volume increment, then by a conversion/expansion factor into total above-ground biomass. 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, the area of 122.8 Mha was assumed to be constant over the period 1990 to 1999.

Forest growth rates are not available by age or maturity class for the wood production forest. Therefore, a long-term average value referred to as the mean annual increment (m.a.i) to maturity has been applied to the entire growing area. The m.a.i is defined as the mature merchantable wood volume per hectare divided by the stand age. Use of this growth rate is believed to be the greatest source of uncertainty in the estimation of CO₂ 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 mortality and growth reduction due to non-stand-replacing disturbances, competition and disease.

The m.a.i value, retrieved by ecozones, is assumed to be constant since 1990. 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 agricultural 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. Although very minor, the contribution of urban forests were calculated from estimated fractions of non-built-up urban areas and the growth rate of urban trees.

Carbon dioxide emissions from forest harvest have been obtained for the current IPCC method by a series of calculations. Data input to these calculations

include industrial roundwood production, domestic firewood and charcoal consumption and other commodity data, parameters accounting for the bark volume, and wood volume to forest biomass conversion/expansion factors (Sellers and Wellisch, 1998; IPCC, 1997).

Alternative Methods for Emission Calculations

Carbon dioxide emissions resulting from the sustained yield harvest of the wood production forest have been assessed using two other methods which better reflect the Canadian situation: the stock-change method and the flow method. These methods are considered to be improvements over the default method, as they recognize that most of the carbon in harvested biomass converted to wood products is not emitted within the year of harvest. Gross emissions associated with harvest for 1998 range from 171 Mt CO₂ (atmospheric flow method) to 258 Mt CO₂ (current IPCC method).

Both the stock and flow methods address the issue of long-term C storage by assigning commodities into one of two groups: products that last for less than five years; and products with a life span of five or more years. They differ with respect to their allocation of emissions and removals. The stock-change method accounts only for the net C stock change in the domestic long-term wood product reservoir, after imports and exports. The flow method tracks emissions and removals associated with the manufacturing and consumption of wood products within national boundaries. Both methods are more spatially and temporally realistic than the current default, which does not account for emissions where or when they actually 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 the domestic consumption of wood products by the producing country. The flow method is similar to the approach adopted for fossil fuel emissions, involves few additional calculations, and provides a better reflection of when and where emissions and removals actually occur.

2.5.A.1 Tropical Forests

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

This sector does not apply to Canadian conditions.

2.5.A.2 Temperate Forests

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

2.5.A.3 Boreal Forests

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

2.5.A.4 Grasslands/Tundra

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

2.5.A.5 Other: Changes in Forest & Other Woody Biomass Stocks

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

2.5.A.5.a Harvested Wood

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

2.5.B Forest and Grassland Conversion

This subsection estimates CO₂ 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 were addressed. Changes in soil carbon levels are estimated in Section 2.5.D.

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 net increases in agricultural and urban areas, the only time series data available. They have been determined as 10-year average values, as specified in the IPCC Guidelines (IPCC, 1997).

This approach represents 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.

Total area converted equals 81 kha in 1990 and about 113 kha in 1999. It is estimated that about 12 kha were deforested in 1990 and 26 kha in 1999. 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 involves the largest change in above-ground biomass.

Other sources of deforestation have not been included in this assessment owing to deficiencies in data. The data available are insufficient to allocate the change in biomass density to different routes (on-site burning, off-site burning and decay) with any degree of confidence. Consequently, emissions of non-CO₂ trace gases associated with on-site burning after land conversion could not be evaluated. It was assumed that all of the change in carbon density was as a result of conversion of lost biomass to carbon dioxide.

Emission Calculations

Agricultural land area data were 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 (Statistics Canada, #16-200-XKE and CCFM, 1997).

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

Biomass densities before conversion are from the Canadian Forest Service (ESSA, 1996) and the biomass densities after conversion were based on the IPCC default data (IPCC, 1997). Converted areas, all conversion factors and other factors were assembled for Environment Canada to obtain the estimates (Sellers and Wellisch, 1998).

The assumptions that were employed were key to the accuracy of the emissions estimates. At this point these are considered to provide first-order approximations only.

2.5.B.1 Tropical Forests

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

This sector does not apply to Canadian conditions.

2.5.B.2 Temperate Forests

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

2.5.B.3 Boreal Forests

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

2.5.B.4 Grasslands/Tundra

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

2.5.B.5 Other: Forest and Grassland Conversion

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

2.5.C Abandonment of Managed Lands

Estimates were made for CO₂ 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 Section 2.5.D.

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 a cropland or pasture ecosystem. The IPCC recommends that the uptake be evaluated according to two time horizons:

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

Since Canada's *Census of Agriculture's Agricultural Profiles* time series only covers 1961 to the present, the assessment for the second time period only covers land abandoned for 20 to 38 years prior to 1998.

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

Emission Calculations

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

No data exist regarding the specific fate of the abandoned land. Therefore, it was assumed that – of the abandoned areas – half was converted to urban land and the remainder was allowed to regrow to the natural state in estimated proportions (ESSA, 1996; Sellers and Wellisch, 1998).

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

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

2.5.C.1 Tropical Forests

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

This sector does not apply to Canadian conditions.

2.5.C.2 Temperate Forests

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

The methodology employed is described in Section 2.5.C.

2.5.C.3 Boreal Forests

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

The methodology employed is described in Section 2.5.C.

2.5.C.4 Grasslands/Tundra

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

2.5.C.5 Other: Abandonment of Managed Lands

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

2.5.D CO₂ Emissions and Removals from Soil

[Titled *CO₂ Emissions and Removals from Soils from Land-Use Change* in the CGHGI.]

This category estimates CO₂ fluxes to and from soils due to land-use changes (i.e. carbon emissions from land conversion and uptake by soils after land abandonment).

The methods for estimating CO₂ emissions and removals from agricultural soils and liming are discussed in the Agriculture section.

Estimates are considered to be first approximations because of the indirect way the land areas are determined and because of the significant assumptions made on annual rates of CO₂ emission or uptake by soils in different ecosystems.

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

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

Soil Carbon Emissions from Land Conversion

Conversion of land from forest or grassland to agricultural land generally results in a loss of soil carbon.

Emission Calculations

Carbon dioxide emissions were estimated using the methodology used by the Canadian Forest Service (ESSA, 1996).

The acreage data for 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 for each post-conversion land use. Values for forest systems are assumed to include roots as well as soil, leading to an overestimation of soil carbon content in forests.

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.

Emission Calculations

Rates of carbon uptake are those estimated for the Canadian Forest Service (ESSA, 1996). It was assumed that soil C accumulates over a 100-year time period to the average below-ground C content of the natural ecosystem. Note that, for forest soils, these include roots C as well as soil C. It is felt that this technique overestimates the removals strictly attributed to soil.

The carbon uptake rates are multiplied by the data for the total abandoned land area that is not converted to urban use.

2.5.D.1 Cultivation of Mineral Soils

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

2.5.D.2 Cultivation of Organic Soils

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

2.5.D.3 Liming of Agricultural Soils

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

2.5.D.4 Forest Soils

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

2.5.D.5 Other: CO₂ Emissions and Removals from Soil

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

2.5.E Other: Land-Use Change and Forestry

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

While not required by the IPCC Greenhouse Gas Reporting Guidelines, the following sectors and sub-sectors are included in the LUCF section of the CGHGI. The following method description elaborates on the following sources:

1. Fires Caused by Human Activities
 - Prescribed Burning
 - Other Fires in the Wood Production Forest
 - Other Fires Caused by Human Activities Outside the Wood Production Forest
2. Wildfires

2.5.E.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 CO₂ emissions, burning generates non-CO₂ trace gas emissions, CH₄ and N₂O.

Carbon dioxide emissions from prescribed burning are not included in this section. They are included as part of slash emissions in Section 2.5.A.

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

Emission Calculations

Data on the areas exposed to prescribed burning are reported by the Canadian Committee on Forest Fire Management for 1990 to 1995, and were assumed to be constant up to and including 1998. Data for 1999 were provided by the Canadian Forestry Service (Campbell, pers.com.).

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

The Canadian Forest Service has developed emission factors for each trace gas (Taylor and Sherman, 1996).

2.5.E.2 Other Fires in the Wood Production Forest

This sector includes non-CO₂ emissions from fires that are believed to be caused by human activity in the wood production forest, other than prescribed burning.

In Canada, forest fire reporting is not structured to directly provide the area burned in the wood production forest, regardless of the fire origin. Further, it cannot be confirmed that the input data used in the calculations strictly exclude natural or wildfires. It was assumed that any wildfire occurring in the wood production forest could also be indirectly attributed to human activity. The fact that most of the wildfires inventoried occur outside the wood production forest, or managed forest, tends to reduce the uncertainty associated with this approximation.

Emission Calculations

Fire frequency and severity is notoriously variable from one year to another, even in intensively protected areas such as the wood production forest. Further, recent data indicate that overall fire occurrence and areas annually burned have substantially increased over the last two decades.

In the CGHGI, the total area of wood production forest burned annually is calculated as a fixed proportion (15%) of the total area of forest land burned, which is reported annually by the Canadian Council of Forest Ministers (CCFM, 2001). The percentage was derived from estimated fire return intervals in Canada's managed forest between 1980 and 1995 (Kurz et al., 2000). The provincial breakdown is proportional to the distribution of the wood production forest across provinces (Lowe et al., 1996). It should be noted that these estimates of the area burned annually in the WPF remain approximates. Historical data of total forest land burned annually go back to 1970.

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

2.5.E.3 Other: Fires Caused by Human Activities Outside the Wood Production Forest

This sector includes both CO₂ and non-CO₂ emissions from anthropogenic fires outside the wood production forest. In Canada, fire reporting is classified by cause; anthropogenic fires outside the wood production forest are those associated with recreation, residence, railways, other industry, incendiary and other miscellaneous causes.

Emission Calculations

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

Data for 1999 were taken as the average of burned areas over 1990-1998 period.

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

Emission factors for CO₂ and non-CO₂ emissions were provided by the Canadian Forest Service (Taylor and Sherman, 1996).

2.5.E.4 Wildfires

At present, emissions from wildfires do not have to be reported to the UNFCCC.

On average, more than 90% of the total forest area burned annually in Canada is associated with wildfires caused by lightning. An estimated 733 kha were burned in 1990. The estimate for 1999 is 1,926 kha.

Emission Calculations

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

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

To estimate emissions, the total fuel consumption value was combined with the same average emission factors used in Subsection 2.5.E.1.

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

References

- Campbell, I., Personal communication to Dominique Blain, 2001.
- Canadian Council of Forest Ministers (CCFM), *Compendium of Canadian Forestry Statistics*, 1992, 1994 and 1996, National Forestry Database, Canadian Forest Service, Natural Resources Canada, 2001.
- Environment Canada, *Canada's Greenhouse Gas Emissions: Estimates for 1990*, Report EPS5/AP/4, 1992.
- ESSA Technologies Ltd., *International Reporting of Canadian Forest Sector Carbon Inventories: Assessment of Alternative Methodologies*, Prepared for Canadian Forest Service, Northwest Region, 1996.
- Intergovernmental Panel on Climate Change (IPCC) *Land Use, Land-Use Change and Forestry, a Special Report of the IPCC*, Cambridge University Press, 2000.
- IPCC, *Greenhouse Gas Inventory Reporting Instructions*, Vol. 1; and *Greenhouse Gas Inventory Reference Manual*, Vol. 3, Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, 1997.
- Jaques, A.P., F. Neitzert, and P. Boileau, *Trends in Canada's Greenhouse Gas Emissions 1990-1995*, Environment Canada, En49-5/5-8E, April 1997.

Kurz, W.A., D.C.E. Robinson, and S.J. Beukema, *Carbon Stock Changes in the Managed Forest in Canada (1980-2032)*, Prepared by ESSA Technologies Ltd. for the Canadian Forest Service, Natural Resources Canada, 2000.

Lowe J.J., K. Power, and S.L. Gray, *Canada's Forest Inventory 1991: the 1994 version — An addendum to Canada's Forest Inventory 1991*, Pacific Forestry Centre, Canadian Forest Service, Natural Resources Canada, Information Report BC-X-362E, 1996.

Lowe J.J., K. Power, and S.L. Gray, *Canada's Forest Inventory 1991*, Petawawa National Forestry Institute, Canadian Forest Service, Natural Resources Canada, Information Report PI-X-115, 1994.

Sellers, P., and M. Wellisch, *Greenhouse Gas Contribution of Canada's Land-Use Change and Forestry Activities: 1990-2010*, Prepared by MWA Consultants for Environment Canada (according to the IPCC Guidelines for Land-Use Change and Forestry; description of IPCC LUCF Worksheets), Final Draft, July 1998.

Stocks, B.J., Communication to Werner Kurz, ESSA Ltd., "CO₂ Emissions from Wildfires and Prescribed Fires in Canada," 1990.

Taylor, S.W., and K.L. Sherman, *Biomass Consumption and Smoke Emissions from Contemporary and Prehistoric Wildland Fires in British Columbia*, Prepared by the Pacific Forestry Centre, Canadian Forest Service, Natural Resources Canada, FRDA Report 249, March 1996.

2.6 Waste

Much of the waste treated or disposed of is biomass or biomass-based. The carbon dioxide (CO₂) emissions attributable to such wastes are not included in this section. In theory, there are no net emissions if the biomass is sustainably harvested. For example, biomass originating from food wastes are sustainably harvested. Carbon dioxide emitted from the decomposition of food will be consumed by the next year's crop.

If biomass is harvested at an unsustainable rate (i.e. faster than the annual regrowth), net CO₂ emissions will appear as a loss of biomass stocks in the Land-Use Change and Forestry (LUCF) section.

2.6.A Solid Waste Disposal on Land

Emissions are estimated from two types of landfills in Canada:

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

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

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

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

Methane emission totals are derived using the following equation:

Equation 2.12	
Total methane from landfills	= methane produced – methane captured

In Canada, most, if not all, waste disposal on land occurs in municipally managed or privately owned landfills. Very few, if any, unmanaged waste disposal sites exist. Therefore, it has been assumed that all waste is disposed of in managed facilities. Residential, institutional, commercial, industrial, construction and demolition wastes are disposed of in MSW landfills.

Wood waste landfills are privately owned and operated by forest industries, such as saw mills and pulp and paper mills. These industries use the landfills to dispose of surplus wood residue such as sawdust, wood shavings, bark and sludges. The best practice for reducing 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 that produce steam and/or electricity. Wood waste landfills have been identified as a source of methane emissions, however, there is a great deal of uncertainty in the estimates. It is assumed that the actual emissions are most likely of the same order of magnitude as the estimates that have been produced.

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

During the past several decades, the composition and amount of waste landfilled in Canada has significantly changed particularly due to population growth. For this reason, a static model such as the default method is

not felt to be appropriate. Therefore, the emissions from MSW landfills and wood waste landfills in Canada are estimated using the Scholl Canyon model.

The Scholl Canyon Model

The following is an explanation of factors that contribute to landfill gas generation and the Scholl Canyon model that was used to estimate 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.

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

Temperature: Anaerobic digestion is an exothermic process. The growth rates of bacteria tend to increase with temperature until an optimum is reached (Tchobanoglous, 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, MSW contains the necessary nutrients to support the required bacterial populations.

Waste Density and Particle Size: The particle size and density of the waste also influence gas generation. Decreasing the particle size increases the surface area available for degradation and therefore increases the gas production rate. The waste density, which is largely controlled by compaction of the waste as it is placed in the landfill, affects the transport of moisture and nutrients through the landfill, which also effects the gas generation rate.

General Methodology

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

Equation 2.13

G_i	=	$M_i \times k \times L_0 \times \exp^{-k \times t_i}$
where:		
G_i	=	emission rate from the i^{th} section (kg of CH ₄ /year)
k	=	methane generation rate (1/year)
L_0	=	methane generation potential (kg 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)

2.6.A.1 Managed Waste Disposal on Land

Emission Calculations

The Scholl Canyon model was used to estimate emissions.

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 or the Mass of Refuse (M_i)

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

Wood Waste Landfills: The amount of wood waste landfilled in the years 1970 through to 1992 has been estimated at a national level based on the Wood Residue Data Base (NRCan, 1997). The amount of wood residue landfilled in the years 1993 to 1998 was estimated based on information in a study of Pulp and Paper Mill waste (Paprican, 1997), a study of mill residue (SEAFOR, 1990) and an internal Canadian Pulp and Paper Association document (Reid, 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 a study that acknowledges the limited amount of data that was available to estimate the values (Levelton, 1991). The k values are largely based on those determined from tests at various U.S. landfills. The U.S. k values are related to precipitation assuming that moisture content of a landfill is a direct function of the annual precipitation. Based on the U.S. k values and precipitation data, the average annual precipitation and mean daily temperature at Canadian landfills 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 (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_0)

MSW Landfills: The values of theoretical and measured L_0 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_0 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 used to calculate a L_0 value for use in the years 1990 through 1996 (ORTECH, 1994):

Equation 2.14

L_0	=	$(M_c \times F_b \times S)/2$
where:		
M_c	=	tonnes of carbon per tonne of waste landfilled
F_b	=	biodegradable fraction
S	=	stoichiometric factor

The carbon content (M_c) in the waste on a dry basis is determined as a percentage of the waste disposed, 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 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_0 of 117 kg CH_4 /tonne of waste was calculated. As waste disposal practices in Canada change, the L_0 value will be adjusted again to reflect this difference.

Wood Waste Landfills: Equation 2.14 was used to calculate an L_0 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 several sources (SEAFOR, 1990; Paprican, 1997; NRCan, 1997 and Reid, 1998).

Captured Landfill Gas

Some of the methane that is generated in MSW landfills is captured. In order to calculate the net methane emissions from landfills, the captured quantity is subtracted from the estimate generated by the Scholl Canyon model.

Emission Calculations

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

2.6.A.2 Unmanaged Waste Disposal Sites

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

2.6.A.3 Other: Solid Waste Disposal on Land

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

2.6.B Wastewater Handling

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

Municipal wastewater can be aerobically or anaerobically treated. When wastewater is treated anaerobically, 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. However, as discussed earlier, CO_2 emissions originating from the decomposition of food are not to be included with the national estimates according to IPCC Guidelines.

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

Methane Emission Calculations

The IPCC default method was not used because the required data were not available. A method developed for Environment Canada (ORTECH, 1994) was used to calculate an emission factor. Based on the amount of organic matter generated per person in Canada and the conversion of organic matter to methane, it was estimated that 4.015 kg CH_4 /person/year could potentially be emitted from wastewater treated anaerobically.

An emission factor for each province was calculated by multiplying this potential emission rate by the fraction of wastewater treated anaerobically in each province (NIMWWS, 1981).

Emissions are calculated by multiplying the emission factors by the population of the respective province (Statistics Canada, #91-213-XPB).

Nitrous Oxide Emission Calculations

The nitrous oxide emissions were calculated using the IPCC default method (IPCC, 1997). This method estimates emissions based on the amount of nitrogen in sewage and the assumption that 0.01 kg N_2O -N/kg sewage N will be generated.

The amount of nitrogen in sewage was estimated based upon the following two assumptions: protein is 16% nitrogen and Canadian protein consumption is 40.15 kg/person/year.

This resulted in an emissions factor of 0.101 kg N_2O /person/year.

Emissions were calculated by multiplying the emission factor by the population of the respective province (Statistics Canada, #91-213-XPB).

2.6.B.1 Industrial Wastewater

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

Not estimated.

2.6.B.2 Domestic and Commercial Wastewater

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

Included under 2.6.B.

2.6.B.3 Other: Wastewater Handling

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

2.6.C Waste Incineration

Emissions from both MSW and sewage sludge incineration are included in the inventory. Several municipalities in Canada utilize incinerators to reduce the quantity of MSW sent to landfills and to reduce the amount of sewage sludge requiring land application. The majority of emissions in this sector result from MSW incineration.

The 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.

MSW Incineration

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 (RIS, 1996). The greenhouse gases that are emitted from MSW incinerators may include carbon dioxide, methane and nitrous oxide.

As per IPCC Guidelines, the CO₂ emissions from the combustion of biomass waste are not included in this section of the inventory. The only CO₂ emissions included in this section 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.

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

Emission Calculations

Carbon Dioxide Emissions: The IPCC Guidelines do not specify a method to calculate CO₂ emissions from incineration of fossil-fuel-based waste (such as plastics and rubber). Therefore, the following three-step method was developed.

Step 1- Calculating the Amount of Waste Incinerated

The amount of waste incinerated each year is based on an Environment Canada study (RIS, 1996). This study contained detailed provincial incineration data for the year 1992. To estimate the amount of MSW incinerated

in other years, the 1992 data were extrapolated according to population growth using population data (Statistics Canada, #91-213-XPB).

Step 2- Developing Emission Factors

The provincial CO₂ emission factors are based on the assumption that the carbon in the waste undergoes complete oxidation to CO₂. The amount of fossil-fuel-based carbon available in the waste incinerated has been determined using typical percent weight carbon constants (Tchobanoglous, 1993). The amount of carbon per tonne of waste is estimated and converted to tonnes of CO₂ per tonne of waste, by multiplying by the ratio of the molecular mass of carbon dioxide to carbon.

Step 3- Calculating Carbon Dioxide Emissions

Emissions were calculated on a provincial level by multiplying the amount of waste incinerated by the appropriate emission factors.

Nitrous Oxide and Methane Emissions

The emissions of N₂O from MSW incineration were estimated using the IPCC default method (IPCC, 1997). An average factor was calculated assuming that the IPCC five stokers factors were most representative. To estimate emissions, the calculated factor was multiplied by the amount of waste incinerated by each province.

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

Sewage Sludge Incineration

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

Two different types of sewage sludge incinerators are used in Canada, multiple-hearth and fluidized-bed. Prior to incineration, in both types of incinerators, the sewage sludge is partially de-watered. The de-watering is typically done in a centrifuge or using a filter press. Currently, municipalities in Ontario, Quebec and Saskatchewan operate sewage sludge incinerators.

Only methane emissions are estimated from sewage sludge incineration.

Emission Calculations

Methane Emissions: The emissions are dependent on the amount of dried solids incinerated. To calculate the CH₄ 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 in 1994 (Senes, 1994). The data for the years 1993 to 1996 were acquired through telephone surveys of the facilities that incinerate sewage sludge.

Emissions of CH₄ 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 has been considered in calculating emissions from sewage sludge incineration. Emissions have been assumed constant since 1996.

2.6.D Other: Waste

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

References

Intergovernmental Panel on Climate Change (IPCC), *Greenhouse Gas Inventory Reporting Instructions*, Vol. 1; and *Greenhouse Gas Inventory Reference Manual*, Vol. 3, Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, 1997.

Levelton, B.H., Levelton & Associates, *Inventory of Methane Emissions from Landfills in Canada*, Prepared for Environment Canada, June 1991.

Tchobanoglous, G., H. Theisen, and S. Vigil, *Integrated Solid Waste Management, Engineering Principles and Management Issues*, McGraw Hill, New York, 1993.

Canadian Council of Ministers of the Environment (CCME), *Solid Waste, 23% National Reduction in Solid Waste from 1988 to 1994*, www.mbnet.mb.ca/ccme/5e_other-topics/5ec.html, 1998.

Statistics Canada, *Annual Demographic Statistics*, 1998, Catalogue #91-213-XPB.

Natural Resources Canada, *Wood Residue DataBase*, 1997.

Reid, I.D., *Solid Residues Generation and Management at Canadian Pulp and Paper Mills in 1994 and 1995*, 83rd Annual Meeting, Technical Section, Canadian Pulp and Paper Association, 1998, p. A81-A84.

SEAFOR, *British Columbia Forest Industry Mill Residues for Calendar Year 1989*, Prepared for the Ministry of Forests Mill Residue Task Force, May 1990.

Pelt, R., et al., *User's Manual Landfill Gas Emissions Model*, Version 2.0, Prepared for Control Technology Centre, United States Environment Protection Agency (U.S. EPA) and the U.S. EPA Office of Research and Development, 1998.

ORTECH Corporation, *Inventory Methods Manual for Estimating Canadian Emissions of Greenhouse Gases*, Prepared for Environment Canada, 1994.

The National Inventory of Municipal Waterworks and Wastewater Systems in Canada (NIMWWSC), 1981.

Resource Integration Systems Ltd. (RIS), *Perspectives on Solid Waste Management in Canada, An Assessment of the Physical, Economic and Energy Dimensions of Solid Waste Management in Canada*, Vol. I, Prepared for Environment Canada, March 1996.

Antler, Susan, "Composting Comes of Age, Highlights from a new Canada-wide Study," *Solid Waste & Recycling*, October/November 1997.

Section 3

Verification and QA/QC

This chapter provides a description of the Quality Assurance/Quality Control (QA/QC) and verification procedures used in the preparation of the Greenhouse Gas (GHG) inventory. In general, the reference approach and expert review were used as the primary means to ensure the quality of the inventory. The methodologies used for the Canadian inventory have been evolving since the development of the first inventory more than 10 years ago. However, they have not changed significantly since the previous United Nations Framework Convention on Climate Change (UNFCCC) submission and publication of the inventory. The inventory and methodologies are published on a regular basis, which has provided an additional opportunity for public and expert review. Canada has also undertaken the process of identifying inventory key sources. The results of this analysis will form the foundation for future inventory improvements.

3.1 Reference Approach

The reference approach was compared to the sectoral approach as a check of combustion emissions. The check was performed for all years from 1990 to 1999 and is an integral part of the Common Reporting Format (CRF).

Direct comparison of the reference approach and the sectoral approach used in the CRF shows a reference approach total, which is consistently larger than the sectoral approach total. The preprogrammed comparisons in the CRF on table 1A(c) are not appropriate for Canada since they are not comparing similar emission universes. The reference approach, in theory, includes all CO₂ emissions from all fossil fuel uses (combustion and process) in a country and should only be compared with a similar set of emissions from the sectoral approach. In the CRF, the reference approach is directly compared with the sectoral fuel combustion total. This comparison produces a significant discrepancy since the sectoral approach total does not include fossil fuel derived CO₂ from industrial processes. In Canada, a significant amount of fossil fuel is used for feedstocks in industrial processes such as aluminum, ammonia and ethylene production. The emissions resulting from these processes are reported as industrial processes. The Canadian reporting procedure

does follow the Intergovernmental Panel on Climate Change (IPCC) Guidelines. When the comparison is corrected by adding the relevant industrial process data to the sectoral approach the totals match within 2 to 4%. This is deemed a good match for Canada considering the high uncertainty in using the default IPCC emission factors for the reference approach for Canada.

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

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

3.1.A Reference Approach Methodology

General

For the most part, the IPCC designated methods are followed for this evaluation. Fuel quantities are recorded from the *Quarterly Report on Energy Supply-Demand* (QRES D) and entered in their natural units (typically megalitres, thousands of cubic meters, kilotonnes and gigalitres). Apparent consumption is determined and, when necessary, the conversion factor (Tj/unit) is derived using IPCC default (IPCC, 1997), NHV values (Tj/kt) and the fuel-specific density (specific gravity). Since the IPCC values are presented in NCV units, this conversion circumvents the national protocol of reporting energy in GCV.

Crude Oil

The value listed as 'crude oil production' has been adjusted to include the inter-product transfer that would account for crude consumed to supply still gas in the oil sand and bitumen upgraders. Producer consumed upgrader petroleum is not accounted for in marketable production statistics because synthetic crude oil production statistics are based on marketable volumes of crude produced not on volumes of bitumen extracted.

Natural Gas Liquids (NGLs)

NGLS are a virtual composite mixture of ethane, propane and butane. Dependent upon those proportions, a specific gravity and carbon emission factor (tC/Tj) for that year is generated using IPCC default values, and hence maintains the requested NCV dimensions.

Gasoline

This category is a combination of motor gasoline and aviation gasoline with the former dominating the total.

Liquified Petroleum Gas (LPG)

LPG includes stored carbon due to butane to accommodate the lack of consistency between the LPG segregation from the stored carbon worksheet – Table 1.A (d) – and that of the sectoral reference approach – Table 1.A (b) of the CRF.

Refinery Feedstock

The Tj/unit conversion factor is derived using IPCC, Canada-specific NCV for OECD Countries and the specific gravity of the feedstocks.

Other Oils

This category includes Stored Carbon due to Other Products from Table 1.A (d) of the CRF.

Natural Gas

The value listed as 'natural gas production' in the QRES D has been reduced to compensate for the inter-product transfer (which accounts for the natural gas being used as a source of hydrogen in oil sand upgrading). The energy conversion factor is dependent upon the GHV value from the QRES D for natural gas for that specific year and is discounted, according to OECD/IEA, to accommodate the difference between GHV and NHV.

Biomass

Solid biomass includes Canadian industrial and residential sources, whereas liquid biomass addresses spent pulping liquor. All calculations are made using default IPCC values for the conversion factors.

3.2 Inventory Review

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

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

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

gy data which resulted in a complete review of the national energy balances (as described by A. Coombs, 1999). The energy data used for the CGHGI is also the basis for the national energy and emissions forecast.

References

Allen Coombs & Associates Inc., *Major Changes in the Historical Data for the Quarterly Report on Energy Supply and Demand (QRES D)* (1990-1997), December 1999.

3.3 Key Sources

The IPCC manual on *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* identifies as good practice the identification of key source categories of emissions. The identification practice is intended to help inventory agencies prioritize their efforts and improve overall estimates. A key source category is:

...one that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both (IPCC).

This analysis identifies key source categories for the CGHGI according to IPCC approaches.

Good practice first requires that inventories be disaggregated in source categories from which key sources may be identified. Source categories are defined by levels of analyses according to the following guidelines:

- IPCC categories should be used with emissions specified in CO₂ – equivalent units according to standard GWP;
- A category should be identified for *each* gas emitted by the source since the methods, emission factors and related uncertainties differ for each gas; and
- Source categories that use the same emission factors based on common assumptions should be aggregated before analysis.

The Canadian analysis of source categories for key sources proceeds according to the IPCC Tier 1 approach. Using this method, key sources are identified first by *quantitative* methods using a pre-determined cumulative emissions threshold. Second, Tier 1 key sources are determined by *qualitative* approaches. A more comprehensive Tier 2 approach is recommended if source-level uncertainty estimates are available. In

this approach, the results of Tier 1 are multiplied by the relative uncertainty of the source category. Recent Canadian inventory uncertainty analysis is not available, therefore requiring key source determination through Tier 1 methods.

The quantitative approach identifies key sources from two perspectives. The first analyzes the level of emission contribution each source makes to the national total. The second perspective analyzes the trend of emission contributions from each source to identify where the greatest absolute changes (either increases or reductions) have taken place over a given time. The percentage contributions to both levels and trends in emissions are calculated and sorted from greatest to least. A cumulative total is calculated for both approaches. IPCC has determined that a cumulative contribution threshold of 95% for both level and trend assessments is a reasonable approximation of 90% uncertainty for the Tier 1 method of determining key sources (IPCC). The 95% cumulative contribution threshold has been used in this analysis to define an upper boundary for key source identification. Therefore, when source contributions are sorted greatest to least, and when these sources provide at least 95% of the cumulative total of contributions, the sources are considered quantitatively to be key.

Level contribution of each source is calculated according to Equation 3.1:

Equation 3.1	
$L_{x,t} = E_{x,t}/E_t$	
where:	
$L_{x,t}$	= the level assessment for sources x in year t
$E_{x,t}$	= the emission (CO ₂ eq.) estimate of source category x in year t
E_t	= the total inventory estimate (CO ₂ eq.) in year t

Trend contribution of each source is calculated according to Equation 3.2:

Equation 3.2

$$T_{x,t} = L_{x,t} \cdot | \{ [(E_{x,t} - E_{x,0}) / E_{x,t}] - [(E_t - E_0) / E_t] \} |$$

where:

$T_{x,t}$	=	the contribution of the source category trend to the overall inventory trend (i.e. the trend assessment). The contribution is always recorded as an absolute value.
$L_{x,t}$	=	the level assessment for source x in year t (derived in equation 3.1).
$E_{x,t}$ and $E_{x,0}$	=	the emissions estimates of source category x in years t and 0, respectively.
E_t and E_0	=	the total inventory estimates in years t and 0 respectively.

The qualitative approach strengthens the foregoing quantitative analysis by considering more subjective criteria to determine if a category should be listed as a key source. In most cases, the application of these criteria identify identical categories to those prioritized by the quantitative analysis. Additional categories identified as key, however, may be added to the primary list. The IPCC identifies four significant criteria for qualitative analysis. They are as follows:

1. **Mitigation techniques and technologies:** identify those sources where emissions are being reduced significantly through the use of mitigation techniques or technologies.
2. **High expected emission growth:** identify sources with significant growth forecast.
3. **High uncertainty:** identify most uncertain sources as key to help improve the accuracy of the inventory.
4. **Unexpectedly low or high emissions:** identify calculation errors and discrepancies by doing order of magnitude checks. Canadian emission data is published only after review. This fourth criteria is not relevant to key source identification for Canada as unexpectedly high or low emissions are validated before publication. As a result, they are not unexpectedly low or high.

This analysis uses four sources of information to help define qualitative criteria. Through published information and personal communication, these information sources provided valuable insight into qualitative key source assessment:

- The Canadian Climate Change Secretariat has published Canada's first *National Climate Change Business Plan* (CCCS-BP, 2000) and an *Action Plan* (GOC, 2000) outlining significant mitigation measures underway and planned in a range of sectors.
- The Voluntary Challenge Registry, Canada's independent GHG registry for major source categories, has identified significant actions planned and underway amongst some important Canadian industries (VCR, 2001).
- Natural Resources Canada's Emissions Analysis and Modelling Team, has developed forecasts of GHG emissions from source categories for a Business-as-Usual (NRCan, 1999) and a Kyoto (NRCan, 2000) scenario based on discussions with governments and other stakeholders.
- The Greenhouse Gas Division of Environment Canada has carried out research on uncertainties in the Greenhouse Gas Inventory (McCann, 1994).

The overall purpose of identifying key sources is the institution of best practices in greenhouse gas inventory development. Source category definition, therefore, is important in that this first step groups emission sources in meaningful categories that reflect not only sources of emissions but also methods of deriving emission estimates. Thus, while the UNFCCC Common Reporting Format categories provide a basis for identifying sources, some aggregation of these sources can occur if they use the same emission factors based on common emission estimate assumptions. In this analysis, major categories are in keeping with the Common Reporting Format such as Fuel Combustion, Fugitive Emissions, Industrial Processes, Agriculture and Waste.² Within these major categories, considerable grouping can occur if emission estimates are made based on common assumptions about emission factors and on common methods of accumulating activity data. For example, within the Fuel Combustion category, emissions from Residential, Commercial and Agriculture sub-sectors are combined under the Other Sector category.

At the same time, in developing source categories, it is necessary to consider each greenhouse gas separately since estimating methods, emission factors and related uncertainties differ for each gas. Accordingly, source categories are given for each major greenhouse gas (CO₂, CH₄, N₂O, HFC, PFC and SF₆) where that gas is a contributor to the national inventory.

A complete listing of all source categories is shown in Table 3.1 on the following page.

² Minor categories include Solvent and Other Product Use, as well as International Bunkers. Carbon Dioxide from Land-Use Change and Forestry are excluded.

Table 3.1 Source Category Analysis Summary*

Source Table	IPCC Source Categories	Direct Greenhouse Gas	Key Source Categories (Yes or No)	If Yes, Criteria for Identification
1-A-1-a	Fuel Combustion - Public Electricity and Heat Production	CO ₂	Yes	Trend, Level, Quality
1-A-1-a	Fuel Combustion - Public Electricity and Heat Production	CH ₄		
1-A-1-a	Fuel Combustion - Public Electricity and Heat Production	N ₂ O		
1-A-1-b	Fuel Combustion - Petroleum Refining	CO ₂	Yes	Trend, Level, Quality
1-A-1-b	Fuel Combustion - Petroleum Refining	CH ₄		
1-A-1-b	Fuel Combustion - Petroleum Refining	N ₂ O		
1-A-1-c	Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries	CO ₂	Yes	Trend, Level, Quality
1-A-1-c	Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries	CH ₄		
1-A-1-c	Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries	N ₂ O		
1-A-2	Fuel Combustion - Manufacturing Industries and Construction	CO ₂	Yes	Trend, Level
1-A-2	Fuel Combustion - Manufacturing Industries and Construction	CH ₄		
1-A-2	Fuel Combustion - Manufacturing Industries and Construction	N ₂ O		
1-A-3-a	Fuel Combustion - Civil Aviation	CO ₂	Yes	Trend, Level, Quality
1-A-3-a	Fuel Combustion - Civil Aviation	CH ₄		
1-A-3-a	Fuel Combustion - Civil Aviation	N ₂ O		
1-A-3-b	Fuel Combustion - Road Transportation	CO ₂	Yes	Trend, Level, Quality
1-A-3-b	Fuel Combustion - Road Transportation	CH ₄		
1-A-3-b	Fuel Combustion - Road Transportation	N ₂ O	Yes	Trend, Level, Quality
1-A-3-c	Fuel Combustion - Railways	CO ₂	Yes	Trend, Level
1-A-3-c	Fuel Combustion - Railways	CH ₄		
1-A-3-c	Fuel Combustion - Railways	N ₂ O		
1-A-3-d	Fuel Combustion - Navigation	CO ₂	Yes	Trend, Level
1-A-3-d	Fuel Combustion - Navigation	CH ₄		
1-A-3-d	Fuel Combustion - Navigation	N ₂ O		
1-A-3-e	Fuel Combustion - Other Transport	CO ₂	Yes	Trend, Level
1-A-3-e	Fuel Combustion - Other Transport	CH ₄		
1-A-3-e	Fuel Combustion - Other Transport	N ₂ O		
1-A-3-f	Fuel Combustion - Pipeline Transport	CO ₂	Yes	Trend, Level, Quality
1-A-3-f	Fuel Combustion - Pipeline Transport	CH ₄		
1-A-3-f	Fuel Combustion - Pipeline Transport	N ₂ O		
1-A-4	Fuel Combustion - Other Sectors	CO ₂	Yes	Trend, Level
1-A-4	Fuel Combustion - Other Sectors	CH ₄		
1-A-4	Fuel Combustion - Other Sectors	N ₂ O		
1-B-1-a	Fugitive Emissions - Coal Mining	CH ₄	Yes	Trend
1-B-2-(a+b)	Fugitive Emissions - Oil and Natural Gas	CO ₂		
1-B-2-(a+b)	Fugitive Emissions - Oil and Natural Gas	CH ₄	Yes	Trend, Level
1-B-2-c	Fugitive Emissions - Oil and Natural Gas - Venting and Flaring	CO ₂	Yes	Trend, Level, Quality
1-B-2-c	Fugitive Emissions - Oil and Natural Gas - Venting and Flaring	CH ₄	Yes	Quality
2-A-1	Industrial Processes - Cement Production	CO ₂	Yes	Level, Quality
2-A-2	Industrial Processes - Lime Production	CO ₂		
2-A-3	Industrial Processes - Limestone and Dolomite Use	CO ₂		
2-A-4	Industrial Processes - Soda Ash Production and Use	CO ₂		
2-B-1	Industrial Processes - Ammonia Production	CO ₂		
2-B-2	Industrial Processes - Nitric Acid Production	N ₂ O		
2-B-3	Industrial Processes - Adipic Acid Production	N ₂ O	Yes	Trend, Quality
2-C-1	Industrial Processes - Iron and Steel Production	CO ₂	Yes	Level
2-C-3	Industrial Processes - Aluminium Production	CO ₂	Yes	Trend
2-C-3	Industrial Processes - Aluminium Production	PFCs	Yes	Trend, Level, Quality
2-C-4	Industrial Processes - Aluminium Magnesium Production	SF ₆	Yes	Trend, Quality
2-F	Industrial Processes - Other (Undifferentiated Processes)	CO ₂	Yes	Trend, Level
2-F	Industrial Processes - Other (Undifferentiated Processes)	PFCs		
3-E	Consumption of Halocarbons and Sulphur Hexafluoride	HFCs	Yes	Trend, Quality
4-A	Agriculture - Enteric Fermentation	CH ₄	Yes	Trend, Level, Quality
4-B	Agriculture - Manure Management	CH ₄	Yes	Level, Quality
4-B	Agriculture - Manure Management	N ₂ O	Yes	Level
4-D	Agriculture - Agricultural Soils	CO ₂	Yes	Trend, Quality
4-D	Agriculture - Agricultural Soils	N ₂ O	Yes	Trend, Level, Quality
5-E	Fires caused by human activities	CH ₄	Yes	Quality
5-E	Fires caused by human activities	N ₂ O	Yes	Quality
6-A	Waste - Solid Waste Disposal on Land	CH ₄	Yes	Level, Quality
6-B	Waste - Wastewater Handling	CH ₄		
6-B	Waste - Wastewater Handling	N ₂ O		
6-C	Waste - Waste Incineration	CO ₂	Yes	Quality
6-C	Waste - Waste Incineration	CH ₄		
6-C	Waste - Waste Incineration	N ₂ O		

* Qualitative Method Used: Tier 1

3.3.A Level Assessment

Table 3.2 shows key sources indicated from level assessment. Figure 3.1 on the following page shows the contribution of key sources to level assessments.

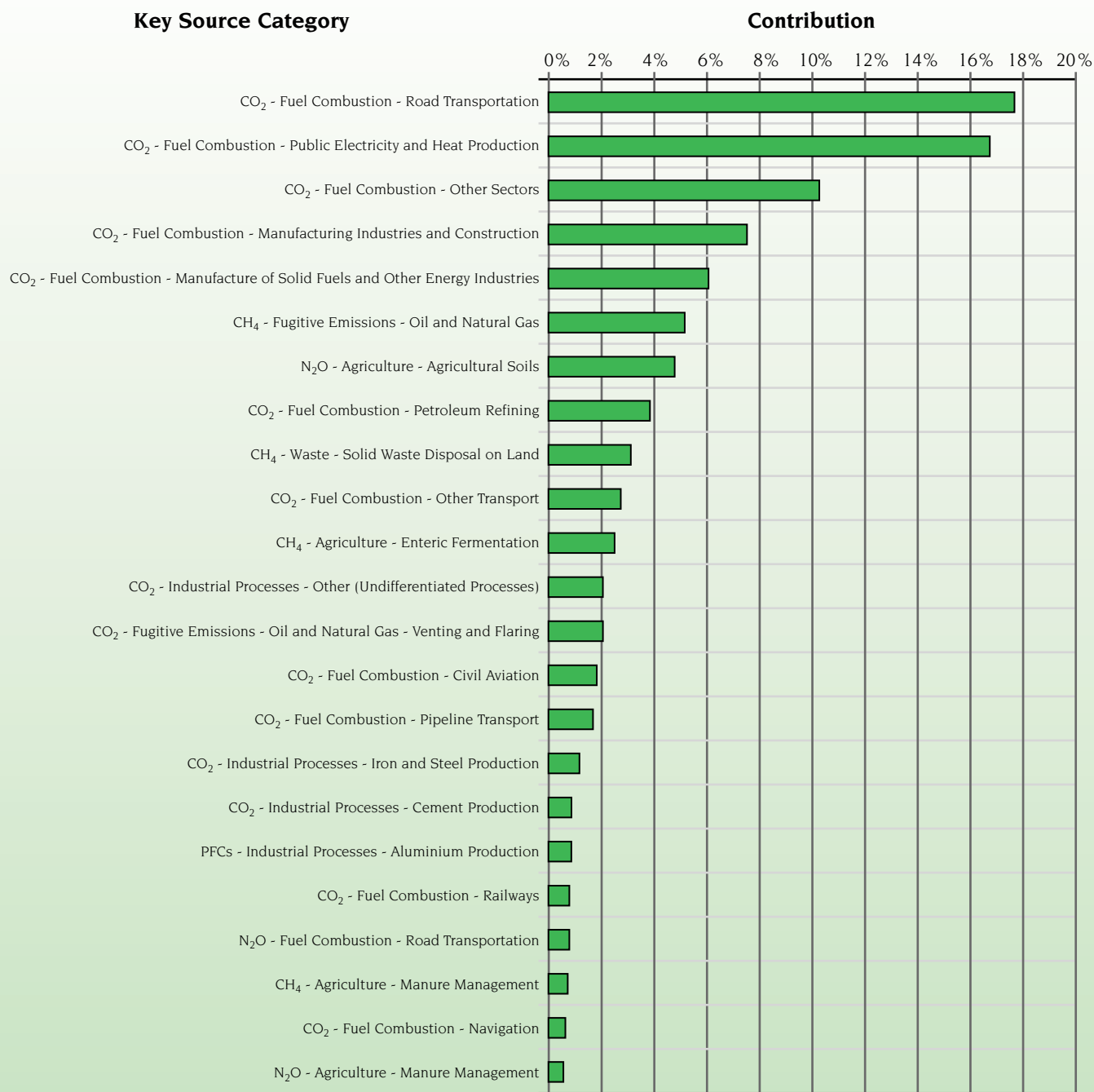
Table 3.2 Key Source Categories Level Assessment*

Source Table	IPCC Categories	Direct Greenhouse Gas	Base Year Estimates (Kt)	Current Year Estimates (Kt)
1-A-3-b	Fuel Combustion - Road Transportation	CO ₂	102 812	124 086
1-A-1-a	Fuel Combustion - Public Electricity and Heat Production	CO ₂	94 745	117 751
1-A-4	Fuel Combustion - Other Sectors	CO ₂	69 415	71 894
1-A-2	Fuel Combustion - Manufacturing Industries and Construction	CO ₂	55 936	52 515
1-A-1-c	Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries	CO ₂	29 709	42 625
4-D	Agriculture - Agricultural Soils	N ₂ O	27 364	33 370
1-A-1-b	Fuel Combustion - Petroleum Refining	CO ₂	25 977	27 294
1-B-2-(a+b)	Fugitive Emissions - Oil and Natural Gas	CH ₄	25 685	36 660
6-A	Waste - Solid Waste Disposal on Land	CH ₄	18 530	21 855
4-A	Agriculture - Enteric Fermentation	CH ₄	15 994	17 820
1-A-3-e	Fuel Combustion - Other Transport	CO ₂	14 882	19 255
2-F	Industrial Processes - Other (Undifferentiated Processes)	CO ₂	11 099	14 508
2-B-3	Industrial Processes - Adipic Acid Production	N ₂ O	10 718	1 749
1-A-3-a	Fuel Combustion - Civil Aviation	CO ₂	10 385	13 168
1-B-2-c	Fugitive Emissions - Oil and Natural Gas - Venting and Flaring	CO ₂	9 787	14 333
2-C-1	Industrial Processes - Iron and Steel Production	CO ₂	7 585	8 501
4-D	Agriculture - Agricultural Soils	CO ₂	7 255	177
1-A-3-f	Fuel Combustion - Pipeline Transport	CO ₂	6 705	12 213
1-A-3-c	Fuel Combustion - Railways	CO ₂	6 315	5 778
2-C-3	Industrial Processes - Aluminium Production	PFCs	5 975	6 183
2-A-1	Industrial Processes - Cement Production	CO ₂	5 873	6 302
1-A-3-d	Fuel Combustion - Navigation	CO ₂	4 733	4 831
4-B	Agriculture - Manure Management	CH ₄	4 595	5 076
4-B	Agriculture - Manure Management	N ₂ O	3 677	4 287

Tier 1 Analysis - Level Assessment - Sorted by Level

* (Using IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories - Chapter 7 - Table 7.2)

Figure 3.1 Contributions of Key Source Categories to Level Assessment



Tier 1 Analysis - Level Assessment

3.3.B Trend Assessment

Table 3.3 shows key sources indicated from trend assessment. Figure 3.2 on the following page shows the contribution of key sources to trend assessments.

Table 3.3 Key Source by Trend Assessment*

Source Table	IPCC Categories	Direct Greenhouse Gas	Base Year Estimates (Kt)
1-A-2	Fuel Combustion - Manufacturing Industries and Construction	CO ₂	55 936
2-B-3	Industrial Processes - Adipic Acid Production	N ₂ O	10 718
1-A-1-a	Fuel Combustion - Public Electricity and Heat Production	CO ₂	94 745
1-A-1-c	Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries	CO ₂	29 709
4-D	Agriculture - Agricultural Soils	CO ₂	7 255
1-A-4	Fuel Combustion - Other Sectors	CO ₂	69 415
1-B-2-(a+b)	Fugitive Emissions - Oil and Natural Gas	CH ₄	25 685
1-A-3-b	Fuel Combustion - Road Transportation	CO ₂	102 812
1-A-3-f	Fuel Combustion - Pipeline Transport	CO ₂	6 705
1-B-2-c	Fugitive Emissions - Oil and Natural Gas - Venting and Flaring	CO ₂	9 787
1-A-1-b	Fuel Combustion - Petroleum Refining	CO ₂	25 977
1-A-3-e	Fuel Combustion - Other Transport	CO ₂	14 882
4-D	Agriculture - Agricultural Soils	N ₂ O	27 364
2-F	Industrial Processes - Other (Undifferentiated Processes)	CO ₂	11 099
2-C-4	Industrial Processes - Aluminium Magnesium Production	SF ₆	2 870
1-A-3-b	Fuel Combustion - Road Transportation	N ₂ O	3 643
1-A-3-c	Fuel Combustion - Railways	CO ₂	6 315
1-A-3-a	Fuel Combustion - Civil Aviation	CO ₂	10 385
1-B-1-a	Fugitive Emissions - Coal Mining	CH ₄	1 914
3-E	Consumption of Halocarbons and Sulphur Hexafluoride	HFCs	0
2-C-3	Industrial Processes - Aluminium Production	CO ₂	2 636
2-C-3	Industrial Processes - Aluminium Production	PFCs	5 975
1-A-3-d	Fuel Combustion - Navigation	CO ₂	4 733
4-A	Agriculture - Enteric Fermentation	CH ₄	15 994

Tier 1 Analysis - Trend Assessment - Sorted by % Contribution to Trend

* (Using IPCC - Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories - Chapter 7 - Table 7.2.)

Figure 3.2 Contributions of Key Source Categories to Trend Assessment

Tier 1 Analysis - Trend Assessment

3.3.C Qualitative Assessment

3.3.C.1 Mitigation Techniques and Technologies

Mitigation techniques are important to good practice, in particular if they are inclined to produce departures from the norm under which activity data and

emission factors are estimated. Table 3.4 on the following page shows key sources identified as a result of having significant mitigation techniques and technologies introduced which have had (since 1990) or will have an impact on emissions estimates.

Table 3.4 Key Sources Identified Using Mitigation Techniques and Technologies

Key Source	GHG	Reference	Comments
Fugitive Emissions – Oil & Natural Gas – Flaring & Venting	CO ₂	NRCan, 2001	Upstream oil and gas industry is planning to reduce flaring by 50% by 2006 with use of micro turbines: Voluntary measure
Fuel Combustion – Road Transportation	CO ₂	GOC, 2000; CCCS-BP, 2000	Voluntary efficiency standards, increased ethanol use: Voluntary measure
Fuel Combustion – Public Electricity and Heat Production	CO ₂	GOC, 2000; CCCS-BP, 2000; NRCan, 1999	Utility deregulation opens market to distributed power and reduced barriers to interprovincial trade. Natural gas replaces coal and oil generation: Voluntary measure
Fuel Combustion – Manufacture of Solid Fuels and Other Energy Industries	CO ₂	GOC, 2000; CCCS-BP, 2000	Demonstrate CO ₂ capture and storage: Voluntary measure
Industrial Processes – Cement Production	CO ₂	VCR, 2001	Move to dry kiln technique and use of fly ash: Voluntary measure
Waste – Solid Waste on Land	CH ₄	EC, 2001; VCR, 2001	Landfills are collecting methane emissions for combustion or power generation: Policy measure
Fugitive Emissions – Oil & Natural Gas – Flaring & Venting	CH ₄	NRCan, 2001; VCR, 2001	Upstream oil and gas industry is reducing pipeline and exploration venting: Voluntary measure
Industrial Processes – Adipic Acid Production	N ₂ O	EC, 2001; NRCan, 2001	Canada's one plant has introduced technology to reduce emissions in the mid-90s. Reduction is expected to be over 98% in the next few years: Voluntary measure
Industrial Processes – Aluminum Production	PFC	VCR, 2001	Reduction through computer controls: Voluntary measure
Industrial Processes – Aluminum & Magnesium Production	SF ₆	NRCan, 1999	Elimination by 2005 of SF ₆ in magnesium casting and smelting: Voluntary measure

3.3.C.2 High Emission Growth

Table 3.5 on the following page shows key sources identified as a result of having a high-emission growth forecast of over 20% between 1997 and 2020.

Designation as key anticipates significant changes in the sector and a need to establish sound estimating practices.

Table 3.5 Key Sources Identified From Anticipated High Emission Growth

Key Source	GHG	Reference	Comments
Fuel Combustion – Manufacture of Solid Fuels and Other Energy Industries	CO ₂	NR, Can 1999	Increased heavy oil production
Fuel Combustion – Petroleum Refining	CO ₂	NRCan, 1999; CCCS-BP, 2000	Increased heavy oil use
Fuel Combustion – Transport – Road	CO ₂	NRCan, 1999	Growth in road transport use
Fuel Combustion – Transport – Civil Aviation	CO ₂	NRCan, 1999	Growth in air travel, passenger and freight
Fuel Combustion – Transport – Other	CO ₂	NRCan, 1999	Growth in off-road use, especially fossil- fuel mining
Fuel Combustion – Transport – Road	N ₂ O	NRCan, 1999	Growth in road transport use
Consumption of HFC and SF ₆	HFC	NRCan, 1999	Increase due to replacement of CFCs
Industrial Processes – Aluminum & Magnesium Production	SF ₆	VCR, 2001	An increase expected due to plant openings, then drop in emissions due to process changes

3.3.C.3 High Uncertainty

The McCann study of uncertainty associated with 1990 inventory estimates is the most current source of information for key sources (McCann, 1994). In this study, uncertainties are reported in categories similar to the UNFCCC Common Reporting Format so that reconciliation of key source determination with the McCann report proceeded (as with the determination of all source categories). If uncertainty was attributed to only a sub-component of a source category, that category was nevertheless identified as key. For example, a 25% uncertainty was given to the combustion of still gas (McCann, 1994). Fuel Combustion – Petroleum Refining (where still gas is used in its entirety) was therefore identified as key source even though emission estimates for other aspects of petroleum refining may not have had this high a level of uncertainty.

Table 3.6 on the following page shows key sources identified as having a relatively high composite uncertainty (meaning both activity and emission factor uncertainties) compared to the expected norm. Sources were identified as key when uncertainty limits were > +/- 15% for CO₂ and > +/- 30% for CH₄ and N₂O.

3.3.D Summary Assessment

The results of key source assessment in accordance with IPCC *Guidelines for Good Practice Guidance and Uncertainty Management* are given in Table 3.1 (see page 63).

The first column of Table 3.1 gives an indication of source table. These are found in the UNFCCC Common Reporting Format. The key for categorization of the tables within the Format can be found in Table 3.7 on the following page.

Table 3.6 Key Sources With a High Composite Uncertainty

Key Source	GHG	Reference
Agriculture – Agricultural Soils	CO ₂	EC, 2001
Fuel Combustion – Manufacturing of Solid Fuels & Other Energy Industries	CO ₂	McCann, 1994
Fuel Combustion – Petroleum Refining	CO ₂	NRCan, 2001; McCann, 1994
Waste – Waste Incineration	CO ₂	McCann, 1994
Agriculture – Enteric Fermentation	CH ₄	McCann, 1994
Agriculture – Manure Management	CH ₄	McCann, 1994
Anthropogenic Fires LUCF	CH ₄	McCann, 1994
Waste – Wastewater Handling	CH ₄	McCann, 1994
Fuel Combustion – Road Transportation	N ₂ O	McCann, 1994
Agriculture – Agricultural Soils	N ₂ O	EC, 2001; McCann, 1994
Anthropogenic Fires LUCF	N ₂ O	McCann, 1994

Table 3.7 Categorization of Source Tables

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

References

Canadian Climate Change Secretariat (CCCS), *Canada's First National Climate Change Business Plan*, October 2000.

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

Government of Canada, *Government of Canada Action Plan 2000 on Climate Change*, 2000.

Intergovernmental Panel on Climate Change (IPCC), *IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, Chapter 7: Methodological Choice and Recalculation.

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

Natural Resources Canada, *Canada's Emissions Outlook: An Update*, Analysis and Modelling Team, National Climate Change Process, December 1999.

Natural Resources Canada, *An Assessment of The Economic and Environmental Implications for Canada of the Kyoto Protocol*, Analysis and Modelling Team, National Climate Change Process, November 2000.

B. Rawson, Chief Analyst, Voluntary Challenge Registry, Personal communication, March 2001.

Section 4

Uncertainty Associated with Emission and Removal Estimates

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

- differences in the interpretation of source and sink category definitions, assumptions, units, etc.;
- inadequate and incorrect 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.

Early Uncertainty Estimates - Methods and Results

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 available in the original study (T.J. McCann, 1994).

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.

The approach taken to developing uncertainties made use of Monte Carlo stochastic computer simulations. Individual uncertainty range estimates by industry experts were skewed in some cases (i.e. not *normally* distributed). This necessitated the use of Monte Carlo stochastic computer simulations to develop group and then overall uncertainty estimates for each 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 1990 inventory, many data sources and emission rates have remained the same, as have the methods used to estimate emissions. It is therefore reasonable to assume that the uncertainty in the carbon dioxide and methane emissions are still of the same order.

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

Rounding Protocol

In the interim, some guidance can be provided as to the approximate level of uncertainty which each of the current emission estimates represent. Thus, engineering approximations of precision have been developed for the new emission categories and previous studies have been drawn upon for the older categories. Data quality is then reflected in published summary tables by presenting the emissions to an appropriate number of significant figures. The number of significant figures to which each source category has been rounded is shown in Table 4-1, which depicts typically summarized categories. The data in the Common Reporting Format has not been rounded since the UNFCCC software is not designed to accommodate this.

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

- One significant figure: greater than 50% uncertainty
- Two significant figures: 10% to 50% uncertainty
- Three significant figures: less than 10% uncertainty

The above-listed 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 above listed intervals would dictate. This has been done to maintain consistency between categories within a sector. It should be noted that emissions from agricultural soils, carbon dioxide from land-use change and forestry, perfluorocarbon (PFC) and Hydrofluorocarbon (HFC) emissions have a very high uncertainty (IPCC, 1997; Schiff, 1996) and so only one significant figure has been shown for these estimates.

References

Intergovernmental Panel on Climate Change (IPCC)/Organization for Economic Co-operation and Development (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*, Prepared for Environment Canada, March 1994.

Table 4.1 Number of Significant Figures Applied to Greenhouse Gas Summary Tables*

GHG Source or Sink (New Categories)	CO₂	CH₄	N₂O	HFCs	PFCs	SF₆	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 & 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						

* Based on the Uncertainty of Emission Estimates

Section 5

Criteria Air Contaminants

Criteria air contaminants (also called common air contaminants) of interest to the UNFCCC are:

- Sulphur dioxide (SO₂);
- Nitrogen Oxides (NO_x);
- Carbon Monoxide (CO); and
- Non-methane Volatile Organic Compounds (NMVOCs).

These gases are inventoried separately using different methodologies from the direct greenhouse gases and are commonly called Criteria Air Contaminants (CACs).

At the time of preparation of this report, CAC estimates updated from the previous UNFCCC submission were not available. As a result, no CAC estimates are included in this report.

Appendix I Emission Factors

This section summarizes the development and selection of emission factors used to prepare the national greenhouse gas inventory.

Fuel Combustion

Natural Gas and Natural Gas Liquids (Stationary Combustion Sources)

Carbon Dioxide

Carbon dioxide emission factors for fossil fuel combustion are primarily dependant on the properties of the fuel and, to a lesser extent, the combustion technology.

For natural gas there are two major qualities of fuels combusted in Canada, marketable fuel (processed) and non-marketable fuel (unprocessed). Emission factors have been developed for these two categories based on data from the chemical analysis of representative natural gas samples (McCann, 2000) and an assumed fuel combustion efficiency of 99.5% (IPCC, 1997). The emission factor for marketable fuel matches closely with previous factors based on energy contents reported in the *Quarterly Report on Energy Supply and Demand* (QRES) (Jaques, 1992). The factor for non-marketable natural gas is higher than that for marketable fuels. This is expected due to the raw nature of the fuel which results in higher levels of natural gas liquids (NGLs) in the fuel.

The natural gas liquid (ethane, propane, butane) emission factors were developed based on chemical analysis data for marketable fuels (McCann, 2000) and an assumed fuel combustion efficiency of 99.5% (IPCC, 1997). The emission factors are lower than those developed on the assumption of pure fuels (Jaques, 1992) due to the presence of impurities in the fuels.

Methane

Emissions of methane from fuel combustion are technology dependant. Emission factors for sectors have been developed based on technologies typically used in Canada. The factors were developed from a review of emission factors for combustion technologies and an analysis of combustion technologies (SGA, 2000). The

emission factor for the producer consumption of natural gas was developed based on a technology split for the upstream oil and gas industry (Clearstone, 2000) and technology specific emission factors from the AP 42 (EPA, 1996).

Nitrous Oxide

Emissions of nitrous oxide from fuel combustion are technology dependant. Factors for sectors have been developed based on technologies typically used in Canada. The factors were developed from a review of emission factors for combustion technologies and an analysis of combustion technologies (SGA, 2000).

Energy Stationary Combustion Sources

	CO ₂	CH ₄	N ₂ O
Natural Gas	g/m ³	g/m ³	g/m ³
Electric Utilities	1 891 ¹	0.49 ²	0.049 ²
Industrial	1 891 ¹	0.037 ²	0.033 ²
Producer Consumption	2 389 ¹	6.5 ^{4, 5}	0.033 ²
Pipelines	1 891 ¹	1.9 ²	0.05 ²
Residential, Commercial, Agriculture	1 891 ¹	0.037 ²	0.035 ²
Natural Gas Liquids	g/l	g/l	g/l
Ethane	976 ¹	n/a	n/a
Propane	1 500 ¹	0.024 ²	0.108 ²
Butane	1 730 ¹	0.024 ²	0.108 ²

References

- 1 Adapted from McCann, T.J., 1998 *Fossil Fuel and Derivative Factors*, March 2000.
- 2 SGA Energy Limited, *Emission Factors and Uncertainties for CH₄ & N₂O from Fuel Combustion*, August 2000.
- 3 Jaques, A.P., *Canada's Greenhouse Gas Emissions: Estimates for 1990*, Environment Canada, Report EPS 5/AP/4, December 1992.
- 4 U.S. EPA, *Compilation of Air Pollutant Emission Factors. Volume 1, Stationary Point and Area Sources*, U.S. EPA, AP-42, Fifth Edition.
- 5 Canadian Association of Petroleum Producers (CAPP), *CH₄ and VOC Emissions from Upstream Oil and Gas Operations in Canada*, Volume 2, CAPP Publication # 1999-0010, 1999.

Refined Petroleum Products (Stationary Combustion Sources)

Carbon Dioxide

Carbon dioxide emission factors for fossil fuel combustion are primarily dependant on the properties of the fuel and, to a lesser extent, the combustion technology.

Emission factors have been developed for each major class of refined petroleum product. Emission factors have been developed based on standard fuel properties and an assumed fuel combustion efficiency of 99.0% (Jaques, 1992).

The composition of petroleum coke is process specific. Factors have been developed for both coker derived and catalytic cracker derived cokes. Average factors have been developed based on data provided by industry (J. Nyboer, 1996). The industry factors were provided from industry on a mass basis and were converted to a volumetric basis for comparability with the national energy data using the density of coke used by Statistics Canada (QRESO).

Methane

Emissions of methane from fuel combustion are technology dependant. Emission factors for sectors have been developed based on technologies typically used in Canada. The factors were developed from a review of emission factors for combustion technologies and an analysis of combustion technologies (SGA, 2000).

An emission factor for petroleum coke could not be found in the literature, due to a lack of research in this area. It was assumed to be the same as that of heavy fuel oil used in industry.

An emission factor for refinery fuel gas (still gas) could not be found, so it was assumed to be similar to that of natural gas combustion in industry.

Nitrous Oxide

Emissions of nitrous oxide from fuel combustion are technology dependant. Emission factors for sectors have been developed based on technologies typically used in Canada. The factors were developed from a review of emission factors for combustion technologies and an analysis of combustion technologies (SGA, 2000).

An emission factor for petroleum coke could not be found, so it was assumed to be the same as that of heavy fuel oil use in industry.

Energy Stationary Combustion Sources

	CO ₂ g/l	CH ₄ g/l	N ₂ O g/l
Light Fuel Oil			
Electric Utilities	2 830 ³	0.18 ²	0.031 ²
Industry	2 830 ³	0.006 ²	0.031 ²
Producer Consumption	2 830 ³	0.006 ²	0.031 ²
Residential	2 830 ³	0.026 ²	0.006 ²
Other Small Combustion	2 830 ³	0.026 ²	0.031 ²
Heavy Fuel Oil			
Electric Utilities	3 090 ³	0.034 ²	0.064 ²
Industry	3 090 ³	0.12 ²	0.064 ²
Producer Consumption	3 090 ³	0.12 ²	0.064 ²
Residential, etc.	3 090 ³	0.057 ²	0.064 ²
Kerosene			
Electric Utilities	2 550 ³	0.006 ²	0.031 ²
Industry	2 550 ³	0.006 ²	0.031 ²
Producer Consumption	2 550 ³	0.006 ²	0.031 ²
Residential, etc.	2 550 ³	0.026 ²	0.006 ²
Other Small Combustion	2 550 ³	0.026 ²	0.031 ²
Diesel			
Electric Utilities	2 730 ³	0.133 ²	0.4 ²
Producer Consumption	2 730 ³	0.133 ²	0.4 ²
Petroleum Coke			
Petroleum Coke Others	4 200 ⁷	0.12 ²	0.064 ²
Producer Consumption	4 200 ⁷	0.12 ²	0.064 ²
Coke from Cat Crackers	3 800 ⁷	0.12 ²	0.064 ²
Still Gas			
	g/m ³	g/m ³	g/m ³
Still Gas	2 000 ³	0.037 ²	0.002 ²

References

- ² SGA Energy Limited, *Emission Factors and Uncertainties for CH₄ & N₂O from Fuel Combustion*, August 2000.
- ³ Jaques, A.P., *Canada's Greenhouse Gas Emissions: Estimates for 1990*, Environment Canada, Report EPS5/AP/4, December 1992.
- ⁷ Boileau, P., Personal communication to J Nyboer, January 1996.

Coal and Coal Products (Stationary Combustion Sources)

Carbon Dioxide

Carbon dioxide emission factors for coal combustion are dependant on the properties of the fuel and, to a lesser extent, the combustion technology.

Coal emission factors have been developed for each province based on the rank of the coal and the region of supply. Emission factors have been developed based on data from chemical analysis of coal samples for electric utilities which comprise the vast majority of coal consumption and a fuel combustion efficiency of 99.0% (Jaques, 1992). The factors for coal were reviewed in 1999 because the supply and quality of coal used may change over time. Based on this review it was determined that updated factors should be used for the more recent years. The factors for the period 1990 to 1994 are based on supply and quality data from 1988 (Jaques, 1992). For 1995 to the present year, factors are based on 1998 coal quality and supply (McCann, 2000).

Coke and coke oven gas emission factors were developed based on industry data (Jaques, 1992).

Methane

Emissions of methane from fuel combustion are technology dependant. Emission factors for sectors have been developed based on technologies typically used in Canada. The factors were developed from a review of emission factors for combustion technologies and an analysis of combustion technologies (SGA, 2000).

Nitrous Oxide

Emissions of nitrous oxide from fuel combustion are technology dependant. Emission factors for sectors have been developed based on technologies typically used in Canada. The factors were developed from a review of emission factors for combustion technologies and an analysis of technologies (SGA, 2000).

Energy Stationary Combustion Sources

Coals	1990-1994 g/kg	1995-1999 g/kg
Nova Scotia		
Canadian Bituminous	2 300 ³	2 249 ¹
U.S. Bituminous	2 330 ³	2 288 ¹
New Brunswick		
Canadian Bituminous	2 230 ³	1 996 ¹
U.S. Bituminous	2 500 ³	2 311 ¹
Quebec		
U.S. Bituminous	2 500 ³	2 343 ¹
Anthracite	2 390 ³	2 390 ³
Ontario		
Canadian Bituminous	2 520 ³	2 254 ¹
U.S. Bituminous	2 500 ³	2 432 ¹
Sub-Bituminous	2 520 ³	1 733 ¹
Lignite	1 490 ³	1 476 ¹
Anthracite	2 390 ³	2 390 ³
Manitoba		
Canadian Bituminous	2 520 ³	2 252 ¹
Sub-Bituminous	2 520 ³	1 733 ¹
Lignite	1 520 ³	1 424 ¹
Saskatchewan		
Lignite	1 340 ³	1 427 ¹
Alberta		
Canadian Bituminous	1 700 ³	1 852 ¹
Sub-Bituminous	1 740 ³	1 765 ¹
Anthracite	2 390 ³	2 390 ³
British Columbia		
Canadian Bituminous	1 700 ³	2 072 ¹
All Provinces		
Metalurgical Coke	2 480 ³	2 480 ³
Coke Oven Gas (g/m ³)	1 600 ³	1 600 ³

References

- 1 Adapted from McCann, T.J., 1998 *Fossil Fuel and Derivative Factors*, March 2000.
- 3 Jaques, A.P., *Canada's Greenhouse Gas Emissions: Estimates for 1990*, Environment Canada, Report EPS 5/AP/4, December 1992.

Energy Stationary Combustion

	CH ₄	N ₂ O
All Coals	g/kg	g/kg
Utility	0.022 ²	0.032 ²
Industry	0.03 ²	0.02 ²
Residential	4 ²	0.02 ²
Metalurgical Coke	0.03 ²	0.02 ²
Coke Oven Gas	g/m ³	g/m ³
	0.037 ²	0.035 ²
References		
² SGA Energy Limited, <i>Emission Factors and Uncertainties for CH₄ & N₂O from Fuel Combustion</i> , August 2000.		

Mobile Combustion

Carbon Dioxide

Carbon dioxide emission factors for mobile combustion are dependant on fuel properties and are the same as those used for stationary combustion for all fuels.

Methane

Emissions of methane from fuel combustion are technology dependant. Emission factors for sectors have been developed based on technologies typically used in Canada. The factors were developed from a review of emission factors for combustion technologies and an analysis of combustion technologies (SGA, 2000).

Nitrous Oxide

Emissions of nitrous oxide from fuel combustion are technology dependant. Factors for sectors have been developed based on technologies typically used in Canada. The factors were developed from a review of emission factors for combustion technologies and an analysis of technologies (SGA, 2000). Rational for factor selection is also provided in the Transport section of the Inventory Report (see Section 2.1.A.3).

Energy Mobile Combustion Sources

	CO ₂ g/l	CH ₄ g/l	N ₂ O g/l
On-Road Transport			
Gasoline			
Autos (LDGA)			
- Tier 1, 3-way Catalyst	2 360 ³	0.25 ²	0.26 ²
- Tier 0, New 3-way Catalyst	2 360 ³	0.32 ²	0.25 ²
- Tier 0, Aged 3-way Catalyst	2 360 ³	0.32 ²	0.58 ²
- Oxidation Catalyst	2 360 ³	0.42 ²	0.2 ²
- Non-Catalyst	2 360 ³	0.52 ²	0.028 ²
Light-Duty Trucks (LDGT)			
- Tier 1, 3-way Catalyst	2 360 ³	0.19 ²	0.41 ²
- Tier 0, New 3-way Catalyst	2 360 ³	0.41 ²	0.45 ²
- Tier 0, Aged 3-way Catalyst	2 360 ³	0.41 ²	1 ²
- Oxidation Catalyst	2 360 ³	0.44 ²	0.2 ²
- Non-Catalyst	2 360 ³	0.56 ²	0.028 ²
Heavy-Duty Vehicles (HDGV)			
- 3-way Catalyst	2 360 ³	0.17 ²	1 ²
- Non-Catalyst	2 360 ³	0.29 ²	0.046 ²
- Uncontrolled	2 360 ³	0.49 ²	0.08 ²
Motorcycles (MC)			
- Non-Catalytic Controlled	2 360 ³	1.4 ²	0.046 ²
- Uncontrolled	2 360 ³	2.3 ²	0.046 ²
Diesel			
Light-Duty Diesel Autos (LDDA)			
- Advance Control	2 730 ³	0.05 ²	0.2 ²
- Moderate Control	2 730 ³	0.07 ²	0.2 ²
- Uncontrolled	2 730 ³	0.1 ²	0.2 ²
Light-Duty Diesel Trucks (LDDT)			
- Advance Control	2 730 ³	0.07 ²	0.2 ²
- Moderate Control	2 730 ³	0.07 ²	0.2 ²
- Uncontrolled	2 730 ³	0.08 ²	0.2 ²
Heavy-Duty Diesel Vehicles (HDDV)			
- Advance Control	2 730 ³	0.12 ²	0.08 ²
- Moderate Control	2 730 ³	0.13 ²	0.08 ²
- Uncontrolled	2 730 ³	0.15 ²	0.08 ²
Natural Gas Vehicles	1.89 ¹	0.022 ²	0.00006 ²
Propane Vehicles	1500 ¹	0.52 ²	0.028 ²
Off-Road Vehicles			
Other Gasoline Vehicles	2 360 ³	2.7 ²	0.05 ²
Other Diesel Vehicles	2 360 ³	0.14 ²	1.1 ²
Diesel Rail Transportation			
Diesel Rail Transportation	2 730 ³	0.15 ²	1.1 ²
Marine Transportation			
Gasoline Boats	2 360 ³	1.3 ²	0.06 ²
Diesel Ships	2 730 ³	0.15 ²	1.00 ²
LFO Ships	2 830 ³	0.3 ²	0.07 ²
HFO Ships	3 090 ³	0.3 ²	0.08 ²
Air Transportation			
Conventional Aircraft	2 330 ³	2.19 ²	0.23 ²
Jet Aircraft	2 550 ³	0.08 ²	0.25 ²
References			
¹ Adapted from McCann, T.J., 1998 <i>Fossil Fuel and Derivative Factors</i> , March 2000.			
² SGA Energy Limited, <i>Emission Factors and Uncertainties for CH₄ & N₂O from Fuel Combustion</i> , August 2000.			
³ Jaques, A.P., <i>Canada's Greenhouse Gas Emissions: Estimates for 1990</i> , Environment Canada, Report EPS 5/AP/4, December 1992.			

Fugitive Emission Factors Coal Mining

Fugitive emissions from coal mining are predominantly methane. The emissions result from the release of entrained methane from the coal formation during mining. The factors are developed based on mine-specific and basin-specific data (King, 1994). The development of the factors is described in the Fugitive section of the Inventory Report.

Fugitive Sources - Coal Mining

Province	Method	Coal Type	t CH ₄ /kt
Nova Scotia	Underground	Bituminous	13.79
Nova Scotia	Surface	Bituminous	0.13
New Brunswick	Surface	Bituminous	0.13
Saskatchewan	Surface	Lignite	0.06
Alberta	Surface	Bituminous	0.45
Alberta	Underground	Bituminous	1.76
Alberta	Surface	Sub-Bituminous	0.19
British Columbia	Surface	Bituminous	0.58
British Columbia	Underground	Bituminous	4.1

References

Adapted from King, B., *Management of Methane Emissions from Coal Mines: Environmental, Engineering, Economic and Institutional Implication of Options*, March 1994.

Industrial Processes

Emissions from industrial processes are process and technology specific. The development of the factors for each source are described in detail in the Industrial Processes section of the Inventory Report.

Industrial Process Sources

Source	CO ₂	N ₂ O	CF ₄	C ₂ F ₆
Mineral Use g/kg feed				
Limestone Use				
In Iron & Steel, Glass,				
Non-Ferrous Metal Production	440	-	-	-
Soda Ash Use				
In Glass Manufacture	415	-	-	-
Mineral Products g/kg product				
Cement Production				
Limestone Calcination	500	-	-	-
Lime Production				
Limestone Calcination	790	-	-	-
Chemical Industry kg/t product				
Ammonia Production				
From Natural Gas	1 600	-	-	-
Nitric Acid Production				
Plants with catalytic converters	-	-	-	0.66
Plants with extended				
absorption for NO _x (type 1)	-	-	-	9.4
Plants with extended				
absorption for NO _x (type 2)	-	-	-	12
Adipic Acid Production				
Plants without abatement				0.303
Metal Production g/kg product				
Primary Aluminum				
Electrolysis Process	(1.54-1.83)	-	(0.3-1.1)	(0.02-0.1)
g/kg feed (Coke)				
Iron and Steel Production	2 480	-	-	-

References

CO₂ 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).

Iron and Steel, Jaques 1992.

N₂O Emission Factors: Adipic Acid Production - Thiemens and Trogler, 1991.

CF₄, C₂F₆ Emission Factors: Primary Aluminum Production - Unisearch Associates, 1994, adapted by Environment Canada.

Non-Energy Use of Fossil Fuels

Carbon Dioxide

The use of fossil fuels as feedstocks or for other non-energy uses may result in emissions during the life of manufactured products. The emissions are process and technology specific. General emission rates have been developed based on lifecycle analysis of the processes and products where these fuels are used as feedstocks. Industry average factors have been developed based on IPCC default emission rates (IPCC, 1997) and the carbon content of Canadian fuels (McCann, 2000). The factors are presented on a gCO₂ per unit of fossil fuel used as feedstock or non-energy product.

Hydrocarbon Non-Energy Products	
	CO ₂ g/L
Description	
Ethane Use	197
Butane Use	349
Propane Use	303
Petrochemical Distillate Use for Feedstocks	500
Naptha Used for Various Products	625
Petroleums Used for Lubricants	1 410
Petroleums Used for Other Products	1 450
	t/m ³
Natural Gas Use for Chemical Products	1 274
References	
IPCC, IPCC Guidelines for National Greenhouse Gas Inventories, Reference Manual, 1997.	
McCann T.J., Fossil Fuel and Derivative Factors, March 2000.	

Solvent and Other Product Use

The emissions resulting from the use of solvents or products are process and technology specific. The emission factor development is described in the Solvent and Other Product Use section of the Inventory report.

Solvent and Other Product Emission Factors			
		N ₂ O	HFCs
Product	Application	g/capita	kg loss/ kg consumed
Nitrous Oxide Use	Anaesthetic Usage	46.2	
	Propellant Usage	2.38	
HFC Use	Aerosols		0.8
	Foams		1
	AC OEM		0.04
	AC Service		1
	Refrigeration		0.1
	Total Flooding Systems		0.35
References			
N ₂ O Emission Factors: Anaesthetic Usage - Fettes, 1994.			
HFC's, Intergovernmental Panel on Climate Change (IPCC) 1997.			

Biomass Combustion

Carbon Dioxide

Emissions of CO₂ from the combustion of biomass (whether for energy use, from prescribed burning or wildfires of human origin) are not included in national inventory totals. These emissions are estimated and recorded as a loss of biomass stock in the Land-Use Change and Forestry section.

The emissions related to energy use are reported as memo items in the Common Reporting Format as required by the UNFCCC. Emissions from this source are primarily dependant on the characteristics of the fuel being combusted. The methodology for deriving the emission factors are described in the Biomass Combustion section of the inventory report.

Carbon dioxide emissions from prescribed burning are included in the emissions from the on-site, natural decay of post-harvest residues (slash). The carbon emitted as CO₂ during forest fires is considered as a reduction in C sequestration rate.

Methane

Emissions of methane from fuel combustion are technology dependant. The factors were derived from a review of emission factors for combustion technologies (SGA, 2000). The factors are from the U.S. EPA AP 42 Supplement – (EPA, 1996).

Methane emissions from prescribed burns and wildfires are obtained from the estimated average fuel consumptions (kt biomass/ha) and the emission factors (g/kg biomass consumed). Emission factors for both prescribed burns and wildfires were taken from Taylor (1996).

Nitrous Oxide

Emissions of nitrous oxide from fuel combustion are technology dependant. The factors were developed from a review of emission factors for combustion technologies and an analysis of combustion technologies typically used in Canada (SGA, 2000). The factors are from the U.S. EPA AP-42 Supplement – (EPA, 1996).

Nitrous oxide emissions from prescribed burns and wildfires are obtained from the estimated average fuel consumptions (kt biomass/ha) and the emission factors (g/kg biomass consumed). Emission factors for both prescribed burns and wildfires were taken from Taylor (1996).

Biomass Emission Factors

	CO ₂	CH ₄	N ₂ O
Source	g/kg	g/kg	g/kg
Wood Fuel /Wood Waste			
Industrial Combustion	950 ⁸	0.05 ⁸	0.02 ^{10,11}
Accidental Forest Fires			
Open Combustion	1 630 ¹²	3 ¹²	1.75 ¹²
Prescribed Burns			
Open Combustion	1 620 ¹²	6.2 ¹²	1.3 ¹²
Spent Pulping Liquor			
Industrial Combustion	1 428 ³	0.05 ⁸	0.02 ^{10,11}
Residential Combustion			
Conventional Stoves	1 500 ⁹	15 ⁸	0.16 ⁸
Conventional Fireplaces and inserts	1 500 ⁹	15 ⁸	0.16 ⁸
Stoves/Fireplaces with advanced technology or catalytic control	1 500 ⁹	6.9 ⁸	0.16 ⁸
Other Wood Burning Equipment	1 500 ⁹	15 ⁸	0.16 ⁸

Note: CO₂ emission from biomass sources are not included in inventory totals. CH₄ and N₂O emissions are inventoried under Energy, except for Accidental Forest Fires and Prescribed Burns, which are reported under Land-Use Change and Forestry.

References

- 3 Jaques, A.P., *Canada's Greenhouse Gas Emissions: Estimates for 1990*, Environment Canada, Report EPS 5/AP/4, December 1992.
- 8 U.S. EPA, 1996 Compilation of Air Pollutant Emission Factors, Vol. Stationary and Area Sources, U.S. EPA AP-42 Fifth Edition, Supplementary B, January 1996.
- 9 ORTECH, 1994.
- 10 Radke, L.F., D.A. Hegg, P.V. Hobbs, J.D. Nance, J.H. Lyons, K.K. Laursen, R.E. Weiss, P.J. Riggan, and D.E. Ward, "Particulate and Trace Gas Emissions from Large Biomass Fires in North America," in *Global Biomass Burning: Atmospheric Climatic and Biospheric Implications*, J.S. Levine (ed.), Massachusetts Institute of Technology, Cambridge, Massachusetts, 1991.
- 11 Rosland, A., and M. Steen, *Klimgass-Regnskap For Norge*, Statens Forurensningstilsyn, Oslo, Norway, 1990.
- 12 Taylor, S.W., and K.L. Sherman, *Biomass Consumption and Smoke Emissions from Contemporary and Prehistoric Wildland Fires in British Columbia*, Prepared by the Pacific Forestry Centre, Canadian Forest Service, Natural Resources Canada, FRDA Report 249, March 1996.

Appendix II

Canada's Emission Summary Tables 1990 - 1999

The following tables are yearly summaries of greenhouse gas emissions in Canada. In general, the summaries follow the categorization of the Common Reporting Format (CRF) designated by the UNFCC, but in some cases are grouped slightly differently to provide more information in a concise manner.

The emissions totals in these summary tables are the same as those in the CRF.

Canada's Greenhouse Gas Emission Estimates from 1990 to 1999

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
	All Gases kt CO ₂ eq	All Gases kt CO ₂ eq	All Gases kt CO ₂ eq	All Gases kt CO ₂ eq	All Gases kt CO ₂ eq	All Gases kt CO ₂ eq	All Gases kt CO ₂ eq	All Gases kt CO ₂ eq	All Gases kt CO ₂ eq	All Gases kt CO ₂ eq
ENERGY										
FUEL COMBUSTION										
Fossil Fuel Industries	51 500	49 500	52 100	52 600	53 300	54 700	55 300	51 000	56 500	65 100
Electricity and Steam Generation	95 300	96 700	103 000	93 800	96 000	101 000	99 700	111 000	124 000	119 000
Mining	6 190	5 030	4 790	7 370	7 490	7 860	8 740	8 970	8 020	7 680
Manufacturing	54 500	52 100	51 500	49 100	52 200	52 900	54 700	54 600	52 400	51 700
Construction	1 880	1 630	1 750	1 390	1 400	1 180	1 270	1 260	1 120	1 170
TRANSPORTATION										
Gasoline Cars	53 700	51 200	51 600	51 800	52 300	51 300	49 900	50 000	49 700	50 000
Light-Duty Gasoline Trucks	21 700	22 200	24 000	25 600	27 400	28 500	29 900	32 000	32 800	34 700
Heavy-Duty Gasoline Vehicles	3 140	3 320	3 730	4 070	4 480	4 760	4 980	5 050	5 490	5 880
Motorcycles	230	220	218	219	221	214	210	221	232	237
Off-Road Gasoline Vehicles	5 010	4 550	3 640	3 850	3 930	3 940	4 680	4 310	5 840	5 450
Diesel Cars	672	633	631	624	617	594	602	600	597	576
Light-Duty Diesel Trucks	591	507	456	429	432	416	402	505	455	403
Heavy-Duty Diesel Trucks	24 600	23 900	24 300	25 700	28 500	30 800	32 500	35 500	35 600	36 900
Off-Road Diesel Vehicles	11 300	9 960	9 480	10 900	12 000	12 700	13 200	14 100	14 800	15 700
Propane and Natural Gas Vehicles	2 210	2 320	2 680	2 030	1 920	2 100	1 980	1 840	1 780	1 520
Domestic Air	10 700	9 530	9 720	9 410	10 100	10 900	11 900	12 400	13 000	13 600
Domestic Marine	5 050	5 250	5 100	4 480	4 660	4 380	4 470	4 530	5 150	5 160
Rail	7 110	6 590	6 890	6 860	7 100	6 430	6 290	6 380	6 140	6 510
Vehicles Subtotal	146 000	140 000	143 000	146 000	154 000	157 000	161 000	168 000	171 000	177 000
Pipelines	6 900	7 640	9 890	10 400	10 800	12 000	12 500	12 500	12 500	12 600
Transportation Subtotal	153 000	148 000	152 000	156 000	164 000	169 000	173 000	180 000	184 000	189 000
Residential	44 000	42 300	43 500	45 500	46 300	44 900	49 700	46 400	41 000	43 000
Commercial and Institutional	25 800	26 500	27 000	28 100	27 400	29 000	29 600	30 000	27 200	28 900
Other	2 420	2 760	3 270	3 060	2 560	2 790	2 950	2 940	2 610	2 690
Fuel Combustion Subtotal	434 000	424 000	439 000	437 000	451 000	463 000	475 000	487 000	496 000	508 000
FUGITIVE										
Solid Fuels (i.e. Coal Mining)	1 900	2 100	1 800	1 800	1 800	1 700	1 800	1 600	1 400	1 100
Oil and Gas	36 000	38 000	41 000	43 000	45 000	48 000	51 000	51 000	51 000	52 000
Fugitive Subtotal	38 000	40 000	42 000	44 000	47 000	50 000	53 000	53 000	52 000	53 000
Energy Total	472 000	464 000	482 000	482 000	498 000	513 000	528 000	539 000	549 000	561 000
INDUSTRIAL PROCESSES										
Non-Metallic Mineral Production	8 160	6 980	6 640	6 880	7 510	7 690	8 030	8 180	8 370	8 670
Ammonia Adipic & Nitric Acid Prod.	15 000	14 000	14 000	13 000	15 000	16 000	16 000	15 000	9 700	6 800
Ferrous Metal Production	7 590	8 900	9 080	8 760	8 090	8 440	8 290	8 100	8 320	8 500
Aluminum and Magnesium Production	11 000	13 000	12 000	13 000	13 000	11 000	11 000	11 000	11 000	12 000
Other & Undifferentiated Production	11 000	11 000	11 000	12 000	13 000	13 000	14 000	14 000	14 000	14 000
Industrial Processes Total	53 000	54 000	53 000	54 000	56 000	56 000	57 000	56 000	52 000	50 000
SOLVENT & OTHER PRODUCT USE	400	400	400	400	400	900	1 000	1 000	1 000	1 000
AGRICULTURE										
Enteric Fermentation	16 000	16 000	17 000	17 000	18 000	18 000	18 000	18 000	18 000	18 000
Manure Management	8 300	8 300	8 500	8 500	8 900	9 200	9 300	9 300	9 400	9 400
Agricultural Soils **	30 000	30 000	30 000	30 000	30 000	30 000	30 000	30 000	30 000	30 000
Agriculture Total	59 000	58 000	58 000	58 000	60 000	61 000	61 000	61 000	61 000	61 000
LAND-USE CHANGE AND FORESTRY *	2 500	3 300	2 600	3 100	4 100	5 100	1 600	870	3 100	2 400
WASTE										
Solid Waste Disposal on Land	19 000	19 000	20 000	20 000	20 000	20 000	20 000	21 000	21 000	22 000
Wastewater Handling	1 200	1 200	1 300	1 300	1 300	1 300	1 300	1 300	1 300	1 300
Waste Incineration	320	320	330	330	330	330	340	340	340	350
Waste Total	20 000	21 000	21 000	22 000	22 000	22 000	22 000	23 000	23 000	24 000
TOTAL	607 000	600 000	616 000	619 000	641 000	658 000	672 000	682 000	689 000	699 000
CO ₂ from Land-Use Change & Forestry **	-70 000	-70 000	-50 000	-40 000	-40 000	-20 000	-30 000	-20 000	-20 000	-20 000

* CH₄ and N₂O 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 1990 Greenhouse Gas Emission Summary

GHG Source and Sink Category	CO ₂ kt	CH ₄ kt	CH ₄ kt CO ₂ eq	N ₂ O kt	N ₂ O 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	49 500	78.0	1 600	1.0	310				51 500
Electricity and Steam Generation	94 700	1.8	38	1.8	550				95 300
Mining	6 150	0.1	2.7	0.1	37				6 190
Manufacturing	54 100	1.7	36	1.2	370				54 500
Construction	1 860	0.0	0.7	0.1	17.0				1 880
TRANSPORTATION									
Gasoline Cars	51 500	8.9	190	6.3	1 900				53 700
Light-Duty Gasoline Trucks	20 400	4.0	83	4.2	1 300				21 700
Heavy-Duty Gasoline Trucks	2 990	0.4	8.8	0.4	140				3 140
Motorcycles	225	0.2	3.8	0.0	1.4				230
Off-Road Gasoline Vehicles	4 860	5.6	120	0.1	32				5 010
Diesel Cars	656	0.0	0.4	0.0	15				672
Light-Duty Diesel Trucks	578	0.0	0.3	0.0	13				591
Heavy-Duty Diesel Trucks	24 300	1.2	25	0.7	220				24 600
Off-Road Diesel Vehicles	10 000	0.5	11	4.0	1 300				11 300
Propane and Natural Gas Vehicles	2 160	1.7	36	0.0	13.0				2 210
Domestic Air	10 400	0.7	14	1.0	320				10 700
Domestic Marine	4 730	0.4	7.4	1.0	310				5 050
Rail	6 310	0.4	7.3	2.5	790				7 110
Vehicles Subtotal	139 000	24	500	20	6 300				146 000
Pipelines	6 700	6.7	140.0	0.2	55				6 900
Transportation Subtotal	146 000	31	640	21	6 400				153 000
Residential	41 300	100	2 100	1.7	530				44 000
Commercial and Institutional	25 700	0.5	10	0.5	150				25 800
Other	2 400	0.0	0.8	0.1	17				2 420
Combustion Subtotal	422 000	210	4 500	27	8 400				434 000
FUGITIVE									
Solid Fuels (i.e. Coal Mining)		91	1 900						1 900
Oil and Gas	9 800	1 200	26 000						36 000
Fugitive Subtotal	9 800	1 300	28 000	0	0				38 000
Energy Total	431 000	1 600	33 000	27	8 400				472 000
INDUSTRIAL PROCESSES									
Non-Metallic Mineral Production	8 160								8 160
Ammonia Adipic & Nitric Acid Prod.	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	11 000								11 000
Industrial Processes Total	33 000	0	0	37	11 000		6 000	2 900	53 000
SOLVENT & OTHER PRODUCT USE	0	0	0	1	420	0			400
AGRICULTURE									
Enteric Fermentation		760	16 000						16 000
Manure Management		220	4 600	12	3 700				8 300
Agricultural Soils **	7 000			90	30 000				30 000
Agriculture Total	7 000	980	21 000	100	31 000				59 000
LAND-USE CHANGE & FORESTRY *		70	1 000	3	1 000				2 500
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	54				320
Waste Total	250	900	19 000	3.0	920				20 000
TOTAL	472 000	3 500	73 000	170	53 000	0	6 000	2 900	607 000
CO ₂ from Land-Use Change & Forestry **	-70 000								

* CH₄ and N₂O 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 Estimates

GHG Source and Sink Category	CO ₂ kt	CH ₄ kt	CH ₄ kt CO ₂ eq	N ₂ O kt	N ₂ O 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	47 600	74.0	1 500	1.0	300				49 500
Electricity and Steam Generation	96 100	1.7	36	1.8	550				96 700
Mining	5 000	0.1	2.3	0.1	32				5 030
Manufacturing	51 700	1.6	34	1.2	360				52 100
Construction	1 610	0.0	0.6	0.1	16.0				1 630
TRANSPORTATION									
Gasoline Cars	48 900	8.3	170	6.7	2 100				51 200
Light-Duty Gasoline Trucks	20 600	4.0	83	4.9	1 500				22 200
Heavy-Duty Gasoline Trucks	3 170	0.4	9.3	0.5	150				3 320
Motorcycles	215	0.2	3.6	0.0	1.3				220
Off-Road Gasoline Vehicles	4 420	5.1	110	0.1	29				4 550
Diesel Cars	618	0.0	0.4	0.0	14.0				633
Light-Duty Diesel Trucks	496	0.0	0.3	0.0	11				507
Heavy-Duty Diesel Trucks	23 600	1.2	24	0.7	210				23 900
Off-Road Diesel Vehicles	8 850	0.5	10	3.6	1 100				9 960
Propane and Natural Gas Vehicles	2 260	2.0	41	0.0	14.0				2 320
Domestic Air	9 240	0.6	11	0.9	280				9 530
Domestic Marine	4 940	0.4	8	1.0	300				5 250
Rail	5 850	0.3	6.7	2.4	730				6 590
Vehicles Subtotal	133 000	23	480	21	6 500				140 000
Pipelines	7 430	7.4	160.0	0.2	61				7 640
Transportation Subtotal	141 000	30	630	21	6 500				148 000
Residential	39 800	95	2 000	1.7	510				42 300
Commercial and Institutional	26 300	0.5	10	0.5	160				26 500
Other	2 740	0.0	0.8	0.1	18				2 760
Fuel Combustion Subtotal	411 000	200	4 300	27	8 500				424 000
FUGITIVE									
Solid Fuels (i.e. Coal Mining)		99	2 100						2 100
Oil and Gas	10 000	1 300	27 000						38 000
Fugitive Subtotal	10 000	1 400	30 000	0	0				40 000
Energy Total	422 000	1 600	34 000	27	8 500				464 000
INDUSTRIAL PROCESSES									
Non-Metallic Mineral Production	6 980								6 980
Ammonia Adipic & Nitric Acid Prod.	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	33 000	0	0	35	11 000		6 000	3 300	54 000
SOLVENT & OTHER PRODUCT USE	0	0	0	1	420	0			400
AGRICULTURE									
Enteric Fermentation		770	16 000						16 000
Manure Management		220	4 600	12	3 700				8 300
Agricultural Soils **	7 000			90	30 000				30 000
Agriculture Total	7 000	990	21 000	98	30 000				58 000
LAND-USE CHANGE & FORESTRY *		90	2 000	5	1 000				3 300
WASTE									
Solid Waste Disposal on Land		910	19 000						19 000
Wastewater Handling		17	360	2.8	880				1 200
Waste Incineration	260	0.5	9.5	0.2	54				320
Waste Total	260	930	20 000	3.0	930				21 000
TOTAL	462 000	3 600	76 000	170	52 000	0	6 000	3 300	600 000
CO ₂ from Land-Use Change & Forestry **	-70 000								

* CH₄ and N₂O 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 ₂ O kt	N ₂ O 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	50 100	77.0	1 600	1.0	310				52 100
Electricity and Steam Generation	102 000	2.3	49	1.9	590				103 000
Mining	4 760	0.1	2.2	0.1	33				4 790
Manufacturing	51 100	1.6	34	1.1	360				51 500
Construction	1 730	0.0	0.6	0.1	17.0				1 750
TRANSPORTATION									
Gasoline Cars	49 100	8.1	170	7.5	2 300				51 600
Light-Duty Gasoline Trucks	22 100	4.2	88	5.9	1 800				24 000
Heavy-Duty Gasoline Trucks	3 560	0.5	10	0.5	160				3 730
Motorcycles	213	0.2	3.6	0.0	1.3				218
Off-Road Gasoline Vehicles	3 540	4.0	85	0.1	23				3 640
Diesel Cars	617	0.0	0.4	0.0	14.0				631
Light-Duty Diesel Trucks	445	0.0	0.3	0.0	10				456
Heavy-Duty Diesel Trucks	24 100	1.2	25	0.7	220				24 300
Off-Road Diesel Vehicles	8 420	0.4	9	3.4	1 100				9 480
Propane and Natural Gas Vehicles	2 610	2.2	47	0.1	16.0				2 680
Domestic Air	9 430	0.5	11	0.9	290				9 720
Domestic Marine	4 790	0.4	8	1.0	300				5 100
Rail	6 120	0.3	7.1	2.5	760				6 890
Vehicles Subtotal	135 000	22	460	23	7 000				143 000
Pipelines	9 610	9.6	200.0	0.3	78				9 890
Transportation Subtotal	145 000	32	670	23	7 100				152 000
Residential	41 000	94	2 000	1.7	510				43 500
Commercial and Institutional	26 900	0.5	10	0.5	160				27 000
Other	3 250	0.0	1.0	0.1	24				3 270
Fuel Combustion Subtotal	426 000	210	4 400	29	9 100				439 000
FUGITIVE									
Solid Fuels (i.e. Coal Mining)		87	1 800						1 800
Oil and Gas	11 000	1 400	30 000						41 000
Fugitive Subtotal	11 000	1 500	32 000	0	0				42 000
Energy Total	436 000	1 700	36 000	29	9 100				482 000
INDUSTRIAL PROCESSES									
Non-Metallic Mineral Production	6 640								6 640
Ammonia Adipic & Nitric Acid Prod.	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	11 000								11 000
Industrial Processes Total	33 000	0	0	35	11 000		7 000	2 200	53 000
SOLVENT & OTHER PRODUCT USE	0	0	0	1	430	0			400
AGRICULTURE									
Enteric Fermentation		790	17 000						17 000
Manure Management		220	4 700	12	3 800				8 500
Agricultural Soils**	6 000			90	30 000				30 000
Agriculture Total	6 000	1 000	21 000	100	31 000				58 000
LAND-USE CHANGE & FORESTRY *		70	1 000	4	1 000				2 600
WASTE									
Solid Waste Disposal on Land		930	20 000						20 000
Wastewater Handling		17	360	2.9	890				1 300
Waste Incineration	260	0.5	10	0.2	55				330
Waste Total	260	950	20 000	3.0	940				21 000
TOTAL	475 000	3 700	79 000	170	53 000	0	7 000	2 200	616 000
CO ₂ from Land-Use Change & Forestry **	-50 000								

* CH₄ and N₂O 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 ₂ O kt	N ₂ O 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	50 600	77.0	1 600	1.0	310				52 600
Electricity and Steam Generation	93 200	2.5	53	1.8	550				93 800
Mining	7 320	0.2	3.2	0.2	48				7 370
Manufacturing	48 700	1.5	32	1.1	340				49 100
Construction	1 370	0.0	0.5	0.0	10.0				1 390
TRANSPORTATION									
Gasoline Cars	49 100	7.8	160	8.2	2 500				51 800
Light-Duty Gasoline Trucks	23 300	4.3	91	6.9	2 100				25 600
Heavy-Duty Gasoline Trucks	3 880	0.5	11	0.6	180				4 070
Motorcycles	214	0.2	3.6	0.0	1.3				219
Off-Road Gasoline Vehicles	3 740	4.3	90	0.1	25				3 850
Diesel Cars	610	0.0	0.4	0.0	14				624
Light-Duty Diesel Trucks	420	0.0	0.2	0.0	9.5				429
Heavy-Duty Diesel Trucks	25 400	1.2	26	0.7	230				25 700
Off-Road Diesel Vehicles	9 640	0.5	10	3.9	1 200				10 900
Propane and Natural Gas Vehicles	1 970	2.0	43	0.0	12.0				2 030
Domestic Air	9 120	0.5	11	0.9	280				9 410
Domestic Marine	4 190	0.3	6.5	0.9	280				4 480
Rail	6 090	0.3	7.0	2.5	760				6 860
Vehicles Subtotal	138 000	22	470	25	7 700				146 000
Pipelines	10 100	10.1	210.0	0.3	82				10 400
Transportation Subtotal	148 000	32	680	25	7 800				156 000
Residential	42 900	99	2 100	1.7	530				45 500
Commercial and Institutional	27 900	0.5	10	0.6	170				28 100
Other	3 040	0.0	1.0	0.1	22				3 060
Fuel Combustion Subtotal	423 000	210	4 500	31	9 700				437 000
FUGITIVE									
Solid Fuels (i.e. Coal Mining)		87	1 800						1 800
Oil and Gas	11 000	1 500	31 000						43 000
Fugitive Subtotal	11 000	1 600	33 000	0	0				44 000
Energy Total	434 000	1 800	37 000	31	9 700				482 000
INDUSTRIAL PROCESSES									
Non-Metallic Mineral Production	6 880								6 880
Ammonia Adipic & Nitric Acid Prod.	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	12 000								12 000
Industrial Processes Total	35 000	0	0	32	9 900		7 000	2 000	54 000
SOLVENT & OTHER PRODUCT USE	0	0	0	1	430	0			400
AGRICULTURE									
Enteric Fermentation		800	17 000						17 000
Manure Management		220	4 600	12	3 900				8 500
Agricultural Soils **	5 000			90	30 000				30 000
Agriculture Total	5 000	1 000	21 000	100	32 000				58 000
LAND-USE CHANGE & FORESTRY *		80	2 000	5	1 000				3 100
WASTE									
Solid Waste Disposal on Land		960	20 000						20 000
Wastewater Handling		18	370	2.9	900				1 300
Waste Incineration	260	0.3	6.5	0.2	56				330
Waste Total	260	970	20 000	3.1	950				22 000
TOTAL	474 000	3 900	81 000	180	54 000	0	7 000	2 000	619 000
CO ₂ from Land-Use Change & Forestry **	-40 000								

* CH₄ and N₂O 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 ₂ O kt	N ₂ O 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	51 300	81.0	1 700	1.0	310				53 300
Electricity and Steam Generation	95 400	2.6	54	1.8	570				96 000
Mining	7 440	0.2	3.2	0.2	53				7 490
Manufacturing	51 800	1.6	34	1.1	350				52 200
Construction	1 390	0.0	0.5	0.0	10.0				1 400
TRANSPORTATION									
Gasoline Cars	49 400	7.6	160	8.9	2 800				52 300
Light-Duty Gasoline Trucks	24 900	4.5	95	7.9	2 500				27 400
Heavy-Duty Gasoline Trucks	4 270	0.6	13	0.6	200				4 480
Motorcycles	216	0.2	3.6	0.0	1.3				221
Off-Road Gasoline Vehicles	3 810	4.4	92	0.1	25				3 930
Diesel Cars	603	0.0	0.4	0.0	14				617
Light-Duty Diesel Trucks	423	0.0	0.2	0.0	9.6				432
Heavy-Duty Diesel Trucks	28 200	1.4	29	0.8	260				28 500
Off-Road Diesel Vehicles	10 600	0.6	11	4.3	1 300				12 000
Propane and Natural Gas Vehicles	1 870	2.0	42	0.0	11.0				1 920
Domestic Air	9 770	0.5	11	1.0	300				10 100
Domestic Marine	4 350	0.3	6.6	1.0	300				4 660
Rail	6 310	0.4	7.3	2.5	790				7 100
Vehicles Subtotal	145 000	22	470	27	8 400				154 000
Pipelines	10 500	10.4	220.0	0.3	85				10 800
Transportation Subtotal	155 000	33	690	27	8 500				164 000
Residential	43 700	99	2 100	1.8	540				46 300
Commercial and Institutional	27 300	0.5	11	0.6	180				27 400
Other	2 540	0.0	0.8	0.1	19				2 560
Fuel Combustion Subtotal	436 000	220	4 600	34	11 000				451 000
FUGITIVE									
Solid Fuels (i.e. Coal Mining)		84	1 800						1 800
Oil and Gas	12 000	1 600	33 000						45 000
Fugitive Subtotal	12 000	1 700	35 000	0	0				47 000
Energy Total	448 000	1 900	39 000	34	11 000				498 000
INDUSTRIAL PROCESSES									
Non-Metallic Mineral Production	7 510								7 510
Ammonia Adipic & Nitric Acid Prod.	3 700			38	12 000				15 000
Ferrous Metal Production	8 090								8 090
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	56 000
SOLVENT & OTHER PRODUCT USE	0	0	0	1	440	0			400
AGRICULTURE									
Enteric Fermentation		830	18 000						18 000
Manure Management		230	4 800	13	4 100				8 900
Agricultural Soils **	4 000			100	30 000				30 000
Agriculture Total	4 000	1 100	22 000	110	34 000				60 000
LAND-USE CHANGE & FORESTRY *		90	2 000	7	2 000				4 100
WASTE									
Solid Waste Disposal on Land		970	20 000						20 000
Wastewater Handling		18	370	2.9	910				1 300
Waste Incineration	270	0.3	6.5	0.2	56				330
Waste Total	270	980	21 000	3.1	960				22 000
TOTAL	488 000	4 000	84 000	190	60 000	0	7 000	2 000	641 000
CO ₂ from Land-Use Change & Forestry**	-40 000								

* CH₄ and N₂O 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 ₂ O kt	N ₂ O 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	52 600	83.0	1 700	1.0	320				54 700
Electricity and Steam Generation	100 000	3.0	63	1.9	600				101 000
Mining	7 800	0.2	3.4	0.2	59				7 860
Manufacturing	52 500	1.7	36	1.2	370				52 900
Construction	1 170	0.0	0.4	0.0	9.7				1 180
TRANSPORTATION									
Gasoline Cars	48 400	7.1	150	9.0	2 800				51 300
Light-Duty Gasoline Trucks	25 800	4.5	95	8.5	2 600				28 500
Heavy-Duty Gasoline Trucks	4 530	0.6	13	0.7	210				4 760
Motorcycles	209	0.2	3.5	0.0	1.3				214
Off-Road Gasoline Vehicles	3 820	4.4	92	0.1	25				3 940
Diesel Cars	581	0.0	0.3	0.0	13				594
Light-Duty Diesel Trucks	407	0.0	0.2	0.0	9.2				416
Heavy-Duty Diesel Trucks	30 500	1.5	31	0.9	280				30 800
Off-Road Diesel Vehicles	11 200	0.6	12	4.5	1 400				12 700
Propane and Natural Gas Vehicles	2 050	2.0	43	0.0	12.0				2 100
Domestic Air	10 500	0.6	12	1.0	320				10 900
Domestic Marine	4 060	0.3	6.0	1.0	310				4 380
Rail	5 710	0.3	6.6	2.3	710				6 430
Vehicles Subtotal	148 000	22	460	28	8 700				157 000
Pipelines	11 700	11.6	240.0	0.3	95				12 000
Transportation Subtotal	159 000	34	710	28	8 800				169 000
Residential	42 400	95	2 000	1.7	530				44 900
Commercial and Institutional	28 800	0.5	11	0.6	200				29 000
Other	2 770	0.0	0.8	0.1	21				2 790
Fuel Combustion Subtotal	448 000	220	4 600	35	11 000				463 000
FUGITIVE									
Solid Fuels (i.e. Coal Mining)		82	1 700						1 700
Oil and Gas	13 000	1 700	35 000						48 000
Fugitive Subtotal	13 000	1 800	37 000	0	0				50 000
Energy Total	461 000	2 000	41 000	35	11 000				513 000
INDUSTRIAL PROCESSES									
Non-Metallic Mineral Production	7 690								7 690
Ammonia Adipic & Nitric Acid Prod.	4 050			37	12 000				16 000
Ferrous Metal Production	8 440								8 440
Aluminum and Magnesium Production	3 540						6 000	1 900	11 000
Other & Undifferentiated Production	13 000								13 000
Industrial Processes Total	36 000	0	0	37	12 000		6 000	1 900	56 000
SOLVENT & OTHER PRODUCT USE	0	0	0	1	440	500			900
AGRICULTURE									
Enteric Fermentation		860	18 000						18 000
Manure Management		240	5 000	14	4 200				9 200
Agricultural Soils **	3 000			100	30 000				30 000
Agriculture Total	3 000	1 100	23 000	110	35 000				61 000
LAND-USE CHANGE & FORESTRY *		100	2 000	9	3 000				5 100
WASTE									
Solid Waste Disposal on Land		970	20 000						20 000
Wastewater Handling		18	380	3.0	920				1 300
Waste Incineration	270	0.3	7.2	0.2	57				330
Waste Total	270	990	21 000	3.1	980				22 000
TOTAL	501 000	4 200	88 000	200	61 000	500	6 000	1 900	658 000
CO ₂ from Land-Use Change & Forestry **	-20 000								

* CH₄ and N₂O 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 kt	CH ₄ kt	CH ₄ kt CO ₂ eq	N ₂ O kt	N ₂ O 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	53 200	84.0	1 800	1.1	330				55 300
Electricity and Steam Generation	99 100	2.6	55	1.9	590				99 700
Mining	8 680	0.2	3.7	0.2	60				8 740
Manufacturing	54 300	1.7	35	1.2	360				54 700
Construction	1 260	0.0	0.4	0.0	10.0				1 270
TRANSPORTATION									
Gasoline Cars	47 100	6.5	140	8.5	2 600				49 900
Light-Duty Gasoline Trucks	27 100	4.6	96	8.6	2 700				29 900
Heavy-Duty Gasoline Trucks	4 750	0.7	14	0.7	220				4 980
Motorcycles	205	0.2	3.4	0.0	1.2				210
Off-Road Gasoline Vehicles	4 540	5.2	110	0.1	30				4 680
Diesel Cars	588	0.0	0.3	0.0	13				602
Light-Duty Diesel Trucks	393	0.0	0.2	0.0	8.9				402
Heavy-Duty Diesel Trucks	32 100	1.6	33	0.9	290				32 500
Off-Road Diesel Vehicles	11 700	0.6	13	4.7	1 500				13 200
Propane and Natural Gas Vehicles	1 930	1.9	40	0.0	12.0				1 980
Domestic Air	11 600	0.6	13	1.1	350				11 900
Domestic Marine	4 160	0.3	6.2	1.0	310				4 470
Rail	5 580	0.3	6.4	2.3	700				6 290
Vehicles Subtotal	152 000	22	470	28	8 700				161 000
Pipelines	12 200	12.1	250.0	0.3	98				12 500
Transportation Subtotal	164 000	34	720	28	8 800				173 000
Residential	47 100	94	2 000	1.8	550				49 700
Commercial and Institutional	29 400	0.5	11	0.6	190				29 600
Other	2 930	0.0	0.9	0.1	20				2 950
Fuel Combustion Subtotal	460 000	220	4 600	35	11 000				475 000
FUGITIVE									
Solid Fuels (i.e. Coal Mining)		84	1 800						1 800
Oil and Gas	13 000	1 800	37 000						51 000
Fugitive Subtotal	13 000	1 900	39 000	0	0				53 000
Energy Total	473 000	2 100	44 000	35	11 000				528 000
INDUSTRIAL PROCESSES									
Non-Metallic Mineral Production	8 030								8 030
Ammonia Adipic & Nitric Acid Prod.	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	14 000								14 000
Industrial Processes Total	38 000	0	0	40	12 000		6 000	1 400	57 000
SOLVENT & OTHER PRODUCT USE	0	0	0	1	450	900			1 000
AGRICULTURE									
Enteric Fermentation		870	18 000						18 000
Manure Management		240	5 100	14	4 300				9 300
Agricultural Soils **	2 000			100	30 000				30 000
Agriculture Total	2 000	1 100	23 000	120	36 000				61 000
LAND-USE CHANGE & FORESTRY *		40	800	3	800				1 600
WASTE									
Solid Waste Disposal on Land		970	20 000						20 000
Wastewater Handling		18	380	3.0	930				1 300
Waste Incineration	270	0.3	6.9	0.2	58				340
Waste Total	270	990	21 000	3.2	990				22 000
TOTAL	513 000	4 200	89 000	200	62 000	900	6 000	1 400	672 000
CO ₂ from Land-Use Change & Forestry**	-30 000								

* CH₄ and N₂O 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 ₂ O kt	N ₂ O 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	49 100	78.0	1 600	1.0	310				51 000
Electricity and Steam Generation	111 000	3.2	67	2.1	650				111 000
Mining	8 900	0.2	3.8	0.2	63				8 970
Manufacturing	54 200	1.7	35	1.2	360				54 600
Construction	1 250	0.0	0.4	0.0	9.8				1 260
TRANSPORTATION									
Gasoline Cars	47 300	6.0	130	8.3	2 600				50 000
Light-Duty Gasoline Trucks	29 100	4.6	97	8.9	2 800				32 000
Heavy-Duty Gasoline Trucks	4 820	0.7	14	0.7	220				5 050
Motorcycles	216	0.2	3.6	0.0	1.3				221
Off-Road Gasoline Vehicles	4 180	4.8	100	0.1	27				4 310
Diesel Cars	587	0.0	0.3	0.0	13				600
Light-Duty Diesel Trucks	494	0.0	0.3	0.0	11				505
Heavy-Duty Diesel Trucks	35 200	1.7	36	1.0	320				35 500
Off-Road Diesel Vehicles	12 500	0.6	14	5.1	1 600				14 100
Propane and Natural Gas Vehicles	1 790	2.1	43	0.0	11.0				1 840
Domestic Air	12 100	0.6	13	1.2	370				12 400
Domestic Marine	4 220	0.3	6.3	1.0	300				4 530
Rail	5 660	0.3	6.5	2.3	710				6 380
Vehicles Subtotal	158 000	22	460	29	8 900				168 000
Pipelines	12 200	12.2	260.0	0.3	100				12 500
Transportation Subtotal	170 000	34	720	29	9 000				180 000
Residential	43 800	94	2 000	1.7	530				46 400
Commercial and Institutional	29 800	0.5	11	0.7	200				30 000
Other	2 920	0.0	0.9	0.1	21				2 940
Fuel Combustion Subtotal	471 000	210	4 500	36	11 000				487 000
FUGITIVE									
Solid Fuels (i.e. Coal Mining)		78	1 600						1 600
Oil and Gas	14 000	1 800	38 000						51 000
Fugitive Subtotal	14 000	1 900	39 000	0	0				53 000
Energy Total	485 000	2 100	44 000	36	11 000				539 000
INDUSTRIAL PROCESSES									
Non-Metallic Mineral Production	8 180								8 180
Ammoni Adipic & Nitric Acid Prod.	4 140			34	11 000				15 000
Ferrous Metal Production	8 100								8 100
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	450	900			1 000
AGRICULTURE									
Enteric Fermentation		870	18 000						18 000
Manure Management		240	5 000	14	4 300				9 300
Agricultural Soils **	1 000			100	30 000				30 000
Agriculture Total	1 000	1 100	23 000	120	36 000				61 000
LAND-USE CHANGE & FORESTRY *		20	500	1	400				870
WASTE									
Solid Waste Disposal on Land		1 000	21 000						21 000
Wastewater Handling		19	390	3.0	940				1 300
Waste Incineration	280	0.3	6.9	0.2	58				340
Waste Total	280	1 000	21 000	3.2	1 000				23 000
TOTAL	525 000	4 200	89 000	190	60 000	900	6 000	1 400	682 000
CO ₂ from Land-Use Change & Forestry **	-20 000								

* CH₄ and N₂O 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 1998 Greenhouse Gas Emission Summary

GHG Source and Sink Category	CO ₂ kt	CH ₄ kt	CH ₄ kt CO ₂ eq	N ₂ O kt	N ₂ O 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	54 300	92.0	1 900	1.1	350				56 500
Electricity and Steam Generation	123 000	3.9	82	2.3	720				124 000
Mining	7 960	0.2	3.4	0.2	58				8 020
Manufacturing	52 000	1.7	36	1.2	360				52 400
Construction	1 110	0.0	0.4	0.0	9.7				1 120
TRANSPORTATION									
Gasoline Cars	47 100	5.5	120	8.0	2 500				49 700
Light-Duty Gasoline Trucks	30 000	4.5	94	8.7	2 700				32 800
Heavy-Duty Gasoline Trucks	5 240	0.7	15	0.8	240				5 490
Motorcycles	227	0.2	3.8	0.0	1.4				232
Off-Road Gasoline Vehicles	5 670	6.5	140	0.1	37				5 840
Diesel Cars	583	0.0	0.3	0.0	13				597
Light-Duty Diesel Trucks	445	0.0	0.3	0.0	10				455
Heavy-Duty Diesel Trucks	35 200	1.7	36	1.0	320				35 600
Off-Road Diesel Vehicles	13 100	0.7	14	5.3	1 600				14 800
Propane and Natural Gas Vehicles	1 730	2.1	44	0.0	11.0				1 780
Domestic Air	12 600	0.6	13	1.2	380				13 000
Domestic Marine	4 830	0.4	7.6	1.0	310				5 150
Rail	5 460	0.3	6.3	2.2	680				6 140
Vehicles Subtotal	162 000	23	490	29	8 800				171 000
Pipelines	12 100	12.1	250.0	0.3	99				12 500
Transportation Subtotal	174 000	35	740	29	8 900				184 000
Residential	38 400	95	2 000	1.7	510				41 000
Commercial and Institutional	27 000	0.5	10	0.6	180				27 200
Other	2 590	0.0	0.8	0.1	17				2 610
Fuel Combustion Subtotal	481 000	230	4 800	36	11 000				496 000
FUGITIVE									
Solid Fuels (i.e. Coal Mining)		65	1 400						1 400
Oil and Gas	14 000	1 800	37 000						51 000
Fugitive Subtotal	14 000	1 800	39 000	0	0				52 000
Energy Total	494 000	2 100	43 000	36	11 000				549 000
INDUSTRIAL PROCESSES									
Non-Metallic Mineral Production	8 370								8 370
Ammonia Adipic & Nitric Acid Prod.	3 900			19	5 800				9 700
Ferrous Metal Production	8 320								8 320
Aluminum and Magnesium Production	3 820						6 000	1 500	11 000
Other & Undifferentiated Production	14 000								14 000
Industrial Processes Total	39 000	0	0	19	5 800		6 000	1 500	52 000
SOLVENT & OTHER PRODUCT USE	0	0	0	2	460	900			1 000
AGRICULTURE									
Enteric Fermentation		860	18 000						18 000
Manure Management		240	5 100	14	4 300				9 400
Agricultural Soils **	700			100	30 000				30 000
Agriculture Total	700	1 100	23 000	120	37 000				61 000
LAND-USE CHANGE & FORESTRY *		70	1 000	5	2 000				3 100
WASTE									
Solid Waste Disposal on Land		1 000	21 000						21 000
Wastewater Handling		19	390	3.1	950				1 300
Waste Incineration	280	0.3	6.9	0.2	58				340
Waste Total	280	1 000	22 000	3.2	1 000				23 000
TOTAL	534 000	4 300	90 000	180	57 000	900	6 000	1 500	689 000
CO ₂ from Land-Use Change & Forestry **	-20 000								

* CH₄ and N₂O 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 1999 Greenhouse Gas Emission Summary

GHG Source and Sink Category	CO ₂ kt	CH ₄ kt	CH ₄ kt CO ₂ eq	N ₂ O kt	N ₂ O 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	62 300	110.0	2 400	1.3	410				65 100
Electricity and Steam Generation	118 000	3.5	74	2.2	680				119 000
Mining	7 620	0.2	3.2	0.2	55				7 680
Manufacturing	51 400	1.7	36	1.2	360				51 700
Construction	1 160	0.0	0.4	0.0	9.8				1 170
TRANSPORTATION									
Gasoline Cars	47 500	5.1	110	7.8	2 400				50 000
Light-Duty Gasoline Trucks	31 900	4.5	94	8.8	2 700				34 700
Heavy-Duty Gasoline Trucks	5 610	0.8	17	0.8	260				5 880
Motorcycles	232	0.2	3.9	0.0	1.4				237
Off-Road Gasoline Vehicles	5 290	6.0	130	0.1	35				5 450
Diesel Cars	563	0.0	0.3	0.0	13				576
Light-Duty Diesel Trucks	394	0.0	0.2	0.0	8.9				403
Heavy-Duty Diesel Trucks	36 500	1.8	38	1.1	330				36 900
Off-Road Diesel Vehicles	14 000	0.7	15	5.6	1 700				15 700
Propane and Natural Gas Vehicles	1 470	1.9	40	0.0	9.0				1 520
Domestic Air	13 200	0.6	13	1.3	400				13 600
Domestic Marine	4 830	0.4	7.5	1.0	320				5 160
Rail	5 780	0.3	6.7	2.3	720				6 510
Vehicles Subtotal	167 000	22	470	29	9 000				177 000
Pipelines	12 200	12.2	260.0	0.3	100				12 600
Transportation Subtotal	179 000	35	730	29	9 100				189 000
Residential	40 500	95	2 000	1.7	520				43 000
Commercial and Institutional	28 700	0.5	11	0.6	190				28 900
Other	2 670	0.0	0.8	0.1	18				2 690
Fuel Combustion Subtotal	491 000	250	5 200	37	11 000				508 000
FUGITIVE									
Solid Fuels (i.e. Coal Mining)		51	1 100						1 100
Oil and Gas	14 000	1 800	37 000						52 000
Fugitive Subtotal	14 000	1 800	38 000	0	0				53 000
Energy Total	506 000	2 100	44 000	37	11 000				561 000
INDUSTRIAL PROCESSES									
Non-Metallic Mineral Production	8 670								8 670
Ammonia Adipic & Nitric Acid Prod.	4 050			8.2	2 500				6 600
Ferrous Metal Production	8 500								8 500
Aluminum and Magnesium Production	3 820						6 000	1 700	12 000
Other & Undifferentiated Production	14 000								14 000
Industrial Processes Total	39 000	0	0	8	2 500		6 000	1 700	50 000
SOLVENT & OTHER PRODUCT USE	0	0	0	2	460	900			1 000
AGRICULTURE									
Enteric Fermentation		850	18 000						18 000
Manure Management		240	5 100	14	4 300				9 400
Agricultural Soils **	200			100	30 000				30 000
Agriculture Total	200	1 100	23 000	120	38 000				61 000
LAND-USE CHANGE & FORESTRY *		60	1 000	4	1 000				2 400
WASTE									
Solid Waste Disposal on Land		1 000	22 000						22 000
Wastewater Handling		19	400	3.1	950				1 300
Waste Incineration	280	0.3	6.9	0.2	59				350
Waste Total	280	1 100	22 000	3.3	1 000				24 000
TOTAL	546 000	4 300	90 000	170	54 000	900	6 000	1 700	699 000
CO ₂ from Land-Use Change & Forestry **	-20 000								

* CH₄ and N₂O 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.

