CANADA’S GREENHOUSE GAS INVENTORY
1990 - 1998

FINAL SUBMISSION TO THE UNFCCC SECRETARIAT

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Volume 1 of 2

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Canada's Greenhouse Gas Inventory

1990 -1998

Final Submission to the UNFCCC Secretariat

Volume 1 of 2

Greenhouse Gas Division
Pollution Data Branch
Air Pollution Prevention Directorate

Environment Canada

October 2000

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 1 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 1990-1998*, and its companion document, *Trends in Canada's Greenhouse Gas Emissions 1990-1998*, have been prepared by the staff of the Greenhouse Gas Division of Environment Canada in consultation with a wide range of stakeholders. This two-volume document constitutes Canada's official greenhouse gas inventory submission to the UNFCCC for 2000.

In December of 1997, at the 3rd Conference of the Parties in Kyoto, Japan, Annex 1 Parties to the UNFCCC agreed to differentiated targets that would, overall, reduce greenhouse gas emissions from 1990 levels over a 5 year commitment period: (2008-2012). The Kyoto Protocol, once ratified, legally binds Canada to a 6% reduction of 1990 emissions and stipulates that progress in achieving this reduction commitment will be measured through the use of a set of internationally agreed to emissions and removals inventory methodologies and reporting guidelines. 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 contained in this report are thought to be as accurate a representation of emissions and removals in Canada as is currently possible.

A. Jaques, October 2000

Readers' Comments

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Of the many individuals and organizations that provided advice and information, the Greenhouse Gas Division is especially indebted to Ron Rasia, Gary Smalldridge, Serge Grenier and Lucie Cloutier 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 (CFS), Ray Desjardins, Henry Janzen, Richard Riznek 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, Vadim Belotserkovsky and Steve Lapp of SGA Energy Limited, for augmenting the work of Frank Neitzert and other members of the Division to produce the sectoral and regional trends analysis, and Doug Cope, of D. Cope Enterprises for his efforts in summarizing the methods used to develop the emission estimates. 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 trends analysis. The inventory estimates for 1998 were developed by Chia Ha. Pascale Collas, along with Dominique Blain and Chang Liang undertook analysis of the forestry and agriculture sectors. Other members of the Greenhouse Gas Division, including Scott McKibbon, were responsible for the energy export emissions analysis and the editing.

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EXECUTIVE SUMMARY

The current submission has been prepared to comply with the new United Nations Framework Convention on Climate Change (UNFCCC) reporting Guidelines. As such, it consists of two volumes. The main report, this volume, contains a short summary and a description of inventory methodologies, quality control and verification procedures, and the uncertainty associated with the greenhouse gas emission estimates. The second volume, entitled ‘Appendices’, contains comprehensive emissions data, including a full set of tables and notes in the new Common Reporting Format (CRF).

Greenhouse Gas Estimates

Direct Greenhouse Gas Estimates - Highlights

Current estimates for Canada’s 1998 greenhouse gas emissions indicate that they were 13 per cent higher in 1998, as compared to 1990. The 1990 to 1998 growth is about 1% higher than ’90 to ’97. Analysis of the short-term change shows that 1998 emissions were 2.3 per cent higher than 1996 emissions.

Growth between 1996 and 1998 was lower than in the 1990 to 1996 period. From 1990 to 1996 emissions rose at an average rate of 1.7% annually, while from 1996 to 1998 they grew by 1.1% per year. There are two primary reasons for this difference – the first (and most important) is the fact that the 1997 and 1998 Canadian winters were considerably warmer than those in the earlier 1990s. The second reason is that there has been a drop in greenhouse gas emissions from some industries (see Table ES 1).

Compared to Environment Canada’s last published inventory, the present estimates for 1990 are about 2% higher. This is a result of improvements to agricultural and HFC emissions methodologies and corrections made by Statistics Canada to the underlying energy data. Use of the new energy data has had an impact on greenhouse gas emission trends. Previously calculated to have grown by 13% from 1990 to 1997, estimates now indicate an emission increase of 12% over that period, and 13% from 1990 to 1998.

Comment on Sulphur Dioxide and Ozone Precursors

No new estimates have been provided for these gases. In Canada’s 1999 submission, national estimates of Criteria Air Contaminants (SO_2, NO_x, CO and NMVOC) were provided for 1995. This is still the latest year for which Criteria Air contaminants have been inventoried.

Table ES 1: Canada's 1990-1998 Greenhouse Gas Emission Trends by Primary Sector

GHG Source and Sink Category	**1990** Total *Mt CO_2 eq*	**1998** Total *Mt CO_2 eq*	Change 90 to 98	***Short Term*** Change 96 to 98
Fossil Fuel Industries Fuel Combustion	43.8	47.5		
Electricity and Steam Generation Fuel Combustion	95.5	124.9		
Mining Fuel Combustion	6.2	9.9		
Fugitive (Oil, Gas and Coal mining)	37.9	52.4		
ENERGY INDUSTRIES TOTAL	**183**	**235**	**28%**	**13%**
Manufacturing Fuel Combustion	54.7	52.5		
Construction Fuel Combustion	1.9	1.1		
Industrial Processes	53	51		
MANUFACTURING, CONSTRUCTION AND INDUSTRIAL PROCESSES TOTAL	**110**	**105**	**-4%**	**-7%**
Cars	54.4	50.1		
Light Duty Trucks	22.3	33		
Heavy Duty Vehicles	27.8	42.4		
Off Road Vehicles	16.3	19.5		
Motorcycles, Propane and Natural Gas Vehicles	2.5	2		
Domestic Air	10.7	13		
Domestic Marine	5	5.1		
Rail	7.1	6.1		
Pipelines	6.7	12.1		
TRANSPORTATION TOTAL	**153**	**183**	**20%**	**6%**
Residential Fuel Combustion	46.9	43.7		
Commercial and Institutional Fuel Combustion	25.7	27		
RESIDENTIAL, COMMERCIAL AND INSTITUTIONAL TOTAL	**73**	**71**	**-3%**	**-15%**
AGRICULTURE TOTAL	**68**	**70**	**2%**	**-2%**
Other Fuel Combustion	2.4	2.6		
Solvent and Other Product Use	0.4	1.3		
Land Use Change and Forestry*	2.5	1.7		
Waste	20	23		
OTHER TOTAL	**25**	**29**	**13%**	**2%**
SUM	**612**	**692**	**13%**	**2.30%**

* CH_4 and N_2O emissions from Prescribed and Other Fires

Totals may not add due rounding. Rounding reflects the relative uncertainty of the data.

1.0 INTRODUCTION

This report was prepared in response to Decision 3/C.P.1 of the Framework Convention on Climate Change (FCCC), which states Annex 1 parties should submit “national inventory data on emissions by sources and removals by sinks”. The report is divided into two volumes, the first contains the textual body of the report and the second contains primarily data tables.

The main report, this volume, contains a description of inventory methodologies, quality control and verification procedures, and the uncertainty associated with the greenhouse gas emission estimates. The second volume, entitled ‘Appendices’, contains comprehensive emissions data, including a full set of tables and notes in the new Common Reporting Format (CRF) which has been developed by the UNFCCC secretariat to simplify analysis and comparability of parties inventory data.

2.0 METHODOLOGY

This chapter provides an outline of the methods currently employed by the GHG Division of Environment Canada to construct the *Canadian Greenhouse Gas Inventory* (CGHGI). In general the methods used to generate the data in this report are unchanged from the previous version of the Inventory (Neitzert et. al, 1999)

The CGHGI has been structured to match the reporting requirements of the *United Nations Framework Convention on Climate Change* (UNFCCC), the *Kyoto Protocol*, and the *Intergovernmental Panel on Climate Change* (IPCC). Therefore, it is divided into six main categories:

- Energy
- Industrial Processes
- Solvents 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 (CO_2)
- Methane (CH_4)
- Nitrous Oxide (N_2O)
- Hydrofluorocarbons (HFCs)
- Perfluorocarbons (PFCs)
- Sulphur Hexafluoride (SF_6)

The UNFCCC also requires emissions estimates for:

- Sulphur dioxide (SO2), and
- The Ozone Precursors:
- Nitrogen Oxides (NOx),
- Carbon Monoxide (CO), and
- Non-methane Volatile Organic Compounds (NMVOC).

These gases (referred to as the *Criteria Air Contaminants*) are inventoried separately and using different methodologies from the direct GHGs. The general methods that were employed are presented 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 will be virtually impossible for any country to capture them all. The best a country can accomplish is to 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 emissions and removals estimates may be derived for a given process or combination of operations by one or more of the following methods:

- ***Direct Measurement*****:** with a few exceptions, GHG emissions or removals measurements apply to Point Sources. At present for 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) to 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.

- ***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 average EFs can be combined with company specific, sector specific, process specific or general activity and population data to calculate emissions. Average or general Emission Factors for most of the sectors in the inventory have been developed by Environment Canada, in consultation with other government departments, industry associations, and other agencies and organizations. These values reflect the most accurate methodologies based on currently available data, and include information currently being developed by the IPCC for the UNFCCC. In general, CO_2 emission factors are well developed for many sources, CH_4 factors are less well defined and N_2O, PFC, HFC, and SF_6 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: *General*

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

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, EXCEL Draft*, November 1999.

IPCC, *Greenhouse Gas Inventory Reporting Instructions, Vol. 1,* and the IPCC, *Greenhouse Gas Inventory Reference Manual, Vol. 3,*Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, 1997.

2.1 Energy

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

This category is divided into two broad sections based on the processes that generate the emissions:

A. Fuel Combustion, and
B. Fugitive Emissions.

Fugitive emissions comprise activity such as the escape or leakage and venting of methane (CH_4) and carbon dioxide (CO_2) during the extraction, processing and delivery of fossil fuels.

For all Energy sources, CO_2, CH_4, and N_2O are the only GHG's inventoried.

2.1.A Fuel Combustion Activities (Sectoral Approach)

[Titled *Fuel Combustion* in CGHGI.]

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:

Quantity of Fuel Combusted x EF per physical unit of Fuel = Emissions

Equation 1

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 that were employed in estimating the emissions for the current GHG inventory are illustrated Tables 1 to 5:

- *Table 1 - Gaseous Fuels* - The EFs for CH_4 vary by type of boiler.
- *Table 2 - Liquid Fuels* - The EFs vary with boiler type and with fuel characteristics.
- *Table 3 - Solid Petroleum Fuels* - The EFs vary with derivation of the fuel.
- *Table 4 and 5 - Coal Fuels* - The EFs for CO_2 vary with the properties of the coal and therefore, EFs are assigned for different provinces based upon the origins of the coal used; and the EFs for CH_4 and N_2O vary with the design of the combustion bed.

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

CO_2 Emissions

Fuel combustion CO_2 emissions depend upon the amount of fuel consumed, the carbon content of the fuel and the fraction of the fuel oxidized (Jaques, 1992). The basis of the CO_2 emission factor derivations has been discussed in previous publications. (Jaques, 1992) The factors have been obtained and developed from a number of studies conducted by Environment Canada, the

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 CO_2 emissions. It is assumed that CO in the atmosphere undergoes complete oxidation to CO_2 shortly after combustion (within 5 to 20 weeks of emission). 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 commonly reported in physical units.

Emission Factors for all non- CO_2 GHG's from combustion activities vary to a lesser or greater degree with:

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

CH_4 Emissions

During combustion of carbon based fuels some of the fuel remains unoxidized as methane. Additional research is necessary to better establish *CH_4* emission factors for many combustion processes. **CH_4** is produced in small quantities due to the incomplete combustion of hydrocarbons in fuel. In several sectors, methane EFs are not known.

N_2O 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 ***N_2O*** emission factors for many combustion processes. In several sectors, nitrous oxide EFs are not known.

Biomass Combustion

There are emissions of CO_2 from the combustion of biomass used to produce energy. However, as per UNFCCC requirements, CO_2 emissions from biomass fuels are *not* included in the *Energy* category totals nor in the sectors or sub-sectors. They are accounted for in the *Land Use Change and Forestry* (LUCF) category as a loss of biomass (forest) stocks. CO_2 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* category in their appropriate sub-sectors.

Statistics Canada Energy-Use Data – the QRESD

The fossil fuel energy-use data used to estimate combustion emissions are from the *Quarterly Report on Energy Supply-Demand* (QRESD) compiled by the national statistics agency;

Statistics Canada, 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. While the QRESD also provides fuel-use estimates at a provincial level, the accuracy of this data is not as high as that of the national data. Statistics Canada generally collects the fuel data for the QRESD by surveying the producers and suppliers of energy. 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 QRESD) may be capable of providing more accurate information at the sector level for future inventories.

References: *Fuel Combustion Activities (Sectoral Approach)*

IPCC, *Greenhouse Gas Inventory Reporting Instructions, Vol. 1,* and the IPCC, *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,* Report EPS5/AP/4, Environment Canada, 1992.

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

2.1.A.1 Energy Industries

Stationary Fuel Combustion

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.).

All mobile source fuel combustion emissions are included in the *Transportation* sector. Fugitive and flaring emissions are included under *B. Fugitive Emissions*.

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

[In the CGHGI this sector is titled *Electricity and Heat Production* and certain tables use the title *Electricity and Steam Generation.*]

This section includes fuel combustion emissions associated with the generation of electricity, and the production of steam, for commercial or public sale. In the case of steam turbine-generated electricity, electricity and heat may be produced simultaneously (cogeneration).

The UNFCCC and *Intergovernmental Panel on Climate Change Reporting Guidelines* require the Electricity and Heat Production sector to include only energy 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 category, 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. separate the electricity component from the heat component). Statistics Canada does distinguish industrial electricity generation data, but aggregates it into one category "industrial electricity generation". As a result we are unable to reallocate industrial electricity generation emissions to specific industrial sub sectors. Consequently, emissions associated with all electricity and heat production are 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. Solar electricity is used in remote locations, but solar panels are not generally connected to the electrical supply grid. 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 (gas turbine and reciprocating) engines.

Steam-turbine boilers are fired with coal, heavy fuel oil, natural gas, wood, or spent pulping liquors. (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: Electricity Production

The emissions associated with the *Electricity Production* sector are calculated using Equation 1. Greenhouse gas emissions are estimated based upon the quantities of fossil fuels consumed and, to some extent, the technology used to produce electricity. The emission factors employed to estimate emissions for electricity generation are sub-divided by the type of fuel used. It is important to note that these Canadian specific EFs differ from those of the UNFCCC in that they relate emissions to the quantity of fuel consumed and not to the energy content of the fuel. 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* (QRESD) compiled by the national statistics agency, Statistics Canada. (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: Heat Production

The emissions associated with the *Heat Production* sector are calculated using Equation 1. The EFs that were employed in estimating the GHG emissions for the current GHG inventory are illustrated Tables 1 to 5. The fuel data is from steam generation line in QRESD.

References: ***Public Electricity and Heat Production***

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

IPCC, *Greenhouse Gas Inventory Reporting Instructions, Vol. 1,* and the IPCC, *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* (QRESD), #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 QRESD does not explicitly report all the fuel consumption of the petroleum refining industry. Therefore, fuel usage has been estimated by summing the 'Producer Consumption' of refined petroleum products with the explicitly reported fuels purchased by the petroleum refining industry (i.e. those designated by *Standard Industrial Classification* (SIC) code #3611).
- 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.
- The QRESD does not differentiate between catalytic cracker coke and oven-derived petroleum coke; however these are produced by significantly different processes and have different carbon contents. It is assumed that 40% of the petroleum coke used by refineries on a national basis is generated in a catalytic cracker.

Emission Calculations: Petroleum Refining

The fuel combustion emissions associated with the *Petroleum Refining* sector are calculated using Equation 1. The EFs that were employed in estimating the GHG emissions for the current GHG inventory are illustrated Tables 1 to 3.

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) and the *Mining Industry*.

The fuel-use data reported in the QRESD combine marketable fuels purchased by mining, petroleum and natural gas production companies under one catchall economic sector called ‘mining’. Producer-consumed fuels (self-generated and used) in the *Upstream Oil and Gas Industry* are allocated separately under ‘Producer Consumption’, even though they may be consumed at the same establishment. This sector is also not covered under the ICE survey.

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

The *Mining* sector includes emissions resulting from combustion of the fuels reported under ‘mining’ (which includes *Upstream Oil and Gas* as well as metallic and non-metallic mineral mining) in the QRESD. The ‘producer consumption’ fuel-use data from the QRESD includes natural gas flared in the *Upstream Oil and Gas Industry*.

To avoid double-counting the *Flaring* emissions, estimated under *2.1.B Fugitive Emissions*, are subtracted from the total calculated for *Other Energy Industries* sector.

Emissions from transportation fuels are allocated to the transportation sector.

Emission Calculations: Manufacture of Solid Fuels & Other Energy Industries

The emissions associated with the *Manufacture of Solid Fuels & Other Energy Industries* sector are calculated using Equation 1. The EFs that were used to estimate the GHG emissions for the current GHG inventory are illustrated in Tables 1 to 5.

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 QRESD.

Emissions of CH_4 and N_2O from the combustion of biomass are included in the pulp and paper industrial sub-sector. CO_2 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.

2.1.A.2.a Iron and Steel

Facilities that conform to *1980 SIC Code #291* are accounted for in this sector.

Emission Calculations: Iron and Steel

All fuel-use data for this sector were obtained from the QRESD (Statistics Canada, #57-003) reported as Iron and Steel.
The fuel combustion emissions for each sub-sector within the *Manufacturing Industries and Construction* sector are calculated using Equation 1. The EFs that were employed in estimating the GHG emissions for the current GHG inventory are illustrated Tables 1 to 5.

Detailed information on the boilers, etc. for each point source was not available. Therefore, in order to calculate emissions for the various activities, it was necessary to make assumptions regarding the type of equipment employed. In general, the EFs for *Industrial Boilers* (see tables 1 to 5) were used.

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 *1980 SIC Code #295* are accounted for in this sector.

Emission Calculations: Non-Ferrous Metals

All fuel-use data for this sector were obtained from the QRESD (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 1. The EFs that were employed in estimating the GHG emissions for the current GHG inventory are illustrated Tables 1 to 5.

Detailed information on the boilers, etc. for each point source was not available. Therefore, in order to calculate emissions for the various activities, it was necessary to make assumptions regarding the type of equipment employed. In general, the EFs for *Industrial Boilers* (see tables 1 to 5) were used.

2.1.A.2.c Chemicals

Facilities that conform to *1980 SIC Codes* #371 & #3721 are accounted for in this sector.

Emission Calculations: Chemicals

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

The fuel combustion emissions for each sub-sector within the *Manufacturing Industries and Construction* sector are calculated using Equation 1. The EFs that were employed in estimating the GHG emissions for the current GHG inventory are illustrated Tables 1 to 5.

Detailed information on the boilers, etc. for each point source was not available. Therefore, in order to calculate emissions for the various activities, it was necessary to make assumptions regarding the type of equipment employed. In general, the EFs for either *Industrial* or *Commercial Boilers* (see tables 1 to 5) were used.

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

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

Facilities that conform to *1980 SIC Codes* #271 & #2512 are accounted for in this sector.

The common industrial grouping in Canada is Pulp Paper and Sawmills and this is reflected in the QRESD. Therefore, the sub-sector title was changed to *Pulp Paper and Sawmills* in the CGHGI. For the CGHGI, combustion emissions associated with *print* are included in the *Other Manufacturing* sub-sector.

Emission Calculations: Pulp, Paper and Print

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

The fuel combustion emissions for each sub-sector within the *Manufacturing Industries and Construction* sector are calculated using Equation 1. The EFs that were employed in estimating the GHG emissions for the current GHG inventory are illustrated Tables 1 to 5.

Emission Factors for methane and nitrous oxide releases from the combustion of biomass are illustrated in Table 11.

Detailed information on the boilers, etc. for each point source was not available. Therefore, in order to calculate emissions for the various activities, it was necessary to make assumptions regarding the type of equipment employed. In general, the EFs for *Industrial Boilers* (see tables 1 to 5) were used.

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 QRESD. Emissions from the *Food Processing, Beverage and Tobacc*o sector included in the *Other*, Section 3.1.1.2.6.

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

[Titled *Other Manufacturing* in the CGHGI.]

Facilities that conform to *1980 SIC Codes* #352 for *Cement*, #10 to #39 for *Other Manufacturing* and #401 to #429 for *Construction* are accounted for in this sector.

Emission Calculations: Other (Manufacturing Industries and Construction)

All fuel-use data for this sector were obtained from the QRESD (Statistics Canada, #57-003) as reported under cement, construction and other manufacturing.

The fuel combustion emissions for each sub-sector within the *Manufacturing Industries and Construction* sector are calculated using Equation 1. The EFs that were employed in estimating the GHG emissions for the current GHG inventory are illustrated Tables 1 to 5.

Detailed information on the boilers, etc. for each point source in the country was not available. Therefore, in order to calculate emissions for the various activities in a wide variety of industries, it was necessary to make assumptions regarding the type of equipment employed. In general, the EFs for either Industrial or Commercial Boilers (see tables 1 to 5) were used for each sub-sector.

References: ***Manufacturing Industries & Construction***

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*, *EXCEL Draft*, November 1999.

2.1.A.3 Transport

[Titled *Transportation* in the CGHGI.]

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

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

General Emission Calculations: Transport

The fuel combustion emissions associated with the *Transport* sector are calculated using various adaptations of Equation 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 Emissions 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 1999 to include new Canadian, U.S. and international findings on N_2O and CH_4 emissions. More accurate data on vehicle populations were also incorporated (Neitzert et al, 1999).

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, Tables 6 and 7.

2.1.A.3.a Civil Aviation

[Titled *Aviation* in the CGHGI.]

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 Transportation*) 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: Civil Aviation

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 QRESD (Statistics Canada, #57-003), reported as domestic air, are multiplied by fuel-specific emission factors, Table 7. Also included are aviation gasoline and aviation turbo fuels used in the public administration and commercial/institutional categories.

Carbon dioxide emission factors were derived by Environment Canada (Jaques, 1992).

Emission factors for methane and nitrous oxide are from published data (De Soete, 1989 and Prigent, 1991).

2.1.A.3.b Road Transportation

[Titled *Road Transport* in the CGHGI.]

M-GEM uses a far more detailed procedure for calculating emissions from *Road Transportation*. 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 sub-divide *Road Transportation* into numerous sub-sectors as emissions are related to vehicle type. So-called *Light-Duty Vehicles* comprise automobiles and light trucks. The IPCC Road Transportation sub-sectors are: (IPCC, 1997, V1)

> ***Cars***: Automobiles designated primarily for transport of persons and having a capacity of 12 persons or fewer. Gross vehicle weight rating of 3900 kg or less.
> ***Light-Duty Trucks**:* Vehicles with a gross vehicle weight rating of 3900 kg or less 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 Transportation* 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, NMVOC and NOx 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 **CO_2** releases from vehicles are not considered to be technology-dependent, **CH_4** and **N_2O** emission levels are affected by changes in emission control equipment. For CH_4 emissions, vehicles equipped with more sophisticated controls tend to have lower emission rates. The effect of pollution-limiting equipment on N_2O emissions is a more complex matter. Catalytic converters began to become the primary means to control hydrocarbon and subsequently, NOx emissions from gasoline vehicles in the late 1970s and early 1980s. Oxidation catalysts appeared first, followed later by the so-called *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 *Light-Duty Vehicles* in North America in 1994. However, to date, research indicates that all catalytic control units increase N_2O 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 N_2O emission performance 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 an 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 with the vast majority being automobiles.

Emission Calculations: *Road Transportation*

The methodology used to evaluate *Road Transportation* 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 Transportation*.

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 Transportation* was obtained from retail pump sales and sales to commercial fleets' data in the QRESD (Statistics Canada, #57-003). Statistics Canada also reports transport fuel use in the agricultural, commercial, industrial and institutional economic sectors, but there is uncertainty as to whether these fuels are used by vehicles on or off-road. In the QRESD, on-road fuel use, is a subset of all (non-rail) ground transportation fuel use.

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

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

$$E = [EF_{Category}] \times [Fuel_{Category}] \qquad \textbf{Equation 1 (vehicles)}$$

Where:

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

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

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

Where:

$Fuel_{Ground\ (non\text{-}rail)}$ = the total fuel used by all categories of ground transport (except rail), as reported by Statistics Canada.
$Fuel_{Road}$ = the quantity of fuel used for on-road transportation.
$Fuel_{Off\text{-}road}$ = the quantity of fuel used for off-road transportation *(Including: agricultural, industrial and construction vehicles as well as snowmobiles, recreational vehicles, etc.)*

For the purposes of this inventory, it was assumed that, for the Transportation sector, all natural gas and propane are used in *Road Transportation* 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:

$$Fuel_{Road\ Category} = [Vehicle\ population] \times [Average\ distance\ driven/year] \times [Fuel\ Consumption\ Ratio] \qquad \textbf{Equation 3}$$

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 (Warbanski, 1998), which was extrapolated to provide estimates for 1997. The above information was sufficient for all vehicle types with the exception of motorcycles. Motorcycle data was obtained from Statistics Canada (Statistics Canada, #53-218). 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 were 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) and 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 determined 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, 1998) 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 U.S., 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 sub-category of light-duty gasoline automobiles and trucks are calculated by apportioning the model-year consumption data according to the vehicle age and control technology 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 were 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 QRESD. 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 Transportation **CO_2** emission factors are fuel-dependent (Jaques, 1992).

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. Methane emission factors adopted for each of these vehicle types were those recommended by the IPCC for North American vehicles (IPCC, 1997). These factors originated with the EPA as a result of its work with the *Mobile5* vehicle emission model, and were reported in 1996. They are given as ranges within each vehicle type, with the actual value dependent upon the type of inspection and maintenance program in effect in the region within which they operate (Weaver, 1996). For Canada, the average value within each range was chosen. For example, the emission rate for older automobiles equipped only with *non-catalytic emission control* is 0.52 g CH_4 /l of gasoline. For vehicles having advanced *Tier 1* technology the rate is 0.25 g CH_4 /l.

Several studies report **emissions of N_2O** from cars equipped with and without catalytic converters (Dasch, 1992; Urban, 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 N_2O. Studies show that N_2O likely represents less than 1% (between 0.4 and 0.75%) of the over-all NOx emissions from either gasoline or diesel engines without catalytic converters. However, N_2O is produced when NO and NH_3 react over the platinum in catalytic converters. The production of N_2O is highly temperature dependent. It was found that platinum-rhodium 3-way catalysts, that decrease NOx emissions, could increase the N_2O concentration in the exhaust during catalyst light-off, yet still produce very little N_2O at medium temperatures (400 to 500ºC). A peak of N_2O formation was observed close to the catalyst light-off temperature and found that the amount of N_2O emitted increased 2 to 4.5 times after aging. The increase in N_2O emissions appeared to be due to a shift in light-off temperature caused by aging. As a consequence, the catalyst operated in the optimum temperature range for N_2O formation (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 10 vehicles with aged converters and 0.4 g/l for the four vehicles with the new, un-aged, 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. N_2O emission rates of 0.25 and 0.58 g/l of fuel, respectively for new and aged 3-way catalyst-equipped *Tier 0* automobiles, have been 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 N_2O emission studies issued by the U.S. EPA (Michaels, 1998), have been incorporated. In the same study also documented EPA tests conducted in 1998 on a small sample of newer technology North American vehicles. These vehicles were equipped with *Tier 1,* aged catalytic converters. Average measured N_2O emission rates were about 50% lower, under standard conditions, than those reported for *Tier 0* vehicles (Barton and Simpson, 1995). On the basis of these tests, 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 N_2O emission rates used in M-GEM are 0.39 g/l for *Tier 1* types and 1.0 g/l for aged *Tier 0* types.

Detailed emission factors are presented in Table 6.

2.1.A.3.c Railways

[Titled *Rail* in the CGHGI.]

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

Emission Calculations: Railways

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

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

CO_2 emission factors were derived by Environment Canada. (Jaques, 1992)

Emission factors for methane and nitrous oxide are from the IPCC. (IPCC, 1997)

2.1.A.3.d Navigation

[Titled *Marine* in the CGHGI.]

The UNFCCC uses the title *Navigation* for this, but lists *International Bunker* related emissions under *Marine*. However, *Marine* seems a more appropriate label for this sub-sector and is used in the CGHGI.

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 currently not available.

Emission Calculations: Navigation

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

Emissions are estimated using the M-GEM model.

Fuel consumption data are from the QRESD (Statistics Canada, #57-003), reported as marine, are multiplied by fuel-specific emission factors, Table 7.

The QRESD lists quantities of each of the refined petroleum products used by marine vessels (i.e., heavy fuel oil, diesel oil, light fuel oil and gasoline), therefore, based upon fuel type, emissions have been disaggregated by these by vessel type.

CO_2 emission factors were derived by Environment Canada. (Jaques, 1992)

Emission factors for methane and nitrous oxide from marine sources are from the IPCC. (IPCC, 1997)

2.1.A.3.e Other: Transport

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

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 Transport

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.

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: Pipeline Transport

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 are from the QRESD (Statistics Canada, #57-0035), reported as pipelines, are multiplied by fuel-specific emission factors.

Fuel-based emission factors are used are those for Industrial Boilers, Tables 1 and 2.

References: *Transport*

IPCC, *Greenhouse Gas Inventory Reporting Instructions, Vol. 1,* and the IPCC, *Greenhouse Gas Inventory Reference Manual, Vol. 3,* Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, 1997.

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, EXCEL Draft,* November 1999.

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2.1.A.4 Other Sectors

[Titled *Non-Industrial Stationary Combustion Sources* in CGHGI.]

Biomass is used as a fuel primarily in the residential sub-sectors, the earlier note regarding biomass combustion applies: (See Section 2.1.A)

There are emissions of CO_2 from the combustion of biomass used to produce energy. However, as per UNFCCC requirements, CO_2 emissions from biomass fuels are not included in the Energy category totals nor in the sectors or sub-sectors. CO_2 are accounted for in the Land Use Change and Forestry (LUCF) category 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. Temperature severity is approximated by using the average number of 'heating degree days' over the winter season. This value is calculated by determining the average, cross-Canada number of days below 18 degrees C and multiplying it by the corresponding number of degrees below this temperature.

Emission Calculations: Commercial/Institutional

The fuel combustion emissions associated with the *Commercial/Institutional* sector are calculated using Equation 1.

The EFs that were employed in estimating the GHG emissions for the current GHG inventory are those as specified for Commercial Boilers in Tables 1 and 2.

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

All transportation fuels are reallocated to the *Transportation* category.

2.1.A.4.b Residential

[*Residential* in the CGHGI.]

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: Residential

The fuel combustion emissions associated with the *Residential* sector are calculated using Equation 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 *Residential Boilers* and *Residential Furnaces* in Tables 1 and 2, respectively.

The EFs for biomass combustion in *Wood-Stoves* and *Fireplaces* are listed in Table 11. The methodology for biomass combustion is detailed in section 2.1.C.3

Fossil Fuel use information is extracted from the residential data in the QRESD (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 were included for the *Agriculture* and *Forestry* portion of the sub-sector only, fishery emissions are reported under either transportation or other manufacturing. Mobile emissions associated with this sub-sector were not disaggregated and are included as off-road, or marine emissions reported under *Transportation*.

Since *Fisheries* fuel use data are not disaggregated in the QRESD, all *Fisheries* emissions are reported under the Marine sector of the Transportation category.

Emission Calculations: Agriculture/Forestry/Fisheries

The fuel combustion emissions associated with the *Agricultural* sub-sector are calculated using Equation 1.

The EFs that were employed in estimating the GHG emissions for the current GHG inventory are those as specified for Commercial and Industrial Boilers in Tables 1 and 2.

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

References: ***Other Sectors***

Statistics Canada, *Quarterly Report on Energy Supply-Demand in Canada* (QRESD), #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 under transportation category, while stationary military use has been included under the institutional category.

2.1.A.5.a Stationary

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

2.1.A.5.b Mobile

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

2.1.B Fugitive Emissions from Fuels

[In the CGHGI this sub-category is entitled *Fugitive Emissions*. 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.

Fugitive emissions from mobile *Transportation* sources (either during fueling or after) in general 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 emission estimates for 1990 (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: Coal Mining

The emissions were estimated by multiplying coal production data (from Statistics Canada, #45-002) by the emission factors in Table 12.

The method used to estimate emission rates from coal mining was based on a modified procedure from the Coal Industry Advisory Board. It consists of a mixture 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. Where measured data was not available, estimates were made (King, 1994).

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

$$Y = 4.1 + (0.023*X) \quad \textbf{Equation 4}$$

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

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

Surface Mines

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

A significant source of emissions from surface mines is the surrounding un-mined strata. An attempt was made to account for this by applying a high-wall adjustment to account for the out-gassing of the surrounding un-mined 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 Table 12 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 1.5m^3 /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 *Other 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* and *Natural Gas Distribution*.

2.1.B.2.a Oil

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

2.1.B.2.b Natural Gas

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

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. Some of the sources include:

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 pigging 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 <900kg/m3). 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 >900kg/m3. 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 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 (NGL) 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 is not included due to insufficient data.

Surface Casing Vent Blows and Gas Migration

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

Emission Calculations: Conventional Upstream Oil and Gas

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 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.

The 1997-8 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 between 1996 and 1998. This method was used on an interim basis until new data are available. The data used for the extrapolations were:

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, Vents Blows, and Gas Migration	Constant at 1996 levels

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

The 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 and that 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: Unconventional Crude Oil Production

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

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: Natural Gas Distribution
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 EPA, other published sources, and engineering estimates.

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

General emission factors were developed for the distribution system based on the study (Radian,1997) data and gas distribution pipeline distances published by Statistics (Statistics Canada, Catalogue No. 57-205).

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

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 CO_2 Releases

Raw natural gas contains carbon dioxide; this is removed and vented to the atmosphere at processing facilities. These are titled *Raw* CO_2 *Releases* and categorized as venting in the CRF.

Emission Calculations: Venting

Emissions are calculated based on the data from the CAPP/EC study (Picard, 1999). 1997 and 1998 data has 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: Flaring

Emissions are calculated based on the data from the CAPP/EC study (Picard, 1999). 1997 and 1998 data has 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: *Fugitive Emissions from Fuels*

Statistics Canada, *Coal and Coke Statistics*, 1990-1998, annual editions, #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., *CH_4 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. *CH 4 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 System*s, 1990-1998, annual editions, Catalogue #57-205.

Statistics Canada, *Crude petroleum and Natural Gas Productio*n, 1990-1998, annual, #26-006.

Statistics Canada, *Gas Utilities, Transport and Distribution System*s, 1990-1998, annual #57-205.

2.1.C Memo Items

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

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 calculations. 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 is 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 QRESD.

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 QRESD.

2.1.C.2 Multilateral Operations

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

2.1.C.3 CO_2 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* category totals. They are accounted for in the *Land Use Change and Forestry* category, and are recorded as a loss of biomass (forest) stocks. Methane and nitrous oxide emissions from biomass fuel combustion were reported in this *Energy* category in the appropriate sectors.

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

Residential Firewood

The wood consumed by various types of wood burning appliances were grouped into six categories:

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

Emission Calculations: Residential Firewood

The calculation of greenhouse gas emissions from the combustion of *Residential Firewood* is based on a study commissioned by the National Emissions Inventory and Projection Task Group (Canadian Facts, 1997). The study collected firewood consumption data in terms of appliance type.

The firewood consumption data was used to extrapolate the amount of wood burned in the years 1990 to 1995, and 1997. Statistics Canada and Natural Resources Canada data were not used, since they appear to greatly underestimate firewood consumption as a significant portion of firewood consumed in Canada is not from commercial sources.

The method used to extrapolate data consisted of two steps. The first step was to develop a growth factor on a provincial level for each year. It was assumed that firewood use would change with heating degree-days below 18 degrees Celsius. Since the firewood data was from 1996, that was considered to be the base year. The growth factor for each year was then calculated by dividing the degree-days of each year by the degree-days of the base year. The second step of the extrapolation was to multiply the tonnes of wood burned in 1996 in each of the appliance categories by the appropriate growth factors. This provided an estimate of the amount of wood burned in the years 1990 to 1995, and 1997.

The nitrous oxide and methane emission factors for different wood burning appliances are from the US EPA's AP-42, supplement B. (EPA, 1996) The EFs are listed in Table 11. These emissions are included in the residential sector of the inventory.

The emission factors for carbon dioxide are from an Environment Canada study. (ORTECH, 1994) The EFs are listed in Table 11.

Emissions were calculated using Equation 1. The amount of wood burned 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 QRESD. (Statistics Canada, #57-003) The Statistics Canada data for 1990 and 1991 were combined for the Atlantic provinces as were the data for the Prairie provinces. Individual provincial data were delineated by employing a data comparison with the 1992 QRESD data. Unfortunately, for 1992, the data for Newfoundland and Nova Scotia was also combined and there were no comparable data to allow separation. Emissions are listed under Nova Scotia.

Emission Calculations: Industrial Firewood & Spent Pulping Liquors

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

Industrial Firewood CO_2 and CH_4 emission factors are those assigned by the US EPA to Wood Fuel/Wood Waste (EPA, 1996) see Table 11. For methane, emission factors were given for three different types of boilers; the EF in Table 11 is an average for the three.

Industrial Firewood N_2O emission factors are those assigned to *Wood Fuel/Wood Waste*, (Rosland, 1990), (Radke, 1991) see Table 11.

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, and
2. There was a 95% conversion of the carbon to carbon dioxide.

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

$$\text{EF } CO_2 = 0.41 * 0.95 * (44 \text{ g/mol}/ 12 \text{ g/mol}) \quad \textbf{Equation 5}$$
$$= 1.428 \text{ tonne } CO_2 / \text{tonne spl}$$

(Note: this EF has been rounded to 1500 g/kg as illustrated in Table 11.)

Spent Pulping Liquor EFs for CH_4 and N_2O are not known. Emissions were not estimated and assumed to be negligible.

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

References: *Memo Items*

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

EPA, *Compilation of Air Pollutant Emission Factors, Volume 1, Stationary Point and Area Sources*, U.S. Environmental Protection Agency, 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, #57-003.

Taylor, S.W. and K.L. Sherman, *Biomass Consumption and Smoke Emissions from Contemporary and Prehistoric Wildland Fires and British Columbia*, FRDA Report 249, Prepared by the Canadian Forest Service, Pacific Forestry Centre, 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 Steen, M., *Klimgass-Regnshap For Norge*, Statens Forurensningstilsyn, Oslo, Norway, 1990.

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

2.2 Industrial Processes

This category 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* category.

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 ($CaCO_3$) from limestone, chalk, or other calcium-rich materials is heated in a high-temperature kiln, forming lime (CaO) and carbon dioxide in a process called *calcination* or *calcining*:

$$CaCO_3 + Heat \rightarrow CaO + CO_2$$ **Equation 6**

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* category and are not considered in this section.

Emission Calculations: *Cement Production*

The emission factor for CO_2 emissions from *Cement Production* is based on the lime content of clinker. It was assumed that the clinker produced in Canada has an average lime content of 63.5% (Jaques, 1992) and that all the cement produced in Canada is of the Portland type (Table 8).

Cement Production data are obtained from the *Canadian Minerals Yearbook* (NRCan, 1999). For provinces where data are confidential, estimates have been made based on plant capacity.

CO_2 emissions are estimated by applying an emission factor of 500g CO_2 /kg cement to the yearly national cement production. (Table 8)

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 *Cement Production*, Section 2.2.A.1.

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

$$CaCO_3 \bullet MgCO_3 \text{ (dolomite)} + \text{heat} \rightarrow CaO \bullet MgO \text{ (dolomitic lime)} + 2CO_2 \quad \textbf{Equation 7}$$

Emissions from the regeneration of lime from spent pulping liquors at pulp mills are not included in the inventory. Since this CO_2 is biogenic in origin, it is recorded as a change in forest stock in the *Land Use Change and Forestry* category.

Emission Calculations: Lime Production

The mass of CO_2 produced per unit of lime manufactured may be estimated from a consideration of the molecular weights and the lime content of products (ORTECH, 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, 1999).

The emissions are estimated by applying an emission factor of 790g CO_2 /kg quicklime produced in Canada. (Table 8)

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 temperature. Therefore, the limestone is calcined to lime, producing CO_2 by the same reaction described for *Cement Production*, 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: Limestone and Dolomite Use

Data on the consumption of raw limestone by the glass and metallurgical smelting industries was obtained from the Canada Minerals Yearbook (NRCan, 1998)

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 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:

$$\text{EF} = 44.01 \text{ g/mole } CO_2 / 105.99 \text{ g/mole } Na_2CO_3 = 415 \text{ kg/tonne } Na_2CO_3 \qquad \textbf{Equation 7}$$

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.

Soda Ash Production: 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: Soda Ash Production and Use

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

[Title not listed in the CGHGI.]

Not estimated

2.2.A.6 Road Paving with Asphalt

[Title not listed in the CGHGI.]

Not estimated

2.2.A.7 Other: Mineral Products

[Title not listed in the CGHGI.]

References: *Mineral Products*

ORTECH International, *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*, Report EPS5/AP/4, Environment Canada, 1992.

NRCan, Natural Resources Canada, *Canadian Minerals Yearbook*, Natural Resources Mining Sector, Ottawa, annual editions 1990 to 1999.

IPCC, *Greenhouse Gas Inventory Reporting Instructions, Vol. 1*, and the IPCC, *Greenhouse Gas Inventory Reference Manual, Vol. 3*,Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, 1997.

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

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

Statistics Canada, *Non-Metallic Mineral Product Industries*, 1990-1993, Statistics Canada #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 procedure is an agricultural application, it is accounted for under CO_2 emissions from soils in the *Agriculture* category. 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 CO_2 emitted by *Ammonia Production*. As far as actual inventory totals are concerned all carbon dioxide emitted from non-energy use of fossil fuels is calculated according to the method of undifferentiated non-energy product use (see Section G. Other).

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: Ammonia Production

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 CO_2 /t NH_3 produced was developed using typical material requirements for ammonia production in Canada. (Jaques, 1992) (Note: this was rounded to 1600 g/kg, Table 8.)

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 (HNO_3) is produced from ammonia (NH_3), nitrous oxide (N_2O) is emitted. Nitrous oxide emissions are in proportion to the amount of ammonia used and the concentration of N_2O in the exhaust gases depends on the type of plant and its emission controls. Canada-specific emission factors were developed, based on the type of abatement technology that is employed at individual plants.

One of the first attempts to estimate emissions of N_2O for this sector used information provided by global industry, which in turn were based on company-specific measurements and calculations (ICI, 1991; Norsk Hydro, 1991). These estimates reported emissions ranged from

2 to 20 kg of N_2O/t of ammonia consumed in the production of HNO_3. However, subsequent investigations indicated that emissions from Canadian plants were at the low end of this range (Collis, 1992).

Emission factors were developed for: (Table 13)

1) plants with catalytic converters,
2) plants with extended absorption for NOx abatement type 1, and
3) plants with extended absorption for NOx abatement type 2.

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

Emission Calculations: Nitric Acid Production

For Alberta it has been assumed that 175 kt HNO_3 are produced by plants with extended type 1 and 30 kt HNO_3 are produced by plants with extended type 2, the remainder were from catalytic converter type plants.

Emission factors are listed in Table 13.

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 N_2O are produced and are usually vented to the atmosphere.

There is one *Adipic Acid Production* facility in Canada. In 1997 emission-abatement technology was installed at that plant. That facility also began a program of emissions monitoring in 1997 to determine the performance of the abatement system.

Emission Calculations: Adipic Acid Production

The emissions factor is listed in Table 13. 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 producer of adipic acid, Dupont Maitland plant. The emissions were estimated based upon their production of adipic acid for the period 1990-96 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: *Chemical Industry*

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

Statistics Canada, *Industrial Chemicals and Synthetic Resin*s, December 1999, #46-006.

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

ICI, Letter from A. McCulloch, 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.

IPCC, *Greenhouse Gas Inventory Reporting Instructions, Vol. 1,* and the IPCC, *Greenhouse Gas Inventory Reference Manual, Vol. 3,*Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, 1997.

Thiemens, M.C. and U.C. Trogler, *Nylon Production: an Unknown Source of Atmospheric Nitrous Oxide*, Science, 251: 932-934, 1991.

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 CO_2 and emitted to the atmosphere. Some carbon is stored in the pig iron. However, this is mostly released to the atmosphere during the steel production process. Steel is made from pig iron and/or scrap steel using electric arc, basic oxygen, or cupola furnaces.

The 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 under *Other*, 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* category.

Emission Calculations: Iron and Steel Production

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).

CO_2 emissions were estimated by applying the combustion emission factor for metallurgical coke (Table 4) 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 the sector 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 (Al_2O_3) is dissolved in a fluorine bath consisting primarily of cryolite (Na_3AlF_6). Passing a current through the resistance of the cell causes the heating effect which maintains the contents in a liquid state. Molten aluminum is evolved while the anode is consumed in the reaction. The aluminum forms at the cathode and gathers on the bottom of the pot.

Three greenhouse gases: carbon dioxide, carbon tetrafluoride (CF_4) and carbon hexafluoride (C_2F_6), are known to be emitted during the reduction process. The latter two, CF_4 and C_2F_6, are classified as perfluorocarbons (PFCs). PFCs are extremely inert, and are potent greenhouse gases. CF_4 has a 100-year *Global Warming Potential* (GWP) of 6500 while C_2F_6 has a GWP of 9200.

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

$$Al_2O_3 + 3/2C \rightarrow 2Al + 3/2CO_2 \qquad \textbf{Equation 7}$$

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 *Other*, Section 2.2.G.

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

$Na_3AlF_6 + 3/4C \rightarrow Al + 3NaF + 3/4\ CF_4$ **Equation 8** and,

$Na_3AlF_6 + C \rightarrow Al + 3NaF + 1/2\ C_2F_6$ **Equation 9**

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: Aluminum Production

CO_2 production based emission factors for Canadian aluminum smelting were calculated, see Table 8. (ORTECH, 1994)

It has been possible to establish average PFC emission rates for all aluminum plants in Canada, Table 8. (Unisearch, 1994)

Aluminum Production data for each facility were estimated by prorating national production data using published yearly plant capacities. (NRCan, 1999).

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 oxidization of the molten metal. It is vented to the atmosphere immediately after use. Although emitted in relatively small quantities, SF_6 is an extremely potent greenhouse gas, with a 100-year GWP of 23900.

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

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

Emission Calculations: SF_6 Used in Aluminum & Magnesium Foundries

SF_6 consumption data were reported directly by the magnesium producers. It was assumed that 100% of the consumed gas was released to the atmosphere.

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

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

Emissions of CO_2 from the oxidation of fossil fuel based reducing agents in the production of other metals are included in the national inventory. These emissions are included under *Other*, 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: ***Metal Production***

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

IPCC, *Greenhouse Gas Inventory Reporting Instructions, Vol. 1,* and the IPCC, *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* CF_4 and C_2F_6 , U.S. 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* CF_4 and C_2F_6 *in the Emissions from Canadian Aluminum Smelters by Tunable Diode Absorption Laser Spectroscopy*, Report to the Canadian Aluminum Association, April 1994.

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

NRCan, Natural Resources Canada, *Canadian Minerals Yearbook*, Aluminum, Natural Resources Mining Sector, Ottawa, annual editions 1990 to 1998.

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

AIA, Association de l'Industrie d'Aluminium du Québec, *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 SF_6

Not occuring

2.2.F Consumption of Halocarbons and SF_6

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

The major emissions are from the use of Hydrofluorcarbons (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.

There is no known production of HFCs in Canada. All HFCs are imported. 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 the others.

1995 HFC emission estimates were based on data from an initial HFC Survey conducted by the Commercial Chemical Division of Environment Canada and used a modified **IPCC Tier 1 Methodology**. The Commercial Chemical Division has since revised the HFC Survey to obtain more detailed HFC activity data in Canada. **IPCC Tier 2 Methodology** was used to estimate **1996, 1997 and 1998 HFC emissions** based on detailed HFC activity data provided by the HFC Survey.

Detailed 1995 HFC data was 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.

2.2.F.1 Refrigeration and Air Conditioning Equipment

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

The major sources of hydrofluorocarbons (HFCs) emissions are *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).

Emission Calculations: Refrigeration and Air Conditioning Equipment

1995 HFC emission estimates used an **adaptation of the IPCC Tier 1** default method (IPCC, 1997). Total potential emissions can be estimated by the Tier 1 methodology, but in this case it must be assumed that no HFCs are destroyed and that all the product distributed in one year is emitted during that year. This method greatly overestimates emissions, since most of the

HFCs consumed are not emitted until the manufactured product is retired. 1995 emission factors were developed, based on loss rates, adapted from the IPCC methodology (IPCC, 1997).

1995 HFC Estimate – 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* are 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:

HFC (refrig) = Charge + Operating Loss **Equation 10**

The IPCC considers that *Operating Loss* is approximately 0.17 *Charge* (IPCC, 1997). Therefore, assuming the total *Charge* remains constant for the short term:

HFC (refrig) = 0.17Charge + Charge = 1.17Charge **Equation 11**
or,
Charge = HFC (refrig)/1.17 **Equation 12**

Assuming assembly leakage is minimal:

Emission = operating loss = 0.17Charge **Equation 13**
Thus,
Emission ~ 0.17{[HFC (refrig)]/1.17} **Equation 14**

1996, 1997 and 1998 HFC emission estimates for 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 from each equipment (IPCC, 1997),

$$E_{\text{assembly, t}} = E_{\text{charged, t}} * k \qquad \textbf{Equation 15}$$

where:

$E_{\text{assembly, t}}$ = emissions during system manufacture & assembly in year t

$E_{\text{charged, t}}$ = the amount of refrigerant charged into new systems in year t

k = assembly losses in percent of the amount charged

The k value was chosen from a range of values that were provided for each equipment category in the revised IPCC guidelines, refer to Table 2.2.F.1-1: Equipment Categories and k values (IPCC, 1997). The amount of refrigerant charged was provided the Commercial Chemical Division's HFC database.

Table 2.2.F.1-1: Equipment Categories and k Values

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

Annual Leakage

The same four categories from System Assembly were used to calculate emissions due to annual leakage. The equation given in the revised IPCC guidelines was used to calculate **1996, 1997 and 1998 HFC** emissions due to annual leakage (IPCC, 1997),

$$E_{\text{operation, t}} = E_{\text{stock, t}} * x \qquad \textbf{Equation 16}$$

Where:

$E_{\text{operation, t}}$ = amount of HFC emitted during system operation in year t

$E_{stock, t}$ = amount HFC stocked in existing systems in year t
x = annual leakage rate in percent of total HFC charge in the stock

The amount of HFC stocked in existing systems includes the HFCs in equipment manufactured in Canada, the amount of HFC in imported equipment, the amount of HFCs in converted CFC equipment and excludes the amount of HFCs in exported equipment. The amount of HFCs that were used in converted CFC equipment were estimated based on the amount of HFCs used for servicing equipment. It was assumed that no leakage occurs in the year of manufacturing or conversion. HFC activity data were obtained from the Commercial Chemical Division's HFC database.

The IPCC guidelines gave 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 are shown in Table 2.2.F.1-2: Annual Leakage Rate (IPCC, 1997).

Table 2.2.F.1-2: Annual Leakage Rate (x)

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

System Disposal

1996, 1997 and 1998 HFC emissions from system disposal was not estimated, since HFCs use only began in 1995 and is assumed to be negligible.

References:

HFC Survey (HFC Database) the *Commercial Chemicals Branch,* Environment Canada

IPCC/OECD/IEC ***Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories***, IPCC London, U.K, 1997

2.2.F.2 Foam Blowing

[Titled Foams in the CGHGI.]

Emission Calculations: Foam Blowing

1995 HFC emission estimates used an adaptation of the **IPCC Tier 1** default method (IPCC, 1997). It was assumed for 1995, that all *Foams* produced are open cell foams. Total potential emissions can be estimated by the Tier 1 methodology, but in this case it must be assumed that no HFCs are destroyed and that all the product distributed in one year is emitted during that year. This method greatly overestimates emissions, since most of the HFCs consumed are not emitted until the manufactured product is retired. 1995 emission factors 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, 1997 and 1998 HFC 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). The Commercial Chemical Division's HFC database contain 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 used are emitted (IPCC, 1997). The remaining quantity of HFCs 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,

$$E_{\text{foam, t}} = 10\%\ E_{\text{manufacturing, t}} + 4.5\%\ E_{\text{foam\_stock, t}} \quad \textbf{Equation 17}$$

Where:

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

$E_{\text{manufacturing, t}}$ = the amount of HFCs used in manufacturing closed cell foam in year t

$E_{\text{foam\_stock, t}}$ = the amount of HFCs in stock in year t

The amount of HFCs used in manufacturing closed cell foam and amount in stock was provided by the Commercial Chemical Division's HFC database.

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:

HFC Survey (HFC Database) the *Commercial Chemicals Branch*, Environment Canada

IPCC/OECD/IEC ***Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories***, IPCC London, U.K, 1997

2.2.F.3 Fire Extinguishers

[Titled Fire Extinguishing Equipment in the CGHGI.]

Emission Calculations: Total Flooding Systems

1995 HFC emission estimates used an **adaptation of the IPCC Tier 1** default method (IPCC, 1997). Total potential emissions can be estimated by the Tier 1 methodology, but in this case it must be assumed that no HFCs are destroyed and that all the product distributed in one year is emitted during that year. This method greatly overestimates emissions, since most of the HFCs consumed are not emitted until the manufactured product is retired. 1995 emission factors were developed, based on loss rates, adapted from the IPCC methodology (IPCC, 1997).

HFC Emissions from Fire Extinguishing

There were 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, 1997 and 1998 HFC emissions** from portable fire extinguishers and total flooding systems (IPCC, 1997).

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 Commercial Chemical Division’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 Commercial Chemical Division’s HFC database.

References:

HFC Survey (HFC Database) the *Commercial Chemicals Branch*, Environment Canada

IPCC/OECD/IEC ***Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories***, IPCC London, U.K, 1997

2.2.F.4 Aerosols/ Metered Dose Inhalers

[Titled *Aerosols* in the CGHGI.]

Emission Calculations: Aerosols/ Metered Dose Inhalers

1995 HFC emissions estimate used an **adaptation of the IPCC Tier 1** default method (IPCC, 1997). Total potential emissions can be estimated by the Tier 1 methodology, but in this case it must be assumed that no HFCs are destroyed and that all the product distributed in one year is emitted during that year. This method greatly overestimates emissions, since most of the HFCs consumed are not emitted until the manufactured product is retired. 1995 emission factors 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, 1997 and 1998 HFC emissions** from aerosols (IPCC, 1997). Following this method, the emissions for the current year are equal to half of the HFCs used to 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 Commercial Chemical Division's HFC database.

References:

HFC Survey (HFC Database) the *Commercial Chemicals Branch,* Environment Canada

IPCC/OECD/IEC ***Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories***, IPCC London, U.K, 1997

2.2.F.5 Solvents

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

Perfluorocarbons (PFCs) are used in some industrial solvents and cleaners. Emissions of PFCs, other than from primary metal manufacture, were not estimated due to lack of data.
Current consumption of PFCs is believed to be insignificant in comparison to the by-product emissions of PFCs from primary aluminum manufacture.

Emissions from HFC used as Solvents

The **IPCC Tier 2 methodology** presented in the revised IPCC guidelines was used to calculate **1996, 1997 and 1998 HFC emissions** from solvents (IPCC, 1997). Following this method, emissions for the current year is equal to half of the HFCs used as solvents in the current year plus half of the HFCs used as solvents in the previous year. The amount of HFCs used each year is equal to the amount of HFCs produced and imported as solvents, and excludes the amount of HFCs exported as solvents. To calculate the amount of each type of HFC used as solvents each year's activity data were provided by the Commercial Chemical Division's HFC database. HFC used as solvents includes the following categories:

- Electronic industries
- Laboratory solvents
- General cleaning

References:

HFC Survey (HFC Database) the *Commercial Chemicals Branch,* Environment Canada

IPCC/OECD/IEC ***Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories***, IPCC London, U.K, 1997

2.2.F.6 Semiconductor Manufacture

Inventoried in Section 2.2.F.5

2.2.F.7 Electrical Equipment

Inventoried in Section 2.2.F.5

2.2.F.8 Other: Consumption of Halocarbons and SF_6

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 CO_2 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: Other (Industrial Processes)

The IPCC average rates of carbon storage in non-energy products were used to develop emission factors, Table 9. (IPCC, 1997)

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. (Tables 1 to 3)

References: *Other* (Industrial Processes)

IPCC, *Greenhouse Gas Inventory Reporting Instructions, Vol. 1,* and the IPCC, *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* (QRESD), #57-003

2.3 Solvent and Other Product Use

One distinction between the sources in the *Solvent and Other Product Use* category and those in the *Industrial Processes* category is that the former are generally *Area Sources*.

The majority of emissions in this category are also related to the use of nitrous oxide (N_2O) as an anaesthetic and a propellant.

> Note: Hydrofluorcarbons (HFCs) as replacements for Chlorofluorocarbons (CFCs) was originally reported in this category, but the UNFCCC now requires these emissions to be reported in the Industrial Processes category (See Section 2.2.F Consumption of Halocarbons and SF_6) Emissions related to HFC consumption are not point sources and would be more appropriately categorized as product use emissions.

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 N_2O 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: Use of N_2O for Anaesthesia

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 is from Statistics Canada (Statistics Canada, #91-213).

2.3.D.2 N_2O from Fire Extinguishers

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

Not known to occur

2.3.D.3 N_2O from Aerosol Cans

[Reported under *Anaesthetic and Propellant Usage* the 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 N_2O used in propellants was emitted to the atmosphere during the year of sale.

Emission Calculations: N_2O from Aerosol Cans

An emission factor was developed for N_2O used in propellants based upon consumption patterns in Canada in 1990, Table 10.

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

2.3.D.4 Other: Use of N_2O

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

References: ***Solvent and Other Product Use***

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

Statistics Canada, *Annual Demographic Statistics*, #91-213, annual editions 1990-1998.

2.4 Agriculture

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* category 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 guidelines reporting instructions since the Canadian activity data is considered to be of high quality..

2.4.A Enteric Fermentation

Large quantities of methane (CH_4) are produced from herbivores through a process called enteric fermentation. During the normal digestive process, microorganisms break down carbohydrates into simple molecules for absorption into the bloodstream, where 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: Enteric Fermentation

Methane (CH_4) emissions from *Enteric Fermentation* were estimated by multiplying the populations of various animals by average emission rates for each type of domestic animal.

The methodology used is considered **IPCC Tier 1**.

The IPCC default emission factors for *cool climate* were used for all regions of Canada. (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 sector.

2.4.A.1 Cattle

[See Section 2.4.A.]

2.4.A.1.a Dairy Cattle

[See Section 2.4.A.]

Dairy Cattle – Includes diary cows and dairy heifers only.

2.4.A.1.b Non-Dairy Cattle

[See Section 2.4.A.]

All other cattle

2.4.A.2 Buffalo

[See Section 2.4.A.]

Considered a negligible source in Canada.

2.4.A.3 Sheep

[Listed under *Other* in the CGHGI.] [See Section 2.4.A.]

2.4.A.4 Goats

[Listed under *Other* in the CGHGI.] [See Section 2.4.A.]

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, #No. 93-350 and #93-356) have been used.

2.4.A.5 Camels and Llamas

[See Section 2.4.A.]

Considered a negligible source in Canada.

2.4.A.6 Horses

[Listed under *Other* in the CGHGI.] [See Section 2.4.A.]

Data were not been available from Statistics Canada #26-603. Therefore, for *Horses*, data from the 1991 and 1996 farm census (Statistics Canada, #No. 93-350 and #93-356) have been used.

2.4.A.7 Mules and Asses

[See Section 2.4.A.]

Considered a negligible source in Canada.

2.4.A.8 Swine

[See Section 2.4.A.]

2.4.A.9 Poultry

[See Section 2.4.A.]

In the case of poultry, yearly population data are available from *Production of Poultry and Eggs* (Statistics Canada, #23-202).

2.4.A.10 Other: Enteric Fermentation

[See Section 2.4.A.]

References: *Enteric Fermentation*

IPCC, *Greenhouse Gas Inventory Reporting Instructions, Vol. 1,* and the IPCC, *Greenhouse Gas Inventory Reference Manual, Vol. 3,* Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, 1997.

Statistics Canada, *Livestock Statistic*s, Agriculture Division, 1991-1998, #23-603.

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

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

Statistics Canada, *Production of Poultry and Egg*s, Agriculture Division, 1991 to 1998 annual editions, #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. The nitrogen excretion rates were reduced by 20% to account for the volatilization of NH_3 and NO_3 (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 system

Emission Calculations: Manure Management

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

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 sector.

2.4.B.1 Cattle

[See Section 2.4.B.]

2.4.B.1.a Dairy Cattle

[See Section 2.4.B.]

Dairy Cattle – Includes diary cows and dairy heifers only.

2.4.B.1.b Non-Dairy Cattle

[See Section 2.4.B.]

In general, beef production uses the *Dry Lot* type of *Manure Management* system.

2.4.B.2 Buffalo

[See Section 2.4.B.]

Considered a negligible source in Canada.

2.4.B.3 Sheep

[Listed under *Other* in the CGHGI.] [See Section 2.4.B.]

2.4.B.4 Goats

[Listed under *Other* in the CGHGI.] [See Section 2.4.B.]

Data were not available from Statistics Canada #26-603. Therefore, for *Goats*, data from the 1991 and 1996 farm census (Statistics Canada, #No. 93-350 and #93-356) have been used.

2.4.B.5 Camels and Llamas

[See Section 2.4.B.]

Considered a negligible source in Canada.

2.4.B.6 Horses

[Listed under *Other* in the CGHGI.] [See Section 2.4.B.]

Data were not been available from Statistics Canada #26-603. Therefore, for *Horses*, data from the 1991 and 1996 farm census (Statistics Canada, #No. 93-350 and #93-356) have been used.

2.4.B.7 Mules and Asses

[See Section 2.4.B.]

Considered a negligible source in Canada.

2.4.B.8 Swine

[See Section 2.4.B.]

2.4.B.9 Poultry

[See Section 2.4.B.]

Production data from *Production of Poultry and Eggs* (Statistics Canada, #23-202) is used.

2.4.B.10 Anaerobic Lagoons

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

2.4.B.11 Liquid Systems

[See Section 2.4.B.]

2.4.B.12 Solid Storage and Dry Lot

[See Section 2.4.B.]

2.4.B.13 Other: Manure Management

[See Section 2.4.B.]

References: Manure Management

IPCC, *Greenhouse Gas Inventory Reporting Instructions, Vol. 1,* and the IPCC, *Greenhouse Gas Inventory Reference Manual, Vol. 3,* Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, 1997.

Statistics Canada, *Livestock Statistic*s, Agriculture Division, 1991-1998, #23-603.

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

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

Statistics Canada, *Production of Poultry and Egg*s, Agriculture Division, 1991 to
1998 annual editions, #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 (CO_2)
and nitrous oxide (N_2O).

Carbon Dioxide Emissions

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

Net CO_2 emissions have decreased since 1990 due to changes in farming practices. The primary reason for the reduced net emissions from soils is believed to be the increasingly common practice of conservation tillage. *No-till farming* was being practiced on over 16% of Canada's (annual) 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 CO_2 emissions that reflects the diverse and myriad complexities that affect carbon fluxes in agricultural soils, a computer model, the CENTURY model was employed. (Parton, 1987) The CENTURY model is considered more appropriate for estimating the rate of change of soil organic carbon in Canada than procedures from the IPCC Guidelines.

Following is a brief summary of the methodology incorporated into the CENTURY model. (Smith, 1997).

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

There is a large degree of uncertainty associated with the estimates provided by the CENTURY model. Comparisons of CENTURY outputs with field measurements suggest that further refinements would improve the reliability of the model in predicting soil carbon change in response to no-till practices in the prairies (McConkey, 1998). The prairies represent 85% of the farmland in Canada.

The CENTURY model also does not take into account emissions from the liming of soils.

Nitrous Oxide Emissions

N_2O 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 processes 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: Agricultural Soils

Carbon Dioxide Emissions

The CENTURY model was used to estimate emissions. The emissions estimates, as prepared by Smith aggregates emissions from the eastern provinces. Emissions were divided among eastern provinces by prorating against the agricultural land area in each province. (Smith, 1997 and Sellers, 1998). The CENTURY model as run by Smith does not provide 1997 and 1998 estimates. This data was estimated by interpolating between 1996 data and a forecasted 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 source, 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 as a result nitrous oxide is emitted.

Emission Calculations: Synthetic fertilizers

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

The average nitrogen-loss rates for various types of fertilizer were compiled and combined with the amount of fertilizer nitrogen applied annually (Korol, 1997 and Monteverde, 1998). The IPCC default uses a single loss rate regardless of fertilizer type.

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

The amount of nitrogen applied is obtained from yearly fertilizer sales data, which are available from regional fertilizer associations (Korol, 1997). 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.

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

Animal Wastes Applied as Fertilizer

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

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

Emission Calculations: Animal Wastes Applied as Fertilizer

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. Since 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 volatilization of NH_3 and NO_3 (IPCC, 1997).

It was assumed that 20% of the excreted nitrogen is lost due to volatilization. The amount of manure nitrogen excreted was reduced by the IPCC default value, 20%, to account for the volatilization of NH_3 and NO_3 (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 sector (See Section 2.4.A Enteric Fermentation.).

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: Plant Biological Nitrogen Fixation

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 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 were using the IPCC values for the average dry matter fractions for crops including: wheat, barley, maize, oats, rye, peas, beans, soya, lentils, sugar beat and a general factor for all other crops. (IPCC, 1997) 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 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 (rather than double) to account for multiple harvests in one season.

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: Crop Residue Decomposition

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

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

The emission rate of 1.25% N_2O-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 old nitrogen-rich organic matter.

In Canada there are over 111 million hectares of peatlands. It is estimated 1.5% is presently under cultivation (NRCan, 1995).

Emission Calculations: Cultivation of Histosols

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

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

Only national data was available for the area under production.

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

Emission Calculations: Manure Application from Grazing Animals

The emissions from manure excreted by *Grazing Animals* were calculated using the **IPCC default methodology**. (IPCC, 1997)

The excretion rates developed in 1998 (Monteverde, 1998) 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 (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 reactions to produce N_2O.

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

Volatilization and Subsequent Redeposition

Emission Calculations: Volatilization and Subsequent Redeposition

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

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

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

Leaching and Runoff

Emission Calculations: Leaching and Runoff

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

The emissions from runoff and leaching were estimated by assuming that 30% of the nitrogen applied as synthetic fertilizer or manure was lost by leaching or runoff. The quantity of estimated N 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: ***Agricultural Soils***

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IPCC, *Greenhouse Gas Inventory Reporting Instructions, Vol. 1,* and the IPCC, *Greenhouse Gas Inventory Reference Manual, Vol. 3,*Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, 1997.

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NRCan, Natural Resources Canada, *Canada Minerals Yearboo*k, Mining Sector, Peat Chapter, 1995.

2.4.E Prescribed Burning of Savannas

[This title is not used in the CGHGI.]

This agricultural sector does not apply in Canada.

2.4.F Field Burning of Agricultural Residues

[This title is not used in the CGHGI.]

The *Field Burning of Agricultural Residues* is not 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.]

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 the amount of biomass in existing stocks such as forests.

Emissions from all anthropogenic activities related to the *Land-Use Change and Forestry* (LUCF) category are covered with the exception of non-CO_2 gases from energy-related activities, which are addressed in the *Energy* category. Carbon dioxide emissions from agricultural soils are reported in the *Agriculture* category.

Vegetation withdraws carbon dioxide from the atmosphere through the process of photosynthesis. Carbon dioxide is returned to the atmosphere by the respiration of the vegetation and the decay of organic matter in soils and litter. The gross fluxes are large; roughly a seventh of the total atmospheric carbon dioxide passes into vegetation each year (on the order of 100 billion tonnes CO_2-C per year). In the absence of significant human disturbance, this large flux of CO_2 from the atmosphere to the terrestrial biosphere is balanced by the return respiration fluxes. 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 CO_2 fluxes associated with that specific land-use, a fact that distinguishes land-use from fossil fuel consumption for purposes of CO_2 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 perspective. 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 to 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. CO_2 Emissions and Removals from Soil - associated with items 2 and 3 (not required by the IPCC), and
5. Other 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 CO_2 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 category 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 chapter 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.

For forestry stocks, the IPCC methodology currently ignores below-ground biomass and soil carbon. Current data on these pools for the wood production forest in Canada are inadequate. Changes in soil C resulting from land-use change activities (see Sections 2.5.B. Forest and Grassland Conversion and 2.5.C Abandonment of Managed Lands), while not required by the IPCC, are nevertheless reported here in Section 2.5.C CO_2 emissions and Removals from Soils.

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

Overview of 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

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

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'.

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:

- CO_2 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 CO_2, 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 below).
- The information on Human Induced Fires are for outside the Wood Production Forest (WPF). CO_2 from fires in WPF is included in Net Change in Forest Stocks. Note that the net CO_2 flux includes emissions from Human-Induced Fires Outside 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, of different species, exposed to various climates and disturbances. For the purposes of defining the area of forest affected by human activity, a decision had to be made regarding the area of 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 available for commercial harvest (148 Mha). The wood production forest represents 35% of Canada's total forestlands (CCFM, 1997). The remainder of the timber productive forest is either reserved for other uses or non-accessible. Within the wood production forest, it is considered that the growing area actually contributing to CO_2 removals, represents 122.8 Mha, once over-mature forests have been excluded (Sellers and Wellisch, 1998).

The Canadian Forest Inventory *1991* (1994 revision), is the main source of information regarding the area of the wood production forest. Commercial forestry is considered to be the dominant anthropogenic activity occurring in Canada's forests that can affect the size of forest stocks and potentially increase or decrease GHG emissions. This includes commercial management, harvest of industrial roundwood and fuelwood, production and use of wood commodities, and establishment and operations of forest plantations.

Virtually all of the CO_2 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 *Changes in Forest and Other Woody Biomass Stocks* sector and those reported in the *Energy* and *Waste* categories (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 (Neitzert et al, 1999).

Emission Calculations: Changes in Forest & Other Woody Biomass Stocks

With the current IPCC method (used to produce the results presented here), the net impact of a removal or emission is calculated as the difference between CO_2 uptake through forest growth and CO_2 emissions resulting from forest harvest. Forest growth is defined as the accumulation of aboveground 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 aboveground 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 1990-1998.

Forest growth rates are not available by age 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 volume per hectare divided by the age. Use of this growth rate is believed to be the greatest source of uncertainty in the estimation of CO_2 removals by the forest. Since it represents a long-term average and an approximation of current growth, it is considered to be a net value that takes into account forest losses by competition, insects, disease, fires and other disturbances.

The m.a.i value, retrieved by ecozones, is assumed to be constant 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 involving data such as 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 and IPCC, 1997)

Alternative Methods for Emission Calculations

Carbon dioxide emissions resulting form 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 180 Mt CO_2 (Atmospheric Flow method) to 257 Mt CO_2 (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: (1) products that last for less than five years, and (2) 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 assigns all the change in forest reservoir to the country in which harvesting occurs, without regard to where the forest products are exported. The flow method assigns the emissions and removals to the country where C-CO_2 is emitted or taken from the atmosphere. The default method is unrealistic both spatially and temporally as emissions are not related to the country where they actually occur, or when they occur. The stock-change method is similar to the default approach, but includes additional sources of stock emissions and removals for the country based on inherited emissions from the decay of long-lived products, and additional pool calculations based only on usage of wood products in the producing country. The flow method is similar to the approach adopted for fossil fuel emissions, and involves a few more calculations, but provides a better reflection of when and where emissions and removals actually occur.

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 CO_2 emissions associated with land use changes such as conversion from forests and grasslands to croplands or other agricultural lands, and conversion of forests, grassland, agricultural and other areas for urban development. Only changes in above-ground carbon were addressed. Changes in soil carbon levels are estimated in Section 2.5.D.

Total area converted equals 81 kha in 1990 and about 111 kha in 1998. It is estimated that about 12 kha were deforested in 1990, and 25 kha in 1998. 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 aboveground biomass.

Other sources of deforestation have not been included in this assessment owing to deficiencies in data.

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.

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

Emission Calculations: Forest and Grassland Conversion

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 additional agricultural and urban lands. Factors were applied to apportion the converted total areas into original land type (temperate forest, boreal forest, grassland etc.) (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 CO_2 removals resulting from the accumulation of aboveground carbon on abandoned, formerly managed lands. These abandoned lands are assumed to return slowly to their natural states. Associated changes in soil carbon are addressed in 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 aboveground biomass. However, conversion into a forest ecosystem is known to increase C storage relative to what is stored in cropland or pasture. The IPCC recommends that the uptake be evaluated according to two time horizons:

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

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 37 years prior to 1998.

CO_2 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: Abandonment of Managed Lands

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 (CCFM, 1997).

No data exist regarding the specific fate of the abandoned land; therefore following assumptions were made:

- half of the abandoned areas was converted to urban land, and
- the remainder was assumed to regrow to the natural state in estimated proportions (ESSA, 1996 and 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.

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 as 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 as 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 CO_2 Emissions and Removals from Soil

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

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

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

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 CO_2 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: Soil Carbon Emissions from Land Conversion

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: Soil Carbon Uptake from Abandonment of Managed Lands

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 belowground 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: CO_2 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.]

The following sectors and sub-sectors are included in the LUCF category of the CGHGI, while not required by the IPCC greenhouse gas reporting guidelines. For a discussion of methods, they have been relocated to this UNFCCC sector:

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 CO_2 emissions, burning generates non-CO_2 trace gas emissions, CH_4 and N_2O.

Carbon dioxide emissions from prescribed burning are not included in this section. They included as part of slash emissions in Section 2.5.A, *Changes in Forest & Other Woody Biomass Stocks.*

The application of *Prescribed Burning* has dropped significantly in the 1990s. It is being practiced mostly in British Columbia (BC). 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: Prescribed Burning

Data on the areas exposed to *Prescribed Burning* are reported by the *Canadian Committee on Forest Fire Management* for 1990 to 1995 For 1998, the area exposed was assumed to be equal to the BC total for 1994.

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

The *Canadian Forest Service* has developed emission factors for each trace gas (Taylor, 1996). The trace gas and CO_2 emission factors that were revised by Environment Canada (Jaques, 1997 and Sellers and Wellisch, 1998) are listed in Table 11.

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

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

Since it cannot be confirmed that the input data used in the calculations strictly exclude natural, or *wildfires*, it was assumed that the so-called *wildfires* could also be indirectly attributed to human activity when they occur in the managed forest. 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: Other Fires in the Wood Production Forest

Historical data for the wood production forest from 1961 to 1990 was obtained from Econnections (Statistics Canada, #16-200- XKE).

Fire frequency is highly variable, even in the wood production forest where fire protection measures are implemented. However, a long-term average from 1961 to 1990 was used to estimate burned areas for 1991 to 1996. The *mean annual increment to maturity* of forests used in Section 2.5.A, *Changes in Forest & Other Woody Biomass Stocks*, an average value over a long period of time, takes into account some disturbances, including fires. Therefore, the CO_2 emissions from human-induced fires are already included in the inventory and are not reported herein.

2.5.E.3 Other: Fires Caused by Human Activities Outside the Wood Production Forest

This Sector includes both CO_2 and non-CO_2 emissions from anthropogenic fires outside the wood production forest area, such as those associated with recreation, residence, railways, other industry, incendiary and other miscellaneous causes.

Emission Calculations: Other Fires Caused by Human Activities

Outside the Wood Production Forest

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, 1997)

Data for 1998 were taken as the average of burned areas over 1990-1995 period.

For fires both inside and outside the *Wood Production Forest*, fuel consumption data were those provided by the *Canadian Forest Service* (Stocks, 1990).

Emission factors for CO_2 and non-CO_2 emissions were provided by the *Canadian Forest Service* (Taylor, 1996).

2.5.E.4 Wildfires

At present, emissions from Wildfires do not have to be reported to the UNFCCC.

Fires occurring outside the *Wood Production Forest* are primarily caused by lightning strikes. An estimated 728 kha were burned in 1990. The estimate for 1998 is 2,616 kha.

Emission Calculations: Wildfires

Data were extrapolated using a 25-year fire average (1970-1995) in the *Wood Production Forest.* (CCFM, 1997).

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 the subsection 2.5.E.1 - Fires Caused by Human Activities.

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

References:

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

Stocks, B.J., Communication to Werner Kurz, ESSA Ltd., *CO_2 Emissions from Wildfires and Prescribed Fires in Canada*, 1990.

2.6 Waste

Much of the waste treated or disposed of is biomass or biomass-based. The carbon dioxide (CO_2) emissions attributable to such wastes are not included in this category. 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 CO_2 emissions will appear as a loss of biomass stocks in the LUCF category.

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 *Municipal Solid Waste* (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:

Total methane from landfills = methane produced – methane captured **Equation 18**

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; there is a great deal of uncertainty in the estimates. However, 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 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, *Municipal Solid Waste* (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)

$$G_i = M_i \times k \times L_0 \times \exp^{-(k \times t_i)} \qquad \textbf{Equation 19}$$

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: Managed Waste Disposal on Land
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 land-filled 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 though 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* (CPPA) 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 US k values and precipitation data, the average annual precipitation and mean daily temperature at Canadian landfills has been calculated and k values have been assigned to each of the provinces (Levelton, 1991).

MSW Landfills: The values of k used to estimate emissions from MSW landfills have been chosen from the range of k value estimates for each province. (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):

$$L_0 = (M_c \times F_b \times S)/2 \qquad \textbf{Equation 20}$$

Where:

Mc = tonnes of carbon per tonne of waste landfilled
Fb = 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 20 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

[This is not a UNFCCC sector heading.]

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: Captured Landfill Gas

> The data on the amount of landfill gas captured was provided by the Environment Canada *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, according to IPCC Guidelines, CO_2 emissions originating from the decomposition of food are not to be included with the national estimates.

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 Emissions from Anaerobic Wastewater Treatment

[This is not an IPCC sector heading.]

Emission Calculations: Methane Emissions from Anaerobic Wastewater Treatment

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 Emissions from Human Sewage

[This is not an IPCC sector heading.]

Emission Calculations: Nitrous Oxide Emissions from Human Sewage

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

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

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

Emission Calculations: MSW Incineration

Carbon Dioxide Emissions: The IPCC Guidelines do not specify a method to calculate CO_2 emissions from incineration of fossil-fuel-based waste (such as plastics and rubber). Therefore, the following three-step method was developed.

Step 1- Calculate 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 Factor:
The provincial CO_2 emission factors are based on the assumption that the carbon in the waste undergoes complete oxidation to CO_2. The amount of fossil-fuel-based carbon available in the waste incinerated have been determined using typical percent weight carbon constants (Tchobanoglous, 1993). The amount of carbon per tonne of waste is estimated and converted to tonnes of CO_2 per tonne of waste, by multiplying by the ratio of the molecular mass of carbon dioxide to carbon.

Step 3- Calculating Carbon Dioxide Emissions:
Emissions were calculated on a provincial level by multiplying the amount of waste incinerated by the appropriate emission factors.

Nitrous Oxide and Methane Emissions
The emissions of N_2O from MSW incineration were estimated using the **IPCC default method**. (IPCC, 1997) An average factor was calculated assuming that the IPCC five stokers 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 the common method for sewage sludge disposal in Canada. This technique is not an ultimate disposal because it converts the sludge to gases and ash, which must be landfilled.

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: Sewage Sludge Incineration

Methane Emissions: The emissions are dependent on the amount of dried solids incinerated. To calculate the CH_4 emissions, the amount of dry solids incinerated are multiplied by an appropriate emission factor. The estimates of the amount of dried solids in the sewage sludge incinerated in the years 1990 to 1992 are from a study completed in 1994 (Senes, 1994). The data for the years 1993 to 1996 was acquired through telephone surveys of the facilities that incinerate sewage sludge.

Emissions of CH_4 are estimated based on an emission factor of 1.6 t/kt of total dried solids for fluidized beds and 3.2 t/kt of dried solids for multiple hearth incinerators. Only methane 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: ***Total Waste***

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2.7 Tables 1-14

TABLE 1 ENERGY: STATIONARY COMBUSTION SOURCES - GASEOUS FUELS

		CO_2	**CH_4**	**N_2O**
Fuel	***Use***	***g / m^3 fuel***	***g / m^3 fuel***	***g / m^3 fuel***
Natural Gas	Utility Boiler	1,880	0.0048	0.02
	Industrial Boiler	1,880	0.048	0.02
	Commercial Boiler	1,880	0.043	0.02
	Residential Boiler Heater	1,880	0.043	0.02
	Other	1,880	0.043	0.02
		g/L HFO* eq	**g/L HFO* eq**	**g/L HFO* eq**
Refinery Fuel ('Still') Gas	Industrial Energy	2,000	-	0.00002

References: * HFO = Heavy Fuel Oil Equivalent

CO_2 Emission Factors: *Natural Gas* - Marland and Rotty, 1983. *Refinery Fuel Gas* - ibid.

CH_4 Emission Factors: *Natural Gas* - U.S. EPA, 1985.

N_2O Emission Factors: *All* - Canadian Electrical Association/CANMET, 1990; U.S. EPA, 1989.

TABLE 2 ENERGY: STATIONARY COMBUSTION SOURCES - LIQUID PETROLEUM FUELS

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

TABLE 3 ENERGY: STATIONARY COMBUSTION SOURCES - SOLID PETROLEUM FUELS

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

CO_2 Emission Factors: *Light and Heavy Distillates, Diesel* - Jaques, 1992. *Natural Gas Liquids* - Derivation assuming pure fuels, 100% oxidation; density information, Institute Of Petroleum, 1973, Perry & Chilton, 1973 as per Jaques, 1992.

CH_4 Emission Factors: *Light & Heavy Distillates, Natural Gas Liquids* - U.S. EPA, 1985 (round off applied to commercial boiler burning heavy oil). *Diesel* - U.S. EPA, 1985; NAPAP, 1987; OECD, 1991.

N_2O Emission Factors: *Diesel*-DeSoete,1989; Prigent & DeSoete, 1989; Pringent etal, 1991; *Light & Heavy Distillates*–EPA 1996.

TABLE 4 ENERGY: STATIONARY COMBUSTION SOURCES - COAL FUELS, PART 1

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

TABLE 5 ENERGY: STATIONARY COMBUSTION SOURCES - COAL FUELS, PART 2

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

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

Table 6	**ENERGY: TRANSPORTATION - GROUND (NON- RAIL) SOURCES**			
		CO_2	**CH_4**	**N_2O**
Fuel	***Use On – Road Transport***	***g / L fuel***	***g / L fuel***	***g / L fuel***
Motor Gasoline	*Autos (LDGA)*			
	- Tier 1 Three-way Catalyst	2,360	0.25	0.21
	- Tier 0, New Three-way Catalyst	2,360	0.32	0.25
	- Tier 0, Aged Three-way Catalyst	2,360	0.32	0.58
	- Oxidation Catalyst	2,360	0.42	0.20
	- Non-Catalyst	2,360	0.52	0.046
	Light Duty Trucks (LDGT)			
	- Tier 1 Three-way Catalyst	2,360	0.19	0.39
	- Tier 0, New Three-way Catalyst	2,360	0.41	0.45
	- Tier 0, Aged Three-way Catalyst	2,360	0.41	1.00
	- Oxidation Catalyst	2,360	0.44	0.20
	- Non-Catalyst	2,360	0.56	0.046
	Heavy Duty Vehicles (HDGV)			
	- 3-way Catalyst	2,360	0.17	1.00
	- Non-Catalyst	2,360	0.29	0.046
	- Uncontrolled	2,360	0.49	0.046
	Motorcycles (MC)			
	- Non-Catalytic Controlled	2,360	1.4	0.046
	- Uncontrolled	2,360	2.3	0.046
Diesel Oil	*Light Duty Diesel Autos (LDDA)*			
	- Advance Control	2,730	0.05	0.1
	- Moderate Control	2,730	0.07	0.1
	- Uncontrolled	2,730	0.10	0.1
	Light Duty Diesel Trucks (LDDT)			
	- Advance Control	2,730	0.07	0.1
	- Moderate Control	2,730	0.07	0.1
	- Uncontrolled	2,730	0.07	0.1
	Heavy Duty Diesel Vehicles (HDDV)			
	- Advance Control	2,730	0.12	0.1
	- Moderate Control	2,730	0.13	0.1
	- Uncontrolled	2,730	0.15	0.1
Natural Gas	*Natural Gas Vehicles*	2	0.022	0.00006
Propane	*Other Diesel Vehicles*	1,530	0.70	0.09

TABLE 7 ENERGY: TRANSPORTATION - RAIL AND NON-GROUND SOURCES

Fuel	Use	CO_2 g / L fuel	CH_4 g / L fuel	N_2O g / L fuel
	Rail Transportation:			
Diesel	Railroad Trains	2.730	0.15	1.1
	Marine Transportation:			
Gasoline	Boats	2,360	1.3	0.06
Diesel	Ships	2,730	0.15	1.00
Light (›Distillate:)Oil	Ships	2,830	0.3	0.07
Heavy (›Residual:) Oil	Ships	3,090	0.3	0.08
	Air Transportation:			
	Conventional Aircraft	2,330	2.19	0.23
	Jet Aircraft	2,550	0.08	0.25

CO_2 Emission Factors: Jaques, 1992.

CH_4 Emission Factors

On-Road Vehicles: *Natural Gas, Propane - U.S. EPA*, 1996; *Gasoline and Diesel* - Engine, Fuel and Emissions Inc., 1996;

All CH_4 values for road vehicles - IPCC/OECD/IEA, 1997.

Off-Road, Ground
(Non-Rail) Vehicles & Rail Transport (Diesel): Andrias, et al (1994), as found in IPCC/OECD/IEA, 1997;

Fuel Densities - Statistics Canada, 57-003 Quarterly.

Marine Transport: *Gasoline and Diesel*: Andrias, et al, 1994, as found in IPCC/OECD/IEA, 1997;

Fuel Densities - Statistics Canada, 57-003 Quarterly; *Light and Heavy Fuel Oil* - Lloyd's Register, 1995, as found in IPCC/OECD/IEA,1997; *Fuel Densities* - Statistics Canada, 57-003 Quarterly;

HHV to LHV conversion - IPCC/OECD/IEA, 1997.

Aviation Transport: U.S. EPA (1985), NAPAP (1987), OECD, 1991;

Density information - Institute of Petroleum, 1973, Perry and Chilton, 1973; Jaques, 1992.

N_2O Emission Factors

Gasoline On-Road Vehicles: *Tier 1 LDGA & LDGT* - U.S. EPA, 1998; *Tier 0 LDGA & LDGT* - Environment Canada, 1994;

Ratio aged to new- DeSoete, 1989; *Oxidation & Non-Catalyst LDGA and LDGT* - H. Michaels, U.S. EPA, 1998; *HDGV, Three-way Catalyst* - Environment Canada, 1994; *HDGV, Non Catalytic and Uncontrolled* - H. Michaels, U.S. EPA, 1998; *Motorcycles* - H. Michaels, U.S. EPA, 1998.

Diesel On-Road Vehicles: *LDDT, LDDA & HDDV* - Dietzman et al, 1980 and DeSoete, 1989;

Fuel efficiencies conversions - U.S. EPA developed by Engine, Fuel & Emissions Eng. Inc, 1996.

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

Off-Road, Ground (Non-Rail) Vehicles: Andrias, et al, 1994, as found in IPCC/OECD/IEA, 1997;

Fuel Densities - Statistics Canada, 57-003 Quarterly.

Rail Transport (Diesel): Andrias, et al, 1994, as found in IPCC/OECD/IEA, 1997;

Fuel Densities - Statistics Canada, 57-003 Quarterly.

Marine Transport: *Gasoline and Diesel* - Andrias, et al, 1994, as found in IPCC/OECD/IEA, 1997;

Fuel Densities - Statistics Canada, 57-003 Quarterly; *Light and Heavy Fuel Oil* - Lloyd's Register, 1995, as found in IPCC/OECD/IEA, 1997; *Fuel Densities* - Statistics Canada,57-003 Quarterly; *Fuel energy densities* - Statistics Canada 57-003, - Quarterly; *HHV to LHV conversion* - IPCC/OECD/IEA, 1997.

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

TABLE 8 INDUSTRIAL PROCESS SOURCES

		CO_2	N_2O	CF_4	C_2F_6	SF_6
Source	***Description***	***g / kg feed***				
Mineral Use						
Limestone Use	In Iron & Steel, Glass, Non-Ferrous Metal Prod.	440	-	-	-	-
Soda Ash Use	In Glass Manufacture	415	-	-	-	-
		g / kg product	***g / kg product***	***g / kg product***	***g / kg product***	***g / kg gas use***
Mineral Products						
Cement Production	Limestone Calcination	500	-	-	-	-
Lime Production	Limestone Calcination	790	-	-	-	-
Chemical Industry						
Ammonia Production	From Natural Gas	1,600	-	-	-	-
Metal Manufacture						
Primary Aluminum	Electrolysis Process	(1.54-1.83)	-	(0.3-1.1)	(0.02-0.1)	-

CO_2 Emission Factors: *Limestone Use* - ORTECH, 1994. *Soda Ash Use* - DOE/EIA, 1993. *Lime Production* - ORTECH, 1991 *Cement Production* - Orchard, 1973; Jaques 1992. *Ammonia Production* - Industrial Chemicals, 1980; Jaques 1992. *Primary Aluminum* - ORTECH, 1994 (emission factors vary with technology used).

CH_4 Emission Factors: *Adipic Acid Production* - Thiemens and Trogler, 1991.

CF_4, C_2F_6 Emission Factors: *Primary Aluminum Production* - Unisearch Associates, 1994, adapted by Environment Canada; emission factors vary with smelting technology.

TABLE 9 HYDROCARBON NON-ENERGY PRODUCTS

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

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

TABLE 10 SOLVENT AND OTHER PRODUCT EMISSION SOURCES

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

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

TABLE 11 BIOMASS EMISSION FACTORS

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

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

References:

CO_2 Emission Factors: Wood Fuel/Wood Waste -, US EPA (1996); Accidental Forest Fires and Prescribed Burns - Taylor (1996).

CH_4 Emission Factors: *Wood Fuel/Wood Waste* - U.S. EPA (1985); Accidental Forest Fires and Prescribed Burns - Taylor (1996).

N_2O Emission Factors: *Wood Fuel/Wood Waste* - Rosland & Steen (1990), Radke *et al.* (1991); Accidental Forest Fires and Prescribed Burns - Taylor (1996).

TABLE 12 ENERGY: FUGITIVE SOURCES

Province	***Method***	***Coal Type***	**Emission Factor t CH_4/kt coal**
Nova Scotia	Underground	Bituminous	13.79
Nova Scotia	Surface	Bituminous	0.13
New Brunswick	Surface	Bituminous	0.13
Saskatchewan	Surface	Lignite	0.06
Alberta	Surface	Bituminous	0.45
Alberta	Underground	Bituminous	1.76
Alberta	Surface	Sub-Bituminous	0.19
British Columbia	Surface	Bituminous	0.58
British Columbia	Underground	Bituminous	4.1

TABLE 13 INDUSTRIAL PROCESS SOURCES – part 2

Source	***Description***	**N_2O**
		kg /t product
Nitric Acid Production		
	plants with catalytic converters	0.66
	plants with extended absorption for NOx abatement type 1	9.4
	plants with extended absorption for NOx abatement type 2	12
		kg / kg
Adipic Acid Production		0.303

TABLE 14 HFC CONSUMPTION

	HFCs
Application	***kg loss/ kg consumed***
Aerosols	0.8
Foams	1
AC OEM	0.04
AC Service	1
Refrigeration	0.1
Total Flooding Systems	0.35

3.0 VERIFICATION and QA/QC

This chapter provides a description of the QA/QC and verification procedures used in the preparation of the 1998 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 but have not changed significantly since the previous UNFCCC submission and publication of the 1997 GHG Inventory. The Inventory and methodologies are published on a regular basis, which has provided an additional opportunity for public and expert review. This review process is informal in nature, Canada recognizes the need for a formalized QA/QC protocol and is planning to develop this in the near future.

3.1 Reference Approach

The reference approach was compared to the sectoral approach as a check of combustion emissions. It was performed for both 1990 and 1998 and is an integral part of the CRF.

Direct comparison of the reference approach and the sectoral approach used in the CRF shows a reference approach total, which is significantly larger than the sectoral approach total, for both 1990 and 1998. 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 and 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 IPCC guidelines. When the comparison is corrected by adding the relevant industrial process data to the sectoral approach the totals match within 2-4%, which 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 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 USA, 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 NHV since there were no readily available GHV based EF's for some of the raw fuels used in the reference approach. As a result many of the default IPCC factors were used. Many of the IPCC default factors provide a wide range of values which can have a large impact on the emission total (such as Crude oil, which has two default factors listed of 20 or 21 tC/TJ, this difference alone can vary the reference approach total 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 QRESD 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). As 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. As synthetic crude oil production statistics are based on marketable volumes of crude produced not on volumes of bitumen extracted. As a result producer consumed upgrader petroleum would not be accounted for in marketable production statistics.

NGL's (Natural Gas Liquids)

A virtual composite mixture comprised of Ethane, Propane and Butane represents Natural Gas Liquids. For 1998, the blend is 39.9% Ethane, 39.1% Propane and 20.9% Butane by volume. Dependent upon those proportions, a Specific Gravity and Carbon Emission Factor (tC/Tj) for that year is generated using IPCC default values and hence maintaining the requested NCV dimensions.

Gasoline
This category is a combination of Motor Gasoline and Aviation gasoline with the former dominating the total.

LPG
Includes Stored Carbon due to Butane to accommodate the lack of consistency between the LPG segregation from the Stored Carbon Worksheet Table1.A (d) and that of the Sectoral Reference Approach Table1.A (b).

Refinery Feedstock
The Tj/unit conversion factor is derived using IPCC, Canada specific NCV for OECD Countries and that fuels specific gravity.

Other Oils
This category includes the Stored Carbon due to Other Products from Table1.A (d).

Natural Gas
The value listed as “Natural Gas Production” in the QRESD has been reduced to compensate for the Inter-Product transfer which would account for the Natural Gas being used as a source of Hydrogen in oil sand upgrading. The energy conversion factor is dependent upon the HHV value from the QRESD for Natural Gas for that specific year and is discounted, according to OECD/IEA, to accommodate the difference between HHV and LHV.

Biomass
Solid Biomass includes all Canadian sources (Industrial, Residential and Prescribed or accidental Fires) 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 has been published several times in the past, with the most recent being the 1990-1997 report published in 1999. This document provides a detailed description of our emission inventory methods. It is distributed to industry, academia and government stakeholders and provides a means for informal comment. The emission estimates for energy and agriculture were 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 methods in this inventory have not changed significantly from previous years.

The activity data used in the CGHGI is generally from published sources. The energy data, population, and agriculture activity data are all published by the national statistics agency. The Energy Section of the statistics agency 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 energy data which resulted in a complete review of the national energy balances (as described by A. Coombs, 2000). The energy data used for the National GHG Inventory is also the basis for the national energy and emissions forecast.

Canada does not have a formal QA/QC and verification plan at this time. We realize the need for this under the expanded requirements of the UNFCCC and are developing one.

4.0 UNCERTAINTY ASSOCIATED WITH EMISSION AND REMOVALS 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 not warranted in this report and readers are referred to the original study for further details (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), necessitating the use of Monte Carlo stochastic computer simulation to develop group and then overall uncertainty estimates for each greenhouse gas. Up to 100,000 iterations were used in these simulations to provide the final estimates of uncertainty at confidence levels ranging from 85 to 95%. While the uncertainties were calculated for the 1990 inventory, many data sources and emission rates have remained the same, as have the methods used to estimate emissions, so it is reasonable to assume that the uncertainty in the carbon dioxide and methane emissions are still of the same order.

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 can only provide 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.

Table 4-1: NUMBER OF SIGNIFICANT FIGURES APPLIED TO GREENHOUSE GAS SUMMARY TABLES
Based on the Uncertainty of Emission Estimates

GHG Source and Sink Category (New Categories)	CO_2	CH_4	N_2O	HFCs	PFCs	SF_6	Total
ENERGY							
FUEL COMBUSTION							
Fossil Fuel Industries	3	2	2				3
Electricity and Steam Generation	3	2	2				3
Mining	3	2	2				3
Manufacturing	3	2	2				3
Construction	3	2	2				3
Transportation							
Gasoline Cars	3	2	2				3
Light Duty Gasoline Trucks	3	2	2				3
Heavy Duty Gasoline Trucks	3	2	2				3
Motorcycles	3	2	2				3
Off Road Gasoline Vehicles	3	2	2				3
Diesel Cars	3	2	2				3
Light Duty Diesel Trucks	3	2	2				3
Heavy Duty Diesel Trucks	3	2	2				3
Off Road Diesel Vehicles	3	2	2				3
Propane and Natural Gas Vehicles	3	2	2				3
Domestic Air	3	2	2				3
Domestic Marine	3	2	2				3
Rail	3	2	2				3
Vehicles subtotal	**3**	**2**	**2**				**3**
Pipelines	3	2	2				3
Transportation Subtotal	**3**	**2**	**2**				**3**
Residential	3	2	2				3
Commercial and Institutional	3	2	2				3
Other	3	2	2				3
COMBUSTION SUBTOTAL	**3**	**2**	**2**				**3**
FUGITIVE							
Solid Fuels (i.e. Coal Mining)		2					2
Oil and Gas	2	2					2
FUGITIVE SUBTOTAL	**2**	**2**					**2**
ENERGY TOTAL	**3**	**2**	**2**				**3**
INDUSTRIAL PROCESSES							
Non Metallic Mineral Production	3						3
Ammonia, Adipic & 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**						

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

One significant figure: greater than 50% uncertainty
Two significant figures: 10% to 50% uncertainty
Three significant figures: less than 10% uncertainty

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 LUCF, PFC and HFC emissions have a very high uncertainty (IPCC, 1997; Schiff, year) and so only one significant figure has been shown for these estimates.

References

International Panel on Climate Change /OECD/IEA, *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*; IPCC, Bracknell, UK, 1997.

Schiff, H., Personal communication with researcher who performed measurements of PFC emissions from aluminum smelters in Canada, 1996. Note that a factor of uncertainty of two is equivalent to a statistical uncertainty of about 30%.

T.J. McCann and Associates, *Uncertainties in Canada's 1990 Greenhouse Gas Emission Estimates.* Report prepared for Environment Canada, Pollution Data Branch, Hull, March, 1994.

5.0 CRITERIA AIR CONTAMINANTS

Criteria air contaminants (also called common air contaminants) of interest to the UNFCCC are:

- Sulphur dioxide (SO_2), and
- The Ozone Precursors:
- Nitrogen Oxides (NOx),
- Carbon Monoxide (CO), and
- Non-methane Volatile Organic Compounds (NMVOC).

These gases are inventoried separately and using different methodologies from the direct GHGs and are commonly called Criteria Air Contaminants (CAC).

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.